Sadness, but not all negative emotions, heightens addictive substance use

Charles A. Dorison[a,1], Ke Wang[a], Vaughan W. Rees[b], Ichiro Kawachi[b], Keith M. M. Ericson[c], and Jennifer S. Lerner[a,d]

[a]Harvard Kennedy School, Harvard University, Cambridge, MA 02138; [b]Harvard T.H. Chan School of Public Health, Harvard University, Boston, MA 02115; [c]Questrom School of Business, Boston University, Boston, MA 02115; and [d]Department of Psychology, Harvard University, Cambridge, MA 02138

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Do negative feelings in general trigger addictive behavior, or do specific emotions play a stronger role? Testing these alternative accounts of emotion and decision making, we drew on the Appraisal Tendency Framework to predict that sadness, specifically, rather than negative mood, generally, would 1) increase craving, impatience, and actual addictive substance use and 2) do so through mechanisms selectively heightened by sadness. Using a nationally representative, longitudinal survey, study 1 (n = 10,685) revealed that sadness, but not other negative emotions (i.e., fear, anger, shame), reliably predicted current smoking as well as relapsing 20 years later. Study 2 (n = 425) used an experimental design, and found further support for emotion specificity: Sadness, but not disgust, increased self-reported craving relative to a neutral state. Studies 3 and 4 (n = 918) introduced choice behavior as outcome variables, revealing that sadness causally increased impatience for cigarette puffs. Moreover, study 4 revealed that the effect of sadness on impatience was more fully explained by concomitant appraisals of self-focus, which are specific to sadness, than by concomitant appraisals of negative valence, which are general to all negative emotions. Importantly, study 4 also examined the topography of actual smoking behavior, finding that experimentally induced sadness (as compared to neutral emotion) causally increased the volume and duration of cigarette puffs inhaled. Together, the present studies provide support for a more nuanced model regarding the effects of emotion on tobacco use, in particular, as well as on addictive behavior, in general.

emotion | smoking | addictive behavior | impatience | appraisal tendency

Scholarly papers examining the ways in which emotion influences decision making have more than doubled in recent years (for reviews, see refs. 1–4). One key insight emerging from this corpus is the value of linking specific emotions (as opposed to global positive/negative moods) to specific choice outcomes in order to increase predictive power and precision in decision models (for reviews, see refs. 1, 2, and 5–13).

Yet at least 1 gap remains, despite its potential theoretical and practical import. Research has not yet systematically examined the influence of specific emotions on harmful health decisions, generally, and addictive substance-use decisions, specifically (for reviews, see refs. 14–17). Indeed, influential models of substance-use behavior have long concluded that undifferentiated "negative affect is the prototypic setting event for drug use and relapse in the addicted drug user" (18). Whether such undifferentiated negative affect provides the best model has not been systematically tested. A metaanalysis by Heckman et al. (15), which included all experiments examining the effect of affective manipulations on cigarette cravings, concluded that extant research "could not delineate the influence of … discrete aversive emotions (e.g., disgust, shame) upon smoking motivation, as all but one of the negative affect manipulations … were nonspecific" (15).

Theoretical Aims. The present paper aims to examine whether a valence-based model versus an emotion-specific model best predicts decision making for addictive substance use outcomes. Valence-based models emphasize generalized affect (e.g., ref. 18) and would predict that 1) all—or nearly all—negative emotions have approximately equivalent relationships with substance use, and 2) any given negative emotion state (e.g., sadness) should increase substance use behaviors primarily because of the emotion's underlying negative valence.

In contrast, emotion-specific models, such as the Appraisal Tendency Framework (ATF) (19, 20) emphasize the importance of distinguishing a broader array of cognitive appraisal dimensions than just valence. Cognitive appraisals (i.e., the way people interpret and make sense of their environments) (10) persist throughout the experience of an emotion. Such emotion-related appraisal tendencies, in turn, define how specific emotions color subsequent choices by prioritizing specific concerns. The ATF would hypothesize that 1) only a subset of negative emotions should predict substance use and 2) negative valence (i.e., unpleasantness) is 1 of multiple cognitive appraisal dimensions that might mediate an emotion's effect on substance use. In sum, the ATF aims to add predictive power by hypothesizing that the conceptual match between the cognitive appraisals of the specific emotion and the target decision, as opposed to the valence of the emotion alone, determines the effect of the emotion on the target choice.

Sadness and Reward Seeking. Sadness typically arises from experiences of irrevocable loss (21). Such losses may occur in a wide range of domains, including relationships (e.g., loss of a loved one), material possessions (e.g., loss of a home), or social/occupational roles (e.g., loss of a job). In turn, sadness implicitly prioritizes

Significance

The epidemic of deaths attributable to addictive substances, including tobacco, highlights the need to better understand ways in which emotions drive substance craving and consumption. In a test of alternative theories of emotion and decision making, we found that sadness, specifically, rather than negative mood, generally, increased addictive substance use. In a nationally representative, longitudinal sample, sadness—but not other negative emotions—reliably predicted current smoking and relapse 20 y later. In laboratory experiments with real smokers, sadness increased both impatience for cigarette puffs and actual volume of puffs taken. Results provide not only theoretical implications but also policy implications for the design of antismoking public service announcements, which could unintentionally increase cigarette cravings among smokers if they trigger sadness.

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[1]To whom correspondence may be addressed. Email: cdorison@g.harvard.edu.

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choices that replace loss (i.e., provide rewards) over choices that reduce uncertainty (21). Indeed, research reveals that sadness, more than other negative emotions, tends to trigger reward-seeking behavior (21–23). Importantly, some negative emotions do not appear to trigger reward seeking at all. Sadness, but not disgust, increases how much decision makers are willing to pay in order to acquire goods (23, 24) and increases impatience for financial rewards (i.e., individuals in a sad state choose immediate, smaller sums rather than waiting for later, larger sums) (25).

Attentional focus. Studies have yet to comprehensively identify the mechanisms linking sadness to reward seeking. Initial evidence, however, highlights a key (likely nonconscious) role for the appraisal dimension of attentional focus. In addition to evidence linking depression to self-focus (26), multiple studies have found that sadness (but not other negative emotions, such as anger) triggers heightened attentional focus on the self (27–29). Such self-focus can activate brain regions associated with reward-related processing (30) and also mediate the effect of sadness on reward seeking (31). Indeed, prior research found that the more decision makers in a sad state focused on themselves, the more they subsequently spent on consumer goods (31). Thus, sadness, which arises from irrevocable loss, may have especially strong associations with reward seeking, generally, and substance use, specifically. Moreover, this association may be mediated in part by concomitant attentional focus (dwelling) on the self.

The Present Research. The present studies examined reward seeking in the form of cigarette smoking. We chose smoking as the key behavioral outcome for 3 reasons. First, smoking remains the leading cause of preventable death in the United States (32). Second, the United States government spends over $500 million annually on antismoking campaigns (33). Third, given its legal standing, smoking is 1 of the few addictive behaviors that is ethically feasible to investigate in controlled laboratory settings.

Study overview. Study 1 tested whether sadness—but not every negative emotion—would correlate with smoking behavior in a nationally representative, longitudinal sample across 20 y of data collection. Study 2 tested whether sadness, but not another negative emotion, would increase self-reported craving for cigarettes among smokers as compared to a neutral state. Study 3 and its independent replication developed a novel behavioral–economic paradigm to assess the causal effects of sadness on smokers' impatience for hypothetical cigarette puffs. Finally, in a laboratory study with (biochemically verified) abstinent smokers, study 4 examined whether sadness would increase impatient choices for real smoking reward because of its negative valence, because of emotion-specific appraisals (e.g., self-focus), or both. It also assessed the causal effects of sadness on the volume, velocity, and duration of cigarette puffing, indices of appetitive smoking behavior. Thus, the studies harnessed the respective benefits of field data, longitudinal design, behavioral–economic experimental design, and bio-behavioral assessments.

Open science statement. In keeping with guidelines for open science (34), we report in each study how we determined our sample size, all manipulations, and all measures. For each experiment, we sought to obtain 80% power for detecting small to medium effect sizes. Data and code for all studies are available at https://osf.io/x4aes/?view_only=b55c4099c74c49cc96a92edd371e5857. In addition, preregistrations and materials are available for all experimental studies.

To take the most conservative approach, all analyses reported in the main text were conducted on full samples with no participants excluded. Results with exclusions revealed the same general pattern of effects and are available in the *SI Appendix*.

Study 1

Overview. In study 1, we sought to test whether sadness, but not all negative emotions, would be associated with smoking status in a nationally representative, longitudinal sample. To do so, we examined field data from the Midlife in the United States (MIDUS) survey, collected across 2 decades from 1995 to 2014 (collective n = 10,685).*

Results and Discussion. Consistent with the ATF prediction that sadness is positively associated with smoking status, sadness significantly predicted self-reported smoking status even after controlling for other negative emotions (bs = 0.23, 0.29, 0.51; all zs > 2.50; all Ps ≤ 0.01). No other emotion significantly predicted smoking status in more than a single wave, with average βs comparatively small in combined-samples analyses (fear: 0.12; anger: 0.14; shame: 0.02). The result held after controlling for income, age, and gender (Fig. 1). Full details for all regressions, including a second measure of effect size (odds-ratio), are available in *SI Appendix*.

While the foregoing results documented emotion specificity, they represented associations observed in a cross-sectional design. Taking advantage of the longitudinal design, we sought to examine the relationship between sadness and smoking across time.

Even after controlling for demographic factors (gender, age, socioeconomic status [SES]) at time 1, sadness reported at time 1 among nonsmokers predicted smoking 10 y (b = 0.35, P = 0.002) and 20 y (b = 0.36, P = 0.030) later. Given that the large majority of lifelong smokers begin smoking before the age of 18, it is not surprising that sadness at time 1 predicted subsequent relapse among former smokers (i.e., individuals who had smoked previously but not currently) 10 (b = 0.43, P = 0.001) and 20 (b = 0.39, P = 0.032) y later, but did not predict initiation 10 or 20 y later by individuals who had never smoked previously (Ps > 0.17).

Summary.† Consistent with emotion-specific models, study 1 found that sadness yielded a stronger association with smoking status than other negative emotions and that this relationship held independently from demographic variables. Additionally, sadness was associated with relapse (but not initiation of smoking) both 10 and 20 y later.

Despite its longitudinal design, however, study 1 did not allow for causal tests. It could be that a third variable, such as negative life events, drives variation in both sadness and smoking. The question remains, therefore, whether sadness, but not all negative moods, exerts causal effects on smoking behavior.

Study 2

Overview. In study 2, we sought to test whether sadness, but not another negative emotion, would causally increase craving for cigarettes. We predicted that whereas sadness would increase self-reported craving as compared to a neutral state, disgust would not do so. We recruited 425 smokers from the online data-collection platform Prolific (35), which provided 80% power to detect effect sizes of d > 0.35. We randomly assigned smokers to 1 of 3 emotion-induction conditions: Sadness, disgust, or neutral. We chose disgust as a control negative emotion because it triggers a desire to expel (e.g., ref. 23) and, if anything, should reduce craving. Drawing directly on prior research (e.g., refs. 23, 25, and 31), the emotion inductions used a 2-part procedure that involved watching a film clip and completing a writing task. Participants in the sadness condition watched a clip from a movie entitled *Up* (in which a man loses his life partner) and then wrote about a time they themselves had experienced significant loss. Participants in the disgust condition watched a clip from a movie entitled *Trainspotting* (in which a man uses an unsanitary toilet) and then wrote about an unsanitary experience in their own life. Participants in the neutral condition watched a clip

*See *SI Appendix* for details on the nationally representative characteristics of these datasets and analytic procedure to identify smokers.

†The same pattern of results held when we reran all analyses with only the subsample of nondepressed respondents and when we controlled for other psychologically related variables (see *SI Appendix* for details).

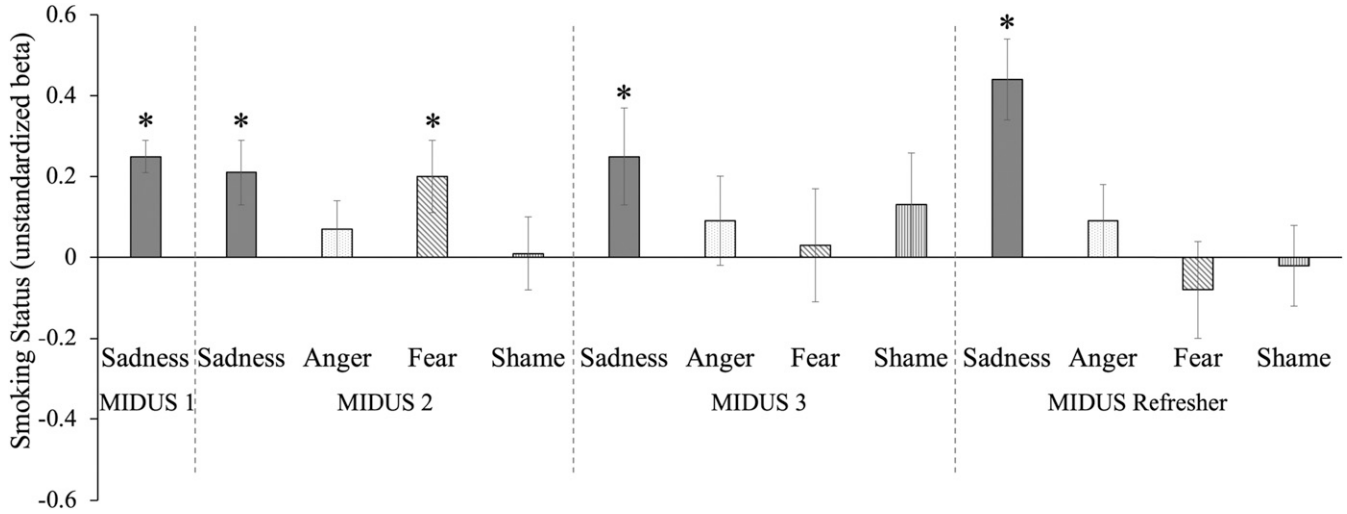

Fig. 1. Across a longitudinal, population-based dataset, only sadness reliably predicted smoking status. The *x* axis displays the self-reported trait emotions measured in each dataset. The *y* axis displays the unstandardized beta in simultaneous regressions with smoking status as the dependent variable after controlling for age, gender, and SES. Smoking status was defined by self-reported daily smoking. Error bars represent 1 SE. *$P < 0.05$.

about wooden furniture making and then wrote about their work environment. Both before and after the emotion induction, we measured craving using 3 self-report questions adapted from the Brief Questionnaire on Smoking Urges (36), which included face-valid questions regarding current craving for cigarettes (e.g., "I want a cigarette right now").

Results and Discussion. In this and all following experiments, the emotion manipulations were effective in both magnitude and specificity. We report full results in *SI Appendix*.

We next turned to our primary hypothesis: Whether sadness, but not disgust, had a causal effect on craving for cigarettes. We preregistered to test 3 pairwise contrasts using ANCOVA, in which the dependent variable was craving after the emotion induction, the independent variable was condition, and a covariate was included for craving measured before the emotion induction. As predicted, we found evidence that sadness increased craving as compared to a neutral state ($b = 0.58$, SE = 0.21, $t = 2.82$, $P = 0.005$, $d = 0.29$). We found directional, but not statistically significant, evidence that disgust decreased craving as compared to a neutral state ($b = -0.35$, SE = 0.22, $t = -1.56$, $P = 0.12$, $d = -0.09$). Finally, we found evidence that sadness significantly increased craving as compared to disgust ($b = 0.96$, SE = 0.25, $t = 3.84$, $P < 0.001$, $d = 0.35$). The statistical significance of all 3 pairwise contrasts remain unchanged after accounting for multiple hypothesis testing.

Summary. Consistent with predictions, sadness, but not disgust, exerted a causal effect on increased craving for cigarettes. If anything, disgust exerted an opposite effect. We designed study 3 to test whether sadness would increase desire for immediate rewards at the expense of larger, later rewards.

Study 3

Overview. In study 3 and an independent replication, we sought to test the causal effect of sadness on smokers' self-reported desire for cigarette puffs across time. We predicted that smokers in the sadness condition would be more impatient for smoking rewards than would smokers in the neutral condition. We recruited 398 (study 3) and 362 smokers (study 3 replication) from Amazon's Mechanical Turk, which provided 80% power to detect effect sizes of approximately $d = 0.30$ (the effect size observed in study 2). We randomly assigned smokers to either a sadness- or a neutral-emotion induction condition. The emotion inductions were the same as those used in study 2.

After the emotion induction, we measured desire for cigarette puffs by adapting behavioral economic-based paradigms for reward impatience (e.g., ref. 37; for a review, see ref. 38; on addictive substances, see: ref. 39; see also ref. 40). Participants (all current smokers) received a series of hypothetical choices between whether to smoke sooner but with fewer puffs, or later but with more puffs. Participants chose between different numbers of puffs on a cigarette at various delays, ranging from immediately to 30 min (e.g., "Would you prefer 2 puffs now or 5 puffs in 20 minutes?").

Traditional choice tasks involving tradeoffs between monetary rewards arriving at different times have been criticized as not directly measuring impatience (because money, like cigarettes, is fungible across time and needn't be spent/consumed when received) (38–40; see also refs. 41–43). The present paradigm addressed this limitation by measuring preferences over the timing of consumption itself (i.e., puffs).

Results and Discussion. As predicted, smokers in the sadness condition showed greater impatience for hypothetical cigarette puffs than did smokers in the neutral condition ($b = 0.43$, SE = 0.18, $t = 2.42$, $P = 0.016$, $d = 0.19$; SEs adjusted for repeated measures in this and all subsequent analyses of impatient choices). To test for robustness, we ran a replication study, which showed nearly identical results ($b = 0.32$, SE = 0.18, $t = 1.80$, $P = 0.073$, $d = 0.15$). Combined-sample analyses of study 3 and its replication provide strong evidence for a causal effect of sadness on impatient choices ($b = 0.38$, SE = 0.13, $t = 3.00$, $P = 0.003$, $d = 0.17$).

We hypothesized that the effect of sadness on impatience would wane when 1) there was no immediate reward present or 2) participants had not abstained from smoking for very long (i.e., under 4 h). Contrary to predictions, the sadness effect was robust to these specifications: Indeed, none of the variables we tested (i.e., availability of an immediate option, duration since last time smoking, depression, nicotine dependence, household income) consistently moderated the effect of sadness on impatient choices. The *SI Appendix* provides greater detail.

To assess the size of the sadness effect, we calculated a required rate of return (RRR). The RRR indicated the average increase in number of puffs per minute smokers required to wait for a delayed reward, where higher numbers indicated higher

levels of impatience (for detail, see *SI Appendix*). Smokers in the neutral condition had an RRR of 6.9%, indicating that (on average) they required an increase in puffs of 6.9% per minute to wait for a delayed reward. Smokers in the sadness condition were more impatient: They had an RRR of 8.1%, indicating an 18% increase from smokers in the neutral control. Thus, sadness steepened their discount rate for cigarette puffs, as sadness has been shown to steepen discount rates for monetary reward (25).

Summary. Whereas study 2 examined craving in the present, study 3 (and its replication) provided evidence for the causal effect of sadness on smokers' impatience for cigarette puffs over time. Although studies 2 and 3 offer causal leverage, their respective results may be limited by the hypothetical nature of the puffs participants evaluated and their lack of control over how much time had elapsed since each participant last smoked when they completed the study. We designed study 4 to overcome these limitations.

Study 4

Overview. Study 4 examined whether the effect of sadness on impatient choices would replicate with real cigarette puffs and with bio-chemically verified abstinence from smoking. Study 4 also examined whether the underlying mechanisms driving the effect of sadness on impatient choices were specific to sadness, general to negative valence, or a combination of both. We predicted 1) that smokers in the sadness condition would be more impatient for smoking reward than would smokers in the neutral condition and 2) that this difference would be driven by underlying appraisal tendencies other than negative valence. Additionally, we measured actual smoking behavior and predicted 3) that smokers in the sadness condition would puff more intensively than would smokers in the neutral condition.

We recruited 158 smokers from a community sample, which provided 80% power to detect effect sizes of $d > 0.45$. Costs and facility constraints associated with studying actual smoking behavior precluded us from collecting a larger sample of 200 smokers, which we initially preregistered. We did not analyze any results before terminating data collection. We hypothesized that effect sizes might be larger in this study due to the real (instead of hypothetical) nature of the choices at hand. As in study 3, we randomly assigned smokers to either a sadness- or neutral-emotion induction condition. The emotion inductions were the same as those used in prior studies.

After the emotion induction, we measured desire for cigarette puffs using the same impatience measure as study 3. In order to unconfound a desire to leave the study early, participants were told that their choices would not influence the time spent in the study (and were quizzed on this detail). After they made these choices, we implemented 1 of the choices, according to a probabilistic formula, and measured a key outcome of interest: Participants' actual smoking behavior. Finally, participants filled out a set of questionnaires measuring underlying appraisal tendencies (described in greater detail below), the manipulation check, and a variety of exploratory and demographic measures.

Results and Discussion. As expected, due to the 8-h abstinence requirement, participants entered our study with a high level of baseline craving. Participants in the control condition were significantly more impatient in study 4 (mean = 4.27) than in study 3 (mean = 3.10; $b = 1.17$, SE = 0.25, $t = 4.79$, $P < 0.001$, $d = 0.50$) or its replication (mean = 3.21; $b = 1.06$, SE = 0.25, $t = 4.23$, $P < 0.001$, $d = 0.45$). This resulted in high levels of response censoring (44): Overall, 35.52% of participants demonstrated levels of impatience at the top of our scale (i.e., always preferred the immediate option). In line with our preregistration, we used tobit regression to account for this high level of censoring.

We next turned to whether sadness had a causal effect on impatient choices for real cigarette puffs. Smokers in the sadness condition showed marginally greater impatience for real cigarette puffs than did smokers in the neutral condition ($b = 1.54$, SE = 0.90, $t = 1.70$, $P = 0.088$, $d = 0.53$). Combined-sample analyses of the 3 datasets (study 3, study 3 replication, study 4) again provided strong evidence for an effect of sadness on impatient choices ($b = 0.41$, SE = 0.12, $t = 3.39$, $P < 0.001$, $d = 0.17$).

For robustness, we also conducted an exploratory set of Bayesian analyses.‡ We used Bayesian parameter estimation to assess whether data from study 4 strengthened the evidence from prior studies (45, 46). We found this to be the case: The estimated probability of the effect of sadness on impatience being larger than the region of practical equivalence to the null value increased from 88% (after study 3 and its replication) to 91% (after including study 4). The *SI Appendix* provides full details.

As in study 3, the effect of sadness on impatience was again robust to potential boundary conditions we had originally hypothesized and preregistered. We did not find a significant interaction between the sadness condition and depression, nicotine dependence, or SES.

Turning to underlying mechanisms, we examined whether increases in sadness drove impatient choices because of an appraisal dimension of negativity, an appraisal dimension specific to sadness, or both. Consistent with a valence-based model, sadness could drive impatient choices solely due to its negative valence. Or, consistent with an emotion-specific model, negative valence could be 1 of multiple cognitive appraisal dimensions that could explain the effect of sadness on impatient choices. We tested 2 such sadness-specific appraisal dimensions: Self-focus and sense of loss.

To test whether changes in sadness drove impatient choices through negativity, self-focus, perceptions of loss, or some combination of the 3, we fit a structural equation model using the lavaan package in R (47). The results of the structural equation model are depicted in Fig. 2. Smokers in the sadness condition showed significantly greater increases in sadness (postsadness – presadness) than smokers in the control condition. Changes in sadness significantly triggered all 3 appraisal dimensions: Self-focus, negativity, and sense of loss ($zs > 4.15$, $Ps < 0.001$, $\beta s > 0.32$). However, while self-focus in turn predicted impatient choices ($z = 2.60$, $P = 0.009$, $\beta = 0.22$), neither sense of loss ($z = 0.91$, $P = 0.363$, $\beta = 0.08$) nor generalized negativity ($z = -1.46$, $P = 0.142$, $\beta = -0.13$) was significantly correlated with impatience. This resulted in a significant indirect path through sadness and self-focus ($z = 2.17$, $P = 0.030$, $\beta = 0.04$), but not through sadness and negative valence or through sadness and perception of loss ($Ps > 0.15$). Thus, consistent with prior studies (31) and our hypotheses, self-focus appeared to be the most important pathway through which sadness increases appetitive behavior.

As valuable as behavioral–economic measures of impatience may be for modeling choice behavior, it remained crucial to test whether one could obtain converging evidence from other methodologies. While impatient choices were our primary preregistered outcome variable, in a final set of analyses we sought to address the effect of sadness on actual smoking behavior. Because emotion is expected to decay over time (e.g., ref. 48; for review, see ref. 6) and to cease influencing choices once decision makers engage in extensive evaluation of their feelings (49), we used only the sample that received immediate puffs ($n = 75$ unique participants across 233 puffs) and not those that completed the 14-item emotion induction manipulation check during the waiting period.

We tested the effect of sadness on 3 indices of smoking intensity—puff volume, velocity, and duration—in which puff volume equaled the product of puff velocity and duration. We

‡We thank an anonymous reviewer for this suggestion, as well as Uri Simonsohn and Steve Worthington for statistical consultation.

found that smokers in the sadness condition inhaled 30% greater volume per puff than did smokers in the neutral condition (Fig. 3) ($mean_{sad}$ = 62.80 mL vs. $mean_{neutral}$ = 48.69 mL) and that this difference was statistically significant (b = 14.09, SE = 5.69, t = 2.48, P = 0.016, d = 0.39). This difference in total puff volume was explained by smokers in the sadness condition (vs. neutral condition) taking puffs of greater duration ($mean_{sad}$ = 2.40 s vs. $mean_{neutral}$ = 1.94 s, b = 0.43, SE = 0.21, t = 2.04, P = 0.045, d = 0.30) rather than at a greater velocity of smoke intake ($mean_{sad}$ = 27.20 mL/s vs. $mean_{neutral}$ = 25.86 mL/s, b = 1.51, SE = 1.66, t = 0.91, P = 0.367, d = 0.17).

Cautionary Notes. A few cautionary points regarding interpretations of study 4 merit note. First, our sample size was limited due to cost and facility constraints associated with running real, biologically verified, smokers 1 at a time in a laboratory study. As such, our study may have been underpowered. Second, while we found a significant causal effect of sadness on impatience collapsing across the 3 studies, the causal effect of sadness on impatience in study 4 was only marginally significant. Finally, with respect to the path analysis, while we found evidence that self-focus mediates the effect of sadness on impatience, future research is needed to replicate this important mechanistic pathway.

Summary. Study 4 found evidence that sadness increased impatient choices for cigarette puffs through the emotion-specific pathway of self-focus. Importantly, study 4 also provided converging evidence from bio-behavioral measures that the causal effect of sadness extended from impatient choices to actual smoking behavior.

General Discussion

The present studies provide evidence for an emotion-specific, rather than valence-general, model of decision making for addictive substance use. Specifically, study 1 revealed that, across a longitudinal, nationally representative dataset, only sadness (and not other negative emotions) reliably predicted current smoking status. This association between sadness and smoking held after controlling for demographic factors and predicted relapse up to 20 y later. Study 2 demonstrated that sadness, but not disgust, causally increased self-reported craving for cigarettes relative to a neutral state. Studies 3 and 4 demonstrated that sadness causally increased impatient choices for both hypothetical and real cigarette puffs. In addition, consistent with prior studies guided by the ATF (19, 20), study 4 revealed that the effect of sadness on impatient choices was more fully explained by concomitant appraisals of self-focus than by concomitant appraisals of negative valence. Finally, study 4 revealed that sadness increased the volume of cigarette puffs by increasing puff duration rather than increasing puff velocity.

The present results advance the respective fields of emotion science, addiction science, and behavioral economics in multiple ways. First, while the majority of previous studies have focused

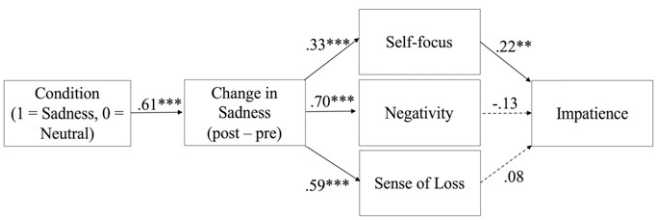

Fig. 2. Individuals randomly assigned to the sadness (vs. neutral) condition experienced greater state sadness, which in turn predicted impatient choices for cigarette puffs via enhanced self-focus. Numbers indicate standardized betas. Solid lines indicate significant paths. Dashed lines indicate nonsignificant paths. $^{**}P < 0.01$, $^{***}P < 0.001$.

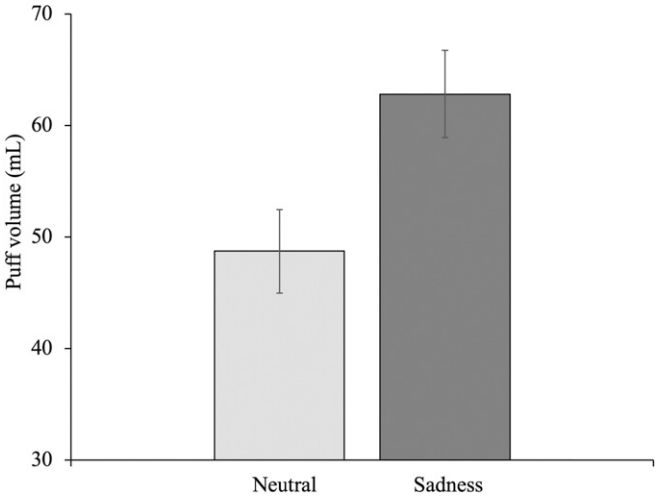

Fig. 3. Participants randomly assigned to the sadness condition inhaled 30% greater volume (mL) per puff than did participants in the neutral condition. Error bars represent 1 SE at the participant level.

on the role of undifferentiated negative affect in addictive substance use (for reviews, see refs. 15–17; see also ref. 50), the present results document the specific effect of sadness on reward seeking for an addictive substance (see also related work on fear in ref. 51). In addition, the present results extend the ATF (19, 20) to addictive substances.

Second, the present results add empirical content to process predictions from the ATF. Specifically, they replicate and extend understanding of underlying pathways linking sadness to decision behavior: Namely, the role of attentional focus. Previous work has found that sadness, but not all other negative emotions, triggers heightened attentional focus on the self (26–29). Additionally, Cryder et al. (31) documented that self-focus mediates the effect of sadness on financial spending. The present work draws on this existing literature to find that self-focus also mediates the effect of sadness on impatience for addictive substance use and does so more than other potential pathways. Identifying the process through which heightened self-focus triggers reward seeking, and interventions that can break this link, remain promising areas for future investigation.[§]

Third, the current research highlights complementarities among multiple methodologies (e.g., field datasets and novel behavioral–economic incentive-compatible choices). Work by Bickel and colleagues (39, 40, 52, 53) pioneered the application of delay discounting to addiction science. However, theory predicts that fungible rewards such as money may not be discounted the same way as consumption experiences (54; for a review, see ref. 55). The present research overcomes the fungibility concern by measuring preferences for cigarette puffs (time-dated consumption) over shorter intervals. Furthermore, the present work provides converging evidence between behavioral–economic choice paradigms and bio-behavioral measures of actual smoking behavior. Future research could compare not only convergence (vs. divergence) among different behavioral paradigms, but also among existing research and paradigms in animal models of behavior (e.g., ref. 56).

Finally, the present work integrates theories and methodologies from judgment and decision making (JDM) with research on addictive behavior. The field of JDM has uncovered

[§]For now, it is interesting to note that 12-step programs like Alcoholics Anonymous include a prayer for reduced self-focus ("...relieve me of the bondage of self").

important insights into medical and health decision making, including vaccine use (57), weight loss (58), and medication adherence (59). However, relatively little research has studied decision making among actual addicts in contexts where they are using an addictive substance (for exceptions, see refs. 60 and 61). We hope that the present work provides a framework for future research integrating addictive behavior into research on JDM, shedding light not only on applications for medical and health decision making, but also on fundamental JDM processes.

Caveat. The present research does not hypothesize that sadness is unique among negative emotions in triggering addictive substance use. Rather, we hypothesize and find that sadness is more potent than other negative emotion states at triggering substance use. Indeed, some negative emotions (e.g., disgust) may not trigger substance use at all. It may be that sadness elicits an implicit motivational drive to reestablish equilibrium, to replace loss through enhanced consumption (for related discussion, see ref. 22). Future research should investigate the generalizability and boundary conditions of this hypothesis.

Limitations. Although the present findings advance the field along multiple interdisciplinary lines, they have limitations. Most importantly, although this research aimed to understand whether an emotion-specific or valence-general model best predicted substance use, our results are limited to smoking behavior. Blindly overgeneralizing to all addictive substances would be unwise; future research should examine the potential harmful effects of sadness on other addictive behaviors, such as opioid or alcohol use. Another potential limitation is that only study 4, and not studies 2 and 3, used real behavior rather than judgments or hypothetical choices. While experiments with hypothetical rewards frequently show generalizability to real behavior (e.g., refs. 62–64), it is critical to test for convergence in future research on sadness and addictive behavior.

Conclusion. The present findings extend theoretical understanding in emotion theory, behavioral economics, and addiction science. Taking this intentionally multidisciplinary and multimethod approach with smoking may serve as a model not only for other kinds of tobacco-control research efforts but also for research on a broad spectrum of drug use behaviors that have critical affective components. Indeed, the results provide not only theoretical implications but also implications for antismoking public service announcements, which could have the unintended consequence of heightening craving for cigarettes among smokers if they trigger sadness.

Materials and Methods

Overview. All experimental studies were reviewed and approved by the Harvard University Institutional Review Board, and all participants gave their informed consent to participate. Due to space constraints, additional details for materials and procedures are available in *SI Appendix*.

Study 1. We analyzed data from the MIDUS surveys, a publicly available dataset supported by the MacArthur Foundation. Smoking status was assessed as a binary variable of whether the person currently smokes regularly (1) or does not currently smoke regularly (0). Sadness was measured as a single Likert item asking, "During the past 30 days, how often did you feel so sad nothing could cheer you up?" and answered on a 5-point scale ranging from 1 (none of the time) to 5 (all of the time). Anger, fear, and shame were also measured in MIDUS waves 2, 3, and Refresher. Additionally, all 4 waves included a variety of demographic measures, including gender, age, and objective SES. Objective SES was calculated as the standardized average of 1) education and 2) log household income.

Study 2. We recruited 425 current American smokers (202 male, 221 female, 2 nonbinary/other, mean age = 37, age range = 18 to 79 y) through the online data collection platform Prolific. We initially aimed for 450 participants. Because of a shortage of verified smokers on this platform, we ended data collection with less than our preregistered goal but a sufficient sample to detect small to medium effects.

Participants completed 14 items adapted from previous research on emotion and decision making (e.g., ref. 32) used to assess their current emotional state. Three items tapped sadness (sad, blue, depressed), 3 tapped disgust (disgusted, repulsed, nauseated), and 3 tapped neutrality (indifferent, neutral, unemotional). We also included 5 other filler emotion items (e.g., angry, fearful, thankful). Next, participants indicated how true each of 3 statements were of them on an 11-point scale from 0 (not true of me at all right now) to 10 (extremely true of me right now). The 3 items ("I crave a cigarette right now"; "I have an urge for a cigarette right now"; "All I want right now is a cigarette") were adapted from the Brief Questionnaire on Smoking Urges (36) to focus on immediate craving.

After indicating baseline levels of craving, participants were randomly assigned to 1 of 3 emotion-induction conditions. Per standard procedures (e.g., ref. 25), participants in all 3 conditions watched a short prevalidated film clip and completed a writing task. Immediately following the emotion induction, participants answered the same 3 craving items from earlier in the survey. After completing the craving measure, participants answered questions regarding the emotion manipulation check, exploratory items, and demographics.

Study 3. We recruited 398 current smokers through Amazon's Mechanical Turk (217 male, 181 female, mean age = 35, age range = 18 to 79 y). The recruitment materials, study requirements, and initial emotion assessment were identical to study 2. Participants were randomly assigned to either the sadness or neutral condition. Immediately following the emotion induction, all participants made choices between a smaller number of puffs (2 to 3 puffs) earlier (immediately, after a 15-min delay) and a larger number of puffs (3 to 10 puffs) later (after a 15-min delay, after a 20-min delay, and after a 30-min delay) on 8 lists. Each list had 7 pairs of options between smaller, sooner puffs and larger, later puffs. In 4 of the 8 lists, the sooner option was immediate. In the other 4 lists, the sooner option was not immediate. After completing the 8 lists, participants responded to exploratory items, the emotion manipulation check, and demographic items.

Study 4. We recruited 158 current smokers from the Boston area who self-reported no intention to quit in the next 30 d (102 male, 55 female, 1 nonbinary/other, mean age = 37 y, age range = 21 to 65 y). Participants were instructed to abstain from smoking for at least 8 h overnight before their morning appointment in the laboratory. At the start of each laboratory session, laboratory personnel verified participants' smoking abstinence using a carbon monoxide breath test (cf. ref. 65).

The next set of procedures closely mirrors procedures from study 3. Participants completed the same preemotion measures, same random assignment to emotion condition, and the same 8 choice lists measuring impatience (although this time 1 choice was selected to be actualized). Participants were told that their choices would not influence the time they spent in the laboratory.

After completing the 8 choice lists, participants were told which choice had been randomly selected. While we selected choices in a probabilistic way, we weighted the probabilities such that all participants were able to smoke either immediately or after a 5-min delay. Participants who received the "immediate option" were told by the experimenter that they could begin smoking. After smoking, participants then filled out the same emotion manipulation check used in studies 2 and 3. Participants who received the "delayed option" first completed the emotion manipulation check (along with other surveys if they had leftover time during the 5-min delay), then were told that they could begin smoking. Once smoking and manipulation checks were complete, participants answered 9 items measuring underlying appraisal dimensions of negative valence, self-focus, and sense of loss. Finally, all participants completed a variety of exploratory items and demographics.

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1. J. S. Lerner, Y. Li, P. Valdesolo, K. S. Kassam, Emotion and decision making. *Annu. Rev. Psychol.* **66**, 799–823 (2015).
2. E. A. Phelps, K. M. Lempert, P. Sokol-Hessner, Emotion and decision making: Multiple modulatory neural circuits. *Annu. Rev. Neurosci.* **37**, 263–287 (2014).
3. G. F. Loewenstein, E. U. Weber, C. K. Hsee, N. Welch, Risk as feelings. *Psychol. Bull.* **127**, 267–286 (2001).
4. G. Loewenstein, Out of control: Visceral influences on behavior. *Organ. Behav. Hum. Decis. Process.* **65**, 272–292 (1996).
5. J. So *et al*., The psychology of appraisal: Specific emotions and decision-making. *J. Consum. Psychol.* **25**, 359–371 (2015).
6. D. Keltner, J. S. Lerner, "Emotion" in *Handbook of Social Psychology*, S. T. Fiske, D. T. Gilbert, G. Lindzey, Eds. (John Wiley & Sons, 2010), pp. 317–352.
7. G. Loewenstein, J. S. Lerner, "The role of affect in decision making" in *Handbook of Affective Sciences*, R. J. Davidson, K. R. Scherer, H. H. Goldsmith, Eds. (Oxford University Press, 2003), pp. 619–642.
8. M. Zeelenberg, R. M. A. Nelissen, S. M. Breugelmans, R. Pieters, On emotion specificity in decision making: Why feeling is for doing. *Judgm. Decis. Mak.* **3**, 18–27 (2008).
9. A. D. Angie, S. Connelly, E. P. Waples, V. Kligyte, The influence of discrete emotions on judgement and decision-making: A meta-analytic review. *Cogn. Emot.* **25**, 1393–1422 (2011).
10. E. J. Horberg, C. Oveis, D. Keltner, Emotions as moral amplifiers: An appraisal tendency approach to the influences of distinct emotions upon moral judgment. *Emot. Rev.* **3**, 237–244 (2011).
11. M. N. Shiota *et al*., Beyond happiness: Building a science of discrete positive emotions. *Am. Psychol.* **72**, 617–643 (2017).
12. C. Y. Chen, M. T. Pham, Affect regulation and consumer behavior. *Couns. Psychol. Rev.* **2**, 114–144 (2019).
13. R. Ferrer, W. Klein, J. S. Lerner, V. Reyna, D. Keltner, "Emotions and health decision making: Extending the Appraisal Tendency Framework to improve health and healthcare" in *Behavioral Economics and Public Health*, C. A. Roberto, I. Kawachi, Eds. (Oxford University Press, 2015), pp. 101–131.
14. D. M. Williams, D. R. Evans, Current emotion research in health behaviour science. *Emot. Rev.* **6**, 277–287 (2014).
15. B. W. Heckman *et al*., Influence of affective manipulations on cigarette craving: A meta-analysis. *Addiction* **108**, 2068–2078 (2013).
16. T. B. Baker, M. E. Piper, D. E. McCarthy, M. R. Majeskie, M. C. Fiore, Addiction motivation reformulated: An affective processing model of negative reinforcement. *Psychol. Rev.* **111**, 33–51 (2004).
17. D. DeSteno, J. J. Gross, L. Kubzansky, Affective science and health: The importance of emotion and emotion regulation. *Health Psychol.* **32**, 474–486 (2013).
18. T. H. Brandon, Negative affect as motivation to smoke. *Curr. Dir. Psychol. Sci.* **3**, 33–37 (1994).
19. J. S. Lerner, D. Keltner, Beyond valence: Toward a model of emotion-specific influences on judgement and choice. *Cogn. Emot.* **14**, 473–493 (2000).
20. J. S. Lerner, D. Keltner, Fear, anger, and risk. *J. Pers. Soc. Psychol.* **81**, 146–159 (2001).
21. R. Raghunathan, M. T. Pham, All negative moods are not equal: Motivational influences of anxiety and sadness on decision making. *Organ. Behav. Hum. Decis. Process.* **79**, 56–77 (1999).
22. N. Garg, J. S. Lerner, Sadness and consumption. *J. Consum. Psychol.* **23**, 106–113 (2013).
23. J. S. Lerner, D. A. Small, G. Loewenstein, Heart strings and purse strings: Carryover effects of emotions on economic decisions. *Psychol. Sci.* **15**, 337–341 (2004).
24. S. B. Shu, J. Peck, Psychological ownership and affective reaction: Emotional attachment process variables and the endowment effect. *J. Consum. Psychol.* **21**, 439–452 (2011).
25. J. S. Lerner, Y. Li, E. U. Weber, The financial costs of sadness. *Psychol. Sci.* **24**, 72–79 (2013).
26. J. V. Wood, J. A. Saltzberg, L. A. Goldsamt, Does affect induce self-focused attention? *J. Pers. Soc. Psychol.* **58**, 899–908 (1990).
27. P. Salovey, Mood-induced self-focused attention. *J. Pers. Soc. Psychol.* **62**, 699–707 (1992).
28. Y. E. Chentsova-Dutton, J. L. Tsai, Self-focused attention and emotional reactivity: The role of culture. *J. Pers. Soc. Psychol.* **98**, 507–519 (2010).
29. J. D. Green, C. Sedikides, Affect and self-focused attention revisited: The role of affect orientation. *Pers. Soc. Psychol. Bull.* **25**, 104–119 (1999).
30. G. Northoff, D. J. Hayes, Is our self nothing but reward? *Biol. Psychiatry* **69**, 1019–1025 (2011).
31. C. E. Cryder, J. S. Lerner, J. J. Gross, R. E. Dahl, Misery is not miserly: Sad and self-focused individuals spend more. *Psychol. Sci.* **19**, 525–530 (2008).
32. US Department of Health and Human Services, "The health consequences of smoking—50 years of progress: A report of the surgeon general" (Tech. Rep. 32, US Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Chronic Disease Prevention and Health Promotion, Office on Smoking and Health, Atlanta, 2014).
33. Campaign for Tobacco Free Kids, History of spending for state tobacco prevention programs. https://www.tobaccofreekids.org/assets/factsheets/0209.pdf. Accessed 10 August 2018.
34. J. P. Simmons, L. D. Nelson, U. Simonsohn, False-positive psychology: Undisclosed flexibility in data collection and analysis allows presenting anything as significant. *Psychol. Sci.* **22**, 1359–1366 (2011).
35. S. Palan, C. Schitter, Prolific.ac—A subject pool for online experiments. *J. Behav. Exp. Finance* **17**, 22–27 (2018).
36. L. S. Cox, S. T. Tiffany, A. G. Christen, Evaluation of the brief questionnaire of smoking urges (QSU-brief) in laboratory and clinical settings. *Nicotine Tob. Res.* **3**, 7–16 (2001).
37. R. Thaler, Some empirical evidence on dynamic inconsistency. *Econ. Lett.* **8**, 201–207 (1981).
38. J. D. Cohen, K. M. M. Ericson, D. I. Laibson, J. M. White, Measuring time preferences. https://www.nber.org/papers/w22455.pdf (1 Aug 2016). Accessed 9 December 2019.
39. W. K. Bickel, A. L. Odum, G. J. Madden, Impulsivity and cigarette smoking: Delay discounting in current, never, and ex-smokers. *Psychopharmacology (Berl.)* **146**, 447–454 (1999).
40. G. J. Madden, N. M. Petry, G. J. Badger, W. K. Bickel, Impulsive and self-control choices in opioid-dependent patients and non-drug-using control participants: Drug and monetary rewards. *Exp. Clin. Psychopharmacol.* **5**, 256–262 (1997).
41. M. Coller, M. B. Williams, Eliciting individual discount rates. *Exp. Econ.* **2**, 107–127 (1999).
42. U. Balakrishnan, J. Haushofer, P. Jakiela, How soon is now? Evidence of present bias from convex time budget experiments. https://www.nber.org/papers/w23558.pdf (June 2017). Accessed 9 December 2019.
43. K. M. M. Ericson, J. M. White, D. Laibson, J. D. Cohen, Money earlier or later? Simple heuristics explain intertemporal choices better than delay discounting does. *Psychol. Sci.* **26**, 826–833 (2015).
44. J. Tobin, Estimation of relationships for limited dependent variables. *Econometrica* **26**, 24–36 (1958).
45. J. K. Kruschke, Bayesian assessment of null values via parameter estimation and model comparison. *Perspect. Psychol. Sci.* **6**, 299–312 (2011).
46. J. K. Kruschke, Rejecting or accepting parameter values in Bayesian estimation. *Adv. Methods Pract. Psychol. Sci.* **1**, 270–280 (2018).
47. Y. Rosseel, Lavaan: An R package for structural equation modeling and more. Version 0.5–12 (BETA). *J. Stat. Softw.* **48**, 1–36 (2012).
48. A. S. Garrett, R. J. Maddock, Time course of the subjective emotional response to aversive pictures: Relevance to fMRI studies. *Psychiatry Res.* **108**, 39–48 (2001).
49. N. Schwarz, G. L. Clore, Mood, misattribution, and judgments of well-being: Informative and directive functions of affective states. *J. Pers. Soc. Psychol.* **45**, 513–523 (1983).
50. R. F. Krueger *et al*., Etiologic connections among substance dependence, antisocial behavior, and personality: Modeling the externalizing spectrum. *J. Abnorm. Psychol.* **111**, 411–424 (2002).
51. H. Leventhal, Findings and theory in the study of fear communications. *Adv. Exp. Soc. Psychol.* **5**, 119–186 (1970).
52. W. K. Bickel, L. A. Marsch, Toward a behavioral economic understanding of drug dependence: Delay discounting processes. *Addiction* **96**, 73–86 (2001).
53. K. N. Kirby, N. M. Petry, W. K. Bickel, Heroin addicts have higher discount rates for delayed rewards than non-drug-using controls. *J. Exp. Psychol. Gen.* **128**, 78–87 (1999).
54. N. Augenblick, M. Niederle, C. Sprenger, Working over time: Dynamic inconsistency in real effort tasks. *Q. J. Econ.* **130**, 1067–1115 (2015).
55. K. M. M. Ericson, D. Laibson, "Intertemporal choice" in *Handbook of Behavioral Economics: Applications and Foundations*, B. D. Bernheim, S. DellaVigna, D. Laibson, Eds. (Elsevier, 2019), pp. 1–67.
56. S. N. Haber, B. Knutson, The reward circuit: Linking primate anatomy and human imaging. *Neuropsychopharmacology* **35**, 4–26 (2010).
57. B. A. Lehmann, G. B. Chapman, F. M. Franssen, G. Kok, R. A. Ruiter, Changing the default to promote influenza vaccination among health care workers. *Vaccine* **34**, 1389–1392 (2016).
58. K. G. Volpp *et al*., Financial incentive-based approaches for weight loss: A randomized trial. *JAMA* **300**, 2631–2637 (2008).
59. K. G. Volpp *et al*., A test of financial incentives to improve warfarin adherence. *BMC Health Serv. Res.* **8**, 272 (2008).
60. K. G. Volpp *et al*., A randomized, controlled trial of financial incentives for smoking cessation. *N. Engl. J. Med.* **360**, 699–709 (2009).
61. G. J. Badger *et al*., Altered states: The impact of immediate craving on the valuation of current and future opioids. *J. Health Econ.* **26**, 865–876 (2007).
62. G. J. Madden, A. M. Begotka, B. R. Raiff, L. L. Kastern, Delay discounting of real and hypothetical rewards. *Exp. Clin. Psychopharmacol.* **11**, 139–145 (2003).
63. G. J. Madden *et al*., Delay discounting of potentially real and hypothetical rewards: II. Between- and within-subject comparisons. *Exp. Clin. Psychopharmacol.* **12**, 251–261 (2004).
64. A. G. Wilson, C. T. Franck, M. N. Koffarnus, W. K. Bickel, Behavioral economics of cigarette purchase tasks: Within-subject comparison of real, potentially real, and hypothetical cigarettes. *Nicotine Tob. Res.* **18**, 524–530 (2016).
65. N. L. Benowitz *et al*.; SRNT Subcommittee on Biochemical Verification, Biochemical verification of tobacco use and cessation. *Nicotine Tob. Res.* **4**, 149–159 (2002).