Clinical Neurophysiology 127 (2016) 1358–1365

Contents lists available at ScienceDirect

Clinical Neurophysiology

journal homepage: www.elsevier.com/locate/clinph

Atypical valuation of monetary and cigarette rewards in substance dependent smokers

Travis E. Baker [a,b,*], Jonathan M.A. Wood [a], Clay B. Holroyd [a]

[a] Department of Psychology, University of Victoria, British Columbia, Canada
[b] Centre de recherche du CHU Ste-Justine, University of Montreal, Quebec, Canada

ARTICLE INFO

Article history:
Accepted 3 November 2015
Available online 11 November 2015

Keywords:
Addiction
Reward positivity
Midbrain dopamine system
Reinforcement learning
Nicotine
Anterior cingulate cortex

HIGHLIGHTS

- Non-drug relative to drug-related rewards were compared using the reward positivity.
- Cigarette relative to monetary rewards elicited a larger reward positivity.
- Obtaining drug-related rewards engages the anterior cingulate cortex (ACC) to exert control over behaviors in substance dependent (SD) individuals.

ABSTRACT

Objective: Substance dependent (SD) relative to non-dependent (ND) individuals exhibit an attenuated reward positivity, an electrophysiological signal believed to index sensitivity of anterior cingulate cortex (ACC) to rewards. Here we asked whether this altered neural response reflects a specific devaluation of monetary rewards relative to drug-related rewards by ACC.
Methods: We recorded the reward positivity from SD and ND individuals who currently smoke, following an overnight period of abstinence, while they engaged in two feedback tasks. In a money condition the feedback indicated either a monetary reward or no reward, and in a cigarette condition the feedback indicated either a drug-related reward or no reward.
Results: Overall, cigarette relative to monetary rewards elicited a larger reward positivity. Further, for the subjects who engaged in the money condition first, the reward positivity was smaller for the SD compared to the ND participants, but for the subjects who engaged in the cigarette condition first, the reward positivity was larger for the SD compared to the ND participants.
Conclusions: Our results suggest that the initial category of feedback "primed" the response of the ACC to the alternative feedback type on subsequent trials, and that SD and ND individuals responded differently to this priming effect.
Significance: We propose that for people who misuse addictive substances, the prospect of obtaining drug-related rewards engages the ACC to exert control over extended behaviors.

1. Introduction

Neurocognitive alterations to mesocorticolimbic reward function by drugs of abuse are thought to facilitate a progression towards excessive drug use (Schultz, 2011; Redish et al., 2008). Much attention in the field has focused on the contributions of subcortical brain regions such as the ventral striatum to drug-induced changes to behavior (Volkow et al., 2007). Although there is compelling evidence that cortical brain regions, including orbitofrontal cortex, dorsolateral prefrontal cortex, anterior cingulate cortex (ACC), and insula, are also heavily involved (Hyman et al., 2006), their contribution to this process is relatively less explored. Here we focus on the role of the ACC in substance dependence. The function of ACC is highly debated, but we have recently proposed that the ACC utilizes dopamine reward signals to learn the value of extended, context-specific sequences of behavior directed toward particular goals (Holroyd and McClure, 2015; Holroyd and Yeung, 2012). This theoretical framework suggests that the

* Corresponding author at: Department of Neurology and Neurosurgery, Montreal Neurological Institute, McGill University, 3801, Rue University, Montreal, Quebec, H3A 2B4, Canada. Tel.: +1 514 867 9676.
E-mail address: travis.e.baker@gmail.ca (T.E. Baker).

http://dx.doi.org/10.1016/j.clinph.2015.11.002
1388-2457/

ACC may be centrally concerned with regulating goal-directed behaviors underling substance use and misuse.

In humans, the reward processing function of ACC can be investigated using a component of the event-related brain potential (ERP) called the reward positivity (also called the feedback-related negativity; for reviews see Walsh and Anderson, 2012; Sambrook and Goslin, 2015). We have previously proposed that the reward positivity is produced by the impact of reward prediction error signals (RPEs) carried by the midbrain dopamine system onto motor areas in ACC, where they are utilized for the adaptive modification of behavior according to principles of reinforcement learning (Holroyd and Coles, 2002). RPEs constitute the learning term in powerful reinforcement learning algorithms that indicate when events are "better" or "worse" than expected (Sutton and Barto, 1998). Over the past two decades substantial evidence has supported the proposition that RPE signals are encoded in the brains of humans and other animals as phasic increases and decreases of midbrain dopamine neuron activity (Schultz, 2010), and numerous reward positivity studies have elucidated how the ACC processes dopamine-like RPE signals in both normal (Walsh and Anderson, 2012; Sambrook and Goslin, 2015) and atypical (Proudfit, 2015) populations.

Notably, we demonstrated across a series of studies that young adults meeting criteria for substance dependence exhibited an attenuated reward positivity to stimuli indicating small monetary gains, suggesting that they value such rewards as if they were non-rewarding (Baker et al., 2011, 2015a). Because the dependency measure was sensitive to polydrug use – such that the affected population tended to misuse a broad range of substances including alcohol, nicotine, and cannabis – the smaller reward positivity appears to reflect a general reward processing impairment that cuts across specific drug types. If the ACC is indeed responsible for the selection and execution of extended, goal-directed behaviors, as proposed (Holroyd and McClure, 2015; Holroyd and Yeung, 2012), then our finding of reduced reward positivity amplitude suggests abnormal goal-directed behavior in this population, whether as a consequence of the drug use itself, a preexisting vulnerability, or both (Baker et al., 2011, 2015a).

An unresolved question concerns whether the reduced reward positivity in substance dependent (SD) individuals reflects a global impairment in reward processing that affects all types of rewards, or a specific devaluation of non-drug-related compared to drug-related rewards (Ahmed, 2004, 2005; Ahmed et al., 2002). In regards to the latter possibility, enhanced valuation of drug-related cues could bias the ACC to select extended behaviors that ultimately converge on drug use in lieu of other behaviors directed toward non-drug related goals. Alternatively, a blunted response by ACC to rewards in general – whether drug-related or not – would suggest decreased effortful pursuit of a wide range of rewarding behaviors. These disparate possibilities would point toward distinct avenues for the study and treatment of substance dependence.

To investigate this issue, we examined whether the abnormal reward positivity observed in SD individuals reflects impaired reward valuation per se or a specific devaluation of small monetary rewards relative to drug-related rewards. To do so, we replicated a previous study that demonstrated that SD individuals, relative to non-dependent (ND) individuals, produce a smaller reward positivity to feedback indicating small monetary rewards (Baker et al., 2011). As before, the level of substance dependence was determined according to participant responses to an inventory that assesses problematic substance use aggregated across a broad range of addictive substances including tobacco, alcohol, cannabis, and other drugs. Crucially, in addition to the standard condition in which the feedback indicated that subjects either would or would not earn 5 cents for that trial, we included a second condition in which the feedback indicated that subjects either would or would not earn a drug-related reward for that trial. But because alcohol and illicit drugs were not advisable for this sample of undergraduate students, we adopted nicotine as a drug reward that would be of interest to polysubstance users. To increase craving for the reward, participants were asked to abstain from smoking for the 24 h preceding the study; compliance was verified by measuring participant carbon monoxide (CO) levels. In short, we screened for SD and ND individuals who currently smoke, and following an overnight period of abstinence, recorded the reward positivity to feedback indicating forthcoming drug-related and non-drug related rewards in the same individuals.

We specifically examined 3 questions. First, because the reward positivity to drug-related feedback stimuli has not yet been investigated, we examined whether or not cigarette-related rewards elicit this ERP component. Second, we tested whether, consistent with our previous findings, feedback stimuli indicating small monetary rewards would elicit an attenuated reward positivity in SD compared to ND individuals. Third, we asked whether drug-related rewards would normalize this impairment in SD individuals. We predicted that if feedback stimuli indicating potential puffs on a cigarette increased reward positivity amplitude for SD individuals, then the ACC would appear to devalue the pursuit of small monetary rewards relative to drug-related rewards in this sample. Alternatively, if the reward positivity to drug-related feedback were also attenuated, then ACC function would appear broadly impaired in this population.

2. Methods

2.1. Participants

Participants were recruited from the University of Victoria Department of Psychology subject pool. Each subject received course credit for their participation in a two-session study spanning a 1–2 week interval. They were required to be current smokers who were not currently trying or planning to quit smoking. All participants had normal or corrected-to-normal vision and all gave informed consent. The study was approved by the local research ethics committee and was conducted in accordance with the ethical standards prescribed in the 1964 Declaration of Helsinki.

For the purpose of replicating our previous study (Baker et al., 2011, 2015a), participants were classified as either SD or ND according to their scores on the Global Continuum of Substance Risk (GCR) scale of the Alcohol, Smoking and Substance Involvement Screening Test (ASSIST), a validated screening test that uses DSM-specific criteria for identifying the degree of problematic substance use across a range of drugs (i.e., tobacco, alcohol, cannabis, cocaine, amphetamine-type stimulants, sedatives, hallucinogens, inhalants, opioids and "other drugs") (Humeniuk et al., 2008). Specifically, participants with GCR scores falling within the bottom (score < 22) and top (score > 39) quartiles of our sample were classified as ND (12 participants) and SD (12 participants), respectively. These scores are comparable with the cut-offs established in previous validation studies of the ASSIST for non-dependence (score < 15) and dependence (score > 39.5) (Newcombe et al., 2005), as well as in our previous studies (ND: score < 16, $n = 18$; and SD: score > 41, $n = 18$, Baker et al., 2011; see also Baker et al., 2013, 2015a).

2.2. Procedures

Informed consent, questionnaire data, and a baseline measure of breath carbon monoxide levels (see below) were obtained from participants during Session 1; the EEG data were collected during