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The value of novelty in schizophrenia

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ABSTRACT

Influential models of schizophrenia suggest that patients experience incoming stimuli as excessively novel and motivating, with important consequences for hallucinatory experience and delusional belief. However, whether schizophrenia patients exhibit excessive novelty value and whether this interferes with adaptive behaviour has not yet been formally tested. Here, we employed a three-armed bandit task to investigate this hypothesis. Schizophrenia patients and healthy controls were first familiarised with a group of images and then asked to repeatedly choose between familiar and unfamiliar images associated with different monetary reward probabilities. By fitting a reinforcement-learning model we were able to estimate the values attributed to familiar and unfamiliar images when first presented in the context of the decision-making task. In line with our hypothesis, we found increased preference for newly introduced images (irrespective of whether these were familiar or unfamiliar) in patients compared to healthy controls and this to correlate with severity of hallucinatory experience. In addition, we found a correlation between value assigned to novel images and task performance, suggesting that excessive novelty value may interfere with optimal learning in patients, putatively through the disruption of the mechanisms regulating exploration versus exploitation. Our results suggest excessive novelty value in patients, whereby even previously seen stimuli acquire higher value as the result of their exposure in a novel context – a form of ‘hyper novelty’ which may explain why patients are often attracted by familiar stimuli experienced as new.

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1. Introduction

As humans, we are often faced with the dilemma of choosing between a familiar and novel option; whether to order ‘the usual’ or try a new dish in a restaurant, book last year's holiday destination or go somewhere new are all examples where the values of the known and the unknown are weighted and compared with each other. The choice is not inconsequential as the two options hold different motivational value and satisfy different goals: exploring novel options permits the acquisition of new information in order to optimise behaviour in the long run, whereas pursuing options with known values facilitates the efficient exploitation of available information. It has been argued that humans have developed mechanisms aimed at increasing the value of novel stimuli as a way to promote exploration of unknown options (Kakade and Dayan, 2002). However, high novelty value and novelty-seeking behaviour are only appropriate if the balance between exploration and exploitation is kept at optimal levels (Pezzulo et al., 2013), as dysfunctions in this regulatory mechanism may lead to motivational

disturbance and maladaptive behaviour (Averbeck, 2015; Friston et al., 2015).

In schizophrenia, several considerations hint that there may be an important deficit in the balance between the value attributed to old and novel stimuli. Within a Bayesian inference framework, influential models of schizophrenia propose that patients give relatively excessive weight to incoming sensory evidence compared to prior beliefs, resulting in heightened sense of novelty and an on-going state of surprise (Adams et al., 2013; Fletcher and Frith, 2009). Other theories have also emphasised patients' alterations in novelty processing as central to the disorder, suggesting that key symptoms, such as delusions and hallucinations, may be consequent upon aberrant salience attribution associated with novelty processing. This is supported by observations of patients with psychosis perceiving routine stimuli as novel-like and excessively engaging, with a consequent elaboration of the importance of this sense of novelty into delusional belief and hallucinatory experience (Kapur, 2003; Kapur et al., 2005). Hence, such theories propose that patients may exhibit motivational dysfunctions as the result of aberrant novelty processing, but the nature of this aberrance remains unclear.

That there is an imbalance in the proper allocation of novelty value in schizophrenia is further supported by evidence pointing towards a

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link between novelty-seeking traits and several behaviours such as excessive drug (Kim et al., 2007) and alcohol consumption (Dervaux et al., 2010), impulsivity (Ouzir, 2013) and violent behaviour (Fresán et al., 2007). Novelty-seeking has also been associated with non-adherence to medication (Margetić et al., 2011) and increased hospital admissions (albeit only in males; Miralles et al., 2014). In line with models of motivational regulation, these findings suggest that excessive attraction towards novel stimuli may disrupt motivational regulation and thus interfere with optimal decision-making and behaviour in patients affected by schizophrenia.

However, whether patients exhibit higher novelty-seeking traits relative to healthy controls remains unclear, as effects in both directions have been reported (Ohi et al., 2012). It is important to clarify that the existing studies relied on self-report measures, which suffer from well-recognised limitations (Martinelli et al., 2013; Wilson and Dunn, 2004). In the context of novelty value investigations, the use of self-reports may be particularly misleading, as many of the questions used to assess novelty-seeking behaviour are not relevant to the life style of most patients. Thus, occasional observations of reduced novelty-seeking in patients may be merely reflecting the lack of their engagement in the activities used to assess this trait. It would be much more informative to have a direct on-line behavioural assessment in determining the presence of novelty-seeking alterations in the illness.

Additional support for the involvement of novelty processing in schizophrenia comes from evidence that dopamine, known to play a crucial role in the neurobiological substrate of schizophrenia, may crucially modulate novelty value in healthy individuals. In line with this, a recent study found a correlation between brain activity in the mid-brain and ventral striatum, and value attributed to novelty while engaging in a decision-making task, as well as between the same brain areas and novelty-seeking traits (Wittmann et al., 2008). Moreover, pharmacological manipulation studies observed a correlation between increase in dopamine levels and novelty detection in humans (Rangel-Gomez et al., 2013) as well as novelty-seeking in humans (Rigoli et al., 2016) and animals (Costa et al., 2014). Furthermore, genetic studies have emphasised the importance of D2 receptors in the regulation of exploration versus exploitation behaviour (Frank and Hutchison, 2009). In schizophrenia, evidence of dopamine unbalance playing a key role in the illness (Howes and Kapur, 2009) suggests that patients may experience excessive novelty value as a consequence of their dopaminergic dysregulation.

Despite evidence described above, novelty salience dysfunctions in schizophrenia have not yet been formally tested. In the present study, we studied novelty value in schizophrenia with an armed bandit task (Daw et al., 2006), which has been successfully employed for the investigation of novelty-seeking behaviour in healthy individuals (Wittmann et al., 2008) and those affected by Parkinson's disease (Djamshidian et al., 2011). We tested the hypotheses that: a) patients would exhibit enhanced novelty-seeking compared to healthy controls; b) altered novelty processing in patients would interfere with their decision-making leading to sub-optimal performance; and c) altered novelty value would be associated with severity of psychotic symptoms, namely hallucinations and delusions.

2. Materials and methods

2.1. Participants

On the basis of a previous study (Djamshidian et al., 2011) using the same task on a clinical population and reporting an effect size of $d = 0.91$, we estimated we needed at least 20 subjects per group to ensure a power of 0.80. We thus recruited 24 outpatients from community clinics, with a diagnosis of schizophrenia (based on assessment using the ICD-10 criteria; WHO, 1992), being treated with stable doses of atypical antipsychotic medication, and 24 controls, recruited through local advertisement, without a personal (screened with the MINI

International Neuropsychiatric Interview; Sheehan et al., 1998) or family history of mental illness (based on participants' reports regarding the presence of Axis I psychiatric conditions in first-degree relatives). Due to initial technical difficulties, data from 4 patients were lost, thus the overall sample included 20 patients and 24 controls. The study was approved by the London Chelsea Research Ethics Committee and all participants provided written informed consent before testing. Participants met the following inclusion criteria: 1) capacity to consent; 2) age between 18 and 60 years; 3) sufficient command of the English language to follow the experimental tasks and 4) having an IQ above 80. Participants were excluded if they had: 1) current drug or alcohol dependence; 2) brain disease or damage or if they 3) used psychotropic medication (except patients). Brain disease or damage was assessed by asking participants if they had ever experienced loss of consciousness for longer than 30 s, head injury resulting in loss of consciousness, had any neurological condition, or had ever been referred to a neurologist. All participants underwent IQ assessment through the vocabulary and matrix reasoning scales of the Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1992). The diagnosis of schizophrenia was confirmed by an experienced clinician and symptom severity was assessed using the Positive and Negative Syndrome Scale (Kay et al., 1987).

2.2. Three-armed bandit task

Before the start of the task, subjects underwent a familiarisation phase in which were shown 18 images, eight times each, and asked to judge via button press whether the image depicted a building or a natural landscape. This was done to consolidate encoding by forcing participants to process images semantically. Subsequently, all participants were asked to verbally describe the images one at the time in order to further aid their consolidation in memory.

After the familiarisation phase, participants performed the three-armed bandit task (programmed with the Cogent 2000 in Matlab and administered to participants on a laptop computer). The task comprised of 180 trials lasting approximately 30 min. During the study, each trial consisted of three black and white post-cards (Fig. 1) presented on screen, each associated to a different probability of winning money, varying on three levels (i.e., 0%, 40% and 80%), which remained constant throughout the course of the task. Participants were instructed to select the most rewarded image as many times as possible in order to maximise their earnings, which were paid to participants at the end of the task. Each positive outcome was 0.10p and each negative outcome was 0p. Both visual (image framed in green for gains and in red for no-gains) and auditory feedback (tones at 5 kHz for gains and 2.5 kHz for no-gains) was provided to reinforce feedback learning. Location of pictures was randomised across trials in order to prevent habituation.

During the task, images on the screen were replaced with novel ones on approximately 20% of trials, (i.e., every five trials on average). These newly introduced images could be of two kinds: either unfamiliar or familiar. The unfamiliar images were images that subjects had never seen before, whereas familiar images were those that had been shown to participants during the familiarisation phase preceding the three-armed bandit task. Thus, we will name "familiar" the images shown to participants during the familiarisation phase, "unfamiliar" those never seen before, and "novel" when they are presented for the first time in the bandit task (irrespective of whether these were seen during the familiarisation phase or not). Participants could find out images' reward probabilities only by repeatedly sampling them, thus facing the classic exploration versus exploitation dilemma (Wittmann et al., 2008). Pay-off probabilities associated to the images were equal across the two sets, so that familiar and unfamiliar images did not differ per average value.

To ensure that all participants properly encoded images during the familiarisation phase we performed the following memory checks. First, the experimenter asked participants to identify the unfamiliar image on the first trial of the bandit task (one unfamiliar image was

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