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Research article

Performance monitoring in nicotine dependence: Considering integration of recent reinforcement history

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ABSTRACT

Introduction: Impaired monitoring of errors and conflict (performance monitoring; PM) is well documented in substance dependence (SD) including nicotine dependence and may contribute to continued drug use. Contemporary models of PM and complementary behavioural evidence suggest that PM works by integrating recent reinforcement history rather than evaluating individual behaviours. Despite this, studies of PM in SD have typically used indices derived from reaction to task error or conflict on individual trials. Consequently impaired integration of reinforcement history during action selection tasks requiring behavioural control in SD populations has been underexplored.
Methods: A reinforcement learning task assessed the ability of abstinent, satiated, former and never smokers (N = 60) to integrate recent reinforcement history alongside a more typical behavioural index of PM reflecting the degree of reaction time slowing following an error (post-punishment slowing; PPS).
Results: On both indices there was a consistent pattern in PM data: Former smokers had the greatest and satiated smokers the poorest PM. Specifically satiated smokers had poorer reinforcement integration than former (p = 0.005) and never smokers (p = 0.041) and had less post-punishment slowing than former (p < 0.001), never (p = 0.003) and abstinent smokers (p = 0.026).
Conclusions: These are the first data examining the effects of smoking status on PM that use an integration of reinforcement history metric. The concordance of the reinforcement integration and PPS data suggest that this could be a promising method to interrogate PM in future studies. PM is influenced by smoking status. As PM is associated with adapting behaviour, poor PM in satiated smokers may contribute towards continued smoking despite negative consequences. Former smokers show elevated PM suggesting this may be a good relapse prevention target for individuals struggling to remain abstinent however prospective and intervention studies are needed. A better understanding of PM deficits in terms of reinforcement integration failure may stimulate development of novel treatment approaches.

1. Introduction

Our ability to monitor our own on-going behaviour for errors or conflict (performance monitoring, PM) is an important aspect of adaptive cognition. PM is fundamental to the implementation of top-down control of behaviour so that behavioural adjustments can be made where appropriate and future mistakes or decrements in performance prevented) (Alexander and Brown, 2010). Hyperactive and hypoactive PM are consistently reported in populations with internalising disorders (e.g. anxiety disorders) and externalising disorders (e.g. substance use disorders) respectively (Olvet and Hajcak, 2008). Impaired PM is documented in populations with various dependencies (e.g. opiate users (Forman et al., 2004), cannabis users (Gruber and Yurgelun-Todd, 2005), cocaine users (Franken et al., 2007), alcoholics with a family history of alcohol problems (Fein and Chang, 2008), and those with internet addiction disorder (Zhou et al., 2013). This suggests that hypoactive PM may be a mechanism by which maladaptive behaviours (such as drug taking) persist despite negative consequences and further, that it may be a transdiagnostic, endophenotypic cognitive marker of addiction (Euser et al., 2013).

There is a growing body of research regarding PM and the response to error in tobacco dependence. Electrophysiological and behavioural correlates of PM have been reported in smokers and non-smokers during Flanker tasks (Franken et al., 2010; Luijten et al., 2011). In these

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conflict resolution tasks participants make behavioural selections depending on the identity of a central target that is flanked by either congruent or incongruent distractors (Eriksen and Eriksen, 1974). Diminished electrophysiological correlates of PM in smokers compared to non-smokers were found in both studies and one study also found that smokers had a decreased post-error slowing of reaction time compared to non-smokers (Luijten et al., 2011). Similarly, imaging studies have shown reduced error-related neural activity in smokers compared to non-smokers (de Ruiter et al., 2009; Nestor et al., 2011; de Ruiter et al., 2012). Interestingly, an increased electrophysiological correlate of PM has been reported in intermittent non-dependent smokers compared to both dependent smokers and non-smokers (Rass et al., 2014) and greater error-related brain activation during inhibitory control performance was reported in former smokers compared to both current and never smokers (Nestor et al., 2011). This suggests that intact or enhanced PM may be an important mechanism by which abstinence or reduced consumption is successfully maintained over the long-term. Other research has previously found a reduced electrophysiological correlate of PM in acutely abstinent compared to satiated smokers (Schlienz et al., 2013).

Common across these studies of PM in nicotine dependence is that indices have focused on reaction to error or conflict on individual trials. However rather than simply detecting and evaluating individual trial error or conflict, there is evidence to suggest that PM involves the use of accumulated evidence and learning over a number of trials. Specifically, behaviour is guided by the integration of recent reinforcement (choice and outcome) history (Akitsuki et al., 2003; Kennerley et al., 2006; Walton et al., 2007; Rushworth et al., 2007; Holroyd and Coles, 2008; Santesso et al., 2008). For example, Holroyd and Coles (2002) propose a model of PM whereby midbrain dopaminergic learning signals indicating an actual outcome worse than expected (negative prediction error) are carried to the error processing system (the anterior cingulate cortex). This leads to implementation of control, which in turn results in behavioural adjustments that optimise future performance. Using a decision making task where correctness of individual choice was ambiguous, but where amount of reward received depended on response history, Holroyd and Coles (2008) showed that this error processing system guides behaviour through the integration of reinforcement information over time, rather than the evaluation of individual responses.

The present study is the first to compare PM in current, former and never smokers which considers the ability to integrate reinforcement information over time. To do this we used a reinforcement learning task (RLT) with acquisition and reversal phases (based on Budhani et al., 2006). In this task participants make timed behavioural choices between two differentially rewarded and punished stimuli. In acquisition phases, participants learn which of the stimuli possess the optimum reinforcement properties and during reversal phases the reinforcement properties of some of the stimuli reverse. The changing reinforcement properties of reversing stimuli during the task provides the PM measure of integration of reinforcement information over time (see Materials and methods section). We also included a traditional behavioural PM index based upon reaction to error on individual trials, post-punishment slowing (PPS) of RLT reaction time. Slowing of reaction time following an error (Rabbitt, 1966) may reflect a mechanism for maintaining response accuracy that results from increased response caution as a consequence of the engagement of cognitive control (Dutilh et al., 2012). Indeed, studies have shown that the degree of slowing is correlated with electrophysiological measures of PM (error-related negativity and positivity) (Hajcak et al., 2003; Debener et al., 2005). We included both satiated and abstinent smokers in the study as there is some evidence that acute abstinence from smoking reduces PM (Schlienz et al., 2013). We hypothesised that current smokers would have impaired PM compared to both never and former smokers. We further hypothesised that former smokers would have the greatest levels of PM and that abstinent smokers would have reduced PM compared to satiated smokers. Finally we will assess preliminary validity of the integration of reinforcement history measure. We hypothesise that integration ability will correlate with PPS as both purport to index PM. We also hypothesise that the integration measure will be the most sensitive measure given that it fits more closely with theoretical accounts of PM.

2. Materials and methods

2.1. Participants

Sixty healthy participants (30 current smokers, 15 former smokers and 15 never smokers) aged 18–38 years were recruited using the following criteria: current smokers were required to smoke ≥10 cigarettes per day for ≥12 months, former smokers were required to have had pre-quit smoking levels comparable to the current smoker group and to have remained abstinent for ≥6 months. Never smokers were required to have smoked ≤5 cigarettes in their lifetime. Participants were required to be medication free (excluding contraceptives), refrain from using illicit drugs for ≥1week and arrive at the laboratory having not consumed alcohol for ≥12 h. Current smokers were required to arrive after overnight abstinence and were randomly assigned to either a satiated or abstinent group to create 4 experimental groups: abstinent smokers, satiated smokers, former smokers and never smokers (n = 15 per group). Group size was based on previous studies measuring PM and inhibitory control in smokers (Luijten et al., 2011; Luijten et al., 2013a). Ethical approval was obtained from the University of Brighton School of Pharmacy and Biomolecular Sciences Research Ethics Committee. Participants gave written informed consent, attended one 1.5 h laboratory session and received £12 compensation for their time.

2.2. General procedure

All participants completed an e-mail inclusion criteria screen 0–7 days prior to the laboratory session. Current smokers also completed the Fagerstrom Test for Nicotine Dependence (FTND) (Heatherton et al., 1991) to assess severity of dependence. Upon arrival, all participants were subject to breath alcohol (Lion Alcometer SD-40; Lion Laboratories Ltd., Cardiff, UK) and exhaled carbon monoxide (CO) tests (Bedfont Micro Smokerlyzer; Bedfont Scientific Ltd., Kent, UK) for overnight abstinence compliance. Participants were excluded for a breath alcohol reading > 0 g/L or an exhaled CO level > 10 ppm (Benowitz et al., 2002). As general cognitive ability and personality may affect reinforcement learning and PM, participants completed a battery of questionnaires and tests to assess impulsivity (Barratt Impulsiveness Scale, BIS-11 (Patton et al., 1995)), sensitivity to reward and punishment (Behavioural Inhibition System/Behavioural Activation System Scales, BIS/BAS (Carver and White, 1994)), depression (Beck Depression Inventory, BDI (Beck et al., 1961)), IQ (The National Adult Reading Test, NART (Nelson, 1982)) and short-term memory (Rusted and Warburton, 1989) (immediate word recall, IWR (Jackson et al., 2009)). To reduce smoking/abstinence-related performance expectancies all smokers were told they would smoke at some point during the session, but not when. The satiated group smoked one of their own cigarettes before PM assessment and the abstinent group smoked at the end of the session so they did not leave in a withdrawn state. The effectiveness of the smoking manipulation was assessed with subjective (nicotine-sensitive visual analogue scales (NicVAS) and craving) and physiological (exhaled carbon monoxide (CO) levels). Exhaled CO levels were re-measured before and after PM assessment. NicVAS (based on Perkins et al., 1999) ranged from 0 = 'not at all' to 100 = 'extremely' for the items: 'alert', 'buzzed', 'contented', 'dizzy', 'hungrier than usual', 'impatient', 'irritable', 'jittery', 'relaxed', 'stimulated' and 'thirsty'. NicVAS are known to be sensitive to acute smoking and abstinence (Jackson et al., 2009; Nesic et al., 2011a, 2011b) and