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Assessing Cigarette Craving With a Squeeze

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Abstract
We evaluated the utility of a nonverbal, "visceral" measure of cigarette craving (squeezing a handheld dynamometer). Nicotine-deprived daily smokers ($N = 202$) underwent a cued (lit cigarette) cigarette-craving manipulation and recorded smoking urge in one of four conditions: (a) report urge using a traditional self-report rating scale (verbal measure) and then indicate urge by squeezing a dynamometer, (b) indicate urge by squeezing and then report urge verbally, (c) indicate urge only by squeezing, or (d) report urge only verbally. As hypothesized, the squeeze measure detected increases in urge during cue exposure, correlated with verbal urge, and predicted subsequent smoking motivation as indexed by smoking latency. Order effects were not observed, indicating that the squeeze measure was predictive of smoking motivation regardless of whether it was administered before or after a verbal urge measure. Squeeze measures may be viable additions to the measurement toolkit for assessing urge and other visceral states.

Keywords
craving, urge to smoke, visceral states, cue exposure, smoking behavior, drug/substance abuse, nonverbal behavior, open materials

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The importance of craving, commonly defined as a drug-acquisitive state motivating drug use (Sayette, 2016), is underscored in nearly all models of addiction (e.g., Koob & Volkow, 2010; Loewenstein, 1999; Robinson & Berridge, 2000; Sayette & Creswell, 2016; Tiffany 1990, 2010). Indeed, craving was added as a criterion for the diagnosis of substance use disorders in the most recent edition of the *Diagnostic and Statistical Manual of Mental Disorders* (*DSM–5*; American Psychiatric Association, 2013). Craving is one of the most studied topics in addiction, and interest in the construct of craving continues to flourish, with thousands of studies published on craving in the past decade (Tiffany & Wray, 2012). Nicotine is a particularly good drug to consider when examining craving, as it is an especially addictive drug, with the majority of regular users becoming dependent (Sayette & Creswell, 2016). Furthermore, withdrawal states can be induced via deprivation manipulations in a medically safe manner. Thus, much of the research on craving has been conducted using smoking-cue-exposure paradigms, which offer a way to robustly provoke craving states in laboratory settings to better understand drug-motivational properties (Sayette, Griffin, & Sayers, 2010; Sayette & Tiffany, 2013). Self-reported urge-to-smoke rating scales are the most sensitive measure of craving in cue-exposure studies (see Carter & Tiffany, 1999) and remain the gold standard for assessing craving inside and outside of the lab (e.g., using ecological momentary assessment; see Serre, Fatseas, Swendsen, & Auriacombe, 2015 for a review). Throughout this article, we use the terms *urge* and *craving* interchangeably (see Sayette et al., 2000).

Despite their popularity, these self-report measures of urge to smoke may not always capture the essence of a craving state. Motivational (visceral) states, such

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as drug craving, hunger, thirst, and sexual arousal (see Loewenstein, 1996; Nordgren & Chou, 2011) are inherently nonverbal experiences, and participants may have difficulty translating these inner experiences into symbolic systems (such as numbers and language) required for traditional "verbal" self-report rating scales (Creswell, Sayette, Schooler, Wright, & Pacilio, 2018; Schooler, 2002, 2011, 2014). Furthermore, requiring participants to complete verbal self-reports may actually disrupt the emotional or motivational state being experienced (Kassam & Mendes, 2013; Lieberman et al., 2007; Nisbett & Wilson, 1977; Schooler, 2002; Schooler, Ariely, & Lowenstein, 2003). Finally, in many studies (e.g., when heavy smokers are asked to refrain from smoking for many hours prior to the study), ceiling effects may interfere with a full rendering of craving during smoking cues using traditional verbal measures of craving with Likert scales (Heckman et al., 2017; Sayette, Martin, Wertz, Shiffman, & Perrott, 2001).

Many researchers agree that there is a need to expand the set of craving-related measures beyond traditional self-report rating scales (Griffin & Sayette, 2008; Munafò & Hitsman, 2010; Perkins, 2009; Sayette et al., 2000; Tiffany & Wray, 2009; Waters et al., 2003). Investigators have profitably used psychophysiological recordings (e.g., startle probe; Cinciripini et al., 2006), neuroimaging data (Wilson & Sayette, 2015) and measures of cognitive performance (Field, Munafò, & Franken, 2009; Germeroth, Wray, & Tiffany, 2015), though each has challenges. For instance, it is unclear whether increases or decreases in psychophysiological measures such as heart rate and skin conductance should be linked to craving, since each has functions independent of drug-use motivation (Niaura et al., 1988; Sayette, 2016; Tiffany, 1990). Brain-imaging measures are constrained by the need for expensive and cumbersome imaging laboratories. While there is debate about the degree to which these various responses covary with self-reported urge (at least during high craving states; see Field et al., 2009, and Sayette, 2016, for supportive reviews), it is fair to conclude that these measures often fail to correlate with self-reported urge (see Carter and Tiffany, 1999). In sum, while this expanded set of measures has advanced our understanding of craving and addiction (see Field et al., 2009; Sayette, 2016; Tiffany, 1990), it is clear that (a) the addiction research field lacks a "perfect" measure of drug motivation and (b) novel measures relying on different types of responding are indicated to generate a more comprehensive, multimodal approach to assessment. It remains a research priority to develop new approaches to assess drug motivation to complement the existing set of measures.

One approach that may prove useful for capturing an urge state involves use of a hand-held dynamometer that records grip strength. This measure is nonverbal and arguably more viscerally relevant (i.e., less subject to the limitations of language) than traditional verbal self-reports and may offer a more direct assessment of visceral drive states such as craving (Creswell et al., 2018). Furthermore, a dynamometer "squeeze" measure of smoking motivation has intuitive appeal. Part of its attractiveness is that it is unbounded.[1] A smoker entering a study while in withdrawal can forcefully squeeze the dynamometer for a fairly long time to express a potent craving state. When this already-intense craving is then increased (e.g., by holding a lit cigarette), the smoker still is able to express this elevation by simply squeezing the dynamometer more forcefully and for longer than during the first assessment. That is, the concern with ceiling effects produced by a near-maximal pre-cue-exposure urge rating is addressed. Yet this advantage also raises potential methodological challenges. The initial (precue) squeeze may reflect very different experiences. For example, one person may choose to squeeze for just a few seconds while another may choose a much longer time interval to squeeze. This variability may complicate interpretation of a subsequent squeeze that is expressed during cue exposure. To some degree, this concern is mitigated by the within-subject repeated-measures design in which individual variation in use of the dynamometer is presumably held constant. Still, it remains to be seen whether the degree of precue variability may interfere with the utility of this measure for capturing urge states. (Of course, as we noted in Sayette et al., 2000, there are no objective dimensional anchors for any self-report craving scales, so this limitation of a squeeze measure is not entirely unique). Squeeze values also are unlikely to be normally distributed, and care may be needed to select appropriate forms of analyses (e.g., data transformations, nonparametric analyses).

While there are challenges associated with its use, the ability to capture clinically significant motivational states with a pressure-sensing squeeze device could have considerable impact. For instance, such a measure might compliment a multimodal assessment of craving to test the efficacy of new smoking-cessation interventions, including medication development. Beyond the addiction field, if effective, such devices may also be ideal for measuring other visceral states (e.g., pain) because they allow participants to express the intensity of their feelings in a sensitive and nonverbal way. In an initial nonclinical test, we used a handheld dynamometer to measure hunger using a mostly (86%) college-student sample (see Creswell et al., 2018). Our squeeze measure of hunger was sensitive to an in vivo food (i.e., popcorn)-cue-exposure paradigm; squeeze recordings of hunger increased from pre- to postcue exposure. Furthermore, dynamometer recordings were correlated with verbal self-report ratings of hunger and predictive of actual eating behavior. Verbal overshadowing effects (Schooler & Engstler-Schooler, 1990) were also evident, such that nonverbal dynamometer recordings of hunger were not predictive of eating behavior in participants who were first asked to translate their feelings of hunger into verbal reports (i.e., subsequent nonverbal recordings were "contaminated" by previously completed verbal reports). This finding suggests that dynamometer recordings may work best when they occur prior to verbal assessment; indeed, dynamometer recordings were a better predictor of eating behavior than verbal reports when they occurred prior to verbal assessment.

In the current study we aimed to extend these initial findings with popcorn to a more clinically meaningful population by recruiting a sample of current daily smokers who were asked to abstain from smoking prior to the study. Presumably, this sample would experience stronger urges than were found with a nonclinical sample of popcorn-eating participants (primarily undergraduates), which would create additional challenges for the squeeze measure given the potential for variation in presmoking-cue urge levels. The study had four aims. First, we examined the ability of the squeeze measure to detect increases in cigarette craving from pre- to postsmoking cue. Second, we tested the degree to which the squeeze measure would generate data that correlated with traditional self-report measures of urge. Third, we investigated the extent to which responses on the squeeze measure during cue exposure would predict subsequent smoking motivation and, if it was predictive, whether it was a better predictor than verbal urge measures. Fourth, we evaluated whether the squeeze measure would be subject to interference as a result of initial verbal ratings of self-reported urge prior to squeeze administration (verbal overshadowing).

To accomplish these goals, nicotine-deprived smokers were randomly assigned to one of four experimental conditions that varied the method used to assess urge to smoke during an in vivo smoking-cue-exposure paradigm. Participants in the verbal-first condition (n = 50) first reported their urge to smoke using a traditional verbal measure and then indicated their urge nonverbally by squeezing a dynamometer; participants in the squeeze-first condition (n = 50) first indicated their urge to smoke by squeezing the dynamometer and then reported it on the verbal rating form; participants in the squeeze-only condition (n = 51) indicated their urge to smoke only by squeezing the dynamometer; participants in the verbal-only condition (n = 51) reported their urge to smoke only on the verbal rating form. We hypothesized that squeeze measures of urge would be sensitive to detecting increases in urge during cue exposure (perhaps even more sensitive than a verbal urge measure), would correlate with traditional verbal measures of urge, and would be predictive of subsequent smoking motivation. Given our prior findings, we also tested to see if we would observe verbal overshadowing effects, such that squeeze recordings following verbal reports (in the verbal-first condition) would not be associated with subsequent smoking motivation.

Method

This study was not preregistered, but the aims and hypotheses follow from our prior work (Creswell et al., 2018). Study materials have been made available on the Open Science Framework (https://osf.io/pu6rc/). This study was launched prior to broad preregistration efforts and thus permission to share the data on an online site hosted by a reliable third party was not built into the institutional review board application or consent form. Materials shared on the Open Science Framework include the syntax and output for analyses and the questionnaires. All study conditions are reported, and all measures collected during the experimental session are reported. The following additional questionnaires were administered during the baseline session, with the intention of examining individual difference factors that might relate to smoking-cue reactivity measures in future work: The Self-Consciousness Scale (Scheier & Carver, 1985), the trait version of the PANAS (Watson, Clark, & Tellegen, 1988), the Balanced Inventory of Desirable Responding–6 (Paulhus, 1991), the five items measuring reward responsiveness from the Behavioral Activation/Behavioral Inhibition Scale (Carver & White, 1994), the Five Facets of Mindfulness Questionnaire (Baer, Smith, Hopkins, Krietemeyer, & Toney, 2006), and the Ten-Item Personality Scale (Gosling, Rentfrow, & Swann, 2003).

Participants

We recruited male and female smokers (N = 202) through newspaper and bus advertisements and local fliers inviting inquiries from smokers willing to refrain from smoking or using nicotine-containing products for part of one day. In our previous dynamometer study with a sample of food-deprived young adults (Creswell et al., 2018), we found a small effect size (f^2 = .08) of dynamometer recordings in predicting popcorn consumption. However, given that effect sizes of initial studies may be inflated, we recruited a larger sample size (adding an additional 100 participants), which allowed us to detect a smaller effect size (f^2 = .03) with

Table 1. Participant Characteristics Across Study Conditions

	Conditions							Effect size	
Characteristic and variable	Verbal first	Squeeze first	Squeeze only	Verbal only	χ^2	*F*	*p*	φ	η_p^2
Gender					6.5		.090	0.18	
Male	20 (18.9)	24 (22.6)	30 (28.3)	32 (30.2)					
Female	30 (31.3)	26 (27.1)	21 (21.9)	19 (19.8)					
Race/ethnicity					14.2		.285	0.27	
White	24 (48.0)	24 (48.0)	20 (39.2)	29 (56.9)					
African American	22 (44.9)	9 (38.0)	26 (51.0)	19 (37.3)					
Asian American	0 (0.0)	2 (4.0)	0 (0.0)	1 (2.0)					
More than one race/ethnicity	4 (8.0)	5 (10.0)	3 (5.9)	2 (3.9)					
Other	0 (0.0)	0 (0.0)	2 (3.9)	0 (0.0)					
Marital status					6.2		.400	0.18	
Single	35 (70.0)	43 (86.0)	37 (72.5)	41 (80.4)					
Living with partner	12 (24.0)	6 (12.0)	10 (19.6)	6 (11.8)					
Married	3 (6.0)	1 (2.0)	4 (7.8)	4 (7.8)					
Age, mean (*SD*)	37.6 (8.3)	38.5 (8.1)	36.6 (9.3)	38.3 (10.1)		0.4	.724		0.01
Education, mean (*SD*)	12.6 (2.1)	13.2 (2.4)	13.0 (1.8)	12.7 (2.1)		0.8	.482		0.01
Cigarettes/day, mean (*SD*)	17.3 (8.4)	16.2 (6.2)	16.7 (5.8)	16.8 (6.2)		0.3	.860		0.01
Years smoked, mean (*SD*)	10.7 (8.4)	11.1 (9.0)	13.6 (9.5)	13.0 (10.5)		1.2	.326		0.02
FTND score, mean (*SD*)	5.0 (2.1)	4.8 (1.6)	4.8 (1.7)	4.9 (1.7)		0.1	.939		0.00
Baseline CO level, mean (*SD*)	26.0 (10.9)	24.1 (11.3)	27.4 (13.3)	23.8 (10.4)		1.1	.366		0.02
Experimental CO level, mean (*SD*)	8.6 (5.1)	7.6 (3.7)	8.2 (4.2)	8.2 (4.2)		0.5	.694		0.01
Min since last cigarette, mean (*SD*)	559.8 (266.8)	525.8 (209.7)	563.8 (274.0)	564.5 (275.8)		0.3	.855		0.01

Note: FTND = Fagerström Test for Nicotine Dependence; CO = carbon monoxide.

power = .80 at alpha = .05. We planned for 50 participants per condition, but 2 additional participants were scheduled and were therefore run, resulting in the final sample of 202.

Participants were required to be between the ages of 18 and 50; to have smoked at least 10 cigarettes per day for at least the previous 12 months; to not be currently interested in quitting smoking; to speak, read, and write English fluently; and to have no medical conditions that ethically contraindicated smoking. Informed consent was obtained from all participants. Six participants were excluded for the following reasons: Two participants did not bring their preferred brand of cigarettes to the experimental session and did not like the cigarettes we had available to them in the lab; 1 participant had injured his wrist and was not able to squeeze the dynamometer with his dominant hand; 1 participant was acting erratically, was unable to sit still for the experiment, and appeared to be under the influence of drugs; 1 participant was discharged from the hospital the morning of the experimental session, was using pain medications, and kept falling asleep during the experimental procedures; and 1 participant was run through the wrong experimental condition because of experimenter error. Decisions to exclude these participants were made on the days of each of their experimental sessions, and they were either not run through the protocol or their data were never entered. Thus, these exclusion decisions were made before any data analyses were conducted, and additional participants were run to accommodate these exclusions.

Table 1 presents descriptive statistics for participant characteristics across conditions. As shown, the four groups did not differ on demographic or smoking variables. The difference in gender distribution across the four conditions was near to the nominal cutoff for significance ($p = .090$). However, gender was unrelated to dynamometer recordings of urge during cue exposure ($p = .517$), and controlling for gender in analyses did not change any of the results.

Materials and procedures

Interested participants who contacted the Behavioral Health Research Lab answered screening questions to ensure that they met eligibility criteria. Eligible participants were asked to attend an additional in-person screening session. To verify smoking status, participants needed to provide a breath carbon monoxide (CO) reading of at least 8 ppm at the start of this session (Conklin, Perkins, Robin, McClernon, & Salkeld, 2010; Robinson et al., 2007). Participants who met this criterion were invited to complete a questionnaire battery assessing demographic information, smoking patterns, smoking history, and other variables (e.g., impulsivity) with standard forms (see Wilson, Creswell, Sayette, & Fiez, 2013).

Participants were asked to refrain from smoking or using any nicotine-containing products for at least 6 hours before the experimental session. This was to ensure that participants would experience peak-provoked craving states during the cue-exposure manipulation (Drobes & Tiffany, 1997; McKee, Weinberger, Shi, Tetrault, & Coppola, 2012; Sayette & Parrott, 1999; Sayette & Tiffany, 2013) in order to most effectively test our squeeze measure of urge. They were told that saliva and CO samples would be obtained to ensure they had conformed to these deprivation instructions. Participants were asked to bring a pack of their preferred brand of cigarettes and a lighter to their session. They were randomly assigned to one of the four experimental conditions (described above) for the second session. A random number list created by random-list-generator software was used to assign participants to conditions.

Participants arrived for the experimental sessions between 2:00 and 4:00 p.m. Compliance with deprivation instructions was assessed by asking participants to report the last time they smoked a cigarette or used nicotine-containing products and by measuring their expired CO levels. Participants' CO levels had to be at least 50% lower than their baseline CO level (i.e., during a nondeprived state) or below 10 ppm (Sayette, Schooler, & Reichle, 2010). After the CO assessment, all participants gave their cigarettes to the experimenter, who promised to return them after the session. Participants were told that the purpose of the study was to investigate ways to measure how someone is feeling. They were informed that they might be asked to report their urge to smoke by rating it on a 0 to 100 rating scale (i.e., the verbal measure) and/or by indicating their urge to smoke by squeezing a hand-held dynamometer with their dominant hand (i.e., the squeeze measure). We used a commercially available dynamometer (Vernier Software & Technology; accuracy ±0.6 Newtons; operational range 0–600 Newtons (N); grip size 50 mm × 25 mm) that we had used in our prior research assessing hunger levels (see Creswell et al., 2018). The force of a person's grip (N) was transmitted by universal serial bus (USB) to a computer, where it was recorded by Logger Pro data collection and analysis software. The experimenter explained the dynamometer by stating the following:

> This dynamometer measures two things—how forcefully you squeeze it and how long you squeeze it. So, it measures both force and time. You can squeeze this as forcefully as you like and for as long as you like to show us your urge to smoke at various times throughout the experiment. More time and more force indicate more urge—so if you have a very strong urge to smoke, you will squeeze this device harder and for a longer amount of time. If you have a low urge to smoke, you could show us that too by squeezing less hard and for a shorter amount of time.

Note that area under the curve, which accounts for both force and time, was calculated and used in all dynamometer analyses. These values were log-transformed to meet normality assumptions for analyses (see also Creswell et al., 2018). The experimenter then demonstrated how to use the dynamometer, which was attached to the table in front of participants using a vise grip. After this demonstration, the experimenter left the room to conduct the cue-exposure manipulation via intercom.

Cigarette cue-exposure paradigm. Prior to cue exposure, participants were asked via intercom to provide an urge rating. For the squeeze measure, participants were instructed to wrap their hand around the dynamometer and squeeze to express their urge to smoke "right now at this very moment." For the verbal measure, participants were asked to report their urge to smoke using a rating scale ranging from 0 (*absolutely no urge to smoke at all*) to 100 (*strongest urge to smoke I've ever experienced*) referring to how they were feeling "right now at this very moment" (Griffin & Sayette, 2008; Juliano & Brandon, 1998; Sayette, Loewenstein, Griffin, & Black, 2008). Over the intercom, the experimenter asked participants in the verbal-first condition to complete the verbal rating form and then to indicate their urge nonverbally by squeezing the dynamometer. Participants in the squeeze-first condition were asked to indicate their urge nonverbally by squeezing the dynamometer and then to rate their urge using the verbal form. Participants in the squeeze-only condition were asked to indicate their urge only by squeezing the dynamometer; participants in the verbal-only condition were asked to report their urge only verbally using the rating form.

A tray containing a plastic cover was then placed on the desk in front of participants. They were told not to touch the tray until told to do so. The experimenter then went into an adjacent room and gave further instructions over the intercom system. Participants were instructed via intercom to pick up the cover on the tray and to set it to the side. Under the cover they found the pack of cigarettes they had brought, a lighter, and an ashtray. They were told to remove a cigarette from the pack and to light it without putting it in their mouth (by holding the tip in the flame until the tobacco began to burn). Once the cigarette was lit, they were told to put down the lighter, to hold the cigarette in their non-dominant hand in a comfortable manner, and to look at it. After 10 s and while still holding the cigarette, participants were instructed to again rate their urge to smoke (i.e., post-cue-exposure rating) using the same procedure described above for the pre-cue-exposure rating. Participants were then asked to extinguish the cigarette in the ashtray.

Willingness to accept craving (WTAC). After cue exposure, the experimenter reentered the room and described the WTAC measure, which is a monetary choice task used in our prior smoking research (Sayette et al., 2008; Sayette et al., 2001). The experimenter first informed participants that a 10-min smoke break would occur "right now, before we move on to the next part of the study." Participants were told that the study would last at least another hour (in order to create higher motivation to smoke during the smoke break; see Sayette et al., 2001) and that the room had special air clearance such that they could smoke "right here in this room" if they so wished. All but 3 participants indicated that they wanted to smoke (1 participant in the verbal-first condition, 1 participant in the verbal-only condition, and 1 participant in the squeeze-only condition). Those indicating that they wanted to smoke (99% of the sample) were told that they could earn extra money if they were willing to delay smoking for an additional 5 min. In other words, participants chose between immediate access to a cigarette and delayed access with financial compensation. Specifically, they indicated the minimum amount of money they would accept in order to postpone smoking for 5 min. They were told that if this value was less than a previously set but undisclosed amount, they would receive the amount they requested in return for delaying smoking. This monetary reward was included to enhance participants' belief that their response would have real consequences and to encourage participants to report the smallest acceptable amount of money they required to postpone smoking for 5 min (Sayette et al., 2008). The WTAC was administered in interview form. The experimenter started by asking whether the participant would postpone smoking for 5 min for an additional $20 (only one participant declined to wait for this amount, and they were assigned this maximum value of $20). The experimenter then offered $0.25, and all but 1 participant indicated that they would prefer to smoke immediately rather than accept this low amount (this participant was assigned this minimum value of $0.25). Ten dollars, a value about midway between the unacceptable sum ($0.25) and the acceptable sum ($20), was then offered, and this process was repeated (using $0.50 increments) until the exact crossover point (Griffiths, Rush, & Puhala, 1996) was reached. This point reflected the minimum monetary value of delaying smoking (see Sayette et al., 2008).

Smoking behavior assessment. After the WTAC interview, participants were informed that they did not actually need to wait 5 min to smoke, would in any case be receiving an extra $5, and could smoke at this time. The experimenter stepped out of the room for the participant's 10-min smoke break and unobtrusively videotaped the next 10 min while the participant was free to smoke ab libitum. This recording was later coded for latency to smoke (in seconds) by coders who were blind to the study condition. As is common in the literature, participants who chose not to smoke were assigned the maximum value of 600 s (see also Conklin & Perkins, 2005; Heckman et al., 2017; Leeman, O'Malley, White, & McKee, 2010; McKee et al., 2012; Niaura, Abrams, Pedraza, & Monti, 1992; Payne, Schare, Levis, & Colletti, 1991). Latency values were log-transformed to meet normality assumptions for analyses. A subset of participants (n = 50; 24.7%) was coded for reliability; the interrater reliability was excellent ($\kappa = 0.98$). At the end of the 10-min period, participants were informed that the study was in fact over. They were debriefed and compensated ($90) before leaving the laboratory.

Data analysis

To determine whether the smoking-cue-exposure manipulation increased verbal ratings and squeeze recordings of urge to a similar degree across conditions, we computed a 2 × 2 repeated measures analysis of variance (ANOVA), with condition as a between-subjects variable and time (pre-cue-exposure and post-cue-exposure urge) as a repeated variable. Bivariate correlations were examined to determine whether squeeze recordings of urge to smoke during cue exposure were associated with more traditional verbal ratings during peak-provoked craving. A series of linear regression analyses were conducted to determine whether verbal ratings and squeeze recordings of urge predicted latency to smoke and WTAC values. We tested four predictors in separate models (i.e., precue urge, postcue urge, the mean of pre- and postcue urge, and the change score between pre- and postcue urge) for each of the two dependent variables (i.e., latency to smoke and WTAC values). We examined bivariate correlations to compare the predictive utility of the verbal ratings and squeeze recordings of urge to smoke during cue exposure in predicting latencies to smoke. We used a between-subject comparison (i.e., Fisher's z-test) to compare the predictive utility of responses across the squeeze-only and verbal-only conditions. For the two experimental conditions that included both squeeze

Table 2. Verbal Urge to Smoke, WTAC Values, and Latencies to Smoke Across the Four Experimental Conditions

	Condition			
Variable	Verbal first	Squeeze first	Squeeze only	Verbal only
Precue verbal urge, mean (*SD*)	74.52 (21.09)	75.80 (18.91)	—	70.08 (26.00)
Postcue verbal urge, mean (*SD*)	85.18 (19.42)	86.64 (18.76)	—	84.86 (23.21)
WTAC value, mean (*SD*)	4.49 (3.03)	6.24 (5.09)	4.57 (4.52)	4.56 (3.17)
Latency to smoke, mean, (*SD*)	0.98 (0.42)	0.92 (0.26)	1.00 (0.35)	0.97 (0.43)

Note: WTAC = willingness to accept craving. WTAC values are in dollars; latencies to smoke are in seconds (log-transformed). Participants in the squeeze-only condition were not asked to provide verbal reports.

and verbal assessments of urge (i.e., verbal first and squeeze first), a set of within-subject comparisons (i.e., Steiger's *z*-test) was used to compare the predictive utility of responses.

To evaluate the possibility that reporting urge to smoke on a traditional verbal report would influence the degree to which a subsequent nonverbal squeeze recording predicted latency to smoke (i.e., order effects), we examined whether condition moderated the association between squeeze recordings during cigarette cue exposure and latency to smoke. To test this, we created an orthogonal set of contrast codes comparing (a) the verbal-first condition versus the squeeze-first condition and the squeeze-only condition, and (b) the squeeze-first condition versus the squeeze-only condition (note that we did not expect to see differences between the squeeze-first and squeeze-only conditions because verbal reports were not made prior to squeezing in either condition; see also Creswell et al., 2018). A linear regression model was then used to predict latency to smoke from the interaction between the two condition contrast codes and post-cue-exposure squeeze recordings, with the following covariates entered into the model: condition contrast codes, post-cue-exposure squeeze recordings, and pre-cue-exposure squeeze recordings. Squeeze recordings were centered at their mean to aid in the interpretation of results, including when they were added to interaction terms with the condition contrasts. Similar analyses were used to conduct follow-up tests comparing the verbal-first condition versus the squeeze-first condition and the verbal-first condition versus the squeeze-only condition.

Results

Table 2 presents descriptive statistics for precue- and post-cue-exposure verbal urge assessments, WTAC values, and latencies to smoke across the four experimental conditions. We first examined whether the conditions reported similar urges on the verbal measure at baseline. As expected, there were no differences across the randomly assigned experimental conditions on pre-cue-exposure verbal ratings (p = .399). Next, we examined whether smoking-cue exposure increased verbal urge ratings and whether it did so to a similar degree across the conditions. As predicted, the in vivo cue-exposure manipulation significantly increased urge ratings from pre- to post-cue exposure for the verbal measures, $F(1, 148) = 103.8$, $p < .001$, $\eta_p^2 = .41$, and the increase in verbal urge ratings from pre- to postcue did not differ across conditions (p = .277). Participants reported a strong verbal urge to smoke during cue exposure (i.e., postcue urge; M = 85.6; SD = 20.5), which also did not differ across conditions (p = .899). We then confirmed that the four conditions had similar latencies to smoke once given the chance to do so and manifested similar levels of motivation to avoid postponing smoking on the WTAC. As expected, there also were no differences across experimental conditions on latencies to smoke (p = .692). Although WTAC ratings in the squeeze-first condition were not significantly larger than other conditions by conventional significance cutoffs, $F(3, 195) = 2.18$, $p = .091$, $\eta_p^2 = .03$, we nevertheless tested whether adjusting for WTAC values altered the nonsignificant differences across conditions in smoking latencies noted above; it did not (p = .674). In summary, results suggest that the combination of smoking abstinence and smoking-cue exposure was similarly effective in generating a peak craving state across conditions, creating an optimal situation to test the utility of our squeeze measure of urge.

Are squeeze recordings of urge to smoke sensitive to the cue-exposure manipulation?

Figure 1 depicts precue and postcue squeeze recordings of urge to smoke across the experimental conditions. Of particular interest to the present study, squeeze urge recordings were sensitive to the cue-exposure manipulation; they significantly increased from pre- to post-cue exposure, $F(1, 148) = 58.1$, $p < .001$, $\eta_p^2 = .28$.

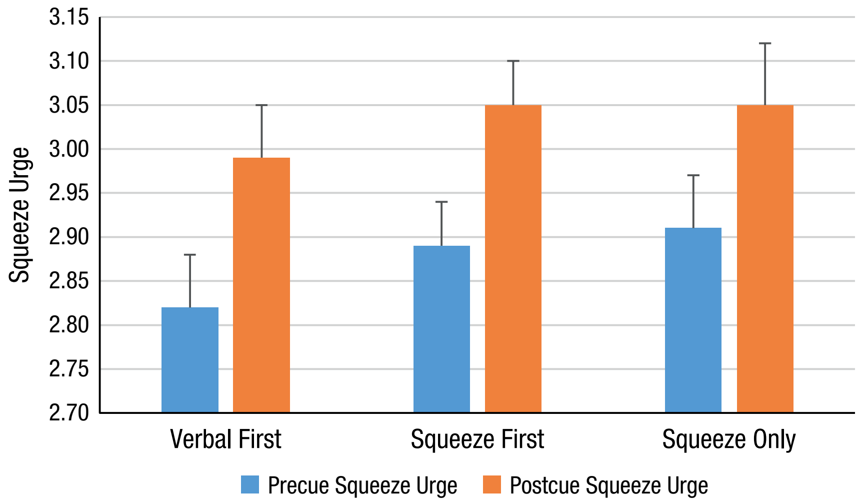

Fig. 1. Squeeze recordings of urge to smoke across experimental conditions. Log-transformed values were used for squeeze recordings. Participants in the verbal-only condition were not asked to provide squeeze recordings. Error bars indicate standard error. $^{**}p < .01$. $^{***}p < .001$.

There were no differences across conditions on precue (p = .540) or postcue (p = .750), or increases in squeeze recordings of urge from pre- to postcue (p = .803).

Are squeeze recordings of urge to smoke associated with more traditional verbal ratings?

Table 3 shows correlations between the squeeze and verbal measures across experimental conditions that included both measures (i.e., verbal first and squeeze first). At both pre- and post-cue-exposure assessment time points, the squeeze and verbal urge measures were highly correlated. These correlations remained similarly robust across conditions (both p values for Fisher's z-tests > .40).

Do squeeze recordings of urge predict smoking behavior and WTAC values?

To further test the validity of the squeeze recordings of urge to smoke, we examined whether they predicted latency to smoke and WTAC values. Squeeze recordings of urge to smoke predicted latencies to smoke in the expected directions (i.e., increased area under the curve values predicted shorter latencies to smoke) after controlling for condition assignment. This was true at both the precue squeeze-recording assessment time point, $b = -.16$, $t(147) = -2.45$, $p = .016$, 95% confidence interval (CI) = [−.29, −.03], $\beta = -0.20$, at the postcue squeeze-recording assessment time point, $b = -.17$, $t(147) = -2.76$, $p = .007$, 95% CI = [−.29, −.05], $\beta = -0.22$), and when using the mean of pre- and postcue squeeze recordings, $b = -.18$, $t(147) = -2.71$, $p = .008$, 95% CI = [−.31, −.05], $\beta = -0.22$). Squeeze change scores were unrelated to latencies to smoke, $b = -.09$, $t(147) = -0.78$, $p = .437$, 95% CI = [−.01, .00], $\beta = -.06$). Results were similar when condition was not controlled for in these models.

We next conducted a similar set of analyses to evaluate how well our traditional self-reported urge measures predicted responses on smoking latency. In contrast to the squeeze measures, verbal reports at pre-cue exposure, $b = .00$, $t(147) = -1.98$, $p = .050$, 95%

Table 3. Correlations Between Squeeze and Verbal Measures of Urge Across Experimental Conditions

	Condition	
Variable	Verbal first	Squeeze first
Precue squeeze with precue verbal	.65***	.54***
Postcue squeeze with postcue verbal	.65***	.57***

$^{***}p < .001$.

CI = [−.01, .00], β = −0.16, post-cue exposure, b = .00, t(147) = −1.66, p = .100, 95% CI = [−.01, .00], β = −0.14, and when using the mean of pre- and postcue verbal reports, b = −.01, t(147) = −1.94, p = .054, 95% CI = [−.01, .00], β = −.16) were near the threshold of significance (at precue and when using the mean) and unrelated (at postcue) to latencies to smoke. Similar to the squeeze measure, verbal report change scores were unrelated to latencies to smoke, b = .00, t(147) = 0.66, p = .511, 95% CI = [−.00, .01], β = 0.06). Results were similar when condition was not controlled for in these models.

We also directly compared the predictive utility of the postcue verbal ratings and squeeze recordings of urge to smoke in predicting latencies to smoke. Squeeze recordings in the squeeze-only condition were more related to latencies to smoke (r = −.20) than verbal reports in the verbal-only condition (r = .06), with a p value near to the threshold for significance (Fisher's z-score = −1.29, p = .098). However, there was no evidence of significant differences in the ability of squeeze recordings versus verbal ratings to predict latencies to smoke in either the verbal-first condition (Steiger's z score = −0.70, p = .244) or the squeeze-first condition (Steiger's z score = −0.16, p = .444).

Finally, we sought to determine whether squeeze recordings of urge accounted for unique variance in latencies to smoke beyond the variance accounted for by verbal urge reports. We tested this in the two conditions that included both squeeze and verbal responses (i.e., verbal-first and squeeze-first conditions). As was the case when participants in the squeeze-only condition were included in this analysis, postcue squeeze recordings in these two groups predicted smoking latencies, b = −.22, t(98) = −2.53, p = .013, 95% CI = [−.39, −.05], β = −0.25. Although in the expected direction, postcue squeeze recordings no longer predicted latencies to smoke once postcue verbal urge reports were entered into the model, b = −.11, t(97) = −0.97, p = .334, 95% CI = [−.33, .11], β = −.12. This is perhaps unsurprising given the considerable overlap between squeeze recordings and verbal reports in these two conditions (r = .61).

WTAC values were predicted by neither verbal ratings (all ps > .278) nor squeeze recordings of urge to smoke (all ps > .363). WTAC values and smoking latencies were not significantly correlated with one another (r = −.10, p = .169).

Are there order (i.e., verbal overshadowing) effects?

We next sought to evaluate the possibility that reporting urge to smoke on a traditional verbal report would influence the degree to which a subsequent nonverbal squeeze recording predicted latency to smoke (i.e., Does condition moderate the association between squeeze recordings during cigarette-cue exposure and latency to smoke?). The interaction between Contrast 1 (i.e., verbal first vs. squeeze first and squeeze only) and squeeze recordings was near to the nominal cutoff for significance, b = .18, t(144) = 1.91, p = .059, 95% CI = [−.01, .37], β = 0.16, but, as expected, the interaction between Contrast 2 (i.e., squeeze first vs. squeeze only) and squeeze recordings was not significant, b = −.10, t(144) = −0.62, p = .540, 95% CI = [−.44, .23], β = −.06. Given the p value near to the nominal level of significance, we investigated further the interaction between Contrast 1 and squeeze recordings. There was no further evidence of order effects when we examined bivariate correlations. Specifically, the association between squeeze recordings and smoking latency in the verbal-first condition (r = −.35) was not significantly different from the association observed in the squeeze-first and squeeze-only conditions (r = −.15; Fisher's z score = −1.21, p = .113). Follow-up tests indicated no evidence of order effects when comparing the verbal-first condition versus the squeeze-first condition or the verbal-first condition versus the squeeze-only condition (ps of .185 and .659, respectively). Note that we focus here only on analyses for latencies to smoke, since WTAC values were unassociated with squeeze recordings and verbal ratings of urge. In sum, the utility of the squeeze measure appeared to be every bit as effective regardless of whether it was administered before or after a verbal urge assessment.

Discussion

Considering all the time and money devoted to examining the role of craving in relapse and to evaluating the effects of anticraving medications, developing a multimodal approach to assessing drug craving (and other visceral states) is a research priority. This study used an in vivo smoking-cue-exposure manipulation to provide support for the validity of a visceral measure of craving (i.e., squeezing a handheld dynamometer) in daily smokers. Findings indicated that a squeeze measure of craving was sensitive to the cue-exposure manipulation, detecting robust increases in cigarette craving from pre- to postsmoking cue, regardless of whether it was the sole measure of urge or whether it was administered before or after a traditional self-report measure of urge. Furthermore, we observed large correlations between cravings assessed with the squeeze measure and traditional self-report measures. Such associations are notable, as correlations across different measures of urge responding are not always observed (Tiffany, 1990). Moreover, responses on the squeeze measure of urge during cue exposure also predicted a subsequent behavioral measure of smoking motivation (i.e., latency to smoke). This link between our squeeze measure and smoking behavior also is noteworthy, as researchers have criticized smoking-cue research for failing to link their cue-reactivity responses back to behavior (see Perkins, 2009). Although the squeeze measure of urge was a stronger predictor of latency to smoke than the verbal measure across conditions, there were no significant differences within conditions between squeeze and verbal urge reports (see also Lopez-Persem, Rigoux, Bourgeois-Gironde, Daunizeau, & Pressiglione, 2017). Finally, we did not find evidence of verbal overshadowing effects, indicating that the squeeze measure of urge was as effective in predicting latency to smoke regardless of whether a verbal measure of urge was administered before or after it. Taken together, findings suggest that the dynamometer measure of urge is a viable tool for assessing cravings.

Despite interest in developing nonverbal measures of craving (e.g., Perkins, 2009; Sayette, 2016; Tiffany & Wray, 2009) and notable shortcomings of traditional verbal self-report measures (e.g., ceiling effects, lack of a one-to-one mapping of verbal reports to hypothetical internal states), addiction researchers still are largely using the same craving measures put forth decades ago (Sayette et al., 2000). The current study suggests a novel and effective assessment instrument that is a viable addition to the measurement toolkit for assessing urge and that overcomes key issues with verbal rating scales of urge. Specifically, the dynamometer measure allowed participants to express how they were feeling in an unbounded way, reducing concerns with ceiling effects produced by near-maximal pre-cue-exposure urge ratings. Indeed, prior to the smoking cue, many of the deprived, daily smokers in this study were already reporting urges near the maximum value of 100 on the scale ($M = 73.46$; $SD = 22.22$), with 30% reporting urges above 90 on the scale. When using a magnitude estimation measure in our prior work (Sayette et al., 2001), these types of abstinent smokers reported that their urges nearly tripled following smoking-cue exposure. An increase in urge of this magnitude cannot be detected on traditional verbal self-report scales when precue urges are near the maximal value of the scale (Donny, Griffin, Shiffman, & Sayette, 2008). Importantly, participants in this study squeezed the dynamometer for only a fraction of the time that participants in prior handgrip studies squeezed. Specifically, the mean durations of squeezes in our study were 7.5 s at precue and 9.9 s at postcue. As a comparison, the mean durations of handgrip squeezes in the Muraven, Tice, and Baumeister (1998) study, when participants were instructed to squeeze for as long as they could, were 69.9 s at Time 1 and 54.8 s at Time 2. Comparisons across these studies indicate that fatigue was unlikely to create a ceiling for the squeeze measure as used in the current study.

In addition, the squeeze measure is not reliant on language, making it particularly amenable to capturing internal drive states that are visceral, nonverbal, and difficult to translate into symbolic systems (Schooler, 2002). Indeed, the squeeze measure of urge performed every bit as well capturing smoking motivation as did the traditional verbal measure of urge. The squeeze measure was also correlated with urge reported on a traditional rating scale, and it was equally predictive of smoking motivation regardless of whether it was administered before or after the verbal measure of urge. Overall, findings suggest that inclusion of the dynamometer measure of urge in smoking-cue-exposure studies can provide a multimodal approach to the assessment of cravings without interfering with traditional urge ratings.

These results have important methodological implications that extend beyond the field of addiction. We now have evidence of the validity of the squeeze measure for two visceral states (hunger and craving) in both a clinical and a nonclinical (Creswell et al., 2018) population. In each case, the squeeze measure predicted a behavioral outcome (popcorn consumed in hungry college students, and latency to smoke in deprived smokers), and did so on par with (in the current study) or better than (in the popcorn study; Creswell et al., 2018) traditional rating scales. Notably, the squeeze measure remained a sensitive and valid assessment tool even during the peak-provoked craving states experienced by deprived daily smokers in the current study. Indeed, squeeze recordings during smoking-cue exposure in this study were 25% higher than squeeze recordings during popcorn exposure in our prior study. It will be important to test the validity of the squeeze measure in other clinical samples and when measuring other drive states (e.g., pain, disgust), but the data so far hold great promise for this innovative assessment technique.

It is notable that verbal ratings of craving also performed well in this study, both in terms of sensitivity to the cue-exposure manipulation and in predicting latency to smoke (at least for the pre-cue-exposure verbal ratings). Furthermore, squeeze recordings did not account for unique variance in latency to smoke once verbal urge reports were entered into the model, likely because of the substantial overlap in these two assessment techniques. This stands in contrast to findings from our prior study on hunger (Creswell et al., 2018), in which the dynamometer showed incremental predictive ability above what was provided by verbal reports. Taken together, these two studies suggest that the dynamometer is a useful addition to the measurement toolkit for assessing urge and other visceral states. Future studies are indicated to establish the conditions under which squeeze measures provide unique information above and beyond verbal reports in the prediction of behavior.

This study had limitations. Only one of our two smoking-motivation measures was related to urge to smoke. Specifically, latency to smoke, a commonly used measure of motivation in the smoking literature (see Gass, Motschman, & Tiffany, 2014 for a review), was predicted by the squeeze measure of urge and, to a lesser extent, urge on a traditional rating scale. In contrast, the WTAC measure, which asks participants to place a monetary value on delaying smoking for 5 min, was unrelated to either measure of urge. Data from our prior work supported the validity of this behavioral choice task; WTAC values differed in expected ways on the basis of varying motivational levels of smokers (e.g., nicotine-deprived vs. nondeprived; Sayette et al., 2008; Sayette et al., 2001), and these money amounts correlated with a composite self-report measure of urge to smoke that accounted for ceiling effects (Sayette et al., 2001). Importantly, however, the absence of a correlation with WTAC was just as apparent for the traditional urge measure as it was for the squeeze measure. Furthermore, the WTAC measure also was unrelated to latency to smoke, suggesting that it may not have been a valid assessment of smoking motivation in this study. Overall, results suggest that latency to smoke was a more sensitive measure of motivated smoking behavior than was the WTAC.

Although squeeze recordings at both pre- and postcue exposure predicted latency to smoke, the change in craving associated with exposure to the in vivo smoking cue (i.e., cue-reactivity recordings) did not. One possible explanation for these null results is that abstinence-induced or background craving may be more predictive than cue-induced craving of smoking behavior. Indeed, it has been observed that self-reported cue reactivity is not predictive of smoking behavior (Perkins, 2009; Tiffany, 1990). Elsewhere we have argued that there may be both conceptual and methodological explanations for why cue-reactivity assessment may not be associated with smoking behavior (Donny et al., 2008; Sayette & Tiffany, 2013). Briefly, we have questioned the assumption that cue-specific cravings can be disentangled from abstinence-based cravings by subtracting precue urge from postcue urge. An alternative approach is to focus on peak-provoked craving states, which are created with the combination of nicotine deprivation and exposure to a potent smoking cue, rather than subtracting out urge ratings during baseline or precue assessments. As reviewed in Sayette and Tiffany (2013), absolute urge scores following a combination of smoking abstinence and cigarette-cue exposure are especially strong predictors of smoking behavior. Consistent with these prior findings, the squeeze measure of urge assessed postcigarette cue (i.e., peak-provoked craving) in the present study was particularly effective at predicting latency to smoke, compared to the verbal urge measure at the same time point or either measure during the precue urge assessment.

Participants were asked to squeeze the dynamometer with their dominant hand, and thus they had to hold their cigarette in their nondominant hand, which could have influenced their craving. We also compared the squeeze measure of urge to a single-item craving scale rather than a multi-item scale for several reasons. Single-item measures consistently support the diagnostic utility of craving (Sayette, 2016; Tiffany & Wray, 2012), and these assessments are commonly used in addiction research when repeated and rapid reporting of craving states is necessary (e.g., in laboratory cue-exposure studies and real-world ecological momentary assessment studies; Sayette, Griffin, & Sayers, 2010; Shiffman, 2009). Furthermore, single-item scales often detect stronger cravings during smoking-cue-exposure paradigms than do multi-item measures (see Heckman et al., 2013, for a meta-analysis of cigarette craving), making them particularly useful assessment tools to compare to the novel squeeze measure tested in the current study. Studies are indicated, though, that compare the dynamometer to other standard self-report (e.g., multi-item scales, joystick dials) and nonverbal assessments of craving (e.g., cognitive processing tasks, expressive behavior, neurobiological responding). In addition, future studies could explore for whom the squeeze measure of urge is most sensitive, especially since drug users differ in the response domains that are most affected during craving states (Shadel, Niaura, Brown, Hutchison, & Abrams, 2001), with some response domains appearing to be particularly well suited to a nonverbal dynamometer measure of urge (e.g., physiological sensations, subjective emotional experience). It would also be interesting to test whether the squeeze measure is particularly effective in participants who are relatively more "viscerally aware" (i.e., those who have increased interoceptive awareness; Critchley, Wiens, Rotshtein, Öhman, & Dolan, 2004), and whether certain dynamometer parameters (e.g., force, duration, velocity to peak force) are more or less reliable and valid in predicting craving and smoking behavior.

It is important to note that, similar to verbal rating scales, the dynamometer measure is an explicit self-report measure that requires some amount of introspection to "decide" how hard/long to squeeze to indicate one's craving. As such, the dynamometer measure might also be disruptive to emotional/motivational states, as verbal reports have been shown to be (e.g., Lieberman et al., 2007). However, the disruption linked to visceral awareness of an urge that is reflected in a response that is untethered to verbalization or quantification is likely to be less pronounced. Several studies have demonstrated that linguistic processing of the emotional aspects of an emotional image produce more disruption of amygdala activity than perceptual processing of the emotional aspects of the same image (Hariri, Bookheimer, & Mazziotta, 2000; Lieberman et al., 2007; Lieberman, Hariri, Jarcho, Eisenberger, & Bookheimer, 2005). Similar patterns of reduced disruption from perceptual relative to verbal processing have also been demonstrated in the verbal overshadowing literature (Brandimonte, Hitch, & Bishop, 1992; Schooler & Engstler-Schooler, 1990). Nonetheless, it will be important to determine if the dynamometer is also disruptive of the underlying emotional/motivational state being assessed, as has been shown for verbal self-reports (Kassam & Mendes, 2013; Lieberman et al., 2007). It will be important to test whether squeeze measures of urge during a craving experience can predict subsequent lapse or relapse processes in quitting smokers, or if they can track craving reductions associated with interventions (e.g., medications to control craving). Future research is also indicated to test the potential for the squeeze measure to index dynamic fluctuations in the craving experience over time. That is, rather than assuming that the craving experience during the time of assessment is static (and using an area under the curve analysis), one could posit that cravings change on a moment-to-moment basis, ebbing and flowing throughout. Indeed, dynamic measures have proved useful in capturing other feeling states (e.g., ambivalence in social judgments) on a moment-to-moment basis (Vallacher, Nowak, & Kaufman, 1994). If so, an alternative approach would require participants to squeeze for a set period of time or until their craving dissipated (in the latter instance, the dynamometer may become more of an intervention than a measure). A variety of different analyses that leverage the temporal nature of the data could then be used to interrogate the trajectories of craving responses over time, including periodic oscillations and intermittent bursts of change (see also Vallacher et al., 1994). Importantly, as noted above, the dynamometer also may prove to be a highly effective assessment tool for capturing other clinically meaningful experiences (e.g., pain, disgust), as it permits individuals to express how they are feeling in a sensitive and nonverbal fashion, thereby avoiding the potential distortions that can otherwise arise from translating these nonverbal experiences into words or numbers. Certainly, at a time when development of additional craving measures is in great demand, the present data support continued evaluation of a squeeze measure as part of a multimodal analysis of craving.

Action Editor

John J. Curtin served as action editor for this article.

Author Contributions

K. G. Creswell and M. A. Sayette developed the study concept and design. Testing and data collection were performed by K. G. Creswell and E. Sehic. K. G. Creswell performed the data analysis and drafted the manuscript, and M. A. Sayette, A. G. C. Wright, C. J. Skrzynski, and J. W. Schooler provided feedback. All authors approved the final version of the manuscript for submission.

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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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Note

1. The squeeze measure is not artificially constrained the way a verbal report is with a limited, defined response set, but there are limits to muscle strength, endurance, and task duration that need to be considered when using the squeeze measure. We provide evidence showing that these limits are not relevant when using the squeeze measure to assess smoking urges.

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