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Response Time to Craving-Item Ratings as an Implicit Measure of Craving-Related Processes

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Abstract

Drug craving is typically measured through explicit ratings of craving levels. We examined response time to craving ratings as an implicit measure of craving processes in cigarette smokers. Response time and inter-item variability were investigated as potential indices of *certainty* in craving ratings. Cigarette smokers, categorized as tobacco dependent or nondependent, completed multiple cue-reactivity sessions with smoking and neutral cues. After each cue, craving level and response time was assessed. Significant inverted-U relationships emerged between craving level and both response time and inter-item variability across conditions, sessions, and groups. Faster response times and less inter-item variability emerged after neutral relative to smoking cues for nondependent smokers and after smoking relative to neutral cues for dependent smokers. Response time provided incremental validity beyond craving level in predicting dependence. Results support use of response time as an implicit measure of craving processes and further distinguish craving experiences between dependent and nondependent smokers.

Keywords

craving; implicit; response time; certainty; smoking; tobacco dependence

Introduction

Craving is often viewed as central to drug addiction (Robinson & Berridge, 1993; Tiffany, 1990; Tiffany, Warthen, & Goedeker, 2009; Tiffany & Wray, 2012) and is frequently cited as a barrier to cessation and a risk factor for cessation failure (Orleans, Rimer, Cristinzio, Keintz, & Fleisher, 1991; Wray, Gass, & Tiffany, 2013). With growing interest in the role of craving in drug addiction, craving assessment has become commonplace in both addictions research and treatment (Tiffany, Friedman, Greenfield, Hasin, & Jackson, 2012; Tiffany & Wray, 2012).

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Declaration of Interests

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Motivational processes in drug use have been assessed predominantly with explicit or direct measures, often in the form of self-report instruments (De Houwer, 2006; Wiers & Stacy, 2006). Self-report measures are relatively easy to administer and interpret, have a high degree of face validity, and generate abundant information about the constructs they index (Paulhus & Vazire, 2007; Sayette et al., 2000). In the case of craving, nearly all theories of craving presume that motivational processes of addiction can be indexed through self-report measures; however, self-report measures may not capture the entirety of the craving experience (Sayette et al., 2000; Tiffany & Wray, 2012).

Recently, researchers have begun to focus on implicit measures of drug addiction due to growing interest in automatic processes and findings indicating that self-reported motivation to use is inconsistently associated with drug-use behavior (Waters & Sayette, 2006). Implicit measures are appealing because they may—through examining automatic affective, cognitive, and motivational processes (Waters & Sayette, 2006)—allow for better understanding of psychological mechanisms that are unavailable to introspection necessary for self-report measures (Asendorpf, Banse, & Mücke, 2002; Wiers & Stacy, 2006). As Wiers and Stacy (2006) noted, even if individuals can access and report on cognitive processes or attitudes, they may respond in socially desirable ways and may not be accurate reporters of subjective experiences. Fazio and Olson (2003) have also suggested that explicit measures may reflect evaluations that are further downstream cognitively from those revealed by implicit measures; explicit, self-report can be influenced by level of task engagement, opportunity to deliberate, and anything else that is automatically activated at that time. Thus, implicit measures may more closely reflect targeted constructs and allow for a fuller understanding of motivational processes of drug use.

The cue-reactivity procedure has been used extensively to study drug-motivational processes in addictive disorders. In this procedure, drug users are presented with stimuli strongly associated with previous episodes of drug use (e.g., a lit cigarette) and responses to these cues are assessed. A wide variety of reactions to drug-paired stimuli have been examined, most commonly including craving level, assessed through self-reported craving after cue presentation. This measure, considered the gold standard of craving assessment, offers an explicit index of craving processes. However, a variety of indirect, implicit measures of cue-reactivity have also been evaluated, including drug self-administration (latency to smoke, smoking topography; e.g., Shiffman et al., 2013a), psychophysiological responding (change in heart rate, skin conductance, blood pressure, salivation; e.g., Saladin et al., 2012), neurobiological responding (neuroimaging of brain activation; e.g., Kühn & Gallinat, 2011; Smolka et al., 2006; Vollstädt-Klein et al., 2010), and expressive facial behavior (e.g., facial EMG; Sayette & Hufford, 1995). Unfortunately, some implicit measures of cue-reactivity have methodological limitations (Rosenberg, 2009) and may or may not serve as indices of craving processes (Sayette et al., 2000). For example, it is unclear whether brain regions identified by fMRI as activated during cue-reactivity procedures are critical for the generation of craving (Hommer, 1999). Additionally, if implicit measures of craving truly reflect craving processes, those measures should display some significant association with self-reported craving. However, self-reported craving is often *not* correlated significantly with implicit measures, including cardiovascular (e.g., Erblich, Bovbjerg, & Sloan, 2011;

LaRowe, Saladin, Carpenter, & Upadhyaya, 2007), electrodermal (e.g., Carter & Tiffany, 2001), and salivation measures (e.g., Coffey, Saladin, Libet, Drobles, & Dansky, 1999).

The likelihood that an implicit measure actually reflects craving processes should be increased when that measure is gathered concurrently with self-reported craving. In the present study, we collected an implicit measure of craving-related processes while smokers completed a cue-reactivity task designed to induce craving. This procedure examined the speed with which smokers generated responses to individual craving items, an implicit measure thought to operate outside of participants' direct awareness (De Houwer, Teige-Mocigemba, Spruyt, & Moors, 2009). Response time to craving items, to the extent that it is sensitive to manipulations that modulate self-report craving, is more likely to capture processes involved in cognitive appraisals of craving as compared to other implicit measures. Although response time should not be isomorphic with craving report (that is, both variables will not co-vary perfectly), we hypothesized that response time should be correlated significantly with craving level. Thus, using the cue-reactivity procedure, which generates heightened craving in response to smoking cues and reduced craving following neutral cues, should allow for the examination of potential changes in response time across a wide range of craving levels.

At present, there are no data on the processes that underlie response choices when smokers rate craving items. However, researchers examining processes behind response choices in other domains have found inverted-U effects between response time and response choice. These effects indicate fast response times for responses located at the extremes of a rating scale and slower response times for responses located in the middle. Though the relationship between response time and response choice is clear, the interpretation of inverted-U response time effects varies depending on the field of research. Personality researchers posit that these effects reflect individuals' self-schemas (e.g., Kuiper, 1981), whereas researchers studying absolute identification (i.e. judgments of line length relative to other lines; e.g., Brown, Marley, Donkin, & Heathcote, 2008) and psychometric tests (e.g., Akrami, Hedlund, & Ekehammar, 2007; Casey & Tryon, 2001) have suggested that these effects result from limited information capacity when mapping stimulus representation to response selection, as well as response selection constraints (Mignault, Marley, & Chaudhuri, 2008).

In the present study, we posited that response time would reflect certainty in responding to craving items. Though response time was the primary measure of interest in the current study, we also examined inter-item variability, a common assessment of response certainty that assesses diversity in responding across continuous response choices. Inverted-U effects have been identified in research examining inter-item variability, indicating less inter-item variability at the extremes of response options and greater inter-item variability at the middle of response options (e.g., Avant, Bevan, & Wing, 1968; Behar, 1963; Mignault et al., 2008). Given the emergence of inverted-U effects between ratings on the construct of interest and both response time and inter-item variability found in previous studies, we hypothesized that inverted-U response time and variability effects would emerge when examining craving level. That is, those who report very low or very high craving would respond more quickly to craving items and with less inter-item variability compared to those endorsing moderate levels of craving. Considering the emergence of inverted-U response time and inter-item

variability effects and the hypothesis (though untested) that inter-item variability may be associated with inverted-U response time effects (e.g., Casey & Tryon, 2001), we hypothesized that response time and inter-item variability would be positively correlated. It is possible, however, that response time and inter-item variability would be associated with one another and display linear relationships with craving level. Given the saliency of heightened craving, response time may be faster and inter-item variability lower when participants experience high craving levels.

The current study evaluated response time to craving items in the context of a cue-reactivity procedure. Presentations of smoking cues have a pronounced impact on self-reported craving (Carter & Tiffany, 2001). These procedures allowed us to explore change in individuals' craving levels and potential simultaneous changes in smokers' response time to craving items. Therefore, we examined whether response time to craving items was similarly affected by cue type (smoking or neutral). Likewise, we also assessed whether differences emerged for inter-item variability as a function of cue type.

We also investigated whether response time and inter-item variability in craving item responses were influenced by level of nicotine dependence. Although both dependent and nondependent smokers report craving for cigarettes, the magnitude and patterning of craving vary as a function of dependence level. Nondependent smokers report heightened craving during episodes of smoking or in the presence of smoking-related stimuli (e.g., Sayette, Martin, Wertz, Shiffman, & Perrott, 2001), but generally report low levels of craving in the absence of cigarette cues. To the extent that response time and inter-item variability reflect craving certainty, we hypothesized that nondependent smokers would be more certain (have fast response time and less inter-item variability) about their craving report when presented with neutral cues that elicit low levels of craving consistent with their low craving experience relative to when confronted with smoking stimuli. In contrast, though dependent smokers report substantial craving when cues are not present (e.g., DiFranza, Ursprung, & Biller, 2012), their craving is strongly augmented by presentations of smoking cues. Therefore, we predicted that dependent smokers would be relatively more certain about their craving report in the presence of smoking cues than in the presence of neutral cues.

Given recent emphasis on studying craving with regard to its relationship with other features of smoking (e.g., Perkins, 2009; Sayette et al., 2000), the current study also examined response time as a predictor of nicotine dependence. Previous research has shown that craving level is associated significantly with level of nicotine dependence (Germeroth, Wray, Gass, & Tiffany, 2013). Consequently, this analysis focused on the potential incremental validity of response time relative to craving level as a predictor of nicotine dependence. The incremental validity of inter-item variability in the prediction of nicotine dependence was also investigated.

Though we examined both craving item response time and inter-item variability, our primary interest was in response time as a novel, implicit measure of craving-related processes. Inter-item variability is limited as it is necessarily restricted at the extreme ends of the scale. That is, people who give uniformly high or low craving ratings will have correspondingly low inter-item variability as a consequence of how this variable is

calculated. Response time, however, is not constrained in this manner and, thus, offers a measure of craving certainty not limited by the craving scale.

Methods

Participants

Two hundred and sixty adult smokers (131 males/129 females) were recruited for the current study. Nondaily smokers (defined as individuals who smoked 1 – 29 days over the past 30 days prior to study entry) were over-recruited to ensure a wide range of smoking levels in the sample. Participants were between 18 and 45 years old, proficient in reading English, not trying to quit over the past month nor intending to quit over the next two months, had not used nicotine or tobacco in any form other than cigarettes in the past 12 months, had smoked at least 25 lifetime cigarettes, and had not been diagnosed with drug dependence (other than nicotine) in the past 12 months. Cue-reactivity procedures occurred at five sessions. Participants were compensated with \$30 at the end of Sessions 1, 2, 3, and 4 and up to \$110 after Session 5. Participants were recruited as part of a larger study evaluating the validity of biomarkers and various self-report assessments of smoking (Wray et al., 2014).

Assessments

Cigarette craving—Baseline cigarette craving was assessed at each session immediately prior to cue presentation using the Craving Questionnaire, a four-item subscale of the Questionnaire on Smoking Urges (Carter & Tiffany, 2001): “All I want right now is a cigarette,” “Nothing would be better than smoking a cigarette right now,” “I have an urge for a cigarette,” and “I crave a cigarette right now.” Participants responded to each item for how they felt about cigarettes “right now,” using a 7-point Likert scale, from 1 (*strongly disagree*) to 7 (*strongly agree*). Participants viewed craving items on a computer monitor one item at a time and answered using a 7-key response box, with each key labeled with its respective number from left (1) to right (7), spaced .75 cm apart. When participants selected their response, the screen advanced to the next item. If participants responded too quickly (200 ms or faster) after item presentation, a message stating, “Please Read Carefully!” appeared on the screen before advancing to the next item. Craving Questionnaire items (and all other items) were presented in random order at each administration.

Cue-specific craving was assessed after the presentation of each cue with the Craving Questionnaire, but the wording of items was altered to capture craving experienced during the just-presented cue (neutral or smoking): “All I wanted right then was a cigarette,” “Nothing would have been better than smoking a cigarette,” “I had an urge for a cigarette,” and “I craved a cigarette.” Participants were instructed to choose the single best answer from 1 to 7 to indicate how they felt *while* looking at the photograph or in vivo cue (either a “cigarette” or “neutral object”). The order of the four craving items was randomized at each presentation. The Craving Questionnaire was highly reliable (all $\alpha = .98-.99$ after smoking and neutral cues) and craving scores were stable across sessions¹ (average $r = .76$ and $.78$ for post-neutral and post-smoking cues, respectively, in the current study).

¹Stability was calculated as correlations across all pairs of sessions.

Smoking history and current use—Participants completed a questionnaire about their smoking history at Session 1. Current cigarette consumption was also assessed at Session 1 using a 28-day Timeline Follow Back Interview (TLFB; Sobell & Sobell, 1996).

Nicotine dependence—Dependence was assessed at Session 1 using the Nicotine Addiction Taxon Scale (NATS; Goedeker & Tiffany, 2008), a 12-item measure that categorizes smokers as dependent or nondependent. The NATS is an empirically-validated instrument that identifies a nicotine addiction taxon derived from analyses of two large sample replications generated from the National Survey of Drug Use and Health (Office of Applied Studies, 2003, 2004). Based on previous research (Goedeker & Tiffany, 2008), individuals scoring ≥ 14.33 were considered within the nicotine addiction taxon ($n = 63$ (24%); M score of 18.1, $SD = 2.9$), whereas scores < 14.33 indicated nondependence ($n = 197$ (76%); M score of 9.7, $SD = 2.3$). The reliability of the NATS total score in the current study was $\alpha = .90$.

Nicotine dependence was also assessed using the 68-item Wisconsin Inventory of Smoking Dependence Motives (WISDM-68; Piper et al., 2004) at a non-cue-reactivity session that took place during week 5. The continuous total score, generated from the WISDM-68's 13 subscales, evidenced high reliability in the current study ($\alpha = .98$). Research has repeatedly confirmed convergent validity of the WISDM-68, with significant correlations found between the WISDM-68 and several other measures of nicotine dependence (Piper, McCarthy, & Baker, 2006; Piper et al., 2008a; Piper et al., 2008b).

Response time—DirectRT Precision Timing software (Empirisoft Corporation, New York, NY) was used for the assessment of response time to participants' craving item ratings collected during the cue-reactivity portion of the sessions. Response time was measured as the time (ms) between item presentation and depression of the chosen response key on the response box (DirectIN High Speed Button-Box, Empirisoft Corporation, New York, NY). Response time was highly reliable in the current study (all $\alpha = .87-.89$ for post-neutral cue and post-smoking cue response times) and was moderately stable across sessions (average $r = .67$ and $.61$ for post-neutral and post-smoking cues, respectively).

Inter-item variability—The calculation of inter-item variability is described in the Data Reduction and Analysis section. Split-half procedures were used to determine the reliability of inter-item variability, which indicated strong correlations after neutral cues (all r s between 0.85 and 0.92, all $ps < .0001$) and after smoking cues (all r s between 0.82 and 0.91, all $ps < .0001$). Inter-item variability was moderately stable in the current study (average $r = .58$ and $.61$ for post-neutral and post-smoking cues, respectively).

Procedures

Participants attended five cue-reactivity laboratory sessions over the course of three months to allow for the examination of stability of response time to craving ratings. There was an inter-session interval of one week for Sessions 1–4 (spanning four weeks) and participants returned 12 weeks after Session 1 to complete Session 5. The NATS, TLFB, and Smoking History Form were completed at the beginning of Session 1. Participants were administered

the Craving Questionnaire at baseline and then completed the cue-reactivity procedure at Sessions 1–5. The WISDM-68 was administered at a non-cue-reactivity session that took place during week 5 (that session will not be discussed further as the cue-reactivity procedure was not administered during that session).

Cue-reactivity procedure—Participants observed smoking and neutral cues, presented as photographic and in vivo cues (objects that the participant held and observed), during the cue-reactivity procedure (based on procedures described in Wray et al., 2014²; Wray, Godleski, & Tiffany, 2011). Before the cue-reactivity procedure began, participants were instructed to take out one cigarette and one neutral object (a neutral object was described as an item that participants did not associate with smoking, such as car keys). If participants did not have a cigarette, a cigarette of the participants' preferred brand was provided. The cigarette and neutral object were placed under separate boxes located behind the participant. Participants sat at a table that contained the response box, placed in front of participants, and a 24-in computer screen located behind the response box. Instruction sets, self-report items, and photographic cues were administered on the computer screen.

Participants engaged in one neutral, photographic and then one neutral, in vivo practice trial. They were first presented with instruction sets describing the upcoming cue administration. When an instruction set was presented during practice trials (and all other cue-reactivity trials), a delay of three s occurred—during which participants could not advance to the next screen—to increase the probability of participants reading instructions. After the three s delay, participants were instructed to “Press any key to continue” to advance to the next screen. Participants were then presented a photographic, neutral cue on the computer screen for 10 s (details about the photographic cues are provided in Wray et al., 2014; Wray et al., 2011). After 10 s, a tone sounded, and the computer advanced to the post-cue Craving Questionnaire items, presented one at a time. When the participant provided a response to a Craving Questionnaire item, the screen automatically advanced to the next item. After the completion of the Craving Questionnaire, participants completed two mood items and two items assessing concentration and distraction during the cue presentation (mood, concentration, and distraction items were not included in analyses and therefore, are not discussed further in the current manuscript). After completing all self-report items, the computer provided instructions sets for engaging in a breathing exercise. The breathing exercise promoted a shift in focus away from the cue previously displayed and was presented at a variable duration between 21 and 25 s. During the breathing exercise, participants were instructed to close their eyes and focus attention on their breathing. The breathing exercise ended when a tone sounded and the participant advanced to the next screen.

Participants then engaged in an in vivo, neutral practice trial. They were first instructed to take their neutral object out of the box and hold it in their hand before advancing to the next instruction set. Once participants advanced to the next screen, they were instructed to hold and look at the object until a tone sounded (after 10 s). When the tone sounded, participants

²The self-reported craving findings of this study are described in considerable detail for nondaily smokers in Wray et al. (2014).

were instructed to put away the object under the box and advance to the next screen after doing so. After the cue was replaced beneath the box and participants advanced to the next screen, participants responded to the self-report items (Craving Questionnaire, mood, concentration, and distraction items) and engaged in a breathing exercise.

After the two practice trials, participants began the cue-reactivity procedure during which data were collected. These procedures were identical to those that participants engaged in during the two practice trials, with the exception that half of the trials were smoking trials and half were neutral. A total of 12 trials with 3 of each cue type and mode of presentation (in vivo smoking, in vivo neutral, photographic smoking, and photographic neutral) were delivered in randomized order during each session.

Data Reduction and Analyses

Craving scores—Post-cue Craving Questionnaire scores were calculated by averaging the 12 craving items within each cue type/cue mode with separate average craving scores for in vivo smoking, in vivo neutral, photographic smoking, and photographic neutral cues.

Response time—An examination of box plots indicated positive skew of response time data as well as outliers. The data were not transformed as log transformations improved Shapiro-Wilk statistics for nondependent smokers' response time data but worsened these statistics for dependent smokers. Thus, outliers that were 3 SDs above the mean were removed (13 and 12 response time values for post-neutral and post-smoking cues, respectively, equivalent to 1% of response time data). Average response times (*ms*) were calculated across the 12 post-cue craving items administered within each cue type/cue mode presented.

Inter-item variability—Variability in responding to Craving Questionnaire items was calculated for each participant, at each session, and for smoking and neutral cues separately³. The following equation shows the calculation of inter-item variability associated with the cue observed (*c*; smoking or neutral) and is described in terms of calculations for smoking cue items (*i*) 1 through 24:

$$\text{inter-item variability}_c = \frac{\left\{ \sum_{i=1}^{24} \sqrt{\{(\bar{x}_c - R_i)^2\}} \right\}}{24}$$

(with $\bar{x}_c$ average of the 24 craving items across all smoking cue trials and R_i each craving item rating after smoking cues).

Analyses—Repeated measures ANOVAs were conducted to analyze effect of cue type (smoking, neutral) and nicotine dependence (dependent, nondependent) on response time to post-cue craving items and on inter-item variability⁴. Given there were no significant interactions with cue mode (photographic relative to in vivo), all craving level, response

³As described in the Results section, there was no effect of cue mode on response time, and thus, all response time and inter-item variability data were collapsed across cue mode.

time, and inter-item variability data were aggregated across cue mode. To evaluate the effectiveness of the cue-reactivity procedure on craving self-report, repeated measures ANOVAs were performed examining the effect of cue type on craving level and change in craving level from baseline to post-neutral and post-smoking cues.

Polynomial regression analyses were also conducted to determine if the associations between post-cue response time and cue-elicited craving and between inter-item variability and cue-elicited craving were best characterized by quadratic trends relative to linear trends. Quadratic was the highest order polynomial assessed due to significance of this order indicating the presence of inverted-U effects. Correlational analyses were performed to assess the association between post-cue response time and inter-item variability.

Finally, sequential multiple regression analyses were performed (using centered predictor variables) with craving level predicting WISDM-68 total scores in Step 1 and the addition of either response time or inter-item variability (performed in separate models) in Step 2. These analyses were conducted using response time and inter-item variability values collapsed across the five sessions.

Results

Participant Characteristics

Two hundred and sixty participants were included in analyses. At Sessions 1–5, $n = 256$, 246, 239, 229, and 213 participated in experimental sessions, respectively. Two hundred and seventeen participants completed all 5 sessions and 15, 9, 8, and 11 participants completed 4, 3, 2, and 1 session, respectively. The following percentages of data were missing at Sessions 1–5, respectively: 2%, 5%, 8%, 12%, and 18%⁵. All data were missing as a consequence of participants not showing to study sessions or DirectRT malfunction and thus, when data were missing for a participant, they were missing on all variables of interest.

Dependent smokers averaged 28.2 years of age ($SD = 7.8$) and 38% were of minority status ($n = 1$ American Indian or Alaska Native, 6 Asian, and 17 Black or African American). On average, these participants had been smoking 13.9 years ($SD = 9.8$) and, according to the TLFB, smoked 14.0 cigarettes per day over the past 28 days ($SD = 9.1$). Approximately 60% had made quit attempts with an average of 3.1 ($SD = 2.1$) quit attempts. Among dependent smokers, 41.3% were employed, 36.5% were students, and approximately 75% completed high school or received higher education.

Nondependent smokers averaged 24.8 years of age ($SD = 5.9$) and 34% were of minority status ($n = 4$ American Indian or Alaska Native, 47 Asian, 1 Native Hawaiian or other Pacific Islander, and 14 Black or African American). On average, these participants had

⁴Multilevel models were also examined to determine effects of attrition. Those analyses, however, indicated similar findings to repeated measures ANOVAs and thus, repeated measures ANOVAs are reported in full in the Results section. See footnotes in the Results section for comparisons of omnibus repeated measures ANOVAs with multilevel model findings.

⁵Data were missing at random, evidenced by creating a categorical dummy variable for each participant indicating whether data were “missing” or “non-missing.” All demographic and smoking variables (age, sex, ethnicity, race, smoking level, nicotine dependence level), as well as primary variables of interest (craving level, response time, inter-item variability), did not predict whether data were missing (all ps between .09 and .93).

been smoking 9.4 years ($SD = 7.4$) and smoked 1.7 cigarettes per day over the past 28 days ($SD = 1.5$). Approximately 50% had made quit attempts with an average of 2.4 ($SD = 1.3$) quit attempts. Among nondependent smokers, 51.7% were employed, 61.9% were students, and approximately 87% completed high school or received higher education. Income and socioeconomic status data were not collected.

Impact of Cue-Reactivity Procedure on Self-Reported Craving

Craving significantly increased from baseline to post-smoking cues and significantly decreased from baseline to post-neutral cues for nondependent smokers (all $ps < .0001$; $\eta^2_{ps} = 0.21$ – 0.28 for smoking cues, and $\eta^2_{ps} = 0.18$ – 0.24 for neutral cues) and dependent smokers (all $ps < .0001$, $\eta^2_{ps} = 0.28$ – 0.46 for smoking cues, and all $ps < .001$, $\eta^2_{ps} = 0.14$ – 0.33 for neutral cues) at all sessions. Post-smoking cue craving was significantly higher relative to post-neutral cue craving for both nondependent (all $ps < .0001$; $\eta^2_{ps} = 0.43$ – 0.56) and dependent smokers (all $ps < .0001$; $\eta^2_{ps} = 0.57$ – 0.65 ; Table 1) at all sessions. Dependent smokers had significantly higher post-neutral and post-smoking cue craving ratings compared to nondependent smokers (all $ps < .0001$ for both cue types; $\eta^2_{ps} = 0.08$ – 0.20 for post-neutral cue craving, and $\eta^2_{ps} = 0.09$ – 0.18 for post-smoking cue craving).

Response Time and Inter-Item Variability Comparisons between Cue Type

Repeated measures ANOVAs indicated a significant 3-way interaction ($2 \times 5 \times 2$) of cue type (neutral, smoking), session (Sessions 1–5), and nicotine dependence (nondependent, dependent) on post-cue response time ($F(4,752) = 7.77$, $p < .0001$, $\eta^2_p = 0.04$)⁶. Analyses also indicated a significant 2-way interaction of cue type and nicotine dependence on inter-item variability ($F(1,199) = 18.98$, $p < .0001$, $\eta^2_p = 0.09$)⁷. Therefore, all response time and inter-item variability analyses were performed separately by cue type, level of nicotine dependence, and session.

For nondependent smokers, response time to craving items was significantly faster after neutral cues compared to after smoking cues at all sessions (Table 2): Session 1 ($F(1,190) = 36.09$, $p < .0001$, $\eta^2_p = 0.16$), Session 2 ($F(1,180) = 19.82$, $p < .0001$, $\eta^2_p = 0.10$), Session 3 ($F(1,174) = 17.97$, $p < .0001$, $\eta^2_p = 0.09$), Session 4 ($F(1,176) = 15.48$, $p = .0001$, $\eta^2_p = 0.08$), and Session 5 ($F(1,162) = 18.28$, $p < .0001$, $\eta^2_p = 0.10$). For dependent smokers, response time to craving items was significantly faster after smoking cues compared to after neutral cues, but this effect was significant at Session 1 only ($F(1,59) = 14.84$, $p = .0003$, $\eta^2_p = 0.20$; Table 2). All other ps were between .26 – .78 for dependent smokers.

For nondependent smokers, inter-item variability was significantly lower after neutral cues compared to after smoking cues at all five sessions (all $ps < .0001$, all η^2_{ps} between 0.09 and 0.18; Table 2). For dependent smokers, inter-item variability was significantly lower after smoking cues compared to after neutral cues at Session 1 ($F(1,61) = 5.09$, $p = .03$, $\eta^2_p =$

⁶A multilevel model with a random intercept indicated findings comparable to those of the repeated measures ANOVA with a significant 3-way interaction of cue type, session, and nicotine dependence predicting response time: $F(4, 2065) = 3.99$, $p = .003$.

⁷A multilevel model with a random intercept indicated findings comparable to those of the repeated measures ANOVA with a significant 2-way interaction of cue type and nicotine dependence predicting inter-item variability: $F(1, 2086) = 68.33$, $p < .0001$.

0.07), Session 2 ($F(1,58) = 5.46, p = .02, \eta_p^2 = 0.09$), and Session 3 ($F(1,57) = 4.16, p = .04, \eta_p^2 = 0.07$). At Sessions 4 and 5, $ps = .42$ and $.75$, respectively.

Examination of Inverted-U Response Time and Inter-Item Variability Effects

Polynomial regression analyses indicated that the associations between craving level and response time as well as inter-item variability were better captured by quadratic than by linear relationships. Significant quadratic relationships were found between response time and craving level after the presentation of both cue types (neutral and smoking) for both nondependent and dependent smokers at all sessions (all ps between $<.0001$ and $.04$ for quadratic trends; Table 3). The associations between inter-item variability and craving level showed the same pattern of significant quadratic relationships across levels of dependence and sessions (all $ps <.001$ for quadratic trends; Table 3). The significant higher order quadratic trends provided evidence of inverted-U response time and variability effects during the cue-reactivity procedure for all smokers at all sessions. The inverted-U response time effect suggested fast response time to craving items for smokers experiencing low or high craving and slower response time to craving items for smokers experiencing moderate craving (see Figure 1 for an example of significant quadratic trends at Session 1 for nondependent and dependent smokers). The inverted-U variability effect suggested less inter-item variability for smokers experiencing low or high craving and greater inter-item variability for smokers experiencing moderate craving.

Association between Response time and Inter-Item Variability

Correlational analyses assessing the relationship between response time and inter-item variability indicated that, for nondependent smokers at each session and for each cue type presented, greater inter-item variability was associated significantly with slower response time (all rs between 0.23 and 0.42 , all $ps <.002$). For dependent smokers, there were significant positive correlations between response time and inter-item variability at each session after smoking cues (all rs between 0.37 and 0.61 , all ps between $<.0001$ and $.003$). Significant positive correlations between response time and inter-item variability also emerged for dependent smokers after neutral cues at Session 1 ($r = 0.30, p = .02$) and Session 5 ($r = 0.32, p = .02$). This association was nonsignificant at Sessions 2, 3, and 4 (all rs between 0.16 and 0.24).

Incremental Validity of Response Time and Inter-Item Variability

Sequential multiple regression analyses indicated significant partial models (Step 1) with craving predicting nicotine dependence levels (for post-smoking cue response times: $F(1,212) = 170.01, p <.0001, B = 6.034, R^2 = 0.44$; for post-neutral cue response times: $F(1,212) = 141.68, p <.0001, B = 6.747, R^2 = 0.40$). Incremental validity of response time was evident when response time was added as a predictor variable in Step 2 (for post-smoking cue response times: $F(1,212) = 7.14, p = .01, B = 0.003, R^2 = 0.46, sr_i^2 = 0.02$; for post-neutral cue response times: $F(1,212) = 13.25, p = .0003, B = 0.005, R^2 = 0.43, sr_i^2 = 0.04$). The positive nonstandardized regression coefficients (B) indicated that, when holding craving level constant, slow response time predicted higher nicotine dependence scores, regardless of cue type. Analyses assessing the incremental validity of inter-item variability

indicated nonsignificance when this predictor was added in Step 2 ($p = .29$ and $.61$ for post-smoking and post-neutral cue inter-item variability, respectively).

Discussion

The current findings suggest that craving item response time can be used as an implicit measure of craving-related processes, and that this measure provides incremental significant prediction of nicotine dependence over and above craving level. The relationship of both response time and inter-item variability with craving report took the form of an inverted-U; this pattern emerged consistently regardless of dependence level, cue type, or session. Similar inverted-U effects, with response time faster at the extremes of the response format and slower at the middle of the response format, have been found repeatedly in previous studies examining other constructs.

The processes underlying inverted-U response time effects have not been thoroughly investigated. Personality researchers have attributed these effects to the consistency or inconsistency of items with one's self-schema (e.g., Kuiper, 1981), but have not directly tested this hypothesis (i.e., manipulated self-schemas and simultaneously observed changes in response time to item responses). Other researchers (e.g., Mignault et al., 2008) have suggested that inverted-U response time *and* variability effects result from the use of common mental processes, such as stimulus representation and response selection, which are generated as a consequence of task constraints. Mignault et al. noted that, as inverted-U effects routinely emerge on tasks in which participants make response choices along a Likert scale, these effects likely reflect the operation of common processes across rating tasks. In the current study, we hypothesized that this general phenomenon may partly reflect certainty in responding to craving items. We characterized response certainty as both response time in responding to craving items and as inter-item variability, a common operationalization of response certainty (e.g., Mignault et al., 2008).

In the current study, small to large correlations (as defined by Cohen, 1988) emerged between response time and inter-item variability. These correlations bolstered our hypothesis that response time and response variability are related and potentially reflect the same underlying construct, which may be craving certainty. Certainty has been typically defined as "a subjective sense of conviction or validity about one's attitude or opinion" (Gross, Holtz, & Miller, 1995, pp. 215). To the extent that people are uncertain about their craving ratings, they will generally respond more slowly and with greater item-to-item variability. Though we operationalized certainty as both response time and inter-item variability, it is unclear exactly what processes underlie certainty in responding or whether these measures reflect a construct other than craving certainty.

Overall, moderate craving ratings were characterized by slowed response times and high inter-item variability. One explanation for this finding is that individuals responding at the middle of the response format simply have more response options to choose from relative to those responding at the extremes. Therefore, smokers endorsing moderate craving levels may have an increased likelihood of choosing different craving ratings on an item-to-item basis relative to smokers endorsing very low or high craving levels, thereby increasing the

likelihood of slowed response latency for middle responders. The middle of Likert scales has also been considered a “dumping ground for not applicable, uncertain, indifferent or ambivalent response orientations” (Kulas & Stachowski, 2009, pp. 489). Thus, those who have increased latency and variability in responding at the middle of the response format may have reduced confidence in their responses or are determining whether or not the item applies to them before opting for the middle-ground rating.

It is also unclear if individuals rating moderate craving are in fact certain about their craving experience, but are simply unsure of what rating to select, thereby resulting in increased response latency. Another possible explanation for the inverted-U effects is the human tendency to categorize and dichotomize (Moberg, 2013). Individuals may make response choices more quickly when they feel they are experiencing very strong or weak craving (ratings at the extremes of a Likert scale), compared to individuals who are experiencing moderate craving and need to spend more time determining where they fall in the middle of the response options. Though we posit that response time and inter-item variability reflect craving certainty, there may be other explanations for these findings, and more data are needed to fully understand the cognitive processes underlying the choices people make when rating their craving.

Although inverted-U effects emerged across both cue types at all sessions for both dependent and nondependent smokers, the data also indicated that there were fundamental differences between dependent and nondependent smokers in their response times to craving items as a function of cue type. Response time was faster and inter-item variability was lower for nondependent smokers after neutral relative to smoking cues and for dependent smokers after smoking relative to neutral cues. To the extent that fast response time and low inter-item variability reflect certainty, these findings support the idea that dependent and nondependent smokers responded to craving items with greater certainty after the presentation of cues that produced craving experiences consistent with what these smokers typically experience. Though nondependent smokers experience heightened craving in response to smoking cues (e.g., Shiffman et al., 2013b), they more often experience low levels of craving in general (e.g., Shiffman, Kassel, Paty, Gnys, & Zettler-Segal, 1994). Therefore, when nondependent smokers were presented with neutral cues, they experienced very little craving, and that was fairly consistent with their common, daily experience of low levels of craving. Dependent smokers, on the other hand, often experience moderate levels of craving in general and strong reactivity to smoking cues (e.g., Sayette et al., 2001). The presentation of smoking cues for these smokers induced high craving levels likely consistent with their typical experience when confronted with smoking-related stimuli. Consequently, these smokers responded with greater certainty (more quickly and with less inter-item variability) to craving items after smoking relative to neutral cues.

Previous research using taxometric analyses has indicated that tobacco dependence may be a categorical as opposed to a dimensional phenomenon (Goedeker & Tiffany, 2008). Response time differences between cue type as a function of the dependence classification is consistent with a taxonic latent structure, highlighted by the fact that the measure used to categorize smokers as dependent or nondependent in previous taxometric research, the Nicotine Addiction Taxon Scale (NATS), was also used in the current investigation.

Response time was also found to be incrementally valid, above craving level, in predicting a continuous measure of nicotine dependence, such that when holding craving level constant, slower response time predicted higher nicotine dependence scores. The extent to which this relationship reflects something specific about dependence and craving or is more generally indicative of slowed response time in dependent as opposed to nondependent smokers cannot be determined from our data. The ease of collecting response time data when craving items are administered via computer with reliable response time data collection methods underscores the feasibility of assessing this craving-related construct. Conversely, inter-item variability, though also easily examined when collected via computer or paper-and-pencil administration of craving items, was not incrementally predictive of nicotine dependence in the current study, thereby bolstering the view that response time is a superior measure of implicit craving-related processes relative to inter-item variability.

Though there were significant differences in response time between cue type at all sessions for nondependent smokers, significant differences were only present at the first session for the dependent smokers. The disappearance of this effect for dependent smokers after the first session might be a function of the smaller number of dependent smokers with the correspondingly lower level of power to detect effects. It is also possible that the dependent smokers became more familiar with the assessments and structure of the laboratory manipulations as the sessions progressed and became more certain about their craving ratings in the presence of neutral cues. In contrast, when nondependent smokers were confronted with smoking cues across sessions, they may have remained more uncertain about the impact of those stimuli on their craving responses.

Implications and Future Directions

Research on craving has often focused on understanding craving-related processes, but more recently, the significance of studying craving and its link to smoking behavior has been highlighted (e.g., Perkins, 2009; Sayette et al., 2000). Cue-reactivity studies have been criticized for failing to examine the association between cue-elicited craving and smoking behavior, and some researchers (e.g., Perkins, 2009) have proposed that non-self report correlates of cue-elicited craving may be stronger predictors of relapse and other smoking behaviors than explicit, self-report craving. Previous research on the ability of self-reported craving to predict smoking behavior has produced mixed results (e.g., Gass, Motschman, & Tiffany, in press; Payne, Smith, Adams, & Diefenbach, 2006; Sayette et al., 2000; Shiffman et al., 2013a; Waters et al., 2004). The generally weak findings for explicit measures of craving as predictors of drug use open the door for exploring the predictive utility of implicit measures of craving. Additionally, research indicating that attitudes held with certainty are more likely to predict relevant behaviors in comparison to attitudes held with less certainty (Gross et al., 1995; Kraus, 1995) underscores the potential value of examining the ability of certainty in craving ratings to predict drug use.

Determining whether implicit measures of craving-related processes, such as response time, are predictive of clinically-relevant outcomes (e.g., relapse) can aid our understanding of smoking maintenance and cessation success or failure. DeMarree and colleagues (2007) indicated that, in the attitudes domain, certainty can influence likelihood of change.

Specifically, attitudes held with certainty are less likely to change than attitudes held with less certainty (Bassili, 1996). Examination of varying certainty levels (via response time and inter-item variability) and simultaneous craving levels may help identify particular subgroups of smokers that are more or less successful at maintaining abstinence. For instance, treatment-seeking smokers reporting strong craving held with certainty may have greater difficulty staying quit than those with strong craving held with less certainty.

Research would also benefit from directly testing different theories underlying inverted-U response time effects. Though the current study examined the relationship between response time and inter-item variability, the findings were correlational in nature and did not include manipulations of certainty. Our findings suggested that response time and inter-item variability were associated and highly correlated in some instances (for dependent smokers after smoking cues at Sessions 3–5). However, the majority of correlations between response time and inter-item variability indicated small to medium correlations, and in some cases (for dependent smokers), were nonsignificant, suggesting that these variables were not tightly coupled. In addition to craving certainty, response time may partially reflect response selection constraints, consistency or inconsistency with self-schema, memory accessibility, or other mental processes. Therefore, future research should consider using experimental manipulations of certainty to establish causality (Stacy & Wiers, 2010). Additionally, the inclusion of self-report items that explicitly reflect certainty has been suggested (e.g., “I am certain about...;” DeMarree, Petty, & Briñol, 2007) and could contribute to our understanding of the relationships between face-valid certainty items and implicit measures hypothesized to reflect certainty.

Future research might also focus on examining potential moderators of the relationship between craving level and response time. For example, dependent smokers experiencing peak-provoked craving (heightened craving due to the combination of abstinence and exposure to smoking cues; Sayette & Tiffany, 2013) may experience faster response times during smoking cues due to the heightened salience of the craving state and, thus, greater confidence in their level of craving. Alternatively, abstinence may introduce cognitive impairment (e.g., Domier et al., 2007) and produce overall slowed response times. Ambivalence about craving may also moderate the relationship between craving level and response time. A smoker who is conflicted about craving (e.g., if interested in quitting smoking) might generate slowed responses to craving items relative to a smoker who is uninterested in quitting.

Finally, future research should aim to replicate the current study’s findings with attention to certain procedural details. At the beginning of Session 1, participants completed the Smoking History Form, which included a variety of dependence and craving measures that may have primed participants to respond in certain ways during the cue-reactivity procedure. Read and colleagues (2004) suggested that priming effects may occur when self-report measures are administered prior to subsequent tasks assessing similar outcomes. Priming effects (or first session novelty effects; LaRowe et al., 2007) may be responsible for response time differences between cue type that emerged for dependent smokers only at Session 1, although it is unclear why these results did not emerge for nondependent smokers. It is also possible that dependent smokers became more familiar with the

assessments and structure of the laboratory manipulations as the sessions progressed and became more certain in their craving ratings in the presence of neutral cues. In order to diminish potential priming effects of smoking-related questionnaires, researchers should consider administering smoking-related questionnaires at the end of study sessions. In addition, participants in the current study were not asked to answer items as quickly and accurately as possible, a common instruction in response time studies, which should be considered in follow-up studies. Further, there was no standardization of hand or finger placement between craving item presentations, and the 1 to 7 rating scale anchors were presented in the same orientation for all participants. Despite these limitations, the overall pattern of results was not clearly attributable to position effects.

Summary

The current study examined a novel, implicit measure of response time that assessed processes underlying craving response choices. Our study revealed inverted-U response time and variability effects at multiple sessions, across several administrations of smoking and neutral cues, and across several administrations of craving items. Inverted-U response time and inter-item variability effects have been examined separately in previous studies (e.g., Mignault et al., 2008). However, until now, researchers have not thoroughly examined the association between these measures despite predictions that inverted-U response time effects may be associated with response variability (Casey & Tryon, 2001). The present study, therefore, added to our general understanding of the association between response time and inter-item variability and how these variables may reflect underlying general processes that emerge with the completion of items on a continuous response format. Our study also examined response time and item variability effects within a cue-reactivity procedure designed to systematically manipulate craving levels. This procedure allowed us to manipulate craving levels and observe simultaneous changes in response time and inter-item variability between dependent and nondependent smokers and between cue type. Differences in response times between dependent and nondependent smokers as a function of cue type bolstered the perspective that dependence is a taxonomic latent structure. Response time also provided incremental validity above craving level in predicting nicotine dependence. Overall, the results indicated that, in addition to self-reports of craving level, the speed with which smokers rate their craving may provide important insight into the cognitive processes that contribute to the generation of craving.

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References

- Akrami N, Hedlund LE, Ekehammar B. Personality scale response latencies as self-schema indicators: The inverted-U effect revisited. *Personality and Individual Differences*. 2007; 43:611–618.10.1016/j.paid.2006.12.005

- Asendorpf JB, Banse R, Mücke D. Double dissociation between implicit and explicit personality self-concept: The case of shy behavior. *Journal of Personality and Social Psychology*. 2002; 83:380–393.10.1037/0022-3514.83.2.380 [PubMed: 12150235]
- Avant LL, Bevan W, Wing H. Effects of varying length of stimulus series and response scale upon response latency, response uncertainty, and transmitted information. *Perception & Psychophysics*. 1968; 3:449–452.10.3758/BF03205753
- Bassili JN. Meta-judgmental versus operative indexes of psychological attributes: The case of measures of attitude strength. *Journal of Personality and Social Psychology*. 1996; 71:637–653.10.1037/0022-3514.71.4.637
- Behar I. On the relation between response uncertainty and reaction time in category judgments. *Perceptual & Motor Skills*. 1963; 16:595–596.10.2466/pms.1963.16.2.595 [PubMed: 13970277]
- Brown SD, Marley AAJ, Donkin C, Heathcote A. An integrated model of choices and response times in absolute identification. *Psychological Review*. 2008; 115:396–425.10.1037/0033-295X.115.2.396 [PubMed: 18426295]
- Carter BL, Tiffany ST. The cue-availability procedure: The effects of cigarette availability on cue reactivity in smokers. *Experimental and Clinical Psychopharmacology*. 2001; 9:183–190.10.1037/1064-1297.9.2.183 [PubMed: 11518094]
- Casey MM, Tryon WW. Validating a double-press method for computer administration of personality inventory items. *Psychological Assessment*. 2001; 13:521–530.10.1037/1040-3590.13.4.521 [PubMed: 11793895]
- Coffey SF, Saladin ME, Libet JM, Drobos DJ, Dansky BS. Differential urge and salivary responsibility to alcohol cues in alcohol-dependent patients: A comparison of traditional and stringent classification approaches. *Experimental and Clinical Psychopharmacology*. 1999; 7:464–472.10.1037/1064-1297.7.4.464 [PubMed: 10609981]
- Cohen, J. *Statistical power analysis for the behavioral sciences*. 2. Hillsdale, NJ: Erlbaum; 1988.
- De Houwer, J. What are implicit measures and why are we using them. In: Wiers, RW.; Stacy, AW., editors. *Handbook of implicit cognition and addiction*. Thousand Oaks, CA: Sage Publications, Inc; 2006. p. 11-28.
- De Houwer J, Teige-Mocigemba S, Spruyt A, Moors A. Implicit measures: A normative analysis and review. *Psychological Bulletin*. 2009; 135:347–368.10.1037/a0014211 [PubMed: 19379018]
- DeMarree KG, Petty RE, Briñol P. Self-certainty: Parallels to attitude certainty. *International Journal of Psychology and Psychological Therapy*. 2007; 7:159–188.
- DiFranza JR, Sanouri Ursprung WW, Biller L. The developmental sequence of tobacco withdrawal symptoms of wanting, craving, and needing. *Pharmacology, Biochemistry and Behavior*. 2012; 100:494–497.10.1016/j.pbb.2011.10.018
- Domier CP, Monterosso JR, Brody AL, Simon SL, Mendrek A, Olmstead R, Jarvik ME, Cohen MS, London ED. Effects of cigarette smoking and abstinence on stroop task performance. *Psychopharmacology*. 2007; 195:1–9.10.1007/s00213-007-0869-x [PubMed: 17634928]
- Erblich J, Bovbjerg DH, Sloan RP. Exposure to smoking cues: Cardiovascular and autonomic effects. *Addictive Behaviors*. 2011; 36:737–742.10.1016/j.addbeh.2011.02.011 [PubMed: 21419576]
- Fazio RH, Olson MA. Implicit measures in social cognition research: Their meaning and use. *Annual Review of Psychology*. 2003; 54:297–327.10.1146/annurev.psych.54.101601.145225
- Gass JC, Motschman CA, Tiffany ST. The relationship between craving and tobacco use behavior in laboratory studies: A meta-analysis. *Psychology of Addictive Behaviors*. (in press).
- Germeroth LJ, Wray JM, Gass JC, Tiffany ST. Diagnostic utility of craving in predicting nicotine dependence: Impact of craving content and item stability. *Nicotine and Tobacco Research*. 2013; 12:1988–1995. [PubMed: 23817585]
- Goedeker KC, Tiffany ST. On the nature of nicotine addiction: A taxometric analysis. *Journal of Abnormal Psychology*. 2008; 117:896–909.10.1037/a0013296 [PubMed: 19025235]
- Gross, SR.; Holtz, R.; Miller, N. Attitude certainty. In: Petty, RE.; Krosnick, JA., editors. *Attitude strength: Antecedents and consequences*. Hillsdale, NJ: Lawrence Erlbaum Associates; 1995. p. 215-245.
- Hommer DW. Functional imaging of craving. *Alcohol Research & Health*. 1999; 23:187–196. [PubMed: 10890814]

- Kraus SJ. Attitudes and the prediction of behavior: A meta-analysis of the empirical literature. *Personality and Social Psychology Bulletin*. 1995; 21:58–75.10.1177/0146167295211007
- Kühn S, Gallinat J. Common biology of craving across legal and illegal drugs- A quantitative meta-analysis of cue-reactivity brain response. *European Journal of Neuroscience*. 2011; 33:1318–1326.10.1111/j.1460-9568.2010.07590.x [PubMed: 21261758]
- Kuiper NA. Convergent evidence for the self as a prototype: The “inverted-U RT effect” for self and other judgments. *Personality & Social Psychology Bulletin*. 1981; 7:438–443.10.1177/014616728173012
- Kulas JT, Stachowski AA. Middle category endorsement in odd-numbered Likert response scales: Associated item characteristics, cognitive demands, and preferred meanings. *Journal of Research in Personality*. 2009; 43:489–493.10.1016/j.jrp.2008.12.005
- LaRowe SD, Saladin ME, Carpenter MJ, Upadhyaya HP. Reactivity to nicotine cues over repeated cue reactivity sessions. *Addictive Behaviors*. 2007; 32:2888–2899.10.1016/j.addbeh.2007.04.025 [PubMed: 17537583]
- Mignault A, Marley AA, Chaudhuri A. Inverted-U effects generalize to the judgment of subjective properties of faces. *Perception & Psychophysics*. 2008; 70:1274–1288.10.3758/PP.70.7.1274 [PubMed: 18927009]
- Moberg, M. Engaging in anthropological theory: A social and political history. New York, NY: Routledge; 2013.
- Office of Applied Studies, Substance Abuse & Mental Health Services Administration. DHHS Publication No. SMA 03-2826, NHSDA Series H-20. Rockville, MD: Author; 2003. State estimates of substance use from the 2001 National Household Survey on Drug Abuse: Volume II. Individual state tables and technical appendices.
- Office of Applied Studies, Substance Abuse and Mental Health Services Administration. NSDUH Series H-25, DHHS Publication No. SMA 04-3964. Rockville, MD: Author; 2004. Results from the 2003 National Survey on Drug Use and Health: National Findings.
- Orleans CT, Rimer BK, Cristinzio S, Keintz MK, Fleisher L. A national survey of older smokers: Treatment needs of a growing population. *Health Psychology*. 1991; 10:343–351.10.1037/02786133.10.5.343 [PubMed: 1935870]
- Paulhus, DL.; Vazire, S. The self-report method. In: Robins, RW.; Fraley, RC.; Kruger, RF., editors. *Handbook of research methods in personality psychology*. New York, NY: The Guilford Press; 2007. p. 224-239.
- Payne T, Smith P, Adams S, Diefenbach L. Pretreatment cue reactivity predicts end-of-treatment smoking. *Addictive Behaviors*. 2006; 31:702–710.10.1016/j.addbeh.2005.05.053 [PubMed: 15979814]
- Perkins KA. Does smoking cue-induced craving tell us anything important about nicotine dependence? *Addiction*. 2009; 104:1610–1616.10.1111/j.13600443.2009.02550.x [PubMed: 19426293]
- Piper ME, Bolt DM, Kim SY, Japuntich SJ, Smith SS, Niederdeppe J, Baker TB. Refining the tobacco dependence phenotype using the Wisconsin Inventory of Smoking Dependence Motives (WISDM). *Journal of Abnormal Psychology*. 2008a; 117:747–761.10.1037/a0013298 [PubMed: 19025223]
- Piper ME, McCarthy DE, Baker TB. Assessing tobacco dependence: A guide to measure evaluation and selection. *Nicotine & Tobacco Research*. 2006; 8:339–351.10.1080/14622200600672765 [PubMed: 16801292]
- Piper ME, McCarthy DE, Bolt DM, Smith SS, Lerman C, Benowitz N, Baker TB. Assessing dimensions of nicotine dependence: An evaluation of the Nicotine Dependence Syndrome Scale (NDSS) and the Wisconsin Inventory of Smoking Dependence Motives (WISDM). *Nicotine & Tobacco Research*. 2008b; 10:1009–1020.10.1080/14622200802097563 [PubMed: 18584464]
- Piper ME, Piasecki TM, Federman EB, Bolt DM, Smith SS, Fiore MC, Baker TB. A multiple motives approach to tobacco dependence: The Wisconsin Inventory of Smoking Dependence Motives (WISDM-68). *Journal of Consulting and Clinical Psychology*. 2004; 72:139–154.10.1037/0022-006X.72.2.139 [PubMed: 15065950]

- Robinson TE, Berridge KC. The neural basis of drug craving: An incentive sensitization theory of addiction. *Brain Research Reviews*. 1993; 18:247–291.10.1016/0165-0173(93)90013-P [PubMed: 8401595]
- Rosenberg H. Clinical and laboratory assessment of the subjective experience of drug craving. *Clinical Psychology Review*. 2009; 29:519–534.10.1016/j.cpr.2009.06.002 [PubMed: 19577831]
- Saladin ME, Gray KM, Carpenter MJ, LaRowe SD, DeSantis SM, Upadhyaya HP. Gender differences in craving and cue reactivity to smoking and negative affect/stress cues. *The American Journal on Addictions*. 2012; 21:210–220.10.1111/j.1521-0391.2012.00232.x [PubMed: 22494223]
- Sayette MA, Hufford MR. Urge and affect: A facial coding analysis of smokers. *Experimental and Clinical Psychopharmacology*. 1995; 3:417–423.10.1037/1064-1297.3.4.417
- Sayette MA, Martin CS, Wertz JM, Shiffman S, Perrott MA. A multi dimensional analysis of cue-elicited craving in heavy smokers and tobacco chippers. *Addiction*. 2001; 96:1419–1432.10.1080/09652140120075152 [PubMed: 11571061]
- Sayette MA, Shiffman S, Tiffany ST, Niaura RS, Martin CS, Shadel WG. The measurement of drug craving. *Addiction*. 2000; 95:S189–S210.10.1080/09652140050111762 [PubMed: 11002914]
- Sayette MA, Tiffany ST. Peak provoked craving: An alternative to smoking cue reactivity. *Addiction*. 2013; 108:1019–1025.10.1111/j.1360-0443.2012.04013.x [PubMed: 23075138]
- Shiffman S, Dunbar M, Kirchner TR, Li X, Tindle HA, Anderson SJ, Scholl SM. Smoker reactivity to cues: Effects on craving and on smoking behavior. *Journal of Abnormal Psychology*. 2013a; 122:264–280.10.1037/a0028339 [PubMed: 22708884]
- Shiffman S, Dunbar M, Kirchner TR, Li X, Tindle HA, Anderson SJ, Scholl SM, Ferguson SG. Cue reactivity in non-daily smokers. *Psychopharmacology*. 2013b; 226:321–333.10.1007/s00213-012-2909-4 [PubMed: 23142992]
- Shiffman S, Kassel JD, Paty J, Gnys M, Zettler-Segal M. Smoking typology profiles of chippers and regular smokers. *Journal of Substance Abuse*. 1994; 6:21–35.10.1016/S0899-3289(94)90052-3 [PubMed: 8081107]
- Smolka MN, Bühler M, Klein S, Zimmermann U, Mann K, Heinz A, Braus DF. Severity of nicotine dependence modulates cue-induced brain activity in regions involved in motor preparation and imagery. *Psychopharmacology*. 2006; 184:577–588.10.1007/s00213-005-0080-x [PubMed: 16133128]
- Sobell, LC.; Sobell, MB. Timeline followback user's guide: A calendar method for assessing alcohol and drug use. Toronto, Canada: Addiction Research Foundation; 1996.
- Stacy AW, Wiers RW. Implicit cognition and addiction: A tool for explaining paradoxical behavior. *Annual Review of Clinical Psychology*. 2010; 6:551–575.10.1146/annurev.clinpsy.121208.131444
- Tiffany ST. A cognitive model of drug urges and drug-use behavior: Role of automatic and nonautomatic processes. *Psychological Review*. 1990; 97:147–168.10.1037/0033295X.97.2.147 [PubMed: 2186423]
- Tiffany ST, Friedman L, Greenfield SF, Hasin DS, Jackson R. Beyond drug use: A systematic consideration of other outcomes in evaluations of treatments for substance use disorders. *Addiction*. 2012; 107:709–718.10.1111/j.13600443.2011.03581.x [PubMed: 21981638]
- Tiffany, ST.; Warthen, MW.; Goedeker, KC. The functional significance of craving in nicotine dependence. In: Bevins, RA.; Caggiula, AR., editors. *The motivational impact of nicotine and its role in tobacco use*. New York, NY: Springer Science + Business Media; 2009. p. 171-197.
- Tiffany ST, Wray JM. The clinical significance of drug craving. *Annals of the New York Academy of Sciences*. 2012; 1248:1–17.10.1111/j.17496632.2011.06298.x [PubMed: 22172057]
- Vollstädt-Klein S, Kobiella A, Bühler M, Graf C, Fehr C, Mann K, Smolka MN. Severity of dependence modulates smokers' neuronal cue reactivity and cigarette craving elicited by tobacco advertisement. *Addiction Biology*. 2010; 16:166–175.10.1111/j.1369-1600.2010.00207.x [PubMed: 20331560]
- Waters, AJ.; Sayette, MA. Implicit cognition and tobacco addiction. In: Wiers, RW.; Stacy, AW., editors. *Handbook of implicit cognition and addiction*. Thousand Oaks, CA: Sage Publications, Inc; 2006. p. 309-338.

- Waters A, Shiffman S, Sayette M, Paty J, Gwaltney C, Balabanis M. Cue provoked craving and nicotine replacement therapy in smoking cessation. *Journal of Consulting and Clinical Psychology*. 2004; 72:1136–1143.10.1037/0022006X.72.6.1136 [PubMed: 15612859]
- Wiers, RW.; Stacy, AW. Implicit cognition and addiction: An introduction. In: Wiers, RW.; Stacy, AW., editors. *Handbook of implicit cognition and addiction*. Thousand Oaks, CA: Sage Publications, Inc; 2006. p. 1-8.
- Wray, JM.; Gass, JG.; Miller, EI.; Wilkins, DG.; Rollins, DE.; Tiffany, ST. An evaluation of self-report measures of cigarette use in nondaily smokers. 2014. Manuscript in preparation
- Wray JM, Gass JG, Tiffany ST. The magnitude and reliability of cue specific craving in nondependent smokers. *Drug and Alcohol Dependence*. 2013; 134:304–308.10.1093/ntr/nts268 [PubMed: 24309295]
- Wray JM, Godleski SA, Tiffany ST. Cue-reactivity in the natural environment of cigarette smokers: The impact of photographic and in vivo smoking stimuli. *Psychology of Addictive Behaviors*. 2011; 25:733–737.10.1037/a0023687 [PubMed: 21553947]

Figure 1.

Scatterplots of regression trends indicating significant quadratic relations between cue-elicited craving and response time for nondependent smokers (a. after neutral cues; b. after smoking cues) and dependent smokers (c. after neutral cues; d. after smoking cues) at Session 1. R^2 values represent the full model. The solid lines represent best-fitting quadratic equations.

Table 1

Craving mean comparisons between cue type.

	Nondependent Smokers		Dependent Smokers	
	M (SD)	F (df)	M (SD)	F (df)
Session 1				
Neutral vs. Smoking	2.19 (1.32) ^a	249.20 [‡] (1,194)	3.89 (1.77) ^a	115.69 [‡] (1,61)
	3.46 (1.79) ^b		5.36 (1.57) ^b	
Session 2				
Neutral vs. Smoking	2.18 (1.35) ^a	183.08 [‡] (1,186)	3.15 (1.54) ^a	106.87 [‡] (1,58)
	3.30 (1.79) ^b		4.63 (1.78) ^b	
Session 3				
Neutral vs. Smoking	2.07 (1.27) ^a	161.59 [‡] (1,180)	3.00 (1.59) ^a	76.60 [‡] (1,57)
	3.15 (1.82) ^b		4.48 (1.88) ^b	
Session 4				
Neutral vs. Smoking	2.05 (1.24) ^a	152.67 [‡] (1,176)	3.01 (1.63) ^a	81.25 [‡] (1,51)
	3.08 (1.74) ^b		4.42 (1.78) ^b	
Session 5				
Neutral vs. Smoking	2.00 (1.27) ^a	125.04 [‡] (1,162)	3.04 (1.63) ^a	82.18 [‡] (1,49)
	2.93 (1.75) ^b		4.53 (1.74) ^b	

Note.

[‡] $p < .0001$;^a Means and SDs corresponding with post-neutral cue craving means and SDs;^b Means and SDs corresponding with post-smoking craving means and SDs.

Table 2

Response time and inter-item variability mean comparisons between cue type.

	Response Time				Inter-Item Variability			
	Nondependent Smokers		Dependent Smokers		Nondependent Smokers		Dependent Smokers	
	M (SD)	F (df)	M (SD)	F (df)	M (SD)	F (df)	M (SD)	F (df)
Session 1								
Neut vs. Smok	2032.09 (739.17) ^a	36.09 [†] (1,190)	2527.26 (813.37) ^a	14.84 ^{**} (1,59)	0.61 (0.56) ^a	18.12 [†] (1,194)	0.83 (0.49) ^a	5.09 [*] (1,61)
	2329.71 (775.43) ^b		2232.68 (788.27) ^b		0.77 (0.48) ^b		0.66 (0.51) ^b	
Session 2								
Neut vs. Smok	1775.88 (692.86) ^a	19.82 [†] (1,180)	2081.40 (759.73) ^a	0.08 (1,57)	0.55 (0.51) ^a	25.87 [†] (1,186)	0.83 (0.52) ^a	5.46 [*] (1,58)
	1975.43 (702.30) ^b		2061.88 (732.22) ^b		0.74 (0.53) ^b		0.64 (0.43) ^b	
Session 3								
Neut vs. Smok	1607.70 (715.18) ^a	17.97 [†] (1,174)	1978.42 (734.47) ^a	1.32 (1,55)	0.51 (0.53) ^a	20.97 [†] (1,180)	0.72 (0.47) ^a	4.16 [*] (1,57)
	1737.47 (679.20) ^b		1886.89 (806.65) ^b		0.70 (0.55) ^b		0.60 (0.46) ^b	
Session 4								
Neut vs. Smok	1520.56 (699.52) ^a	15.48 ^{**} (1,176)	1786.88 (662.56) ^a	0.89 (1,51)	0.54 (0.52) ^a	24.67 [†] (1,176)	0.69 (0.61) ^a	0.67 (1,51)
	1672.11 (730.01) ^b		1729.89 (711.22) ^b		0.74 (0.55) ^b		0.62 (0.41) ^b	
Session 5								
Neut vs. Smok	1477.91 (663.31) ^a	18.28 [†] (1,162)	1765.52 (591.07) ^a	0.12 (1,48)	0.46 (0.53) ^a	36.64 [†] (1,162)	0.59 (0.42) ^a	0.10 (1,49)
	1640.71 (700.45) ^b		1764.47 (633.20) ^b		0.68 (0.55) ^b		0.61 (0.39) ^b	

Note. Neut = neutral; Smok = smoking;

* $p < .05$,

** $p < .001$,

[†] $p < .0001$;

^a Means and SDs corresponding with post-neutral cue response time and inter-item variability means and SDs;

^b Means and SDs corresponding with post-smoking response time and inter-item variability means and SDs.

Polynomial regression analyses with cue-elicited craving as the independent variable and response time (ms) and inter-item variability as the dependent variables.

Table 3

		Response time		Inter-Item Variability					
		Nondependent Smokers		Dependent Smokers		Nondependent Smokers		Dependent Smokers	
		Lin. R^2	Quad. R^2	Lin. R^2	Quad. R^2	Lin. R^2	Quad. R^2	Lin. R^2	Quad. R^2
Session 1									
Neutral	0.15 [‡]	0.26[‡]	0.03	0.29[‡]	0.27 [‡]	0.63[‡]	0.04	0.52[‡]	
Smoking	0.01	0.24[‡]	0.24 [‡]	0.34^{**}	0.02	0.41[‡]	0.26 [‡]	0.57[‡]	
Session 2									
Neutral	0.15 [‡]	0.20^{**}	0.01	0.20[‡]	0.25 [‡]	0.53[‡]	0.03	0.27[‡]	
Smoking	0.01	0.18[‡]	0.08 [*]	0.24^{**}	0.03 [*]	0.48[‡]	0.13 ^{**}	0.32[‡]	
Session 3									
Neutral	0.21 [‡]	0.24[*]	0.00	0.17^{**}	0.40 [‡]	0.61[‡]	0.10 [*]	0.37[‡]	
Smoking	0.00	0.20[‡]	0.01	0.19[‡]	0.04 [‡]	0.51[‡]	0.03	0.52[‡]	
Session 4									
Neutral	0.08 [‡]	0.13^{**}	0.00	0.14^{**}	0.30 [‡]	0.54[‡]	0.01	0.36[‡]	
Smoking	0.00	0.14[‡]	0.02	0.19^{**}	0.02	0.49[‡]	0.04	0.42[‡]	
Session 5									
Neutral	0.09 [‡]	0.14^{**}	0.00	0.09[*]	0.31 [‡]	0.52[‡]	0.00	0.27[‡]	
Smoking	0.00	0.21[‡]	0.12 [*]	0.24^{**}	0.09 [‡]	0.52[‡]	0.05	0.44[‡]	

Note.

* $p < .05$,

** $p < .01$,

[‡] $p < .001$,

[‡] $p < .0001$;

Lin. = linear relationship; Quad. = quadratic relationship; R^2 values for quadratic trends represent the full model; highest order significant polynomial in boldface; associations reported between post-neutral cue craving and post-neutral cue response time, and between post-smoking cue craving and post-smoking cue response time; associations also reported between post-neutral cue craving and post-neutral cue inter-item variability, and between post-smoking cue craving and post-smoking cue inter-item variability.