# Support for Incentive-Sensitization Theory in Adolescent Ad Libitum Smokers Using Ecological Momentary Assessment

Samantha J. Klaver[1], Robert D. Dvorak[1], Ardhys N. De Leon[1], Emily K. Burr[1], Angelina V. Leary[1],
Emma R. Hayden[1], Roselyn Peterson[1, 2], Quinn Allen[1], and Chad J. Gwaltney[3]
[1] Department of Psychology, University of Central Florida
[2] Department of Psychology, Brown University
[3] Center for Alcohol and Addiction Studies, Brown University

The incentive-sensitization theory (IST) has emerged as a potentially useful theory in explaining substance addiction. IST postulates that the prolonged use of a substance can alter neural systems that are often involved in incentive motivation and reward processes, leading to an increased "sensitization" to the substance and associated stimuli. However, this increased sensitization is thought to mediate only the individual's craving of the substance (e.g., their "wanting"), not their enjoyment of the substance (e.g., their "liking"), a process that may involve unconscious implicit changes in cognitive networks linked to specific substances. Consequently, IST may better explain the real-world dissonance reported for individuals who want to accomplish long-term substance cessation but fail to do so, a phenomenon that is common in adolescent smokers. Thus, the present study aimed to examine the principles of IST in a sample of 154 adolescent ad libitum smokers ($M_{age} = 16.57$, $SD_{age} = 1.12$, 61.14% male) utilizing ecological momentary assessment. Data were analyzed utilizing a multilevel structural equation model examining changes in positive affect (PA), negative affect (NA), and stress from Time 1 (T1) and Time 2 (T2) as a function of smoking and tested the influence of implicit cognition (specifically, implicit attitudes about smoking [Implicit Association Test (IAT)]) on these associations. Consistent with the principles of IST, results found a modest significant negative association between smoking status at T1 and PA at T2 ($B = -0.11$, $p = .047$). This association was further moderated by IAT ($B = -0.19$, $p = .029$) and was particularly potentiated at high levels of IAT ($B = -0.44$, $p < .001$), compared to low ($B = -0.05$, $p = .663$) or mean levels of IAT ($B = -0.25$, $p = .004$). Findings from this study provide additional support to the principles underlying IST and indicate that, in adolescents, smoking may result in thwarted PA indicative of a transition from "liking" toward "wanting," and this is especially pronounced among those with stronger implicit smoking cognitions.

*Public Health Significance*
Findings from this study add support to the incentive-sensitization theory as an approach to understanding tobacco addiction in adolescents. These findings have critical implications for improving long-term smoking cessation efforts within this population, suggesting that alterations of substance "wanting" (e.g., a key driver in both prolonged substance use and substance use relapse) may be made through the modification of implicit smoking attitudes.

*Keywords:* addiction, adolescence, incentive-sensitization theory, smoking, substance use

Although there has been a decrease in prevalence in recent years (Miech et al., 2019; Park-Lee et al., 2022), adolescent tobacco use continues to be a public health concern. In the United States, approximately 3.08 million adolescents between the ages of 14 and 18 reported engaging in some form of tobacco use in 2022. Though recent trends have seen a shift in the popularity of different tobacco consumption devices, with a high number of adolescents highlighting electronic cigarettes as their preferred method of tobacco use (i.e., "vaping"; Park-Lee et al., 2022), many adolescents still utilize traditional tobacco cigarettes. Indeed, approximately 16.7% of adolescents still report prolonged ad libitum (i.e., as desired) use of traditional tobacco cigarettes (Park-Lee et al., 2022). This is concerning, as research has consistently found that cigarette smokers are at an increased risk for a variety of adverse physical and mental health outcomes (Farrell et al., 1998; Khaled et al., 2012; Lushniak et al., 2014; U.S. Department of Health and Human Services, 2010).

Unfortunately, adolescent smoking cessation programs are often ineffective in achieving long-term abstinence (Choi et al., 2002; Fanshawe et al., 2017; Grimshaw et al., 2003; Hutton et al., 2011; Turner & Mermelstein, 2004; Villanti et al., 2020). In a systematic review, Bancej et al. (2007) found that nearly 71% of adolescent smokers had unsuccessfully attempted to quit smoking at least once in their lifetime. In fact, most (i.e., 92%) relapsed within 1 year of their cessation attempt (Bancej et al., 2007). Thus, further examination of specific factors that may underlie adolescent smokers' addiction processes may be critical in improving long-term smoking cessation efforts within this population.

Many traditional models of addiction suggest adolescents are particularly vulnerable to positive reinforcement mechanisms (Cooper et al., 2000; MacPherson et al., 2010) and thus may be motivated to engage in prolonged or continued substance use to gain pleasure and enjoyment (Stewart et al., 1984; Thompson & Schuster, 1964; Wise & Bozarth, 1985). More specifically, these models emphasize the neuroanatomical associations of the mesolimbic dopamine system in addiction and highlight the importance of the euphoric or rewarding effects of certain substances (Adinoff, 2004; Volkow et al., 2019). Specifically, they suggest that hedonic "hot spots" within the mesolimbic dopamine system can be stimulated through euphoric reward, thus increasing dopamine neurotransmission, an individual's craving or "want" for a substance, and their overall motivation to continue to use and receive a future reward (Adinoff, 2004; Robinson & Berridge, 2004). As a result, within these traditional models, an individual's "liking" and "wanting" of a substance occur together as a single underlying process that drives both motivation and reward approach behaviors that promote prolonged substance use and addiction.

More recent research, however, has suggested that an individual's "liking" and "wanting" of a substance may be two distinct processes that, although highly linked at the beginning of substance use, may dissociate from one another over time (Berridge et al., 1989; Berridge & Kringelbach, 2015; Hobbs et al., 2005; Ostafin et al., 2010), such that an individual's craving for a substance may increase over time without commensurate changes in their overall enjoyment of a substance. For example, in a recent longitudinal study examining prolonged alcohol use in a sample of adults, King et al. (2021) found that, although both participants' "liking" and "wanting" for alcohol increased across time as a function of their use, their "wanting" showed more robust increases.

Robinson and Berridge (1993) were the first to suggest the possible importance of this dissociation in substance addiction within their IST (Berridge & Robinson, 2003; Robinson & Berridge, 1993), which postulates that the prolonged use of a substance can alter the mesolimbic dopamine system, leading to an increased "sensitization" to the substance and any substance-associated stimuli, like internal (e.g., affective states) and external stimuli (e.g., stressors; Berridge & Robinson, 2003; Swadi, 1999). Importantly, IST suggests that this increased sensitization to the substance and any substance-associated stimuli only mediates the individual's *craving* of the substance (e.g., the "wanting"), not their *enjoyment* of the substance (e.g., the "liking;" Robinson & Berridge, 1993). Thus, individuals no longer derive the same euphoric reward or hedonic pleasure from the substance. As a result, they may engage in prolonged substance use or develop a substance addiction in a "chase" to experience the expected positive reinforcing and/or euphoric effects of the substance that, ultimately, no longer match the increased craving. However, capturing "wanting" and "liking" presents some difficulties, as individuals may not be consciously aware of these related, but discrepant, motivating factors. One way to operationalize this may be through changes in affective states following use. For example, increases in positive affect (PA) following use may serve as a proxy for "liking" at, or after, the moment of use. In contrast, reductions in PA at, or after, the moment of use may represent a thwarted reward state in which "liking" has transitioned. If true, this pattern may be more robust for individuals with stronger implicit drives for smoking.

Indeed, within the IST, the increased "sensitization" to the substance and substance-associated stimuli is hypothesized to occur via unconscious or implicit changes in cognitive networks, including those related to attentional biases toward substance-associated stimuli (Waters & Sayette, 2006), as well as implicit motivations, expectancies, and attitudes (O'Connor & Colder, 2009; Ostafin & Brooks, 2011; Waters et al., 2007; Wiers & Stacy, 2006). Implicit attitudes have been implicated in substance addiction (Marhe et al., 2013), with positive implicit attitudes about a substance being associated with increased substance "wanting" in both adult and adolescent samples (Chassin et al., 2010; Dvorak et al., 2018).

Despite the potential utility of IST in understanding substance use and addiction, little research thus far has specifically examined this theory in a sample of adolescent smokers (Bradley et al., 2003; Grigutsch et al., 2019; Parker & Gilbert, 2008), though the theory has found strong support in adult samples (i.e., in samples of individuals over the age of 18 years). In the only known study examining IST and its principles in a sample of adolescent smokers, Palmeri (2016) asked 570 adolescents (ranging in age from 14 to 16 years) to complete explicit measures of smoking "liking" and smoking "wanting" across a 2-year period. Overall, the findings of this longitudinal study provided initial support for the IST and its principles in this sample, with results demonstrating a strong dissociation of substance "wanting" and substance "liking" over time, with participants self-reporting decreased enjoyment from smoking but increased craving (Palmeri, 2016). However, this study only examined explicit experiences of "liking" and "wanting," which may not fully or comprehensively measure these complex neurological processes.

Further, no research thus far has examined the principles of IST at a momentary level. Although incentive sensitization is hypothesized to develop over an extended period of time via the prolonged use of a

substance (Berridge et al., 1989; Berridge & Kringelbach, 2015; Hobbs et al., 2005; Ostafin et al., 2010), the mechanisms through which this sensitization occurs may manifest at a more momentary level as a result of dampened or thwarted reward expectations immediately following the use of the substance. However, this possibility has yet to be explored empirically.

Given these gaps in the literature, the aim of the present study is to further examine a microlevel mechanism of the IST of addiction in a sample of adolescent ad libitum smokers utilizing ecological momentary assessments (EMAs) of affect, stress, and smoking status. In addition, the present study aimed to examine the influence of implicit cognitive processes on these associations. We hypothesized that, following a smoking event, PA would be lower relative to matched PA that does not follow a smoking event, as adolescents' expectations of enjoyment from smoking are thwarted. Further, we expected that this effect would be more pronounced among individuals with stronger implicit smoking attitudes.

## Method

We report how we determined our sample size, all data exclusions, all manipulations, and all measures in the study. Participants for the study were from a larger study on adolescent smoking cessation ($N = 233$; title: Ecological Momentary Assessment of Adolescent Smoking Cessation) that was approved by Brown University's institutional review board.

### Participants

Participants included 154 adolescent ad libitum smokers who had not yet attempted smoking cessation. Ages of the participants ranged from 14 to 18 years ($M = 16.56$, $SD = 1.12$), and a majority (e.g., 61.15%) identified as male. Additional descriptive information for the final sample, as well as information regarding the present study's principal variables, can be found in Table 1.

### Procedure

Participants were from a larger study on adolescent smoking cessation ($N = 233$). Original data collection for this larger study occurred from December 2007 to April 2011. Participants reported to the lab for their first session, where they provided informed consent. If adolescents were between the ages of 14 and 17 years of age, parental consent was also obtained in addition to participant assent. Further, at this session, participants were trained to use a palmtop computer (e.g., the Teen Electronic Diary [TED]; see Dvorak et al., 2018 for a detailed description) and were asked to complete several paper-and-pencil assessments. After several days carrying the TED, they reported back to the lab to complete the Implicit Association Test (IAT) for smoking. After completing the IAT lab assessment, participants utilized the TED while ad libitum smoking to complete measures of momentary affect and stress at either a self-initiated or random assessment.

### Measures

#### Demographics

Participants completed a demographic questionnaire, which was used to gather information regarding age, race, and gender identity.

**Table 1**

*Descriptive Statistics for Demographic and Principal Variables*

| Variable | N (%) | | |
|---|---|---|---|
| Gender | | | |
|   Male | 94 (61.15) | | |
|   Female | 60 (38.85) | | |
| Race | | | |
|   White/Caucasian | 127 (82.47) | | |
|   Black | 3 (1.95) | | |
|   Asian | 1 (0.65) | | |
|   Multiracial | 15 (9.74) | | |
|   Other | 8 (5.19) | | |
| Ethnicity | | | |
|   Hispanic | 9 (5.84) | | |
|   Non-Hispanic | 144 (93.51) | | |
|   No response | 1 (0.65) | | |

| Variable | M (SD) | Skew (SE) | Range |
|---|---|---|---|
| Positive affect | 4.88 (2.81) | −0.02 | 0–10 |
| Negative affect | 3.01 (2.28) | 0.66 | 0–10 |
| Stress | 3.91 (2.58) | 0.48 | 0–10 |
| IAT | −0.41 (0.56) | 0.16 | −.71 to 1.03 |
| mFTQ | 4.74 (1.47) | −0.09 | 2–8 |
| Age | 16.56 (1.11) | −0.31 | 14–18 |

*Note.* All values are between-subject. $N = 154$; IAT = implicit smoking attitudes, as measured by the Implicit Associations Test; mFTQ = Modified Fägerstrom Tolerance Questionnaire; $SE$ = standard error.

### Momentary PA, Negative Affect, and Stress

To measure participants' momentary PA and negative affect (NA), as well as momentary stress, participants rated current affect and stress at both smoking assessments and at random nonsmoking assessments. Specifically, participants were asked to rate the extent to which they were feeling stressed, sad, irritable, relaxed, fidgety, calm, excited, and/or cheerful on a Likert-type scale that ranged from 0 (*no!!*) to 11 (*yes!!*). PA was computed using the mean of cheerful and excited. NA was computed using the mean of sad, irritable, and fidgety. Stress was computed using the mean of stressed, reverse relaxed, and reversed calm. A multilevel factor analysis of these three factors indicated a reasonable fit to the data: $\chi^2(30) = 383.59$, root-mean-square error of approximation, RMSEA = .04, comparative fit index, CFI = .95, standardized root-mean-square residual, $SRMR_{within} = 0.04$, $SRMR_{between} = .08$. Internal consistency estimates for the three indicators in the present sample was adequate (PA: $\omega_{within} = .72$; $\omega_{between} = .90$; NA: $\omega_{within} = .83$; $\omega_{between} = .84$; stress: $\omega_{within} = .93$; $\omega_{between} = .88$).

### Smoking Status

Smoking status (e.g., whether the participant had smoked prior to the assessment) was identified via two methods: if the participant self-initiated a smoking assessment and confirmed that they had smoked previously (yes/no) and/or if the participant confirmed that they had smoked previously (yes/no) at a random assessment.

### Implicit Smoking Attitudes

To measure participants' implicit smoking attitudes at baseline, participants completed the IAT (Greenwald et al., 1998), a task that

aims to identify automatic associations between specific concepts and attributes. For the purpose of the present study, the IAT was coded using E-Prime (Schneider et al., 2002) and contained seven unique blocks. Block 1 involved 24 trials of practice categorization for the target concepts (e.g., smoking/not smoking). Block 2 involved 24 trials of practice categorization for the target attributes (e.g., good/bad). Block 3 involved 24 trials of a combined categorization task (e.g., "Task 1"; smoking + good/not smoking + bad). Block 4 involved another 48 trials of Task 1. Block 5 involved 24 trials of practice categorization for the target concept, but with the responses in an alternative reverse order (e.g., not smoking/ smoking). Block 6 involved 48 trials of a combined alternative and reversed categorization task (e.g., "Task 2;" not smoking + good/ smoking + bad). Finally, Block 7 involved another 48 trials of Task 2. A full description of the specific IAT task used in the present study, including detailed procedures, can be found elsewhere (e.g., Dvorak et al., 2018). Importantly, for the present study, a valence IAT effect (e.g., the strength of the implicit association) was calculated using an algorithm suggested by Greenwald et al. (2003), whereby the difference between mean reaction times on Tasks 1 and 2 was divided by the pooled standard deviation of reaction times across the task. In general, higher IAT scores indicate more a positive implicit attitude toward smoking, which has been supported elsewhere in the literature (Cunningham et al., 2001). Internal reliability of the IAT in the present sample was good, with a split-half reliability coefficient of .78. Only EMA data collected after the IAT session were used in the analysis.

### Nicotine Dependence

To measure and control participants' overall level of nicotine dependence, participants were asked to complete the Modified Fägerstrom Tolerance Questionnaire (mFTQ; Prokhorov et al., 1996, 1998). The mFTQ is a seven-item self-report questionnaire that can be scored to identify nicotine dependence across three discrete levels of possible dependence. Specifically, total scores of 0–2 suggest no dependence, total scores of 3–5 suggest moderate dependence, and total scores of 6–9 suggest substantial dependence. Internal consistency in the current sample was acceptable ($\alpha = .65$).

### Data Preparation and Analysis Plan

Data were structured such that adolescents' Time 2 (T2) affect and stress were the dependent variables, with Time (T1, which was always the assessment just prior) affect and stress as predictor variables. In addition, smoking status coded as 0 (did not smoke between the T1 and T2 assessments) or 1 (did smoke between the T1 and T2 assessments) was added as a predictor variable. Interactions between smoking status, the T1 affect, and stress variables were created. The timeline of affect/stress and smoking status is depicted in Figure 1.

A multilevel structural equation model with affect and stress as the outcome variables was specified in Mplus V. 8.8 (Muthén & Muthen, 2020). The analyses examined the associations between smoking and affect at each time point across the day for PA, NA, and stress at Level 1 (event level). At the within-subjects level, PA, NA, and stress at T2 were regressed onto matching affect and stress at T1. In addition, PA, NA, and stress at T2 were regressed onto smoking status (yes/no) at T1 (the assessment just prior). Next, implicit

smoking attitudes, assessed at Level 2, predicted mean levels of T2 NA, PA, and stress. Finally, cross-level interactions of PA (T1) × IAT, NA (T1) × IAT, stress (T1) × IAT, and Smoking × IAT were added to the model.

## Results

### Descriptive and Compliance Statistics

Descriptive statistics for the analysis sample can be found in Table 1. In the larger study that these data were derived from, participants were asked to carry the TED for 1 week prior to a cessation attempt and then for 2 weeks following a cessation attempt (see Roberts et al., 2015). For the present study, only data prior to the cessation attempt were utilized. As a result, participants in the present study carried the TED between 1 and 13 days ($M = 4.20$, $SD = 2.23$). In all, participants carried the TED for a total of 1,069 days of monitoring. During this time, a total of 5,175 random prompts were planned to be sent to participants. However, due to technological complications (i.e., battery difficulties and/or data error), a total of 4,839 (i.e., 93.53%) random prompts were ultimately sent.

Overall, participants completed a total of 7,170 assessments ($M = 8.60$; $SD = 3.31$; though only 6,160 assessments, nested across 1,069 days and 154 participants, were utilized in the final analysis. This included a total of 2,905 self-initiated smoking assessments and 4,265 random assessments, yielding a compliance rate of 88.14%.

### Primary Analysis

A multilevel structural equation model with affect and stress as the outcome variables was specified in Mplus V. 8.6 (Muthén & Muthen, 2020). As previously noted, there were a total of 7,170 ad libitum smoking assessments completed by the participants; however, given the primary analysis required participants to have both pre- and postassessments, a total of 6,160 assessments, nested across 1,069 days and 154 participants, were utilized in the final analysis.

PA, NA, stress, and smoking status at T1 predicted matching affect and stress at T2 (see Figure 1). T1 affect and stress were significantly and positively associated with matching affect and stress at T2 (PA: $B = 0.11$, $p < .001$; NA: $B = 0.10$, $p < .001$; stress: $B = 0.09$, $p < .001$). At Level 2, IAT predicted mean affect and stress and had cross-level interactions with the affect and stress slopes, as well as the smoking status slope (see Figure 1 structural model). Consistent with IST, there was a modest negative association between smoking at the previous assessment, and PA at the next assessment ($B = -0.11$, $p = .047$). This association was moderated by IAT ($B = -0.19$, $p = .029$). PA following a smoking event was compared to PA that did not follow a smoking event at both high (+1 $SD$) and low (−1 $SD$) levels of IAT (see Figure 1 bar graph). At low levels of IAT, there was no difference in PA as a function of smoking ($B = -0.05$, $p = .663$). However, at mean IAT, PA was lower after smoking compared to PA that did not follow smoking ($B = -0.25$, $p = .004$). This effect was even more pronounced at high levels of IAT ($B = -0.44$, $p < .001$). IAT did not moderate any other model effects, and thus these cross-level interactions were removed. Additionally, there were significant positive associations of nicotine dependence scores on mean stress ($B = .213$, $p = .007$) and NA ($B = 0.227$, $p = .009$), but not PA ($B = -0.40$, $p = .640$).

**Figure 1**

*Multilevel Structural Equation Model Examining Affect, Stress, Smoking Status, and Implicit Smoking Attitudes About Smoking*
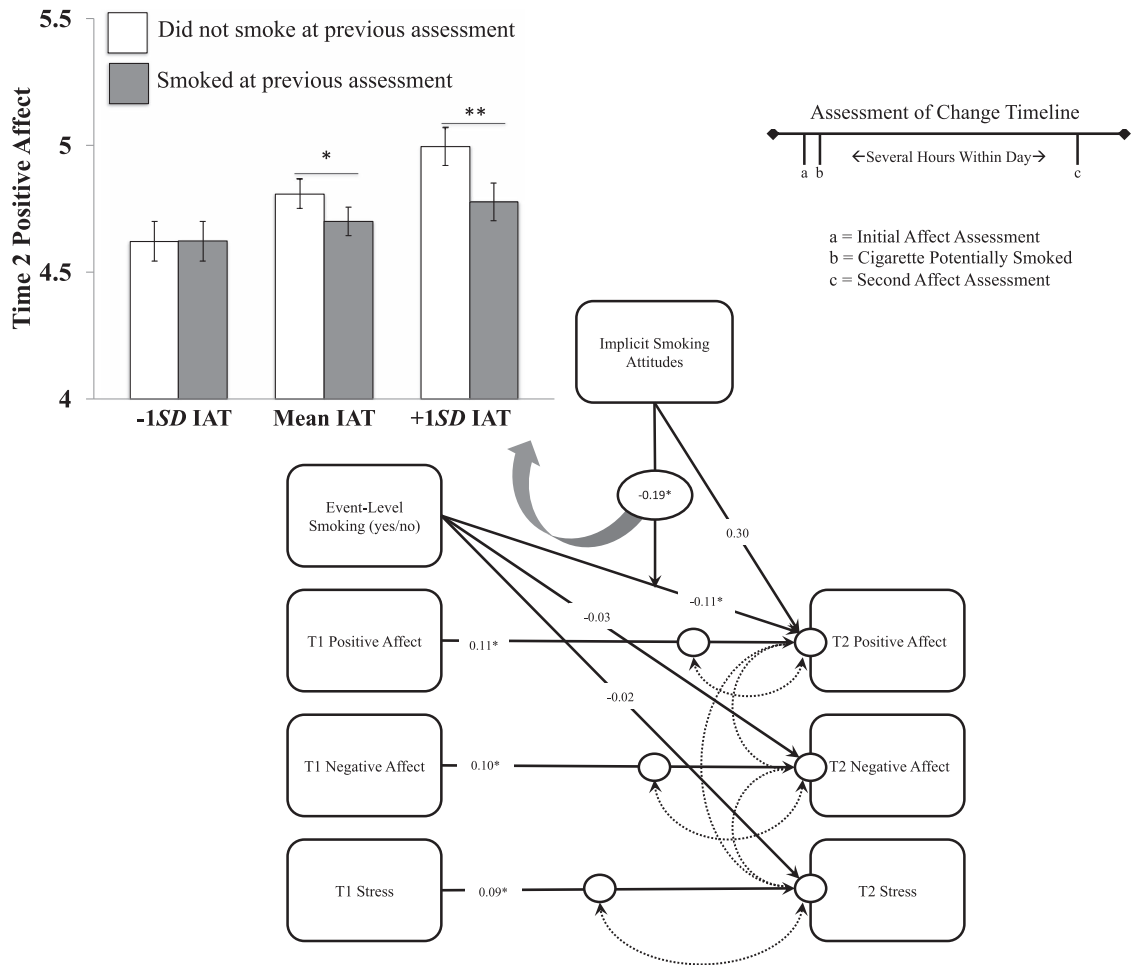


*Note.* T1 = Time 1; T2 = Time 2. *N* participants = 154; *N* observations = 6,101; IAT = Implicit Association Test.
* *p* < .05.   ** *p* < .01.

## Discussion

The aim of the present study was to examine principles consistent with IST at the momentary level within a sample of adolescent smokers utilizing EMA. Further, the present study also aimed to examine the influence of implicit cognitive processes on these associations. In general, there were no significant associations between smoking status and changes in NA or stress. However, there was a significant negative association between smoking and changes in PA. Further, it was found that the negative association between smoking and changes in PA was further moderated by implicit attitudes about smoking, such that individuals with stronger implicit attitudes about smoking experienced lower PA following a smoking event than those with weaker implicit attitudes about smoking.

Results of the present study add support to previous research that showed dissociation of substance "liking" and substance "wanting" over time in smokers and further bolster this theoretical approach in understanding tobacco addiction and high relapse rate in adolescents.

It may be that some adolescent smokers experience feelings of a "thwarted reward" following a smoking event; that is, adolescents may expect to receive some euphoric or rewarding effects as a result of their substance use (e.g., more PA). When this does not occur, their levels of PA are lower than in instances when they had not smoked prior. This may result in stronger implicit substance "wanting" as they continue to seek some concurrent positive reward following their substance use, thereby reinforcing use patterns. Of note, this thwarted reward effect was most pronounced among adolescent smokers who held stronger positive implicit attitudes about smoking, further highlighting the importance of understanding unconscious or implicit changes in cognitive networks in substance addiction.

Taken together, these findings have critical implications for improving long-term smoking cessation efforts within this population. Smoking cessation programs for adolescents are often ineffective in achieving long-term abstinence. The findings of the present study suggest that alterations of substance "wanting" (e.g., a key driver in both prolonged substance use and substance use

relapse; Berridge & Robinson, 2003; Robinson & Berridge, 1993, 2004) may be made through the modification of implicit smoking attitudes. This finding has been supported previously in the literature (Chassin et al., 2010; Lee et al., 2017); however, further research is needed to examine both the feasibility of using implicit attitudes as a treatment target and to develop effective interventions that target this variable.

## Limitations

Although the present study has a number of strengths, including the use of well-validated measures and ecologically valid data collection methods, the findings should also be interpreted within the context of several limitations. First, the present study's sample was primarily comprised White, cisgender male adolescent ad libitum smokers who were preparing for, but not yet engaged in, a cessation attempt. Thus, it is possible that the results of this study may not generalize to adolescent smokers within other ethnic or racial groups, nor to adolescent smokers who are ultimately not seeking substance abstinence.

Further, the present study only examined adolescent smokers who utilize traditional tobacco cigarettes. As mentioned previously, recent trends have seen a shift in the popularity of different tobacco consumption devices, with a high number of adolescents highlighting electronic cigarettes as their preferred method of tobacco use (i.e., "vaping"; Park-Lee et al., 2022). This may hold special relevance for vaping, as this route of administration has other sensory attributes (e.g., flavor) that may enhance PA. Thus, it is unclear whether these findings, as well as the principles of IST more broadly, apply similarly to adolescents who either only use or co-use e-cigarettes. Future research may want to specifically examine, or at least control for, the use of this unique tobacco consumption device/modality.

Additionally, the present study aimed to examine the principles of IST but did not use explicit or implicit measurements of "liking" and "wanting." Instead, the present study aimed to examine these principles by examining changes in affect as a function of smoking. Although measurements of affect pre- and post-substance consumption have been used in previous literature as an approximation for substance "liking" (Nguyen et al., 2021; Tibboel et al., 2015), it is possible that it may not fully be capturing substance "liking." Future research may want to use other measures or methods to better examine the complex neurological processes highlighted by IST. For example, Grigutsch et al. (2019) utilized two newly developed variants of the IAT (specifically, a "liking" IAT and a "wanting" IAT) to examine IST in a sample of adult smokers.

Finally, the accuracy of and compliance with assessments within the present study may have been impacted by the timing of smoking behavior (e.g., before, while, or after smoking) as well as having to carry an additional electronic device throughout the day. Future studies should consider including anchors to assess when smoking is taking place during assessments and additionally consider utilizing a more sophisticated EMA system that can send messages via text messaging to eliminate the burden of, and associated limitations of, carrying an extra device.

## Summary and Conclusions

This study examined the effects of prior smoking on momentary PA, NA, and stress among adolescent smokers. The results indicate that smoking is associated with lower rates of PA but not NA or stress, which may be indicative of thwarted reward, a phenomenon consistent with a decoupling of "liking" and "wanting" that drives drug motivation (e.g., craving). This association was more robust among those with stronger implicit smoking cognitions. These findings highlight the importance of understanding implicit changes in cognitive networks in substance addiction.

## References

Adinoff, B. (2004). Neurobiologic processes in drug reward and addiction. *Harvard Review of Psychiatry*, *12*(6), 305–320. https://doi.org/10.1080/10673220490910844

Bancej, C., O'Loughlin, J., Platt, R. W., Paradis, G., & Gervais, A. (2007). Smoking cessation attempts among adolescent smokers: A systematic review of prevalence studies. *Tobacco Control*, *16*(6), Article e8. https://doi.org/10.1136/tc.2006.018853

Berridge, K. C., & Kringelbach, M. L. (2015). Pleasure systems in the brain. *Neuron*, *86*(3), 646–664. https://doi.org/10.1016/j.neuron.2015.02.018

Berridge, K. C., & Robinson, T. E. (2003). Parsing reward. *Trends in Neurosciences*, *26*(9), 507–513. https://doi.org/10.1016/S0166-2236(03)00233-9

Berridge, K. C., Venier, I. L., & Robinson, T. E. (1989). Taste reactivity analysis of 6-hydroxydopamine-induced aphagia: Implications for arousal and anhedonia hypotheses of dopamine function. *Behavioral Neuroscience*, *103*(1), 36–45. https://doi.org/10.1037/0735-7044.103.1.36

Bradley, B. P., Mogg, K., Wright, T., & Field, M. (2003). Attentional bias in drug dependence: Vigilance for cigarette-related cues in smokers. *Psychology of Addictive Behaviors*, *17*(1), 66–72. https://doi.org/10.1037/0893-164X.17.1.66

Chassin, L., Presson, C. C., Sherman, S. J., Seo, D. C., & Macy, J. T. (2010). Implicit and explicit attitudes predict smoking cessation: Moderating effects of experienced failure to control smoking and plans to quit. *Psychology of Addictive Behaviors*, *24*(4), 670–679. https://doi.org/10.1037/a0021722

Choi, W. S., Ahluwalia, J. S., & Nazir, N. (2002). Adolescent smoking cessation: Implications for relapse-sensitive interventions. *Archives of Pediatrics & Adolescent Medicine*, *156*(6), 625–626. https://doi.org/10.1001/archpedi.156.6.625

Cooper, M. L., Agocha, V. B., & Sheldon, M. S. (2000). A motivational perspective on risky behaviors: The role of personality and affect regulatory processes. *Journal of Personality*, *68*(6), 1059–1088. https://doi.org/10.1111/1467-6494.00126

Cunningham, W. A., Preacher, K. J., & Banaji, M. R. (2001). Implicit attitude measures: Consistency, stability, and convergent validity. *Psychological Science*, *12*(2), 163–170. https://doi.org/10.1177/1745691612455204

Dvorak, R. D., Waters, A. J., MacIntyre, J. M., & Gwaltney, C. J. (2018). Affect, craving, and cognition: An EMA study of ad libitum adolescent smoking. *Psychology of Addictive Behaviors*, *32*(6), 583–594. https://doi.org/10.1037/adb0000392

Fanshawe, T. R., Halliwell, W., Lindson, N., Aveyard, P., Livingstone-Banks, J., & Hartmann-Boyce, J. (2017). Tobacco cessation interventions for young people. *Cochrane Database of Systematic Reviews*, *11*(11), Article CD003289. https://doi.org/10.1002/14651858.CD003289.pub6

Farrell, M., Howes, S., Taylor, C., Lewis, G., Jenkins, R., Bebbington, P., Jarvis, M., Brugha, T., Gill, B., & Meltzer, H. (1998). Substance misuse and psychiatric comorbidity: An overview of the OPCS National Psychiatric Morbidity Survey. *Addictive Behaviors*, *23*(6), 909–918. https://doi.org/10.1016/S0306-4603(98)00075-6

Greenwald, A. G., McGhee, D. E., & Schwartz, J. L. (1998). Measuring individual differences in implicit cognition: The implicit association test. *Journal of Personality and Social Psychology*, *74*(6), 1464–1480. https://doi.org/10.1037/0022-3514.74.6.1464

Greenwald, A. G., Nosek, B. A., & Banaji, M. R. (2003). Understanding and using the implicit association test: I. An improved scoring algorithm. *Journal of Personality and Social Psychology*, *85*(2), 197–216. https://doi.org/10.1037/0022-3514.85.2.197

Grigutsch, L. A., Lewe, G., Rothermund, K., & Koranyi, N. (2019). Implicit 'wanting' without implicit 'liking': A test of incentive-sensitization-theory in the context of smoking addiction using the wanting-implicit-association-test (W-IAT). *Journal of Behavior Therapy and Experimental Psychiatry*, *64*, 9–14. https://doi.org/10.1016/j.jbtep.2019.01.002

Grimshaw, G., Stanton, A., Blackburn, C., Andrews, K., Grimshaw, C., Vinogradova, Y., & Robertson, W. (2003). Patterns of smoking, quit attempts and services for a cohort of 15- to 19-year-olds. *Child: Care, Health and Development*, *29*(6), 457–464. https://doi.org/10.1046/j.1365-2214.2003.00365.x

Hobbs, M., Remington, B., & Glautier, S. (2005). Dissociation of wanting and liking for alcohol in humans: A test of the incentive-sensitisation theory. *Psychopharmacology*, *178*(4), 493–499. https://doi.org/10.1007/s00213-004-2026-0

Hutton, H. E., Wilson, L. M., Apelberg, B. J., Tang, E. A., Odelola, O., Bass, E. B., & Chander, G. (2011). A systematic review of randomized controlled trials: Web-based interventions for smoking cessation among adolescents, college students, and adults. *Nicotine & Tobacco Research*, *13*(4), 227–238. https://doi.org/10.1093/ntr/ntq252

Khaled, S. M., Bulloch, A. G., Williams, J. V., Hill, J. C., Lavorato, D. H., & Patten, S. B. (2012). Persistent heavy smoking as risk factor for major depression (MD) incidence—Evidence from a longitudinal Canadian cohort of the National Population Health Survey. *Journal of Psychiatric Research*, *46*(4), 436–443. https://doi.org/10.1016/j.jpsychires.2011.11.011

King, A., Vena, A., Hasin, D. S., deWit, H., O'Connor, S. J., & Cao, D. (2021). Subjective responses to alcohol in the development and maintenance of alcohol use disorder. *The American Journal of Psychiatry*, *178*(6), 560–571. https://doi.org/10.1176/appi.ajp.2020.20030247

Lee, H. S., Addicott, M., Martin, L. E., Harris, K. J., Goggin, K., Richter, K. P., Patten, C. A., McClernon, F. J., Fleming, K., & Catley, D. (2017). Implicit attitudes and smoking behavior in a smoking cessation induction trial. *Nicotine & Tobacco Research*, *20*(1), 58–66. https://doi.org/10.1093/ntr/ntw259

Lushniak, B. D., Samet, J. M., Pechacek, T. F., Norman, L. A., & Taylor, P. A. (2014). *The health consequences of smoking—50 years of progress: A report of the Surgeon General*. National Library of Medicine.

MacPherson, L., Reynolds, E. K., Daughters, S. B., Wang, F., Cassidy, J., Mayes, L. C., & Lejuez, C. W. (2010). Positive and negative reinforcement underlying risk behavior in early adolescents. *Prevention Science*, *11*(3), 331–342. https://doi.org/10.1007/s11121-010-0172-7

Marhe, R., Waters, A. J., van de Wetering, B. J., & Franken, I. H. (2013). Implicit and explicit drug-related cognitions during detoxification treatment are associated with drug relapse: An ecological momentary assessment study. *Journal of Consulting and Clinical Psychology*, *81*(1), 1. https://doi.org/10.1037/a0030754

Miech, R., Johnston, L., O'Malley, P., Bachman, J., Schulenberg, J., & Patrick, M. (2019). *Monitoring the future national survey results on drug use, 1975–2018: Volume I, secondary school students*. Institute for Social Research.

Muthén, L. K., & Muthen, B. (2020). *Mplus user's guide: Statistical analysis with latent variables, user's guide*.

Nguyen, D., Naffziger, E. E., & Berridge, K. C. (2021). Positive affect: Nature and brain bases of liking and wanting. *Current Opinion in Behavioral Sciences*, *39*, 72–78. https://doi.org/10.1016/j.cobeha.2021.02.013

O'Connor, R. M., & Colder, C. R. (2009). Influence of alcohol use experience and motivational drive on college students' alcohol-related cognition. *Alcoholism, Clinical and Experimental Research*, *33*(8), 1430–1439. https://doi.org/10.1111/j.1530-0277.2009.00973.x

Ostafin, B. D., & Brooks, J. J. (2011). Drinking for relief: Negative affect increases automatic alcohol motivation in coping-motivated drinkers. *Motivation and Emotion*, *35*(3), 285–295. https://doi.org/10.1007/s11031-010-9194-5

Ostafin, B. D., Marlatt, G. A., & Troop-Gordon, W. (2010). Testing the incentive-sensitization theory with at-risk drinkers: Wanting, liking, and alcohol consumption. *Psychology of Addictive Behaviors*, *24*(1), 157–162. https://doi.org/10.1037/a0017897

Palmeri, M. D. (2016). *Evidence for the incentive sensitization model of addiction in adolescent smokers* [Doctoral dissertation, University of Illinois at Chicago].

Park-Lee, E., Ren, C., Cooper, M., Cornelius, M., Jamal, A., & Cullen, K. A. (2022). Tobacco product use among middle and high school students—United States, 2022. *Morbidity and Mortality Weekly Report*, *71*(45), 1429–1435. https://doi.org/10.15585/mmwr.mm7145a1

Parker, A. B., & Gilbert, D. G. (2008). Brain activity during anticipation of smoking-related and emotionally positive pictures in smokers and nonsmokers: A new measure of cue reactivity. *Nicotine & Tobacco Research*, *10*(11), 1627–1631. https://doi.org/10.1080/14622200802412911

Prokhorov, A. V., Koehly, L. M., Pallonen, U. E., & Hudmon, K. S. (1998). Adolescent nicotine dependence measured by the modified Fagerström Tolerance Questionnaire at two time points. *Journal of Child & Adolescent Substance Abuse*, *7*(4), 35–47. https://doi.org/10.1300/J029v07n04_03

Prokhorov, A. V., Pallonen, U. E., Fava, J. L., Ding, L., & Niaura, R. (1996). Measuring nicotine dependence among high-risk adolescent smokers. *Addictive Behaviors*, *21*(1), 117–127. https://doi.org/10.1016/0306-4603(96)00048-2

Roberts, M. E., Bidwell, L., Colby, S. M., & Gwaltney, C. J. (2015). With others or alone? Adolescent individual differences in the context of smoking lapses. *Health Psychology*, *34*(11), 1066–1075. https://doi.org/10.1037/hea0000211

Robinson, T. E., & Berridge, K. C. (1993). The neural basis of drug craving: An incentive-sensitization theory of addiction. *Brain Research. Brain Research Reviews*, *18*(3), 247–291. https://doi.org/10.1016/0165-0173(93)90013-P

Robinson, T. E., & Berridge, K. C. (2004). Incentive-sensitization and drug 'wanting'. *Psychopharmacology*, *171*(3), 352–353. https://doi.org/10.1007/s00213-003-1602-z

Schneider, W., Eschman, A., & Zuccolotto, A. (2002). *E-prime reference guide*. Psychology Software Tools.

Stewart, J., de Wit, H., & Eikelboom, R. (1984). Role of unconditioned and conditioned drug effects in the self-administration of opiates and stimulants. *Psychological Review*, *91*(2), 251–268. https://doi.org/10.1037/0033-295X.91.2.251

Swadi, H. (1999). Individual risk factors for adolescent substance use. *Drug and Alcohol Dependence*, *55*(3), 209–224. https://doi.org/10.1016/S0376-8716(99)00017-4

Thompson, T., & Schuster, C. R. (1964). Morphine self-administration, food-reinforced, and avoidance behaviors in rhesus monkeys. *Psychopharmacology*, *5*(2), 87–94. https://doi.org/10.1007/BF00413045

Tibboel, H., De Houwer, J., & Van Bockstaele, B. (2015). Implicit measures of "wanting" and "liking" in humans. *Neuroscience & Biobehavioral Reviews*, *57*, 350–364. https://doi.org/10.1016/j.neubiorev.2015.09.015

Turner, L. R., & Mermelstein, R. (2004). Motivation and reasons to quit: Predictive validity among adolescent smokers. *American Journal of Health Behavior*, *28*(6), 542–550. https://doi.org/10.5993/AJHB.28.6.7

U.S. Department of Health and Human Services. (2010). *A report of the surgeon general: how tobacco smoke causes disease: what it means to you*. http://www.cdc.gov/tobacco/data_statistics/sgr/2010/consumer_booklet/pdfs/consumer.pdf

Villanti, A. C., West, J. C., Klemperer, E. M., Graham, A. L., Mays, D., Mermelstein, R. J., & Higgins, S. T. (2020). Smoking-cessation interventions for US young adults: Updated systematic review. *American*

*Journal of Preventive Medicine*, *59*(1), 123–136. https://doi.org/10.1016/j.amepre.2020.01.021

Volkow, N. D., Michaelides, M., & Baler, R. (2019). The neuroscience of drug reward and addiction. *Physiological Reviews*, *99*(4), 2115–2140. https://doi.org/10.1152/physrev.00014.2018

Waters, A. J., Carter, B. L., Robinson, J. D., Wetter, D. W., Lam, C. Y., & Cinciripini, P. M. (2007). Implicit attitudes to smoking are associated with craving and dependence. *Drug and Alcohol Dependence*, *91*(2–3), 178–186. https://doi.org/10.1016/j.drugalcdep.2007.05.024

Waters, A. J., & Sayette, M. A. (2006). Implicit cognition and tobacco addiction. In R. W. Wiers & A. W. Stacy (Eds.), *Handbook of implicit cognition and addiction* (pp. 309–338) Sage Publications. https://doi.org/10.4135/9781412976237.n21

Wiers, R. W., & Stacy, A. W. (Eds.). (2006). *Handbook of implicit cognition and addiction*. Sage Publications. https://doi.org/10.4135/9781412976237

Wise, R. A., & Bozarth, M. A. (1985). Brain mechanisms of drug reward and euphoria. *Psychiatric Medicine*, *3*(4), 445–460. https://europepmc.org/article/med/2893431