Schizophrenia Research: Cognition 5 (2016) 41–46

Contents lists available at ScienceDirect

Schizophrenia Research: Cognition

journal homepage: http://www.schizrescognition.com/

Probability and magnitude evaluation in schizophrenia

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ARTICLE INFO

Article history:
Received 21 June 2016
Accepted 27 June 2016
Available online 20 July 2016

ABSTRACT

Alterations in reinforcement learning and decision making in schizophrenia have been linked with orbitofrontal cortex (OFC) dysfunction, a region critical for weighing reward magnitude in the calculation of expected value (EV). However, much of this work has used complex tasks that require combined learning and EV calculation. Here we used a simple "Roulette" task that examined the calculation of EV directly through a combination of text and/or pictorial representation of reward probability and magnitude. Forty-four people with schizophrenia and 30 controls were recruited. Patients were less sensitive to adjustments in a parameter combining probability and magnitude into one EV construct. Breaking down the construct into independent contributions of probability and magnitude, we found that negative symptoms were associated with magnitude sensitivity. This is consistent with the hypothesized role of OFC in actively representing magnitude and the notion that negative symptoms may involve a failure to appropriately estimate and use future reward magnitude to guide decision making.

1. Introduction

Patients with schizophrenia exhibit deficits on a range of decision making and reinforcement learning tasks which often correlate with negative symptom severity (Gold et al., 2008, 2012; Strauss et al., 2011a). However many of the studied tasks involve multiple learning and decision processes so that the specific processes implicated in negative symptoms remain uncertain. For example, the widely used Iowa gambling task (IGT), requires the calculation of expected value (EV: reward magnitude multiplied by reward probability) to guide decision making based on learning from feedback. In general, patients perform worse than controls on the IGT (Sevy et al., 2007) in a manner that suggests less influence of EV on deck selection compared to controls (Brown et al., 2015). However, performance on the IGT is heavily dependent on risk attitudes, learning reward probabilities and magnitudes through experience, and reward/punishment sensitivity (Schonberg et al., 2011). Thus, it is not clear if the patient deficit is due to difficulties in learning from feedback or actual alterations in the way information is weighed in guiding choices.

Several studies (Brown et al., 2013; Gold et al., 2013; Heerey and Gold, 2007; Trémeau et al., 2008) have shown alterations in how patients represent the value of alternative stimuli or potential responses using tasks that do not involve feedback learning. For example, Strauss et al. (2011b) showed reduced transitivity in patients' preference judgements of picture stimuli. That is, if one prefers A > B and B > C the preference for A over C should be expected. However, patients were less likely than controls to show such order preferences, suggesting less precise value representations. The same pattern is seen in patients with damage to ventromedial prefrontal cortex (vmPFC; Fellows and Farah, 2007), an area consistently related to EV (see Chase et al., 2015). This leads to the possibility that patients show less optimal learning from outcomes because they fail to adequately represent the EV of different alternatives, consistent with vmPFC/OFC deficits seen in schizophrenia (Barch and Dowd, 2010; Davatzikos et al., 2005). We have shown similar difficulties in the representation of EV in high negative symptom patients during a reinforcement learning task (Gold et al., 2012).

Using a simpler task in which participants were presented directly with the information necessary to calculate EV, we showed that patients were resistant to the 'Framing effect' (Tversky and Kahneman,

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http://dx.doi.org/10.1016/j.scog.2016.06.003

1981). That is, patients were resistant to the normatively increased likelihood of accepting a gamble despite certain loss (Brown et al., 2013), suggesting that patients had reduced loss-aversion due to poorer tracking of EV (Brown et al., 2013). Interestingly, a number of high negative symptom patients were excluded because they failed the 'catch trials' (where there was an obvious preferable choice if participants could compute EV properly), suggesting that these participants were extremely poor EV calculators.

Recently, Sharp et al. (2012) reported on results from a task that assesses EV calculation where participants were able to calculate directly the EV of an option without needing to maintain a representation of stimulus value from a stored history of reinforcements. In controls, performance was biased towards the prospect with a comparatively higher probability of reward, despite equivalent EV for high reward magnitude options, consistent with Prospect theory (Kahneman and Tversky, 1979). This was formalized through the addition of two parameters to the initial model that adjust for known subjective evaluations of probability and magnitude: a 'Prospect function', that modifies rewards magnitude, and a Prelec function that modifies reward probability. The inclusion of these two modifications resulted in a reduction of the distance between subjects' choices and that of a theoretical rational decision-maker. This task offers a simplified approach to explore weighting of information for decision making in schizophrenia, without the need for learning from feedback.

Using this design, we anticipated a shallower relationship between EV and behavior in the patient group due to poorer integration of magnitude information when calculating EV, consistent with a role for OFC/vmPFC in representing relative reward magnitudes and OFC/vmPFC deficits observed in schizophrenia. We further anticipate that this pattern of poor magnitude integration will correlate with negative symptom severity.

2. Methods

2.1. Participants

Forty-eight participants with a diagnosis of schizophrenia or schizoaffective disorder and 34 controls were recruited. Sample sizes and demographic characteristics are presented in the Results and Table 1. Patients were clinically and pharmacologically stable (>4 weeks) outpatients from the Maryland Psychiatric Research Center or nearby clinics. Diagnosis was determined by the Structured Clinical Interview for DSM–IV Axis I Disorders (SCID) (First et al., 1997; Pfohl et al., 1997), past medical records, and clinician reports. Controls were screened with the SCID and free from a history of psychosis, current Axis I disorder, and family history of psychosis in first-degree relatives. Participants were excluded based on a history of drug dependence, neurological disorder, or cognitively impairing medical disorder. Participants were compensated $15 per hour. Written and informed consent was obtained from every participant. Approval was obtained from the University of Maryland IRB.

2.2. Neuropsychological and symptom measurements

Participants completed a battery of neuropsychological and symptom assessments including the Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999), Wechsler Test of Adult Reading (WTAR; Wechsler, 2001), Brief Psychiatric Rating Scale (BPRS; Overall and Gorham, 1962), Brief Negative Symptom Scale (BNSS; Kirkpatrick et al., 2011), the Scale for the Assessment of Negative Symptoms (SANS; Andreasen, 1984), and the Clinical Assessment Interview for Negative Symptoms (CAINS; Forbes et al., 2010).

2.3. Task

The task was programmed in E-Prime and administered via computer. The task narrative is presented in Supplementary material along with an example test stimulus (Supplementary Fig. 1). Participants were presented with two prospects that differed in EV and responded by clicking on their chosen prospect. Prospects were parametrically manipulated by adjusting the probability of winning and the magnitude of reward to cover a range of EVs. Participants were instructed to select the prospect that they thought would maximize return. Participants were told at the beginning of the experiment that the probabilities and magnitudes were veridical and that outcomes on one trial did not influence outcomes on later trials.

Magnitude information was presented pictorially (casino chips) and in text ($0.02 per unit), while probability information was presented pictorially (chance wheel with 10 segments, probability of winning indicated via filled in sections). There were 10 blocks, with 17 trials per block (14 test stimuli; 3 control stimuli). Side of presentation was counterbalanced within prospect pairs and trial order was randomized within blocks. Participants were told that they would receive the money that they won, translated as $0.02 per magnitude unit.

Pairs of stimuli comprising fourteen EV-ratios were presented to the participant 10 times each. Reward probabilities ranged from 0.6 to 0.8 (Prospect 1) and 0.2 to 0.4 (Prospect 2). Reward magnitudes ranged from 1 to 4 (Prospect 1) and 2 to 5 (Prospect 2). This gave EV-ratios that ranged from −0.91 to 0.91 (see Table 1 in (Sharp et al., 2012) for the full set of combinations used). Three catch trials were included, in each of the three pairs: 1) one Prospect had greater magnitude and probability, 2) one had the same magnitude but different probability, and 3) one had the same probability but different magnitude. In these catch trials, the most optimal Prospect was obvious. These trials were used to assess if subjects were approaching the task rationally.

Table 1
Demographic, neuropsychological and symptom variables.

	HC (N = 30)		SZ (N = 44)			
	Mean	SD	Mean	SD	$t/\chi 2$	p
Age (y)	40.8	10.4	39.1	10.6	0.7	0.47
Gender (M | F)	22 | 12		34 | 14		0.1	0.73
Haloperidol equivalent dose			9.9	8.0		
Number of APs (1 | 2+)			39 | 5			
Education (yrs)	15.2	1.9	12.7	2.1	4.9	<0.0001
Maternal education (y)	13.8	2.6	14.0	2.9	−0.3	0.74
Paternal education (y)	14.3	3.5	15.0	3.2	−1.0	0.38
Cognitive ability						
WMS forward	9.0	1.8	7.6	2.1	3.4	0.001
WMS back	8.3	1.8	6.8	2.1	3.5	0.001
WASI verbal sum IQ	113.6	10.6	96.5	14.8	5.5	<0.0001
WASI performance sum IQ	112.4	12.6	99.7	14.1	3.8	0.0003
WASI combined IQ	118.2	10.6	100.3	14.3	6.5	<0.0001
WTAR	112.0	9.7	97.6	17.4	4.8	<0.0001
Symptom ratings						
SANS asociality anhedonia			8.0	4.2		
SANS role functioning			7.5	4.1		
SANS affective blunting			9.2	6.4		
SANS alogia			1.3	1.8		
SANS total			25.9	13.6		
BPRS affect			5.5	2.7		
BPRS negative symptoms			6.2	2.6		
BPRS reality distortion			7.2	3.0		
BPRS disorganization			3.4	1.0		
BPRS total			32.3	6.3		
BNSS motivation and pleasure			11.7	6.9		
BNSS emotional expressivity			10.5	8.9		
BNSS total			21.6	14.2		