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Reinforcement learning deficits in people with schizophrenia persist after extended trials

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ABSTRACT

Previous research suggests that people with schizophrenia have difficulty learning from positive feedback and when learning needs to occur rapidly. However, they seem to have relatively intact learning from negative feedback when learning occurs gradually. Participants are typically given a limited amount of acquisition trials to learn the reward contingencies and then tested about what they learned. The current study examined whether participants with schizophrenia continue to display these deficits when given extra time to learn the contingences. Participants with schizophrenia and matched healthy controls completed the Probabilistic Selection Task, which measures positive and negative feedback learning separately. Participants with schizophrenia showed a deficit in learning from both positive feedback and negative feedback. These reward learning deficits persisted even if people with schizophrenia are given extra time (up to 10 blocks of 60 trials) to learn the reward contingencies. These results suggest that the observed deficits cannot be attributed solely to slower learning and instead reflect a specific deficit in reinforcement learning.

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1. Introduction

One common deficit associated with schizophrenia is reinforcement learning (Waltz and Gold, 2007; Ziauddeen and Murray, 2010; Dowd and Barch, 2012). This deficit is thought to be associated with dopamine dysregulation (Guillin et al., 2007), and a long line of research suggests that dopamine dysregulation plays an important role in schizophrenia and psychosis (Seeman, 1987; Davis et al., 1991; Laruelle and Abi-Dargham, 1999; Abi-Dargham et al., 2000; Howes and Kapur, 2009; Heinz and Schlagenhauf, 2010). Understanding deficits in reward processing deficit may provide insight into important motivational deficits that may be a future target of treatment in schizophrenia-spectrum disorders (Gold et al., 2008; Ziauddeen and Murray, 2010).

In previous work, one common strategy for assessing reinforcement learning deficits is to give participants a relatively limited number of "acquisition" trials in which participants learn the reinforcement contingencies prior to a "testing" phase in which participants choose among the stimuli (Frank et al., 2004). Several previous studies using this paradigm have shown that people with schizophrenia have difficulty learning from positive feedback, but tend to have intact learning from negative feedback (Waltz et al., 2007; Strauss et al., 2011; Waltz et al., 2011). At the same time, some research has found that people with schizophrenia tend to learn reward contingencies more slowly in rapid learning situations, but to have relatively intact gradual or long-term learning (Gold et al., 2008; Morris et al., 2008; Weiler et al., 2009).

Rapid learning is thought to be mediated by the prefrontal cortex (PFC), while gradual learning is thought to be mediated by the basal ganglia (BG; Frank and Claus, 2006). Previous work has found that patients with schizophrenia seem to have relatively normal basal ganglia-mediated gradual learning, but impairments in rapid trial-to-trial learning mediated by the PFC (Gold et al., 2012). If people with schizophrenia have intact BG-mediated gradual learning, then it is possible that they would "catch up" to healthy controls if given enough trials to learn the reward contingencies. If this is the case, then participants with schizophrenia should show similar learning on both positive feedback and negative feedback to comparison participants if they are given more trials during the acquisition phase to gradually learn the reward contingencies. However, if participants are unable to learn the reward contingencies after extended trials, then we can conclude that the deficit is not simply related to slower learning, but is a deficit related to reward learning specifically.

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The primary goal of the current research was to examine whether participants with schizophrenia would continue to show a deficit in positive feedback learning even if given enough trials to ensure gradual learning of the reward contingencies. In previous research using the same task as the current research, participants are usually given up to 180 trials (three blocks of 60 trials) to acquire reward contingencies. In the current research, participants were given up to 600 trials (10 blocks of 60 trials) to learn reward contingencies before progressing to the testing phase of the study. In addition, to test the pace at which participants learned reward contingencies, we conducted a survival analysis to see if healthy controls learned the reward contingencies more quickly than did participants with schizophrenia.

2. Methods

2.1. Participants

Participants were 54 people with a diagnosis of schizophrenia and 32 non-psychiatric controls. Participants in the schizophrenia group all met criteria for either schizophrenia or schizoaffective disorder and were recruited from a state mental hospital with a largely forensic population. They were 49.1% White, 36.4% African-American, and 10% mixed ethnicities. 87.3% of these participants were male. Participants in the comparison group were recruited via online advertisements on Craigslist and an email sent to all university employees. These comparison participants had no history of Axis I mental disorders, and were 93.9% White, 3% African-American, and 3% other. 90.9% of the control group was male. Participants were matched on sex, age, and parental education. Demographic characteristics for both groups of participants are presented in Table 1. All participants received $30 for participating in the study.

2.2. Materials

2.2.1. Reinforcement learning

The Probabilistic Selection Task (PSS; Frank et al., 2004) was used to measure reinforcement learning. In particular, the PSS assesses participants' ability to learn from positive feedback as well as from negative feedback. Following previous research (Waltz et al., 2011), the PSS was modified for use with participants with schizophrenia. Instead of using unfamiliar Hiragana characters as in the original paper (Frank et al., 2004), more familiar pictures were used (i.e., an egg, bus, wrench, clock, leaf, and cow). Familiar characters were used due to reports in the literature that patients had difficulty learning reward contingencies with unfamiliar symbols (Waltz et al., 2007). The PSS contains two phases: the acquisition and testing phase. In the acquisition phase, participants choose the correct stimulus from stimulus pairs, which are reinforced probabilistically. In the AB pair, A is rewarded 80% of the time, while B is rewarded only 20% of the time. In the CD pair, C is rewarded 70% of the time while D is rewarded only 30% of the time, and in the EF pair, E is rewarded 60% of the time while F is rewarded 40% of the time. Each block of the acquisition phase consists of 60 trials. Participants continue the acquisition phase of the task until they learn to reliably choose A over B (at least 70% of the time), C over D (at least 60% of the time), and E over F (at least 50% of the time) before moving on to the testing phase. Participants were instructed in the task following Frank et al. (2004). No practice trials were done prior to the first acquisition block. In the current research, participants completed the acquisition block up to ten times.

In the testing phase, participants are presented with novel combinations of stimuli (e.g., AD, AF, BC, BF) and asked to choose a stimulus in the absence of feedback. The dependent variables are the percentage of time participants choose A (i.e., positive feedback learning) and the percentage of times participants avoid B by choosing the stimulus paired with B (i.e., negative feedback learning) in the testing phase.

Table 1
Demographic and clinical information.

Variable	Schizophrenia group ($n=54$)	Control group ($n=32$)
Sex (% male)	87.3%	90.9%
Ethnicity (% Caucasian)	49.1%	93.9%
Mean (S.D.) age (years)	41.46 (11.55)	43.00 (9.63)
Mean (S.D.) education (years)	12.61 (7.83)	16.11 (1.76)
Mean (S.D.) parental education	11.82 (1.75)	12.70 (2.07)
Mean (S.D.) BPRS (total)	37.34 (9.13)	
Thought disturbance	13.94 (4.93)	
Negative symptoms	8.53 (2.94)	
Depression/anxiety	9.94 (3.81)	
Disorganization	5.44 (1.81)	
Negative symptoms		
Social anhedonia	15.39 (6.43)	10.36 (7.69)
Physical anhedonia	16.37 (7.21)	11.60 (6.91)

2.2.2. Diagnosis and symptom ratings

Diagnoses were made with the Structured Clinical Interview for the DSM-IV (SCID; First et al., 1998). The SCID has high test–retest and inter-rater reliability (Zanarini et al., 2000; Zanarini and Frankenburg, 2001). Symptoms were rated with the Brief Psychiatric Rating Scale (Overall and Gorham, 1962), and scores are presented in Table 1. Following McMahon et al. (2002), we calculated factor scores for Reality Distortion, Negative Symptoms, Anxiety/Depression, and Disorganization. The intraclass correlation coefficient for BPRS total scores was 0.87.

In addition to BPRS ratings, negative symptoms were measured with the Social Anhedonia Scale (RSAS; Eckbald et al., 1982) and the Physical Anhedonia Scale (PhysAnh; Chapman et al., 1976). The RSAS is a 40-item true-false questionnaire designed to measure lack of relationships and lack of pleasure from relationships. The PhysAnh is a 61-item true/false questionnaire designed to measure a lack of pleasure from or interest in physical sensations. In the current research, the RSAS and PhysAnh both had internal reliabilities of alpha $=0.83$.

2.2.3. Mental status

Participants completed the Mini-Mental Status Exam (MMSE). The MMSE is one of the most commonly used screening measures for cognitive impairment and dementia (Hodges, 1994; Manning et al., 2007). MMSE scores have been found to have high inter-rater reliability (Tombaugh and McIntyre, 1992), internal consistency, and well-established normative data (Tombaugh et al., 1996). In the current research, the MMSE was used to screen for and exclude participants with dementia.

2.3. Procedure

First, participants read and signed the informed consent form. Then, they were given the Mini Mental Status Exam. All participants exceeded the cutoff of 22 on the Mini Mental Status Exam, which suggests that all participants did not have dementia. Then participants completed the Probabilistic Selection Task. Next, the Structured Clinical Interview for the DSM-IV was conducted.

3. Results

3.1. Group comparisons for reward learning

First, we examined the pace at which participants learned the reward contingencies during the acquisition phase. As can be seen in Tables 1, 40.4% of schizophrenia participants and 34.4% of comparison participants did not meet learning criteria (i.e., choose A 70% of the time, C 60% of the time, and E 50% of the time) even after up to 10 blocks of trials. To test whether participants in the comparison group met criteria more quickly than did schizophrenia participants, we conducted a survival analysis with meeting criteria as the status category. As can be seen in Fig. 1, there was a non-statistically significant trend for comparison participants to meet criteria more quickly than did participants with schizophrenia (Wald Statistic$=2.70$, $\beta=0.17$, OR$=1.18$, CI 0.97–1.45). The trend is evident in that the confidence interval of the odds ratio is 0.97–1.45, which nearly does not include 1.00. However, there was not a significant difference between groups in the number of participants who met criteria by the end of 10 blocks ($\chi^2(1)=0.48$, $p=0.49$). Thus, by the end of 10 blocks, there was no significant difference in the percentage of people with schizophrenia and comparison participants who met learning criteria. Participants who met criteria did not differ from participants who did not meet criteria in MMSE scores ($M=27.08$, S.D.$=2.84$ vs. $M=27.23$, S.D.$=2.11$. $t(80)=0.25$, $p=0.80$), and MMSE scores were not correlated with positive feedback ($r=0.08$, $p=0.48$) or negative feedback learning ($r=0.08$, $p=0.48$).

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