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Associations between nicotine product use and craving among stable daily and non-daily users

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Abstract

Nicotine craving typically develops shortly after last use and is conceptualized as essential to the development, maintenance, and treatment of nicotine dependence. Previous research has primarily examined the relationship between craving and use among individuals trying to quit smoking, and less is known about this relationship among active users, particularly e-cigarette users. The current study evaluated the association between craving and use by assessing both constructs twice daily over 7 days in a sample of daily ($n = 80$) and non-daily ($n = 34$) users of combustible tobacco and e-cigarette products. We used negative binomial regression modeling to analyze the relationship between nicotine craving and use in two ways. First, we evaluated a lagged model in which craving at the time of assessment predicted use during the next time period. Next, we evaluated a model in which maximum craving since the last assessment predicted use during the same time period. Maximum craving was significantly and positively associated with nicotine product use ($p < .05$) while craving at the time of assessment was not. These associations did not differ depending on use frequency or on specific products used. Findings provide evidence that self-report ratings of craving are associated with greater nicotine and tobacco product use for both frequent and intermittent users. Furthermore, these results may be useful in developing or modifying interventions for a wide variety of nicotine users, including those who are not yet intending to make a change to their nicotine use.

Introduction

Craving can be defined as a desire, need, or compulsion to engage in a behavior, such as substance use (Drummond, 2001). The experience of nicotine craving is an important component in understanding the development, maintenance, and treatment of nicotine dependence. Craving is a diagnostic indicator of substance use disorders in the DSM-5-TR, which emphasizes that it is more likely to occur in contexts that have been previously associated with use (APA, 2021). While craving is *prima facie* associated with use, characterizations of the relationship between urges and the associated use behaviors are complex. Contemporary models of addiction such as Incentive Salience Theory (IST) differentiate between ‘wanting’ (being motivated to pursue and use substances) and ‘liking’

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(enjoying the reward from substance use) which explains why individuals may continue to use substances despite no longer enjoying the activity (Robinson & Berridge, 1993). IST suggests that chronic substance use leads to sensitization of the mesolimbic dopamine system, which in turn increases motivation to use a substance in response to conditioned cues (Olney et al., 2018). In the context of nicotine and tobacco product (NTP) use, mesolimbic sensitization resulting from repeated pairing of cues and NTP use leads to overreaction to drug cues and contexts – that is, to intense wanting when cue exposure occurs (Berridge & Robinson, 2016). Nicotine craving represents an individual's desire for nicotine, and is associated with ongoing NTP use despite decline in 'liking' and despite other negative consequences (Berridge & Robinson, 2016).

Studies suggest that nicotine craving begins shortly after smoking a cigarette (Schuh & Stitzer, 1995), with peaks occurring approximately 3 to 6 hours after last use (Tiffany et al., 2008). In a review of mostly cross-sectional studies of associations between craving and relapse, Wray and colleagues (2013) suggested that craving is an important but not necessarily universal predictor of relapse after a quit attempt. The relationships between pre-quit craving and treatment outcomes tended to be weaker than associations between post-quit craving and outcome. However, studies using experience sampling procedures, such as ecological momentary assessment (EMA), have consistently found the craving and use relationship to be significant (Serre et al., 2015), perhaps due to the temporal dynamics of craving as well as lower risk of recall bias. Significant positive associations between craving and tobacco use among individuals not engaging in a quit attempt at time of assessment were found in each of 11 studies included in the review, supporting suggestions that craving may predict use among active, predominately heavy (10+ cigarettes/day), tobacco users in pre-quit periods or who did not want to quit (Serre et al., 2015). Those who are contemplating, preparing, or acting to make a quit attempt may be reducing the amount of nicotine they consume, which may then lead to increased withdrawal and associated negative affect (Zhou et al., 2009), perhaps strengthening the relationship between craving and use. While some studies have investigated the relationships between craving and nicotine use among individuals who have not yet quit smoking, these have typically been intervention studies evaluating the mediating effect of nicotine cessation medication such as varenicline (Lawson et al., 2021), bupropion (Hawk et al., 2015), nicotine replacement (Germovsek et al., 2020; Shiffman et al., 2006), or behavioral activation interventions such as exercise (De Jesus & Prapavessis, 2018). Thus, additional studies are needed to fully articulate the relationship between craving and use in active users, especially light or intermittent users.

The relationship between craving and nicotine use is also not well studied for those who use electronic nicotine delivery systems (ENDS; e.g., e-cigarettes, vapes), and may be different when compared to the craving and use relationship among users of combustible tobacco products. An estimated 39.1% of e-cigarette users also currently smoke cigarettes (Mayer et al., 2020), and among those who currently smoke cigarettes, 20.4% report current use of e-cigarettes on some days and nearly 4% report daily e-cigarette use (Rutten et al., 2015). Use occasions are often not equivalent across products. In one early study of individuals who had largely switched to vaping from smoking, only about half used ENDS as they did a cigarette. Another 30% reported using ENDS more frequently, with some describing their use as 'constant' or 'chain-vaping' while others compared their use to 'snacking' or grazing

(Dawkins et al., 2013). Those who engage in dual use (i.e., use multiple forms of nicotine delivery, such as using both combustible tobacco products and ENDS) may also be uniquely affected by craving. Studies suggest both convergent (e.g., increased social benefits, stress reduction, financial consequences) and divergent (e.g. convenience and discreetness of use, social acceptability) (Sanchez et al., 2021) motives for vaping compared with combustible cigarette use. Vaping-specific motives reflect reduced barriers to use that may facilitate vaping initiation and maintenance and impede cessation. Evidence suggests that those who engage in dual use are more nicotine dependent than those who do not (Pulvers et al., 2015), possibly leading to higher levels of craving which may be more easily satiated due to the convenience of dual-use. Ease of ENDS use, when compared to combustible tobacco products, may therefore modulate the relationship between craving and use.

Our study was intended to examine the relationship between nicotine craving and use among a sample of non-treatment seeking active adult users of NTPs. We also examined whether the relationship between nicotine craving and use differed depending on NTP use type (i.e., whether participants were exclusive users of combustible tobacco, ENDS, or used both). Controlling for demographic, nicotine dependence severity, and daily versus nondaily use, we hypothesized that momentary episodic craving would significantly and positively predict subsequent NTP use and maximum level of craving would significantly and positively predict NTP use within the same time period, across users of all NTP types.

Methods

2.1 Participants

Participants (n = 115) were recruited for the study, and 9 were excluded from final analyses for lacking EMA data, but were retained for analyses of missing data patterns. Of the 106 remaining participants, 55.7% were male, 57.5% were White, and 76.4% were non-Hispanic (see Table 1). For the logistic regressions, race was recoded into 'non-White,' 'White,' and 'unknown/declined to report' categories, due to small cell sizes. The sample was recruited electronically via Facebook, Craigslist, and the San Diego Reader. Paper flyers were also placed within the San Diego community. Interested individuals contacted the laboratory and completed an initial telephone assessment to screen for study inclusion. Inclusion criteria for the study were 1) ages 18+, 2) at least weekly NTP during the past 3 months, and 3) NTP use history > 1 year. Exclusionary criteria were 1) non-fluency in English, 2) medical or psychiatric history affecting brain development (i.e., current severe DSM-5 psychiatric disorders other than tobacco use disorders, severe head trauma with loss of consciousness >2 minutes, or history and/or treatment of neurologic disorders), and 3) visual problems that could make completion of study tasks difficult (e.g., severe motion sickness, blindness).

NTP use was defined as use of any tobacco (i.e., cigarette, cigar, hookah) or ENDS product (e.g., e-cigarette, nicotine vaporizer). Participants were categorized according to their reported NTP use type preferences in the previous 3 months at baseline. Those who indicated any use of both combustible and ENDS during this time period were classified as dual users. The remainder were classified according to their reported product use. NTP use type categories were: exclusive combustible tobacco users, exclusive ENDS users, or dual users. Of those using combustible tobacco, two participants reported primarily using hookah

and 3 participants reported primarily smoking cigars, while the rest reported primarily smoking cigarettes. These were all collapsed into the category of “combustible tobacco,” as there was not enough variability to make meaningful within combustible tobacco group comparisons. Nicotine dependence was measured using the PATH Tobacco Dependence index, a reliable and valid measure across different types of tobacco use categories (Strong et al., 2015). Possible dependence scores ranged from 0-80.

NTP use frequency groups were defined based on frequency of any NTP use during the previous 3 months: Daily users (average use on 7 days per week) and non-daily users (average use on 4-27 days per month). Participants were given a full detailing of the study procedures and provided written informed consent in accordance with the provided written informed consent in accordance with the University of California, San Diego Human Research Protections Program. Participants then completed a series of self-report questionnaires to assess demographics, substance use, and psychological health.

2.2 Data Collection

Our study utilized a subset of data from the larger study investigating the psychophysiological correlates of cue-reactivity in a virtual reality paradigm which included a baseline self-report of daily or non-daily NTP use (either combustible tobacco or ENDS), and EMA reports of nicotine craving and use frequency. EMA data collection began the day after the completion of baseline questionnaires. Participants received two prompts at random times during the day (morning and evening), across 7 days for a total of 14 possible time points. Nicotine craving was queried as “*How much are you craving NTPs right now?*” (i.e. current level of craving) and “*What was your highest level of NTP craving since your last report?*” (i.e. maximum craving level since last assessment. “NTP” was defined at the top of the EMA prompt screen as “any nicotine or tobacco product” and referenced repeatedly during the participants’ baseline visit to ensure familiarity with the term. Participants responded on a scale from 0 (no craving) to 7 (high craving). Participants also reported time since last NTP use and the number of times/separate occasions of NTP use since the prior prompt. Reports were made using free text entry in response to the question: “*How many times/separate occasions have you used an NTP since your last report?*” Those who used cigarettes were instructed at baseline to report the number of full or partial cigarettes smoked, while e-cigarette users were instructed to report “use occasions,” separated by engaging in some other activity after puffing on an ENDS/times the ENDS products were put down and picked up. NTP use queries did not differentiate between ENDS and combustible tobacco products. Participants were given two hours to respond to each prompt; non-responses were coded as missing after this time period. Up to three reminder prompts were delivered via app notification, text message, and email during the two-hour period of survey availability. EMA data were captured via the mNCANDA application and managed using REDcap electronic data management software (Cummins et al., 2021). The parent study protocol was approved by the institutional review board of approved by the institutional review board of the University of California, San Diego.

2.3 Statistical Methods

Longitudinal negative binomial regressions were used to model the data in Intercooled Stata 15.0 (StataCorp, College Station, TX). These models exhibited best fit when compared to modeling with assumptions of Poisson and normal distributions. Momentary episodic and maximum cravings since last report were considered separate phenomena that could differentially predict NTP use. They were modeled in two separate analyses to maximize the likelihood of capturing the effect of the relationship while minimizing risks of cue reactivity and recall bias. To analyze momentary episodic craving predicting nicotine use we utilized a lagged modeling approach, such that craving at one timepoint were used to predict NTP use at the subsequent timepoint. In contrast, we reasoned that maximum craving since last report would be associated with nicotine use frequency within the same EMA time period, therefore neither variable was lagged. Prior to hypothesis testing, bivariate tests were conducted to evaluate whether demographic variables (age, sex, race, ethnicity) were associated with craving or use frequency and thus should be included as covariates in hypothesis tests. Nicotine dependence severity, type of NTP use status, daily versus nondaily use were all included in the model to control for their respective variance. Type of NTP use status (i.e., exclusive tobacco, exclusive ENDS, or dual use at baseline) was also tested as a moderator of the craving/use frequency relationship. No assumptions or imputations were made regarding missing data. All models included baseline NTP frequency (daily vs. non-daily) and product count (single vs. dual use) as covariates of interest. For all hypothesis tests, alpha was set to 0.05.

Results

3.1 Preliminary Analyses

See table 1 for demographic and baseline nicotine use characteristics of participants. Each participant was prompted 14 times to provide EMA data (i.e., twice per day across 7 days), for a total of 1,610 possible observations. The average momentary episodic craving was 2.93 ($sd = 2.17$), maximum craving was 4.06 ($sd = 2.01$) and NTP use frequency (between EMA prompts) was 5.90 ($sd = 8.62$). One outlier observation of NTP use was reported as 765 and was coded as missing. Nine other responses of NTP use episodes were reported as between 50 and 100, and while this suggested nearly continuous use of NTP since prior EMA prompt, these data were retained as it is possible that they were using NTP with this level of frequency. All 115 participants were examined (including those with missing EMA data) were analyzed for patterns of missingness. Frequency of missing data (measured as a count of EMA responses) did not vary by gender, race, or ethnicity (see Table S1 for summary of chi square test of group differences). Age was significantly associated with frequency of missing data ($r = -.185$, $p = 0.05$); this variable was therefore retained for the final models. Gender was significantly associated with use frequency over time and was retained for the final models. Race and ethnicity were not significantly associated with either momentary episodic craving, maximum craving, or use frequency over time and these predictors were excluded from the final models.

3.2. Associations between craving and use

The longitudinal negative binomial models are shown in Tables 2 and 3. We found that maximum craving since the last assessment was significantly associated with frequency of NTP use since the last assessment. More specifically, each one-point increase in craving was associated with an 8% increase in the number of NTP use episodes (Incidence Rate Ratio [IRR] = 1.08 [95% confidence interval 1.05, 1.11], $z = 4.79$, $p < .01$). In contrast, momentary episodic craving at the time of assessment was not significantly associated with NTP use between that moment and the following assessment (IRR = 1.01 [0.98, 1.03], $z = 0.56$, $p = 0.58$).

Type of NTP use was not significantly associated with dependence ($F(2,106) = 0.50$, $p = .61$). We tested type of NTP use as a moderator of the relationship between craving and NTP use frequency. This interaction lacked a statistically significant effect in either model and was dropped from each final model analysis. In both models, type of NTP use (i.e., exclusive tobacco, exclusive ENDS, and dual) was not a statistically significant predictor of NTP use frequency. NTP use frequency was significantly associated with baseline NTP frequency (i.e., daily versus nondaily use), with baseline daily users reporting 3.16-3.21 times as many NTP use episodes compared with non-daily users. Every unit increase in dependence was significantly associated with a 1% increase in NTP use for each model. Women reported 1.31-1.45 times as many use episodes when compared to their male counterparts. Age was not a significant predictor in either model.

Discussion

Understanding the relationship between nicotine craving and use is key to addressing nicotine dependence. The aim of this study was to evaluate the relationship between craving and NTP use over the course of seven days in a sample of current active adult users of various NTPs and use levels. We found that maximum past craving ratings were positively associated with NTP use. Stronger craving predicted higher levels of use in the short-term, suggesting that nicotine craving is an important component of the process that maintains NTP use behavior. The significant positive relationship between maximum craving and use frequency supports traditional models of aversion to nicotine withdrawal, in which NTP use is predicted by craving even during times in which the individual does not 'want' to use. However, this finding did not hold for momentary episodic craving.

While the relationship between craving and use may seem apparent, this relationship is more frequently conceptualized among individuals who are making a quit attempt or have recently quit. In each of these scenarios, the user is abstaining from nicotine and tobacco use, which may intensify the experience of the nicotine craving, especially within the first 10 days (Piper et al., 2011). Our findings were that the relationship between maximum level of nicotine craving and NTP use within the same period were significantly related among active users with no immediate intention of quitting. This may suggest that craving plays an important role in maintaining NTP use behaviors, despite the availability of a nicotine delivery device or an individual's motivation (or lack thereof) to quit or remain abstinent.

Somewhat surprising was our finding that momentary episodic craving ratings did not predict subsequent use (within the next EMA period). Perhaps this was because momentary craving at each EMA prompt were, on average, lower than maximum levels of craving report for the past EMA period, which may suggest that momentary craving is not as sensitive when predicting subsequent use. Alternatively, momentary episodic craving is by definition transitory in nature, and the current study design was not optimized to capture cravings in the moment (i.e., participant prompted surveys). Craving is not stable over time, and querying one's maximum level of craving since last EMA period covers a broader time-frame than craving in the moment, which may impact the reliability of the latter. Tiffany and colleagues found a strong correlation ($r = 0.82$) between 'now' (e.g., "What is your craving right now") and 'general' (e.g., "What was your craving over the past week) assessments of cocaine craving (Tiffany et al., 1993), but later note issues with each method, specifically that the 'now' version does not capture the transient nature of craving and the 'general' may be influenced by current levels of craving (Tiffany & Wray, 2012). Additionally, it is possible that when asked about use frequency over a previous time period, they may estimate their maximum level of craving to correspond with their reported use, which could arbitrarily strengthen and confound the temporality of the relationship.

Nicotine dependence severity was a significant predictor of NTP use frequency among our participants, but when controlling for dependence severity, NTP use type was not a significant predictor of use frequency. Contrary to the literature, NTP use type groups did not differ in terms of endorsed nicotine dependence severity. While our sample did not consist of NTP users who were attempting to quit, previous research has indicated that one primary reason that people used ENDS was in effort to quit smoking, reduce their level of smoking, or to reduce health risks (Patel et al., 2016; Rutten et al., 2015). Some within our sample may have been in the process of transitioning from combustible cigarettes to ENDS for these reasons, explicitly or not ('unintended switching'), and may be effortful in monitoring their nicotine consumption such that they do not increase their dependence. It may also be the case that those who engage in dual use satiate their momentary nicotine craving with ENDS, which are more convenient, more discreet, and more socially acceptable than combustible cigarettes. Assuming that dual use of combustible tobacco and ENDS is additive, and results in higher frequency of NTP use overall, may be an oversimplification of an otherwise complex relationship between craving and NTP use behavior. Further investigation into the relationship between craving and NTP use frequency among dual users should first identify the reasons for dual use, as those who are trying to gain health benefits may differ from those who are simply capitalizing on greater ease of nicotine consumption. Future studies should explore the use patterns of those who engage in dual ENDS and combustible tobacco use, which will provide a deeper understanding of the relationship between craving and use of each of these types of products, including whether individuals are more likely (or not) to use ENDS to replace smoking in effort to reduce harm or abstain from tobacco.

Strengths of the current study

There were several notable strengths to the current study. Participants in our study were nearly evenly divided between exclusive users of combustible tobacco, exclusive users

of ENDS, and dual users, which provides external validity to the relationship of craving and use across product types. Few studies have included use of ENDS and dual use of ENDS and combustible tobacco when investigating this relationship, and we explored this relationship among individuals not attempting to make a quit attempt, a subgroup of users that is underrepresented in the literature. Participants were recruited through various vectors, reducing the risk of sampling bias that can occur with single-vector recruitment strategies (i.e., online-only advertisement). The use of repeated assessments over seven days increased power and our ability to capture variation over the course of a week.

Limitations of the current study

The current study was secondary to a larger cue reactivity study. There were some general limitations to the current study that may impact the generalizability of our findings and should be addressed in future studies. The sample size of recruited participants was modest and consisted primarily of individuals who identified as White, yielding a sample that may not be representative of NTP users overall. Craving and NTP use were measured via self-report over a brief period, may be subject to bias, and the timing of EMA queries was unlikely to capture the experience of momentary cravings, which are transitory in nature. Use occasions were treated equally across product type; however use patterns may be different for some participants (i.e., users of ENDS may be more likely to use more frequently but with fewer puffs when compared to users of combustible tobacco). Finally, the fact that use during the EMA component of the study was not differentiated by product type precludes us from evaluating potential differences between use patterns by product type during the seven-day EMA collection, though we were able to compare groups based on baseline dual and single product preference profiles.

Conclusions

We found that one indicator of stronger nicotine craving (i.e., maximum craving level) was significantly and positively associated with NTP use frequency in a sample of adult NTP users not attempting to quit. In contrast, momentary episodic craving at the time of assessment did not predict subsequent use in the next measurement period. NTP use type was not a significant predictor of use frequency and requires further investigation. Taken together, these findings illustrate the complex relationships between combustible tobacco and ENDS mono- and dual use and associated craving (both momentary and at maximum level) among individuals not intending to make a quit attempt. Future research that accounts for the dimensionality of mono- and dual-use and associated craving is needed to further add to our understanding of the relationship between craving and NTP use across time and as a function of NTP use patterns and stages of use.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Table 1

Participant descriptive statistics and nicotine use characteristics

Total participants	106
Male	59 (55.7%)
Female	47 (44.3%)
Race	
White	61 (57.5%)
Asian	9 (8.5%)
Black	3 (2.8%)
Native Hawaiian/Pacific Islander	1 (0.9%)
More than one race	18 (17.0%)
Unknown/declined to answer	14 (13.2%)
Ethnicity	
Hispanic	23 (21.7%)
Non-Hispanic	81 (76.4%)
Unknown/declined to answer	2 (1.9%)
Age [mean (sd)]	31.7 (12.7)
NTP use type	
Primarily using tobacco	38 (35.8%)
Primarily using ENDS	35 (33.0%)
Dual use	33 (31.1%)
NTP use frequency	
Daily	74 (69.8%)
Nondaily	32 (30.2%)

NTP: Nicotine and tobacco product.

ENDS: Electronic nicotine delivery system.

Table 2

Longitudinal lagged regression model of momentary craving as a predictor of NTP use frequency

	I.R.R.	95% CI [LL, UL]	S.E.	Z	p
Time point	0.99	0.98, 1.00	0.01	-2.22	0.03
Momentary craving	1.01	0.98, 1.03	0.01	0.56	0.58
NTP use type					
Mono (tobacco)	0.78	0.55, 1.10	0.14	-1.43	0.15
Mono (ENDS)	0.87	0.65, 1.16	0.13	-0.98	0.33
Daily NTP use	3.21	2.30, 4.51	0.55	6.81	<0.01
Dependence severity	1.02	1.01, 1.02	<0.01	4.15	<0.01
Gender	1.31	1.03, 1.67	0.16	2.22	0.03
Age	1.01	1.00, 1.02	0.01	1.73	0.08

Note. Dual use, non-daily NTP use, and males served as reference groups.

ENDS = Electronic nicotine delivery system. NTP = Nicotine tobacco product.

Table 3

Longitudinal regression model of maximum craving as a predictor of NTP use frequency

	I.R.R.	95% CI [LL, UL]	S.E.	Z	P
Time point	0.99	0.98, 1.00	<0.01	-1.73	0.08
Maximum craving	1.08	1.05, 1.11	0.02	4.83	<0.01
NTP use type					
Mono (tobacco)	0.92	0.66, 1.27	0.15	-0.51	0.61
Mono (ENDS)	0.93	0.72, 1.20	0.12	-0.57	0.57
Daily NTP use	3.16	2.33, 4.31	0.50	7.37	<0.01
Dependence severity	1.01	1.00, 1.01	<0.01	2.22	0.03
Gender	1.45	1.16, 1.80	0.16	3.29	<0.01
Age	1.01	1.00, 1.02	0.01	1.77	0.08

Note. Dual use, non-daily NTP use, and males served as reference groups.

ENDS = Electronic nicotine delivery system. NTP = Nicotine tobacco product.