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Comparing the reward value of cigarettes and food during tobacco abstinence and nonabstinence

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ABSTRACT

Background: Some addiction theories propose that nicotine dependence is characterized by an imbalance between motivation for cigarettes compared to non-drug rewards. This imbalance may become increasingly polarized during abstinence, which further potentiates smoking. The present study evaluated motivation for cigarettes and food during abstinence and nonabstinence in daily smokers. This study modified a previously validated cue-reactivity procedure to include food as a cue condition, thereby allowing the comparison of cigarettes to food and neutral cues. The Choice Behavior Under Cued Conditions (CBUCC) procedure, in which participants are presented with cues and spend money in order to gain immediate access to that cue, generates multiple variables to evaluate motivational factors and drug use behaviors including reward value, craving, seeking, choice time, and consumption.

Methods: Fifty daily cigarette smokers underwent two CBUCC sessions under overnight abstinent and nonabstinent conditions.

Results: As an index of reward value, participants spent more money to access cigarettes than food or water and more for food relative to water. Abstinence increased the reward value of cigarettes but did not significantly affect the reward value of food or water. Participants also demonstrated cue-specific craving for cigarettes and food, although overall cigarette craving was greater than food craving.

Conclusions: This study indicated that motivation was greater for cigarettes than food. Abstinence increased motivation for cigarettes but had little impact on motivation for food. This suggests that heavy smokers do not reallocate motivational resources towards cigarettes during abstinence; rather, motivational processes for food remain constant from nonabstinent to abstinent sessions.

1. Introduction

Tobacco cigarettes are highly addictive, and cigarette smoking is extremely resistant to change, as most quit attempts are unsuccessful (Babb et al., 2017). There are several theories about the motivational role of nicotine in smoking behavior, including the proposal that the increased motivation to use drugs occurs at the expense of non-drug rewards (Goldstein and Volkow, 2002; Koob and Volkow, 2009; Volkow et al., 2010). Moreover, an imbalance between the reward value of drug and non-drug rewards may be magnified during abstinence (Epping-Jordan et al., 1998). Some have hypothesized that an attenuation of the value of non-drug rewards during nicotine withdrawal motivates continued smoking to compensate for changes in reward processing (Barr et al., 2008; Epping-Jordan et al., 1998; Pergadia et al., 2014).

Nicotine dependence and withdrawal may have a particularly pronounced impact on food reward. One study found that, in female smokers, the reinforcement value of snack foods increased during abstinence relative to nonabstinence and was higher relative to nonsmokers (Spring et al., 2003). Overall, smokers weigh less than nonsmokers and often gain weight after quitting (Grunberg, 1985; Klesges et al., 1989), indicating the reward value of food may be altered during smoking and cessation. Rodin (1987) reported that that only some smokers who quit gained weight, and those smokers had an increased preference for sweet foods.

Few studies have examined the relationship between drug and nondrug rewards in the same experimental paradigm using human subjects. The studies addressing this issue have generated somewhat inconsistent results. Tobacco abstinence reliably increases motivation for cigarettes (Epstein et al., 1991; Perkins et al., 1994); however, the results are more varied regarding motivation for non-drug rewards. Sweitzer et al. (2014) showed decreased neural activation during anticipation of monetary rewards during nicotine abstinence, which supports the

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theory that withdrawal is associated with an increased value of drug rewards and decreased value of non-drug rewards (Volkow et al., 2010). Conversely, Bühler et al. (2010) found increased brain activation with anticipation of monetary rewards during abstinence. With regard to behavioral measures of reward value, both Bühler et al. (2010) and Lawn et al. (2015) found that button pressing for alternative non-drug rewards was not significantly affected by abstinence.

Examinations of the relationship between craving and reward value of cigarettes may help clarify the motivation for drug and non-drug rewards. Some studies have found that, during abstinence, there is a negative correlation between drug craving and non-drug reward variables (e.g., non-drug reward responsiveness and anticipation; Peechatka et al., 2015; Sweitzer et al., 2014; Wrase et al., 2007). This supports the argument that withdrawal is associated with increased craving and motivation for drugs and decreased value of non-drug rewards.

The inconsistent results regarding the relative reward value of cigarette and non-cigarette rewards may arise from some limitations in the previous research. In most studies, consumption of rewards was postponed until after the completion of the experimental task, or rewards were hypothetical and therefore could not be consumed. Delays in reward delivery can affect the expectancy of receiving rewards and attenuate responses to drug cues (Carter and Tiffany, 2001; Wilson et al., 2005). Moreover, many studies have not included a neutral consummatory stimulus as a control for typical responses generated under the same conditions as the target rewards. Additionally, most studies used variations of an instrumental learning task where rewards were contingent upon performance, usually button presses (Bühler et al., 2010; Epstein et al., 1991; Lawn et al., 2015; Perkins et al., 1994). These instrumental responses provide a metric of reward value that can be difficult to compare across paradigms, as they use different reinforcement schedules and behavioral responses.

In order to compare drug and non-drug reward values, the present study used the Choice Behavior Under Cued Conditions (CBUCC) procedure, an experimental paradigm that utilizes real money as a measure of reward values. During each trial of the CBUCC task, participants were exposed to either a cigarette, food, or neutral reward and then selected an amount of money that corresponded to the probability they would have access to that reward. Previous research with this procedure has shown that money spent on each trial provides a reliable index of the reward value of cigarettes (Dowd and Tiffany, 2018; Gass and Tiffany, 2017, 2019).

The experimental design of CBUCC addressed several limitations of previous research. The procedure allowed for a comparison of cigarettes with food and neutral stimuli. Previous studies often used concurrent choice tasks, in which cigarettes were simultaneously compared with non-drug rewards, and therefore change in preference for one reward necessitated a change in preference for the alternative reward. With that design, it is difficult to detect absolute changes in reward value, whereas in CBUCC, reward values of the target stimuli are evaluated on separate trials. Additionally, CBUCC utilized in-vivo cues and allowed for immediate as opposed to delayed consumption of these cues as the rewarding stimuli. During CBUCC, participants were shown their preferentially rated cigarette brand and food. Each measure, except for consumption, was obtained on each trial, which allowed for graduated responses. We expected that aggregation across multiple trials of reward value would improve the reliability of that variable in contrast to some instrumental studies that only generate a single estimate of reward value for each participant.

The study used the CBUCC procedure to examine the relative reward value of cigarettes and food and change in reward value and craving as a function of overnight abstinence. We expected that abstinence would increase craving and spending for cigarettes, but given the conflicting past research in this area, no specific predictions were made for spending and craving for food. We also predicted that spending and craving would be significantly associated for both cigarette and food cues.

2. Materials and methods

2.1. Participants

A total of 50 cigarette smokers were recruited using online and flyer advertisements. Participants must have been at least 18 years old, proficient in English, smoked at least ten cigarettes per day (CPD) for at least one year, and maintained smoking abstinence overnight before one laboratory session. Participants were required to have an expired air carbon monoxide (CO) level of at least 10 ppm as assessed at the beginning of their nonabstinent session. They also had to report enjoying eating one of the available candy options in order to be eligible. Participants were excluded if they were currently attempting to cut down or quit smoking, reported using electronic cigarettes or other tobacco products besides cigarettes more than 2 times in the past month, had sought treatment for drug or alcohol problems within the past year, had an eating disorder, or had any health condition that required a specialized diet or affected eating. A power analysis using effect size estimates from Gass and Tiffany (2019) determined that a sample size of 49 was necessary to have adequate power (0.80) to detect a 2-cent difference (Cohen's $f = 0.173$) in spending between cigarette and food rewards. The University at Buffalo Institutional Review Board approved this study.

2.2. Study design

Participants attended two laboratory sessions, one following 12 h overnight abstinence (abstinence condition) and one in which they smoked as usual before the visit (nonabstinence condition). Experimenters were not blind to the abstinence condition. Study sessions occurred no more than one week apart and were scheduled to start between 9am-12pm. Condition order, which was counterbalanced and stratified by gender, was assigned at the phone screen. Participants were asked to abstain from consuming any food the morning of the study session. During the nonabstinent condition, participants were asked to smoke at least one cigarette prior to the beginning of the session in order to ensure they were not abstinent during their session. Participants were compensated between $60 – $127.28 for the study, which included $60 for completing both sessions with bonuses added for meeting certain requirements. Participants were paid a $25 bonus if they successfully maintained overnight abstinence, verified by a minimum 25% reduction in CO during the abstinent compared to nonabstinent session, which was calculated after completion of both sessions so session order could be counterbalanced instead of occurring in a fixed order. Additional bonuses included $5-10 if they arrived to sessions on time and $10 if they brought their own pack of cigarettes to use during CBUCC. Participants were given $9 to spend during CBUCC and were instructed they could keep the money they did not spend during both sessions (between $0.00 and $8.64 at each session). A 25% reduction in CO levels to verify overnight abstinence was selected in order to replicate previous research using CBUCC to examine the effect of abstinence on motivation for cigarettes (Gass and Tiffany, 2019).

2.3. Procedures

During the first laboratory session, participants provided informed consent, and then expired air carbon monoxide levels were assessed with a Vitalograph CO monitor (Vitalograph, Inc., Lenexa, KS). On the first session, participants underwent a taste test to determine the food cue used during CBUCC. The options included Reese's Peanut Butter Cups, Snickers, Kit Kats, Hershey's milk chocolates, Milky Ways, Twix, and 3 Musketeers, all of which are chocolate-based candy bars. The candy with the highest rating was used as the food reward during CBUCC, which also had to be scored 5 or higher on 7-point Likert scale.

Candy was used as the food reward due to past research suggesting that sugar content is related to food reward value, and the possibility to provide participants with a variety of options that were similar in size and macronutrient content (Epstein et al., 2011). Participants then consumed 8oz of water prior to starting CBUCC in order to standardize recent water intake.

2.3.1. CBUCC

E-Prime 2.0 was used to administer all CBUCC questionnaires and instructions on a computer monitor. For a detailed description of the CBUCC procedure, see Gass and Tiffany (2017, 2019) and Dowd and Tiffany (2018). Participants sat in front of a computer monitor and wore headphones. A vertically sliding glass door located to the right of the computer screen opened to a box, where the rewards were placed.

At the beginning of each CBUCC trial, participants were instructed to close their eyes until they heard a tone that prompted them to open their eyes and look at the cue behind the glass door. Within the chamber they saw either a clear plastic cup with water, a small unwrapped candy bar on a plate, or a lit cigarette of the participant's preferred brand on an ashtray. A second tone occurred 8 s later, after which participants rated their craving for cigarettes and food, as well as positive and negative affect.

Next, the Choice Screen was presented (see Supplementary Material, Figure S1*) showing the amount participants could choose to pay for the reward ($0.01 to $0.25) with the corresponding probability (5%–95%) the door would be unlocked on that trial and the reward could be sampled. Higher prices were linearly associated with greater probabilities of receiving access to the reward. Whether or not participants received the reward was determined by a computer algorithm based on the probability associated with the selected payment.

A third tone occurred after eight seconds, which signaled participants to attempt to open the door to the box. Whether the door was locked or unlocked was determined by the computer program using the probability associated with the amount of money the participant chose to spend during the trial. If the door was locked, participants completed the craving and mood assessments. If the door was unlocked, participants were able to consume the reward by taking a single puff of the cigarette, a single bite of candy, or a single sip of water. After consumption, participants completed the craving and mood assessments and rated their liking of the reward. Participants were then instructed to close their eyes until the next trial began. There were 12 trials of each reward type, and the order of the rewards was randomized with no more than three same-item trials in a row.

2.4. Measures

2.4.1. Smoking-related measures

Prior to CBUCC, participants completed assessments of withdrawal and craving using the Minnesota Nicotine Withdrawal Scale – Revised (MNWS-R; Hughes and Hatsukami, 1986) and the Questionnaire of Smoking Urges-Brief (QSU-Brief; Cox et al., 2001). The MNWS-R includes eight items on which participants rate common withdrawal symptoms on scale of 0 (none) to 4 (severe). Reliability (α) in this sample ranged from 0.77 (nonabstinent) to 0.81 (abstinent). The QSU-Brief includes 10 items rated on a scale of 1 (strongly disagree) and 7 (strongly agree) and demonstrated high internal consistency in this sample (α between 0.89-0.93). At the end of the first session, participants completed a demographics and smoking history questionnaire and the Nicotine Addiction Taxon Scale (NATS) to measure nicotine dependence (Goedeker and Tiffany, 2008). The threshold to be categorized as nicotine dependent is 14.33, and 49 participants in this study were above this threshold (α = 0.79). The Timeline Follow Back (TLFB; Sobell and Sobell, 1996) for cigarettes was administered for the previous 28 days to assess current smoking levels.

2.4.2. Mood-related measures

At the beginning of each session, prior to CBUCC, participants completed assessments of positive and negative affect with the Mood Form (Diener and Emmons, 1984). Participants rated their current experiences of nine emotions on a scale of 0 (not at all) to 6 (extremely) and yielded reliabilities (α) between 0.82-0.92. Anhedonia was assessed at the same time points with the Snaith-Hamilton Pleasure Scale (Snaith et al., 1995) on which participants rated how much they would have enjoyed pleasurable experiences in the last few days (α between 0.89–0.91).

2.4.3. Eating-related measures

At the end of the first session, restricted eating patterns were assessed with the cognitive restraint subscale of the Three-Factor Eating Questionnaire (TFEQ; Stunkard and Messick, 1985), which showed good internal consistency (α = 0.88). Selected questions from the Weight Concern Scale (Borrelli and Mermelstein, 1998) were administered to assess participants' use of cigarettes motivated by concern with weight (α = 0.95). Height and weight were recorded to calculate body mass index (BMI). Each session, participants were asked to recall food they consumed over the previous 24 h to verify they had refrained from consuming food the morning of the study. A multi-pass method was used to collect information from participants (Epstein et al., 2011).

2.4.4. Measures collected from CBUCC trials

During CBUCC, reward value was indexed by the amount of money participants spent on each trial for a certain probability of receiving the reward. Cigarette craving was assessed with the QSU-4 (Wray et al., 2011). Questions included "I have an urge for a cigarette," "All I want right now is a cigarette," "I crave a cigarette right now," and "Nothing would be better than smoking a cigarette right now." Food craving questions were created using the same wording as the QSU-4, but "food" replaced the word "cigarette" in the questions. For both cigarette and food craving, two items were randomly administered on each trial from the four-item set. Each item was rated between 1 (strongly disagree) to 7 (strongly agree). Details regarding additional variables collected during the CBUCC procedure (spending choice time, door attempt latency, and cigarette/food/water consumption, mood, liking, hunger, and satiety), which were not the primary focus of the present paper, are described in supplementary material.

2.5. Data analysis

A mixed design analysis of variance (ANOVA) was used to evaluate group differences across cues and smoking conditions. Cue Type (cigarettes, food, water) and Abstinence (nonabstinent, abstinent) were within-subjects factors. Gender and Order (nonabstinent or abstinent session first) were between-subjects factors. Gender was included in these analyses due to gender differences in the reward value of food and the effect of smoking abstinence that have been reported in previous studies (Benowitz and Hatsukami, 1998; Perkins et al., 1995, 1999). Planned comparisons were used to test specific hypotheses related to craving and spending (reward value). To control for multiple comparisons, a Bonferroni (Tabachnick and Fidell, 2013) corrected alpha level of .003 was used to test for significant omnibus effects for all dependent variables. Exploratory correlational analyses examined relationships between craving and spending variables. Additional analyses can be found in Supplementary Materials.

3. Results

A total of 62 participants were enrolled in the study. Two participants did not complete both study sessions, two were removed from the study for expired air CO levels less than 10 ppm on their nonabstinent visit, and five participants did not meet criteria for overnight abstinence. Those five participants completed all study procedures, but

Table 1
Participant demographics and smoking characteristics.

	M (*SD*) or %
Age (years)	36.2 (11.8)
Female %	50
Caucasian %	78.0
Average Household Income	$38,100 ($26,631)
Employed (full or part-time) %	56.0
High school education or higher %	98.0
Cigarettes per day (CPD)	16.7 (7.2)
Age of first cigarette (years)	14.5 (2.9)
Nicotine dependence (NATS)	19.3 (2.6)
Time since last cigarette, nonabstinent session (hours)	0.6 (0.4)
Nonabstinent CO level (ppm)	24.4 (11.3)
Time since last cigarette, abstinent session (hours)	13.1 (3.5)
Abstinent CO level (ppm)	9.4 (5.2)
CO Reduction %	60.6 (13.8)
BMI	28.4 (7.2)
TFEQ-Restraint Subscale (0 – 21)	7.0 (5.2)
Weight Concern (1 – 10)	3.7 (3.2)

Note. NATS = Nicotine Addiction Taxon Scale; CO = carbon monoxide; BMI = Body Mass Index; TFEQ = Three Factor Eating Questionnaire.

their data were excluded from data analyses when their CO reduction did not meet the required reduction during abstinence, and they did not receive the payment bonus for remaining abstinent. Data from these participants were not included in analyses. An additional three participants were excluded from data analyses for various participant- and experimenter-related errors. Data from 50 participants were analyzed (see Table 1 for demographics). At the start of the abstinent session, participants reported significantly higher cigarette craving, $t(49) = 11.35$, $p < .001$, withdrawal symptoms $t(49) = 6.19$, $p < .001$, negative affect $t(49) = 4.34$, $p < .001$, and lower positive affect, $t(49) = -4.34$, $p < .001$, relative to the nonabstinent session. Baseline hunger, satiety, and anhedonia did not significantly differ across abstinence condition (*ps* > .13).

3.1. Reliability

As in previous CBUCC studies (Dowd and Tiffany, 2018; Gass and Tiffany, 2017, 2019), the reliabilities of spending and craving measures were high across all cue types and abstinence conditions (α between 0.84 and 0.97; see Supplementary Materials Table S1*).

3.2. Spending

The majority of participants (88%) spent more than the minimum allowed to access cigarette and food cues. On average, participants spent significantly more on cigarette trials compared to both food, $F(1,46) = 92.46$, $p < .0001$, $\eta_p^2 = 0.67$ and water trials, $F(1,46) = 196.67$, $p < .0001$, $\eta_p^2 = 0.81$, and spent significantly more on food relative to water trials, $F(1,46) = 28.02$, $p < .0001$, $\eta_p^2 = 0.38$ (Fig. 1, Table S2*). There was an interaction between Cue Type and Abstinence, $F(2,92) = 17.46$, $p < .0001$, $\eta_p^2 = 0.28$, such that only spending for cigarettes significantly increased during the abstinent condition, $F(1,46) = 32.96$, $p < .0001$, $\eta_p^2 = 42$; spending for food and water remained the same (*ps* > .26).

3.3. Cigarette craving

Craving for cigarettes was significantly higher in the presence of cigarettes relative to water, $F(1,46) = 51.64$, $p < .0001$, $\eta_p^2 = 0.53$ (Fig. 2a). Examination of a significant Cue x Gender interaction, $F(2,92) = 6.87$, $p = .002$, $\eta_p^2 = 0.13$, revealed that cigarette craving was significantly lower on food compared to water trials for female, F

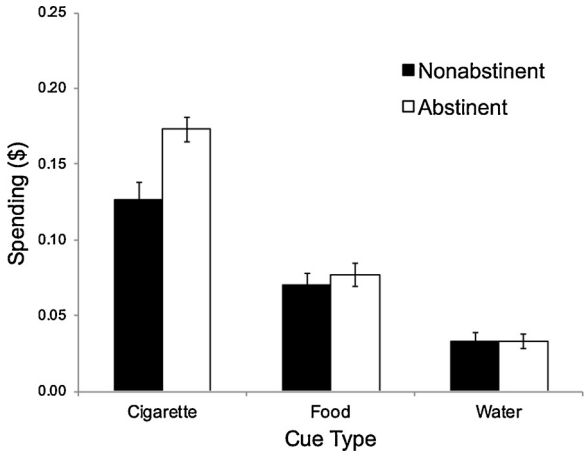

Fig. 1. Average (and SEM) money spent per trial for cigarettes, food, and water for each abstinence condition. Participants spent significantly more on cigarette trials compared to both food and water trials, and more on food relative to water trials (all *ps* < .0001). Spending for cigarettes significantly increased during abstinence relative to nonabstinence sessions ($p < .0001$).

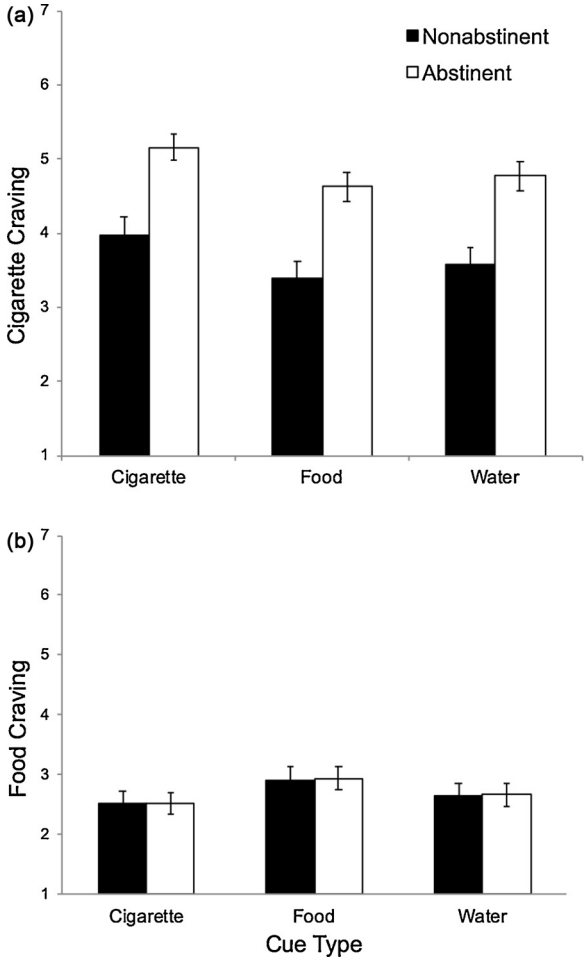

Fig. 2. Average (and SEM) cigarette craving (a) and food craving (b) within each cue type as a function of abstinence condition. The data show significant effects for cue-elicited cigarette craving and food craving (*ps* < .0001). Across all conditions, cigarette craving was significantly higher than food craving ($p < .001$). Cigarette craving was significantly higher during abstinence relative to nonabstinence sessions ($p < .0001$), however there was no main effect of Abstinence on food craving ($p > .92$). Cigarette craving was significantly lower on food compared to water trials for female ($p = .019$), but not male participants, ($p = .17$).

(1,23) = 6.34, $p = .019$, $\eta_p^2 = 0.22$, but not male participants ($p = .17$). Cigarette craving across all cues was significantly higher during abstinence relative to nonabstinent sessions, $F(1,46) = 72.79$, $p < .0001$, $\eta_p^2 = 0.61$. Cigarette craving was significantly higher than food craving when collapsed across cues and abstinence conditions $F(1,46) = 31.87$, $p < .001$, $\eta_p^2 = .41$.

3.4. Food craving

Food craving was significantly higher in the presence of food compared to water trials, $F(1,46) = 27.61$, $p < .0001$, $\eta_p^2 = 0.38$ (Fig. 2b, Table S2*). There was no effect of Abstinence or interaction between Cue and Abstinence on food craving (*ps* > .92).

3.5. Correlations

Due to the small sample size, all correlations reported were exploratory. Across abstinence conditions, higher cigarette craving was associated with greater spending for cigarette cues (*rs* > .43, *ps* < .0017; Table S3*) but not food or water cues (*rs* < .26, *ps* > .07; Tables S4*, S5*). Participants with higher food craving during both abstinence conditions spent more money to access food cues (*rs* > .53, *ps* < .0001).

4. Discussion

The results of this study indicated that the cigarette smokers spent more on cigarette trials than food and water trials and more on food relative to water trials. Overnight abstinence from cigarettes increased spending for cigarettes but did not significantly alter spending for food or water. There was clear evidence of cue-elicited craving for both cigarettes and food; however, cigarette craving was generally greater than food craving.

The CBUCC procedure generated reliable indices of craving and reward value related to cigarettes and food under abstinent and nonabstinent conditions. The majority of participants spent more than the minimum allowed to access cigarette and food cues, and the procedure yielded strong cue-specific caving for cigarettes and food. The findings contribute to the accumulating evidence that CBUCC is a valid procedure for comprehensively assessing cigarette-related motivational processes (Dowd and Tiffany, 2018; Gass and Tiffany, 2017, 2019). The research also showed that CBUCC can capture important facets of food-related motivation, permitting informative comparisons between food and cigarette motivation under conditions of cigarette abstinence.

Participants spent more on cigarettes than food and water, indicating that they valued puffs on a cigarette more than food or water regardless of abstinence status. Additionally, the reward value of food was significantly greater than the water cue during both abstinent and nonabstinent conditions. Two previous studies showed similar preference for cigarettes over food rewards under abstinent and nonabstinent conditions in dependent smokers (Epstein et al., 1991; Lawn et al., 2015). However, other research has shown no difference in cigarette and non-drug reward values as measured by instrumental responses and brain activation (Bühler et al., 2010). Cigarette abstinence selectively increased the reward value of cigarettes but did not significantly affect the reward value of food or water. Increased spending on cigarette trials during abstinence was expected given that abstinence increases motivation for cigarettes (Epstein et al., 1991; Gloria et al., 2009; McClernon et al., 2009). Both Lawn et al. (2015) and Bühler et al. (2010) reported that abstinence had no impact on button press responding for non-drug rewards in dependent smokers. However, these studies did not find increased responding for cigarettes during abstinence, which suggests that the button-pressing task was not sensitive to changes in reward value. Overall, no previous study has obtained the precise pattern of results observed in the present research. As described here, however, elements of previous results have paralleled our findings regarding relative reward value and the effect of abstinence on the reward values of cigarettes and food.

There was no evidence from the CBUCC procedure that abstinence reduced the reward value of non-drug rewards. This contrasts with findings from previous studies suggesting the reward value of non-drug rewards, such as monetary and sensory stimuli, might be decreased during abstinence (Al-Adawi and Powell, 1997; Dawkins et al., 2006; Pergadia et al., 2014; Perkins et al., 2012; Powell et al., 2002; Sweitzer et al., 2014). It also contrasts with research suggesting the value of food rewards increased during abstinence for female smokers (Spring et al., 2003). Most of these studies did not concurrently study cigarettes in direct comparison to the non-drug reward; thus, they did not allow for an exact assessment of the relative reward value of cigarettes and alternative rewards under abstinent and nonabstinent conditions. Lawn et al. (2015) also showed decreased preference for music during abstinence as indexed by number of choices during a concurrent choice task. However, the change in music preference may have been due to increased preference for cigarettes, as the absolute value of preferences could not be isolated in the concurrent choice task.

With the exception of Epstein et al. (1991) and Lawn et al. (2015), none of the previous studies included food as an alternative reward, so it is possible the current results are reward-specific. Work by Perkins and colleagues indicated that the reinforcement-enhancing effects of nicotine may be limited to sensory rewards (e.g., music and videos), and therefore the acute administration and withdrawal of nicotine may have a limited impact on the reward value of food (Perkins and Karelitz, 2013a, 2013b). Additionally, these studies used different indices of reward value, one of which was solely neurobiological instead of behavioral (i.e., fMRI BOLD signals; Sweitzer et al., 2014), making comparisons across studies difficult. These indices likely represent different components of reward motivation and processing, which could account for discrepant results.

The study partially supports theories that addiction is characterized by changes in reward processing, which are affected by abstinence (Goldstein and Volkow, 2002; Koob and Volkow, 2009; Volkow et al., 2010). In this study, abstinence led to increased value of cigarettes but did not significantly affect the reward value of food or water. While the *relative* reward value of cigarettes compared to food increased during abstinence, abstinence only affected the reward value of cigarettes and not food or the neutral stimuli. This suggests that heavy smokers do not reallocate motivational resources towards cigarettes and away from food during abstinence; rather, motivational processes for food remains constant from nonabstinent to abstinent sessions.

As expected, CBUCC generated clear cue-specific craving for cigarettes, with craving levels higher on cigarette relative to water trials. Abstinence led to an overall increase in cigarette craving. However, the cue-specific effect was not significantly affected by overnight abstinence. This result is consistent with considerable previous research (Tiffany et al., 2009) but contradicts one previous study comparing cue reactivity to food and cigarette cues during smoking abstinence and nonabstinence (Alsene et al., 2003). Abstinence produces a generalized increase in cigarette craving but does not selectively enhance cue-specific craving. A cue-specific effect for food craving was also observed, but abstinence had no significant impact on food craving, which is also consistent with previous research (Alsene et al., 2003). The selective impact of abstinence on general cigarette craving, and not cigarette cue reactivity, demonstrated that spending and cue-induced craving represent somewhat dissociated motivational processes. These findings underscore the value of including multiple indices in cue reactivity research for comprehensively examining drug motivation.

As predicted, cigarette craving was significantly and strongly correlated with the money spent on cigarette trials. Although craving and drug-use measures collected in laboratory studies tend to be only modestly related (Gass et al., 2014), we have consistently found fairly robust associations between craving and spending in the CBUCC procedure (Dowd and Tiffany, 2018; Gass and Tiffany, 2017, 2019).

Inconsistent with some previous research, cigarette craving was not significantly related to food craving or other motivational variables on food trials. Previous research suggested that, during abstinence, increased craving for cigarettes would be inversely related to the reward value of food (Peechatka et al., 2015; Sweitzer et al., 2014). These two studies indicated that motivation for cigarettes attenuated motivation for monetary rewards, which was not found in the present study, again suggesting that motivational processes for cigarettes and food were partially dissociated in the present research.

This study improved upon past research comparing the reward value of cigarettes and food during abstinence and nonabstinence. Moreover, because variables were aggregated over multiple trials, the CBUCC procedure generated measures with high levels of reliability. The paradigm utilized real instead of hypothetical rewards, allowed for immediate consumption of rewards, and utilized preferred cigarette and food rewards, thereby enhancing the ecological validity of the outcomes. This study also permitted the separate evaluation of motivational processes related to cigarettes and other cues, which addressed a limitation of concurrent choice tasks where the selection of one cue affects the selection of the alternative.

Though the CBUCC paradigm offers many advantages over previous procedures and studies, it is not without limitations. Participants brought their own cigarettes to smoke; however, they selected their food reward from a limited range of options. Although this was an improvement over past studies that did not take taste preferences into account, it is possible that the limited choices may have restricted the reward value of food for some participants. Additionally, study sessions started before 12 PM, which might reduce motivation for candy, which is not typically consumed in the morning. The length of abstinence for this study was standardized at 12 h; however, this may not be the optimal duration of abstinence to reveal an impact on non-drug reward values. Time since participants' last meal was not standardized in the same way as their water consumption, which may have also affected individual motivation for food. Certain tobacco abstinence effects may only become apparent after smokers have been cigarette deprived for longer periods of time. Given the particular reinforcing effects of nicotine and the impact of nicotine administration and withdrawal on appetite and taste, the results of this study cannot be generalized to other drug and non-drug rewards. Finally, due to the sample size, there was not adequate power to detect smaller changes in spending that may have been present.

Future CBUCC studies with increased sample sizes would allow for examination of more nuanced changes in motivational function and help in exploring factors contributing to individual differences in reward value. As demonstrated in this study and past research, primary CBUCC variables are highly reliable, which allows for meaningful investigation of individual differences with large sample sizes. CBUCC includes multiple trials with varying outcomes, and future studies could examine factors associated with changes in craving and spending on a trial-by-trial basis. Our participant sample was mostly Caucasian with a high school education or higher, and, therefore, replicating these results in a more diverse sample would be necessary. Disorders that affect reward functioning (e.g., depression) were not assessed in the present study. Future studies with the CBUCC paradigm could evaluate whether such conditions modify the relative reward value of cigarettes and non-drug rewards. Future research including a non-smoking control group to compare motivation for non-drug rewards between smokers and nonsmokers would also help reveal how smoking alters motivation for non-drug rewards.

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Contributors

JB and ST both contributed to the conceptualization and design of the study. JB directly supervised the conduct of the research, data extraction, data analysis, and wrote the initial draft of the manuscript. Both authors contributed to editing, manuscript development, and approved the final version.

Declaration of Competing Interest

No conflict declared.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.drugalcdep.2019.04.040.

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