



Neural correlates of choice behavior related to impulsivity and venturesomeness

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ABSTRACT

Impulsivity has been associated with several psychiatric disorders including drug addiction and gambling. Impulsive subjects typically have a preference for short-term over long-term rewards and make risky choices. This study used functional magnetic resonance imaging (fMRI) to investigate the neural correlates of self-rated impulsivity and venturesomeness during tasks involving delayed and risky choice. A broader sampling approach was taken by recruiting participants with behaviors that have been linked to impulsivity (gambling $N=15$, and recreational drug use $N=10$) and those without these behaviors ($N=9$). Selection between delayed or probabilistic rewards was associated with activation in fronto-parietal regions in line with previous research. When selecting between delayed rewards, activity within the pregenual anterior cingulate cortex and ventrolateral prefrontal cortex correlated positively with impulsivity scores while activity within the orbitofrontal cortex, subgenual anterior cingulate cortex and caudate correlated positively with venturesomeness scores. Selection between probabilistic rewards revealed no correlation between scores and regional activations. The results from this study provide targets for future research investigating the neural substrates of impulsivity. They also provide targets for the further investigation into the pathophysiology of addiction and impulse-control disorders.

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1. Introduction

Impulsivity has been linked to a wide range of psychiatric disorders and potentially problematic behaviors. Heightened impulsivity is considered to be an important factor underlying impulse-control disorders identified by the DSM-IV-TR (American Psychiatric Association, 2000), which includes disorders such as pathological gambling. Furthermore, increased impulsivity has also been linked with addiction disorders such as drug abuse (Allen, Moeller, Rhoades, & Cherek, 1998; Kirby & Petry, 2004; Madden, Petry, Badger, & Bickel, 1997). Impulsivity can be divided into several sub-behaviors; lack of forethought prior to behavioral response, decreased ability to withhold inappropriate responses and an inability to tolerate delay (Allen et al., 1998; Dawe & Loxton, 2004; Evenden, 1999; Enticott & Ogloff, 2006). Delay intolerance (also termed “impulsive choice”) has been widely studied in relation to drug and gambling addiction as patients have reliably been shown to express a biased preference for immediate

rewards over long-term, but relatively larger, rewards compared to non-drug using/non-gambling controls (for a review see Reynolds, 2006). Within addicted drug users and gamblers this difference in behavior has been associated with a biased focus on short-term or immediate rewards (e.g. the hedonic aspects of a drug high) over longer-term rewards (e.g. better health). This bias has been linked to differential functioning of regions within the brain, particularly limbic and prefrontal regions that underlie reward-related decision-making (for recent reviews, see Perry & Carroll, 2008; Verdejo-Garcia, Lawrence, & Clark, 2008).

Several recent papers have identified a network of brain regions involved in choice during delay discounting tasks, which measure levels of impulsive choice. This system predominantly includes lateral and ventromedial prefrontal regions, parietal cortex and ventral striatum (Kable & Glimcher, 2007; McClure, Laibson, Loewenstein, & Cohen, 2004; McClure, Ericson, Laibson, Loewenstein, & Cohen, 2007; Peters & Büchel, 2009; Weber & Huettel, 2008; Xu, Liang, Wang, Li, & Jiang, 2009). However, the association between impulsivity and neural function within this system remains unclear. Several papers have investigated the correlation between impulsivity and another sub-behavior of impulsivity, response inhibition. These studies have shown that during response inhibition, impulsivity is correlated with activity in dorsal and ventral lateral regions of the prefrontal cortex, predominantly within the right hemisphere, in addition to the insula (Asahi, Okamoto, Okado, Yamawaki, & Yokota, 2004; Horn, Dolan, Elliott, Deakin, & Woodruff, 2003; Kaladjian, Jeanningros, Azorin, Anton, &

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Mazzola-Pomietto, 2011) indicating that the performance of these areas may be sensitive to individual levels of impulsivity.

One issue when investigating the effects of impulsivity on substance abuse is that it is unclear whether impulsivity pre-dates substance use or is due to neurochemical consequences of substance abuse. The study of pathological gamblers, which has been termed a “behavioral addiction” and thus one where direct physiologically or neuropsychological harmful effects of the addiction are absent, is less confounded by this issue. There is increasing evidence that impulsivity pre-dates gambling addiction and may be a vulnerability marker for the development of other addictive behaviors including substance abuse (for a recent review in this area, see Verdejo-Garcia et al., 2008).

Venturesomeness identifies a different dimension to impulsivity as described above (Kirby & Finch, 2010) and includes sensation or thrill seeking and taking risks for pleasure (Eysenck, Daum, Schugans, & Diehl, 1990; Eysenck, Pearson, Easting, & Allsopp, 1985). It has received relatively less study than impulsivity despite evidence for greater self-reported venturesomeness in pathological samples, such as ecstasy and polydrug users, compared to controls (Butler & Montgomery, 2004; Allen et al., 1998; Morgan, 1998) although a recent paper found no such effect (Clark, Roiser, Robbins, & Sahakian, 2009). Choice involving risk activates decision-making brain networks including prefrontal cortex, parietal cortex, insula and dorsal striatum (Koeneke, Pedroni, Dieckmann, Bosch, & Jäncke, 2008; Koenecke et al., 2008; Smith et al., 2009). Activity within dorsal and ventromedial prefrontal cortices and the insula has been correlated with risk-seeking attitude (Clark et al., 2008; Knoch et al., 2006; Steinberg, 2008) however it is unclear as to how variations in brain activity are linked to venturesomeness.

The current study investigates whether regions of the brain associated with inter-temporal choice and risky choice (using novel delay and probability discounting tasks) are associated with self-reported impulsivity and venturesomeness. Previous studies have predominantly investigated non-gambling/non-drug using participants, or comparisons between pathological and control groups, which may limit the general applicability of such findings to the wider population. To address this, we recruited an enriched sample including drug users and gamblers so as to obtain a range of impulsivity and venturesomeness scores linked to behavioral consequences. We then used a correlational approach to relate region-specific neural responses to choices involving delays or risk similar to that in a previous study of memory (Valdes et al., 2006). Using a broader sampling approach allows investigation of potential biological vulnerability markers for addiction and provides targets for future research into the underlying mechanisms of pathological behavior. Based upon the literature, we hypothesised that intertemporal and risk-related choice would be associated with activity in prefrontal and anterior cingulate cortices (Kable & Glimcher, 2007; Koenecke et al., 2008; McClure et al., 2004, 2007; Peters & Büchel, 2009; Smith et al., 2009; Weber & Huettel, 2008; Xu et al., 2009). We also undertook exploratory analysis to investigate whether impulsivity and venturesomeness would correlate with neural activity in different brain areas during intertemporal and risk-related choice.

2. Materials and methods

2.1. Subjects

Advertisements were placed through the University of Manchester and the GamCare website (www.gamcare.org) asking for regular gamblers, regular drug users and non-gambling, non-drug using individuals. “Regular” was defined as use of drugs or actively gambling at least once a week for the past 6 months. Nine non-gamblers/drug users, 10 regular illicit drug users and 15 regular gamblers were recruited, giving a total sample size of 34 participants. The mean age was 23.82 years (range = 18–49 years) and there were 15 females. One participant met DSM-IV criteria for drug abuse, 1 for drug dependence and 4 for pathological gambling (American

Psychiatric Association, 2000) diagnosed using the Mini International Neuropsychiatric Interview (Sheehan et al., 1997). One regular gambler and one drug user also met criteria for DSM-IV mild major depression and one drug user also had dysthymia. Ethical approval for this study was granted by Bolton Local Research Ethics Committee (U.K.) and the Ethics Committee from the University of Manchester, U.K.

2.2. Questionnaires

All questionnaires were presented in computerised versions.

2.2.1. Impulsivity venturesomeness empathy questionnaire (IVE)

The IVE is a 54-item questionnaire (Eysenck et al., 1985, 1990) consisting of three factors. Impulsivity (IVE-I) is the tendency to act without considering risks and consequences. Venturesomeness (IVE-V) is the tendency to consider the risks and consequences but engage in a risk act regardless of these (e.g. “I enjoy sky-diving”). Empathy measures an individual’s social cognition or ability to understand the emotional states of others, and was not used in this study. The range of possible scores for the IVE-I and IVE-V scales is 0–19 for each. A recent study investigating the hierarchical structure of self-reported impulsivity found that IVE-I and IVE-V items loaded onto separate dimensions; the latter largely being a homogenous construct while the former loaded onto lower level dimensions of impetuosity and being divertible (Kirby & Finch, 2010). Of interest both correlated significantly with a non-performance measure of delay discounting although at a low level of agreement ($r = 0.2$).

2.2.2. Quick test for IQ

The QT assessed IQ based on the ability to use complex language to describe a series of sets of pictures (Ammons & Ammons, 1962).

2.3. Experimental tasks

2.3.1. fMRI discounting tasks

2.3.1.1. Delay discounting task. The delay discounting task presented 56 binary choice trials (Fig. 1). Half of the trials were free choices with the remaining 28 trials being forced choices.

(a) Free choice trial

The rewards associated with alternative A (A) and alternative B (B) were £1 and £2 respectively. All rewards were hypothetical but participants were instructed immediately before scanning to behave as if the choices were real. In the delay discounting task, the delays attached to A (dA) were 2, 4, 6, 8 or 10 s. The delays for B (dB) were based upon a previous study using the tasks in healthy individuals (Hinvest & Anderson, 2009) with a maximum dB of 24 s. Half the values of dB were more difficult choices being close to group-averaged indifference points (e.g. dA 6 s vs. dB 12 s) calculated from the previous study and the other 14 were easy choices with values a long way from the group-averaged indifference points (e.g. dA 6 s vs. dB 20 s). As the fMRI task presented each choice only once we also performed analysis on behavioral discounting tasks outside of the scanner (see below).

(b) Forced choice trial

In order to eliminate any choice preference both alternatives gave exactly the same reward (£1 or £2) with the same delay and participants were instructed in half the trials to press the button for A and in the remaining 14, press the button for B. The delays (same for both alternatives) ranged from 2 to 15 s.

As real delays were employed the total task length was not of a fixed length but was limited to 12 min. Participants were not aware of the exact time limit of the task but were informed that the task would end after a randomly determined time period. All participants completed the task within this time period.

2.3.1.2. Probability discounting task. The probability discounting task had the same structure as the delay discounting task but all outcomes were probabilistic and involved no delays. There were 48 trials (Fig. 1) with half the trials containing free choices and half containing forced choices as in the delay discounting task. The probability of winning the reward (pA) attached to A was 1.0, 0.75, 0.5 or 0.25. The probability of winning on B was based upon a previous experiment in order to provide more difficult and easy choices. The forced choice trials were presented in a similar way to the delay discounting task so that each outcome had the exact same probability of occurrence with the same monetary reward. The probabilities (same for both alternatives) ranged from 1.0 to 0 (in 0.1 intervals).

For each alternative, the chance of winning was represented as a wheel of fortune divided into green and red segments such that the green segment represented the probability of winning the reward and red represented the probability of not winning (Rachlin, Raineri, & Cross, 1991). The timings of the task were the same as in the delay discounting task except that there was a jittered delay (2–4 s) between the choice and presentation of the choice outcome screen. The outcome consisted of the selected wheel presented in the centre of the screen with a static arrow with the location of its point pseudorandomly determined. A point located on a green segment also showed the amount of money won visible; one on a red segment showed no winnings.

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