

# A Single Dose of Nicotine Enhances Reward Responsiveness in Nonsmokers: Implications for Development of Dependence

Ruth S. Barr, Diego A. Pizzagalli, Melissa A. Culhane, Donald C. Goff, and A. Eden Evins

**Background:** Tobacco smoking, driven by the addictive properties of nicotine, is the most prevalent preventable cause of death in the Western world. Accumulated evidence suggests that nicotine may increase appetitive responding for nondrug incentives in the environment.

**Methods:** To test this hypothesis, we conducted a randomized, double-blind, placebo-controlled, crossover study of the effect of a single dose of transdermal nicotine on reward responsiveness in 30 psychiatrically healthy nonsmokers. A novel signal detection task in which correct responses were differentially rewarded in a 3:1 ratio was used to assess the extent to which participants modulated their behavior as a function of reward.

**Results:** Despite expected adverse effects such as nausea, nicotine significantly increased response bias toward the more frequently rewarded condition, at the expense of accuracy, independent of effects on attention or overall vigilance. Additionally, response bias on placebo was greater in participants who received nicotine in the first session, indicating that an effect of nicotine on reward responsiveness or reward-based learning persisted for at least 1 week.

**Conclusions:** These findings suggest that a single dose of nicotine enhances response to non-drug-related rewards in the environment, with lasting effects. This effect may contribute to reinforcement of early smoking behavior and development of nicotine dependence.

**Key Words:** Anhedonia, drug addiction, nicotine, nonsmokers, reward, reward responsiveness

Unlike substances such as cocaine and heroin, euphoric effects of nicotine are mild. Despite this, nicotine is highly addictive (1). Animal studies indicate that reinforcing properties of nicotine may be mediated through enhancement of salience of non-drug-related experiences; nicotine self-administration is associated with increased responsiveness to nondrug reward (2), whereas nicotine withdrawal is associated with refractoriness to reward (3). Phasic dopamine release modulates salience attribution and motivation (4,5), and nicotine may increase appetitive responding for nondrug incentives via activation of presynaptic nicotinic receptors (nAChRs) on mesocorticolimbic dopaminergic neurons (1,2). Consistent with this hypothesis, nicotine enhances the incentive value of monetary reward in smokers following overnight abstinence (6). Whether nicotine enhances responding for nondrug incentives in the absence of potentially confounding effects of nicotine withdrawal or chronic effects of nicotine on reward responsiveness is unknown. We conducted a randomized, double-blind, placebo-controlled, crossover study of a single dose of transdermal nicotine in healthy adult nonsmokers to determine whether responsiveness to nondrug reward is increased in nonsmokers acutely treated with nicotine. This was an ancillary study con-

ducted in conjunction with a larger study of the effect of nicotine on cognitive performance in nonsmokers (7).

## Methods and Materials

The study took place at an urban community mental health clinic (Freedom Trail Clinic) and was approved by Institutional Review Boards of the Massachusetts General Hospital and the Massachusetts Department of Mental Health. All participants were assessed by a doctoral-level investigator as competent to consent and provided written informed consent.

## Participants

Adults, aged 18 to 60, were recruited via local press advertisement and were eligible to participate if they were nonsmokers for  $\geq 3$  months with salivary cotinine  $< 10$  ng/mL (Nicalert, JANT Pharmacal, Encino, California) and expired air carbon monoxide (CO)  $< 9$  ppm (Micro Smokerlyzer III, Bedfont Scientific, Kent, United Kingdom). Participants were excluded if they reported a lifetime history of Axis I psychiatric diagnosis by Structured Clinical Interview for DSM-IV, head injury, first-degree relative with a schizophrenia spectrum disorder, recent exposure to investigational medications, or saliva positive for drugs or alcohol (Accutest Saliva Test, JANT Pharmacal; ALCO Screen, CHEMATICS, North Webster, Indiana). Participants completed the Beck Depression Inventory (BDI) at baseline and were randomized by computer-generated, random number assignment with concealed allocation for order of receiving active or placebo patches. The randomization procedure was conducted by a staff member from another research team and was concealed using opaque envelopes; all study investigators, staff members, and subjects were blind to group allocation for the duration of the study. Participants then attended two study visits, separated by 1–2 weeks, at which they wore two 7-mg nicotine (Nicoderm CQ; GlaxoSmithKline, Research Triangle Park, North Carolina) or identical placebo patches (Alza Corp., Mountain View, California). We elected to use two 7-mg patches instead of a single 14-mg patch to allow for dose reduction if participants experienced

From the Schizophrenia Program (RSB, MAC, DCG, AEE), and the Addiction Research Program (RSB, MAC, AEE) of the Massachusetts General Hospital and Harvard Medical School (RSB, DCG, AEE), and the Department of Psychology (DAP), Harvard University, Boston, Massachusetts.

Address reprint request to A. Eden Evins, M.D., M.P.H., Schizophrenia Program and Director, Center for Addiction Medicine, Massachusetts General Hospital, 60 Staniford St, Boston, MA 02114; E-mail: [a\\_eden\\_evins@hms.harvard.edu](mailto:a_eden_evins@hms.harvard.edu).

Received July 6, 2007; revised September 17, 2007; accepted September 19, 2007.

adverse effects. Following application of patches, participants had lunch and watched an affectively neutral or slightly positive movie of their choice. Tests of reward responsiveness were performed after 3 hours. At the end of the testing period, blood was drawn for serum nicotine concentration, and patches were removed.

### Tasks and Procedures

A signal detection task, designed to measure shift in responding toward a differentially (more) rewarded stimulus, was administered twice, in two separate sessions, 3 hours after nicotine patch and after placebo patch application as an objective measure of reward responsiveness (8–10). This operationalization of response bias as a measure of reward responsiveness fits with the view that reinforcers are stimuli that increase frequency of responding (11). For each trial, participants were asked to choose which of two stimuli (short or long mouth) was presented on a previously mouthless cartoon face by making a corresponding response on a keyboard. At each session, participants performed three blocks, each containing 50 trials of the short and 50 trials of the long mouth. Critically, the difference between mouth sizes (11.5 mm vs. 13 mm) and the stimulus exposure time (100 msec) is small, making the participants' choice difficult and thus allowing the development of a response bias. In line with prior studies (10), an asymmetric reinforcer ratio was used to elicit a response bias. Correct identification of one stimulus was rewarded ("Correct! You won 5 cents") three times more frequently ("rich stimulus") compared with correct identification of the other stimulus ("lean stimulus"). To expose each subject to the intended 3:1 reward ratio, only 40 correct trials (30 rich, 10 lean) were rewarded in each block. Choice of rich stimuli (long vs. short mouth) was counterbalanced between participants and across visits (e.g., if the long mouth was the rich stimulus at the first visit, the short mouth would be the rich stimulus at the second). Before the task, participants were instructed to try to win as much money as possible and told that the money they won would be given to them to keep. They were specifically instructed that not all correct responses would receive a reward feedback, that lack of feedback did not indicate inaccuracy, and that they receive no feedback for errors. They were not informed, however, about the differential reward schedule. Prior studies with this paradigm in healthy subjects have shown that unequal frequency of reward to correct responses to the more frequently (rich) versus less frequently rewarded (lean) stimulus produces a systematic preference for the response paired with the more frequent reward, which typically increases across blocks (8,12,13). Performance was analyzed in terms of response bias, an index of the tendency to choose the more rewarded stimulus and an objective assessment of reward responsiveness. Control analyses were performed for accuracy, discriminability, and reaction time (RT), which provide information about overall task performance. Response bias ( $\log b$ ) and discriminability ( $\log d$ ) were computed as follows (10):

$$\log b = \frac{1}{2} \log \left( \frac{Rich_{correct} * Lean_{incorrect}}{Rich_{incorrect} * Lean_{correct}} \right)$$

$$\log d = \frac{1}{2} \log \left( \frac{Rich_{correct} * Lean_{correct}}{Rich_{incorrect} * Lean_{incorrect}} \right)$$

As evident from the formula, a high response bias is observed if a participant has a high number of correct identifications for the more frequently rewarded (rich) stimulus and a low number of correct identifications for the lean stimulus. Discriminability,

which assessed participants' ability to distinguish between the two stimuli, was used as an indicator of task difficulty. Participants also completed the State Trait Anxiety Inventory (state form) and other cognitive tests reported separately (7).

### Data Reduction and Analyses

Trials with RT less than 150 msec or more than 2500 msec or more than 3 SD from the mean (or both), computed for each subject individually after applying a logarithmic transformation, were identified as outlier responses and excluded. There were a priori criteria to exclude participants with accuracy of less than chance (50%) or total rewards of less than 30 in any block. Data from two participants were removed by these criteria. Data were assessed for distributional properties before analysis, and one variable (RT) required log transformation to meet criteria for normal distribution (pretransformation skew =  $1.71 \pm .31$ , kurtosis =  $3.70 \pm .61$ ; posttransformation skew =  $.97 \pm .31$ , kurtosis =  $1.27 \pm .61$ ). Identical split-plot repeated measures analyses of variance (ANOVA) were performed for response bias and discriminability with *Treatment* (nicotine, placebo) and *Block* (1, 2, and 3) included as within-subject factors, and *Order of Drug Administration* as the between-subject factor. For analyses of RT and accuracy, *Stimulus Type* (lean vs. rich) was included as an additional within-subject factor. In case of significant ANOVA effects, post hoc Newman-Keuls tests were performed. Greenhouse-Geisser corrections were employed when Mauchley's test of sphericity was significant. Data are presented as mean  $\pm$  standard deviation. Analyses were performed using SPSS for Windows version 10 and Statistica.

### Results

All study procedures took place between January 2005 and July 2006. Thirty-two participants completed all study procedures (i.e., a placebo and nicotine session). Data for two participants were lost because they met a priori criteria for exclusion. Data from 30 participants are presented (Supplement 1, Supplement 2). Demographic characteristics are given in Table 1. Serum nicotine levels were higher in the nicotine condition (7.5 vs. <5 ng/mL,  $t = 12.6$ ,  $p < .0001$ ).

### Response Bias

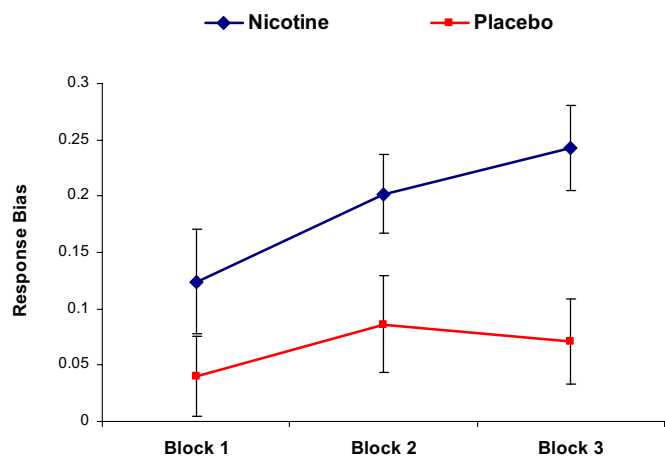
As shown in Figure 1, nicotine increased responding to reward (main effect  $F_{1,28} = 8.18$ ,  $p = .008$ ). It is interesting to note that although there was no overall interaction between

**Table 1.** Baseline Characteristics ( $N = 30$ )

Age	39 (12) years
Gender	14 F, 16 M
Race	24 C, 6 AA
IQ	111 (9)
Expired Air CO	.8 (.9) ppm
Unemployed	23% (7/30)
Education	16 (3) years
Paternal Education	14 (5) years
BDI	2.0 (2.5), range 0–9
BDI Anhedonia Subscale	.5 (.6), range 0–2
Past Smoking	23% (7/30)
Past Cigarettes per Day	5 (7)

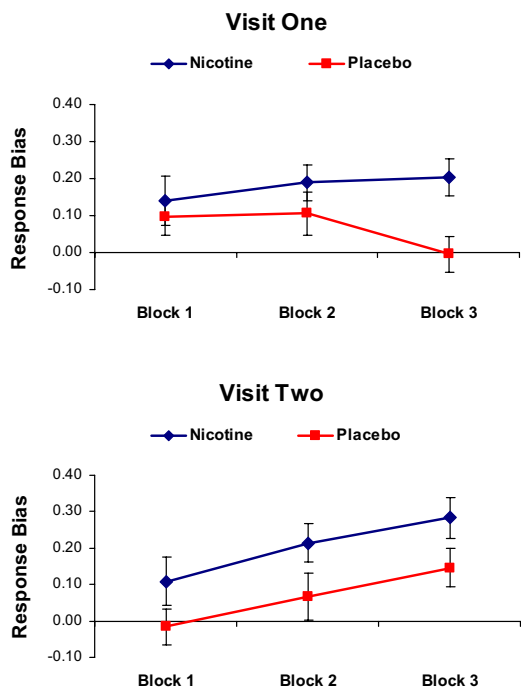
AA, African American; BDI, Beck Depression Inventory; C, Caucasian; F, female; M, male.

Cigarettes per day calculated for former smokers. The BDI anhedonia subscale includes loss of pleasure, loss of interest, loss of energy, and loss of interest in sex (28).

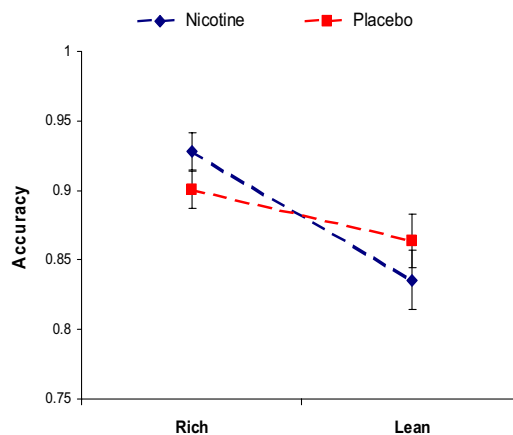


**Figure 1.** Response bias: nicotine treatment increased response bias in the signal detection task (main effect of Treatment:  $F_{1,28} = 8.18, p = .008$ ) indicating increased responding for the more rewarded (rich) Stimulus Type. Data are presented as means  $\pm$  standard error.

Treatment (between-session factor) and Block (within-session factor) ( $F_{1,5,43,0} = .95, p = .37$ ), there was a Treatment by Block by Order of Treatment Administration interaction ( $F_{1,5,43} = 4.29, p = .029$ ). Follow-up ANOVAs, considering each visit separately, revealed a main effect of Treatment in each visit (first visit:  $F_{1,28} = 4.31, p = .047$ ; second visit:  $F_{1,28} = 4.76, p = .038$ ), confirming that participants ( $n = 15$ ) had significantly greater response bias when receiving nicotine than when receiving placebo ( $n = 15$ ) at both visits (Figure 2). To further evaluate the triple interaction, Block by Order of Treatment Administration ANOVAs were run for response bias in nicotine and placebo conditions separately. Importantly, a Block by Order effect



**Figure 2.** Response bias at Visit One and Visit Two: nicotine significantly increased response bias at both visits (main effect of Treatment at Visit One:  $F_{1,28} = 4.31, p = .047$ ; Visit Two:  $F_{1,28} = 4.76, p = .038$ ).



**Figure 3.** Accuracy: a main effect of Stimulus Type ( $F_{1,28} = 36.07, p = <.0001$ ) indicates greater accuracy for the more rewarded (rich) stimulus. A Treatment by Stimulus Type interaction ( $F_{1,28} = 5.08, p = .03$ ) indicated that, compared with placebo, nicotine was associated with greater accuracy for the rich stimulus but lower accuracy for the lean stimulus.

emerged for response bias on placebo ( $F_{1,61,45,14} = 5.20, p = .014$ ), but not nicotine ( $F_{1,36,38,19} = .62, p = .48$ ). This interaction was due to development of greater response bias across the three blocks in the placebo condition for participants who received nicotine first compared with those who received placebo first (RB3-RB1 =  $.16 \pm .19$  vs.  $-.10 \pm .14$ ;  $t_{38} = 4.30, p = .0002$ ).

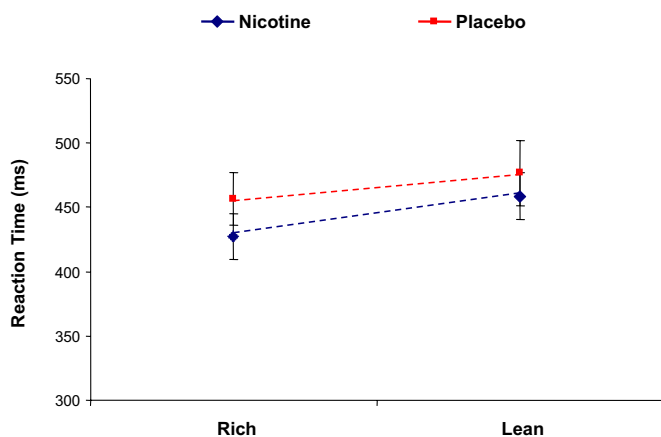
Because of lasting effects of nicotine on response bias observed in this study and reports of persistent effects of chronic nicotine use on cognitive function (14), analyses were repeated in a subsample of 23 participants who reported never having smoked a single cigarette. The effect of nicotine on response bias was unchanged; the main effect of Treatment remained significant ( $F_{1,21} = 13.79, p = .001$ ).

**Control Analyses**

**Accuracy.** The Treatment (placebo, nicotine) by Block (1, 2, and 3) by Order of Drug Administration by Stimulus Type (lean, rich) ANOVA on accuracy scores indicated that the main effect of Treatment was not significant ( $F_{1,28} = .0005, p = .98$ ). Replicating prior studies with independent samples (8,13), accuracy was significantly greater for the more rewarded stimulus type (Stimulus Type:  $F_{1,28} = 36.07, p = <.0001$ ), an effect that was seen in all three blocks (Newman-Keuls,  $ps < .001$ ). In addition, a significant Stimulus Type by Block interaction ( $F_{2,56} = 3.66, p = .032$ ) was due to lower lean accuracy in Blocks 2 (Newman-Keuls,  $p = .050$ ) and 3 (Newman-Keuls,  $p < .060$ ) versus Block 1. Overall, these findings indicate that the differential reinforcement schedule successfully elicited a behavioral preference toward the more frequently rewarded (rich) stimulus. Importantly, this effect was greater on nicotine (Treatment by Stimulus Type interaction  $F_{1,28} = 5.08, p = .03$ ), indicating that when participants were on nicotine, their accuracy was greater in the rich condition and lower in the lean condition than when they were on placebo (Figure 3).

**Discriminability**

There was no main effect of Block on discriminability, indicating no change over the course of the test. There was a trend for an effect of nicotine on discriminability ( $\log d'$  nicotine =  $.98 \pm .34$ ;  $\log d'$  placebo =  $.93 \pm .28$ ) (main effect of Treatment:  $F_{1,28} = 3.12, p = .09$ ).



**Figure 4.** Reaction time (RT): a significant main effect of both Stimulus Type ( $F_{1,28} = 36.6, p = 1.6E^{-6}$ ) and Treatment ( $F_{1,28} = 4.75, p = .04$ ) indicated that RT was faster for the more rewarded (rich) stimulus and in the nicotine condition versus placebo.

### Reaction Time

As expected, RT was faster for the rich stimulus (rich:  $441.9 \pm 103.2$  msec vs. lean:  $467.8 \pm 118.7$  msec; main effect of Stimulus Type:  $F_{1,28} = 36.6, p = 1.6E^{-6}$ ) and in the nicotine condition (main effect of Treatment  $F_{1,28} = 4.75, p = .04$ ; Figure 4).

### Adverse Events

State anxiety was higher in the nicotine condition (STAI =  $33.5 \pm 9.3$  vs.  $29.7 \pm 6.5, t = -2.5, p = .02$ ). Thirteen participants experienced nausea, and four required dose reduction to 7 mg. Other adverse effects included skin irritation ( $n = 12$ ), dizziness ( $n = 9$ ), headache ( $n = 8$ ), and palpitations ( $n = 1$ ). No significant correlation emerged between number and severity of side effects and change in response bias between blocks 1 and 3.

### Discussion

This is the first study to demonstrate that nicotine can enhance responding for a positive response cue and monetary reward in non-nicotine-dependent as well as nicotine-naïve humans. These data suggest that nicotine increases salience of rewarding stimuli in the environment, a property that may contribute to initial development and maintenance of nicotine dependence. Cigarette smoking takes place in the context of many daily activities, and nicotine may increase the salience of environmental reinforcers in these situations. If attempts at smoking cessation are associated with loss of salience of numerous everyday pleasurable experiences, this may make smoking abstinence more difficult to sustain, triggering relapse.

Striatal dopamine and acetylcholine release are believed to play an important role in probabilistic reward-based learning and attention, signaling behavioral significance of environmental events and influencing decision making or choice (15–19). The elimination of cholinergic neurons in the striatum results in impairments in reward-related learning (20), and phasic activation of both striatal dopaminergic and cholinergic neurons has been demonstrated in response to rewarding stimuli (16). Data from animal models investigating the effects of d-amphetamine on responding for conditioned reinforcers (21–23) support a role for phasic dopaminergic activation in enhancing response to reward-related stimuli. On the basis of these animal data, we postulate that effect of nicotine to enhance responding for positive response cues may be mediated via dopamine or

acetylcholine-dependent mechanisms in mesocorticolimbic regions. Future studies are required to test this hypothesis.

Nicotine did not significantly modulate discriminability on the task, indicating that effects on response bias were not mediated by improvement in attention or general task performance. Furthermore, if the effect of nicotine on response bias described were primarily due to improvement in attention and overall vigilance, we would expect improved accuracy for both types of stimuli presented in the task rather than differentially increased responding for the stimulus associated with the more frequent reward at the expense of accuracy for the lean stimulus, as observed. In addition, reaction time was faster on nicotine because of an expected improvement in motor speed. However, the signal detection task measures the tendency to choose the more rewarded response and is independent of speed.

Importantly, a carryover effect of nicotine on reward responsiveness was observed. This is consistent with a finding in animals in which nicotine self-administration was associated with increased reward responsiveness during active use and for 36 days after removal of nicotine availability (2). These results suggest that a single nicotine dose may have lasting effects on reward sensitivity in humans, potentially through its effects on incentive or motivational salience, which may contribute to repeated use and the development of dependence.

The study was conducted in nonsmokers to avoid confounding effects of nicotine use on reward responsiveness (2,24). Although the observed effect of nicotine on reward responsiveness was small, it is possible that even a small enhancement in sensitivity to rewarding environmental stimuli may be sufficient to reinforce smoking behavior in vulnerable individuals. Additionally, nicotine delivered by smoke would have faster pharmacokinetics and may have a greater effect on responsiveness to reward than that observed for transdermal nicotine. There are limitations to our study that require specific mention. Participants had low levels of depressive symptoms as indicated by low BDI scores, limiting our ability to assess clinical correlates of response bias development. The findings of this study may, however, have relevance for those with disorders of hedonic tone such as anxiety, depressive disorders, or schizophrenia who also have high rates of smoking (25–27). These individuals may be particularly vulnerable to become nicotine dependent if they experience a reduction in anhedonia when they smoke. Future studies investigating generalizability of our findings to those with disorders of hedonic tone are warranted.

*This work was supported by the National Institutes on Drug Abuse and the Stanley Medical Research Institute. We thank James O'Shea and Kyle Ratner for technical assistance and Drs. Nancy Rigotti and Maurizio Fava for critical review of the manuscript.*

*Clinical Trials Registry: ClinicalTrials.gov, URL: <http://ClinicalTrials.gov/>. Identifier: NCT00383747.*

*Dr. Evins was supported by National Institutes on Drug Abuse grant 1K23DA00510; has received grant support from Janssen Pharmaceuticals, AstraZenica, and GlaxoSmithKline (GSK); and has a collaborative agreement with GSK as a principal investigator in a Collaborative Drug Discovery Group for Nicotine Dependence funded by NIDA through a U01 mechanism.*

*Dr. Goff has received research funding from the following: Janssen Pharmaceuticals, Pfizer Inc., Bristol Meyer Squibb, GlaxoSmithKline, and Cephalon. In addition, he has received honoraria from Eli Lilly and Company, Janssen Pharmaceuticals, Pfizer Inc., and Bristol Myer Squibb. He is a member of the*

DSMB for Wyeth and serves on the advisory board of Janssen Pharmaceuticals, Pfizer Inc., Bristol Meyer Squibb, GlaxoSmith-Kline, Merck, Solvay Pharmaceuticals, and AstraZeneca Pharmaceuticals.

Dr. Pizzagalli was supported by National Institute of Mental Health Research Grant R01MH68376 and has received research support from GlaxoSmithKline and Merck & Co., Inc. GSK is licensed to use the Nicoderm CQ trademark, and the transdermal preparation of nicotine used in this study was Nicoderm CQ.

Dr. Barr and Ms. Culhane have no relevant financial interests to disclose.

Supplementary material cited in this article is available online.

- Dani JA, Harris RA (2005): Nicotine addiction and comorbidity with alcohol abuse and mental illness. *Nat Neurosci* 8:1465–1470.
- Kenny PJ, Markou A (2006): Nicotine self-administration acutely activates brain reward systems and induces a long-lasting increase in reward sensitivity. *Neuropsychopharmacology* 31:1203–1211.
- Epping-Jordan MP, Watkins SS, Koob GF, Markou A (1998): Dramatic decreases in brain reward function during nicotine withdrawal. *Nature* 393:76–79.
- Berridge KC, Robinson TE (1998): What is the role of dopamine in reward: Hedonic impact, reward learning, or incentive salience? *Brain Res Brain Res Rev* 28:309–369.
- Volkow ND, Fowler JS, Wang GJ, Swanson JM (2004): Dopamine in drug abuse and addiction: Results from imaging studies and treatment implications. *Mol Psychiatry* 9:557–569.
- Dawkins L, Powell JH, West R, Powell J, Pickering A (2006): A double-blind placebo controlled experimental study of nicotine: I—effects on incentive motivation. *Psychopharmacology (Berl)* 189:355–367.
- Barr RS, Culhane MA, Jubelt LE, Mufti RS, Dyer MA, *et al.* (2007): The effects of transdermal nicotine on cognition in non-smokers with schizophrenia and non-psychiatric controls. *Neuropsychopharmacology* [April 18, Epub ahead of print].
- Pizzagalli DA, Jahn AL, O'Shea JP (2005): Toward an objective characterization of an anhedonic phenotype: A signal-detection approach. *Biol Psychiatry* 57:319–327.
- Tripp G, Alsop B (2001): Sensitivity to reward delay in children with attention deficit hyperactivity disorder (ADHD). *J Child Psychol Psychiatry* 42:691–698.
- Tripp G, Alsop B (1999): Sensitivity to reward frequency in boys with attention deficit hyperactivity disorder. *J Clin Child Psychol* 28:366–375.
- Spanagel R, Weiss F (1999): The dopamine hypothesis of reward: Past and current status. *Trends Neurosci* 22:521–527.
- McCarthy DC (1991): Behavior detection theory: Some implications for applied human research. In: Nevin JA, Davison MC, Commons M, editors. *Signal Detection: Mechanisms, Models and Applications*. Hillsdale, NJ: Lawrence Erlbaum.
- Bogdan R, Pizzagalli DA (2006): Acute stress reduces reward responsiveness: Implications for depression. *Biol Psychiatry* 60:1147–1154.
- Ernst M, Heishman SJ, Spurgeon L, London ED (2001): Smoking history and nicotine effects on cognitive performance. *Neuropsychopharmacology* 25:313–319.
- Schultz W, Dayan P, Montague PR (1997): A neural substrate of prediction and reward. *Science* 275:1593–1599.
- Morris G, Arkadir D, Nevet A, Vaadia E, Bergman H (2004): Coincident but distinct messages of midbrain dopamine and striatal tonically active neurons. *Neuron* 43:133–143.
- Dayan P, Balleine BW (2002): Reward, motivation, and reinforcement learning. *Neuron* 36:285–298.
- Daw ND, Doya K (2006): The computational neurobiology of learning and reward. *Curr Opin Neurobiol* 16:199–204.
- Yu AJ, Dayan P (2005): Uncertainty, neuromodulation, and attention. *Neuron* 46:681–692.
- Kitabatake Y, Hikida T, Watanabe D, Pastan I, Nakanishi S (2003): Impairment of reward-related learning by cholinergic cell ablation in the striatum. *Proc Natl Acad Sci U S A* 100:7965–7970.
- Taylor JR, Robbins TW (1984): Enhanced behavioural control by conditioned reinforcers following microinjections of d-amphetamine into the nucleus accumbens. *Psychopharmacology (Berl)* 84:405–412.
- Taylor JR, Robbins TW (1986): 6-Hydroxydopamine lesions of the nucleus accumbens, but not of the caudate nucleus, attenuate enhanced responding with reward-related stimuli produced by intra-accumbens d-amphetamine. *Psychopharmacology (Berl)* 90:390–397.
- Cador M, Taylor JR, Robbins TW (1991): Potentiation of the effects of reward-related stimuli by dopaminergic-dependent mechanisms in the nucleus accumbens. *Psychopharmacology (Berl)* 104:377–385.
- Martin-Solch C, Magyar S, Kunig G, Missimer J, Schultz W, Leenders KL (2001): Changes in brain activation associated with reward processing in smokers and nonsmokers. A positron emission tomography study. *Exp Brain Res* 139:278–286.
- Lasser K, Boyd JW, Woolhandler S, Himmelstein DU, McCormick D, Bor DH (2000): Smoking and mental illness: A population-based prevalence study. *JAMA* 284:2606–2610.
- Hughes J (1986): Prevalence of smoking among psychiatric outpatients. *Am J Psychiatry* 143:993–997.
- de Leon J, Diaz FJ, Rogers T, Browne D, Dinsmore L (2002): Initiation of daily smoking and nicotine dependence in schizophrenia and mood disorders. *Schizophr Res* 56:47–54.
- Joiner TE, Brown JS, Metalsky GI (2003): A test of the tripartite model's prediction of anhedonia's specificity to depression: Patients with major depression versus patients with schizophrenia. *Psychiatry Res* 119:243–250.