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Altered Experiential, But Not Hypothetical, Delay Discounting in Schizophrenia

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Abstract

Delay discounting (DD) is a future-oriented decision making process that refers to whether one is willing to forego a smaller, sooner reward for the sake of a larger, later reward. It can be assessed using hypothetical tasks, which involve choices between hypothetical rewards of varying amounts over delay periods of days to years, or experiential tasks, which involve receiving actual rewards in real time over delay periods of seconds to minutes. Initial studies in schizophrenia have only used hypothetical tasks and have been mixed in finding either elevated or normal levels of DD. 131 outpatients with schizophrenia and 70 healthy controls completed hypothetical and experiential DD tasks involving monetary rewards, and the schizophrenia group was re-tested after four weeks. Although both groups showed qualitatively similar hyperbolic discounting functions on both tasks, they showed a quantitative DD difference. The schizophrenia showed higher DD than controls on the experiential task but normal DD on the hypothetical task. This pattern was not attributable to a range of potential confounds, including smoking status, substance use disorder status, or neurocognition. It was also not attributable to differences in the test-retest reliability, which was good for both tasks. The schizophrenia group's robust pattern of altered experiential but normal hypothetical task performance points to key factors that may contribute to impaired DD in this disorder. These may include increased valuation of small (but not large) monetary rewards, or a hyper-sensitivity to costs associated with waiting inactively for those rewards.

Keywords

Cost-benefit decision making; prospection; psychosis; reward valuation; reliability

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Introduction

Adaptive reward processing is critical for successful goal attainment and functioning across most domains of life. Emerging research has begun to investigate different aspects of reward processing that may be impaired in schizophrenia and contribute to the diminished motivation and goal-directed behavior that often accompany this disorder (Reddy, Horan, & Green, 2016). In addition to studies of reward anticipation and learning (Barch, Pagliaccio, & Luking, 2016; Strauss, Waltz, & Gold, 2014), investigators have examined reward-related decision making processes, such as effort based decision making (M.F. Green & Horan, 2015). Another decision-making process that has received increased attention is "delay discounting" (DD), which refers to whether one is willing to forego a smaller, sooner reward for the sake of a larger, later reward.

Delay discounting is well suited for cross-species translational research, as a number of animal models of DD have been developed (W.K. Bickel, Johnson, Koffarnus, MacKillop, & Murphy, 2014; M. W. Johnson, 2012; Vanderveldt, Oliveira, & Green, 2016). Neurobiological studies in animals demonstrate central roles for the nucleus accumbens core and the orbitofrontal cortex (Dalley, Mar, Economidou, & Robbins, 2008; Weafer, Mitchell, & de Wit, 2014) in DD. In line with these findings, human fMRI studies of DD implicate a limbic circuit (including the ventral striatum, ventromedial prefrontal cortex, and posterior cingulate cortex) showing activity during selection of smaller sooner rewards, prefrontal areas associated with cognitive control (principally dorsolateral prefrontal cortex) showing activity during selection of larger but later rewards, and relative activity across these regions associated with behavioral preference (W. K. Bickel, Pitcock, Yi, & Angtuaco, 2009; McClure, Ericson, Laibson, Loewenstein, & Cohen, 2007; McClure, Laibson, Loewenstein, & Cohen, 2004).

The vast majority of human DD studies use conventional decision making paradigms in which subjects make a series forced choices between smaller, sooner (e.g., $5 today) or a larger, later ($1000 in six months) monetary rewards. In these paradigms, participants either receive no actual rewards, referred to as "hypothetical delay discounting tasks", or are paid out for only one or a few randomly selected trials, referred to as "potentially real reward delay discounting tasks" (Johnson, 2012), but receive no actual rewards or are paid out for only one or a few randomly selected trials. Numerous studies show that, all things being equal, the more a reward is delayed the less subjective value it has. People typically display a monotonically decreasing function such that reward value progressively diminishes as the delay to a reward grows longer. There are, however, substantial individual differences in the degree to which reward values are discounted as delays grow longer. For example, individuals with relatively greater discounting show a steeper reward/delay curve, such that smaller/sooner rewards are more readily chosen than larger/later rewards. Such individuals are more susceptible to proximal rewards and have been described as "temporally myopic" or "impulsive" (Hamilton et al., 2015; Kirby, Petry, & Bickel, 1999; Sellitto, Ciaramelli, & di Pellegrino, 2010). Consistent with this description, steeper discounting curves are associated with impulse control difficulties, including nicotine use, substance use disorders, and unhealthy behaviors (MacKillop et al., 2011; Reynolds, 2006b).

In contrast to conventional paradigms, a more recent development in human research is the use of experiential DD paradigms (M. W. Johnson, 2012; Reynolds & Schiffbauer, 2004) in which subjects make a series of choices between smaller, sooner vs. later, larger monetary rewards and actually receive these rewards in real-time on a trial-by-trial basis. This format much more closely parallels DD tasks used in animal research (Jimura, Chushak, & Braver, 2013; P. S. Johnson, Herrmann, & Johnson, 2015). Like hypothetical tasks, experiential tasks show good sensitivity in differentiating between users and non-users of nicotine and other substances (M. W. Johnson, 2012; Reynolds, 2006a). Further, they may be more sensitive to treatment-related changes than hypothetical tasks (e.g., (Krishnan-Sarin et al., 2007; Reynolds, Richards, & de Wit, 2006)), making them potentially attractive paradigms for endpoints in clinical trials. Despite the fact that both hypothetical and experiential tasks assess DD, they often show only small inter-correlations (M. W. Johnson, 2012; Melanko, Leraas, Collins, Fields, & Reynolds, 2009).

The handful of DD studies in schizophrenia has only used hypothetical tasks. Findings have been mixed with several reporting greater DD (i.e., steeper reward/delay curves) in schizophrenia than controls (Ahn et al., 2011; Heerey, Matveeva, & Gold, 2011; Heerey, Robinson, McMahon, & Gold, 2007b; Weller et al., 2014), but others reporting normal DD (MacKillop & Tidey, 2011; Wing, Moss, Rabin, & George, 2012). Findings regarding associations between DD and certain clinical symptoms and neurocognition have also been mixed. Although it has been proposed that negative symptoms may partly reflect DD disturbances (Strauss et al., 2014), support has been inconsistent (Ahn et al., 2011; Heerey et al., 2011; Heerey, Robinson, McMahon, & Gold, 2007a; Weller et al., 2014; Wing et al., 2012). Similarly inconsistent findings have been reported for associations with neurocognition (Ahn et al., 2011; Heerey et al., 2011; Heerey et al., 2007a; MacKillop & Tidey, 2011; Weller et al., 2014). On the other hand, studies consistently indicate that DD is not significantly related to positive or mood-related symptoms or to antipsychotic medications. Overall, it is difficult to integrate findings across studies and most of the studies have been underpowered (5/6 studies included </= 42 participants with schizophrenia). Further, all studies have been cross-sectional, raising concerns that inconsistencies may reflect problems with the reliability of the paradigms used in these studies.

The current study evaluated DD using a hypothetical task and, for the first time, an experiential task, in a relatively large sample of stabilized outpatients with schizophrenia. We had four primary goals. First, to address concerns about the validity of DD data in schizophrenia (Weller et al., 2014), we examined the orderliness (i.e., whether subjects generate data showing the value of delayed rewards to increase/decrease across delays in a systematic fashion) of the DD data. In addition, we selected paradigms that enabled us to map the shape of the discounting curves to determine if individuals with schizophrenia show the typical hyperbolic shape (L. Green, Fristoe, & Myerson, 1994). Second, we compared discount rates between the schizophrenia and control groups. Although prior studies using hypothetical tasks are mixed and did not support strong directional hypotheses, they led us to predict that the schizophrenia group would show higher DD rates (i.e., steeper reward/delay curves) than controls on both tasks. Third, we evaluated whether DD was related to clinical symptoms and neurocognition. We were particularly interested in whether greater

discounting would relate to higher negative symptoms. Further, we determined whether the use of nicotine and other substances was associated with discounting rates in light of some evidence for steeper discounting rates among individuals with schizophrenia who are smokers (MacKillop & Tidey, 2011; Wing et al., 2012). Fourth, in the schizophrenia group, we evaluated the one-month test-retest stability of the two tasks.

Method

Participants

The sample included 131 individuals with schizophrenia and 70 demographically-matched healthy controls. Individuals with schizophrenia were recruited from outpatient clinics at University of California, Los Angeles (UCLA), the Veterans Affairs Greater Los Angeles Healthcare System (VAGLAHS), and from local clinics and board and care facilities. Selection criteria for included (1) Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition (DSM-IV) diagnosis of schizophrenia determined with the Structured Clinical Interview for DSM-IV (SCID-I/P)(First, Spitzer, Gibbon, & Williams, 1997) (2) age 18–60 years, (3) no clinically significant neurological disease, (4) no history of serious head injury, (5) no evidence of current alcohol, cannabis or other substance dependence disorder (in the past 6 months) or current substance abuse disorder (in past month); lifetime histories of these disorders were acceptable, and nicotine-related disorders were not formally assessed, (6) no history of mental retardation or developmental disability, and (7) clinically stable (i.e., no inpatient hospitalizations for 3 months prior to enrollment, no changes in antipsychotic medication type in the 4 weeks prior to enrollment). Diagnostic assessments were conducted by interviewers trained according to established procedures (Ventura, LIberman, Green, & Shaner, 1998). Eighty-five percent of the participants with schizophrenia were taking a second-generation antipsychotic, 8% a first-generation antipsychotic, 3% were taking both, and 4% were not taking an antipsychotic. The mean chlorpromazine equivalent units (Andreasen, Pressler, Nopoulos, Miller, & Ho, 2010) was 375.95 (SD = 29.57).

Control participants were recruited through advertisements posted on websites. Selection criteria for healthy controls included (1) no psychiatric history involving schizophrenia spectrum disorder (including avoidant, paranoid, schizotypal, or schizoid personality disorders), or other psychotic or recurrent mood axis I disorder according to the SCID-I and SCID-II, (2) no family history of a psychotic disorder among first-degree relatives based on participant report, and (3) no evidence of current or lifetime history of alcohol, cannabis, or other substance dependence disorder, and not evidence of current (in the past month) substance abuse disorder (history of abuse disorder was permitted); nicotine-related disorders were not formally assessed. Criteria concerning age, neurological disease, and head trauma were the same as listed above for the schizophrenia group.

Procedures

Written informed consent was obtained prior to participation in accordance with approval from the local Institutional Review Board. The DD task data was collected as part of a larger grant-funded project on reward processing and negative symptoms in schizophrenia (Horan

et al., 2015; Reddy, Waltz, Green, Wynn, & Horan, 2016) but has not been published elsewhere. An aim of the project was to examine associations between reward processing measures and negative symptoms among individuals with schizophrenia, and a larger clinical than healthy comparison sample was included to evaluate these within-group relationships. The hypothetical DD task was administered earlier in the assessment battery than the hypothetical DD task. The schizophrenia group was administered both DD tasks twice (baseline, 4-week retest); controls only received the tasks at baseline. Both groups completed a neurocognitive battery at baseline.

Hypothetical discounting

$1,000 Delay-Discounting Task (M. W. Johnson & Bickel, 2002). Participants made a series of choices between receiving a $1,000 delayed hypothetical reward and an adjusting smaller immediate reward. The magnitude of the smaller immediate option was adjusted across trials according to a previously described algorithm (Richards, Zhang, Mitchell, & de Wit, 1999) until an indifference point was determined. Once an indifference point was determined, the larger later option was delayed further and the adjustment procedure was repeated with that new delay. Seven delays were assessed: 1 day, 1 week, 1 month, 6 months, 1 year, 5 years, and 25 years. Indifference points were expressed as a proportion of the larger later reward (possible range: 0–1). Unlike the monetary choice questionnaire (Kirby et al., 1999) used in several prior studies of schizophrenia, the present task determined an indifference point for each delay (rather than determining rate based on several choices at various delays and the assumption of a presumed hyperbolic shape), which enabled us to assess the orderliness of indifference points across delays and the shape of the discounting function.

Experiential discounting

The Quick Discounting Operant Task (QDOT; (Johnson, 2012) (programmed in ZBasic) used a coin dispenser for money reward delivery. A visual depiction of the task is shown in Supplemental Figure 1. Before beginning the task, participants were instructed to sit at the desk with eyes open during any waiting periods in the task, and were forbidden from engaging in other behaviors such as reading. The task consisted of 20 discrete choices between a smaller immediate reward presented in a box on the left side of the screen (e.g., “get 40 cents right now”) and an 80¢ delay reward presented in a box on the right side of the screen (e.g., “wait 5 seconds to get 80 cents”). A response button that could register a mouse click was underneath each of the two boxes. At the top center of the screen was a box displaying total earnings on the task. On any trial, if the smaller sooner reward was selected with a single mouse click, the response options disappeared and a button appeared that stated “Click here to bank your amount.” Upon a single mouse click on this button, that amount was dispensed from the coin dispenser, and the total earnings box was updated. If the delayed 80¢ was selected, the response options disappeared and a number in the middle of screen counted down the number of seconds to wait (i.e., counter decreased by 1 every second). When the delay elapsed, a button appeared that required the participant to click to “bank” the 80 cents, at which point the coins (e.g., quarters, dimes, nickels) were delivered and the total earnings were updated. When money was delivered, participants removed the coins from the dispensing tray and dropped them into a glass jar.

There were 5 blocks of 4 trials each, with each block associated with a different delay for the 80 cent reward. The delays were 5, 10, 20, 40, and 80 s, and followed an increasing order across blocks. On the first trial of each block, the immediate reward size was 40¢ (i.e., 50% of 80¢). The smaller reward was then adjusted within the block using a "decreasing adjustment" algorithm, which has been used in previous human studies involving hypothetical rewards (Du, Green, & Myerson, 2002; Kowal, Yi, Erisman, & Bickel, 2007). Specifically, the smaller sooner reward was adjusted by 20, 10, and 5¢ on Trials 2, 3, and 4 of the block, respectively, in the direction that would move choice toward indifference (e.g., the smaller reward on the second trial of the block would be either 20¢ if the immediate 40¢ had been selected on the first trial, or 60¢ if the delayed 80¢ had been selected). The indifference point was defined as the value that would have been presented on a 5th trial (although there was not a 5th trial) had the algorithm continued (i.e., an adjustment of 2.5¢). Indifference points therefore varied by increments of 2.5¢, and were divided by 80¢ to be expressed as the proportion of the larger reinforcer. Indifference points were expressed as a proportion of the larger later reward (possible range: 0–1).

A waiting period was imposed after the final trial to prevent participants from choosing the smaller immediate reward to end the task or session sooner (which potentially confounds monetary reinforcement with the reinforcing or punishing qualities of the experimental context). Participants were told before beginning the task that the total duration of the task would be independent of the choices made during the task, although participants were not explicitly told about the waiting period at the end of the task that was responsible for ensuring approximately equal task duration. The waiting period was defined as 660 s minus the sum of all larger reward delays that the participant experienced throughout the task. Although this manipulation ensured that total programmed waiting time did not substantially differ across participants, differences in participant response latency nonetheless allowed for some variability in total task time. At the end of the task, participants exchanged whole dollar amounts of coins for paper currency.

Clinical characteristics

Symptoms were evaluated by trained raters (Ventura, Green, Shaner, & Liberman, 1993) using four subscales from the Positive and Negative Syndrome Scale (PANSS)(Kay, Opler, & Lindenmayer, 1989): positive, excitement, disorganized, depression/anxiety; and two subscales from the Clinical Assessment Interview for Negative Symptoms (CAINS): Motivation and Pleasure (MAP) and Expression.

Neurocognition

The MATRICS Consensus Cognitive Battery (MCCB)(Nuechterlein & Green, 2006) includes 10 tests to measure seven domains of cognition: speed of processing, attention/vigilance, working memory, verbal memory, visual memory, reasoning and problem solving, and social cognition. Standardized T-scores were computed for each of the seven domains, correcting for age and gender; an overall composite score was examined.

Subjective Value of Money Index

To obtain an index of subjective valuation of money (in the absence of any delay), participants were asked to: “rate how valuable (i.e., how important) the following amounts of money are to you” (Goldstein et al., 2007; Martin-Soelch et al., 2001). Participants rated 7 monetary amounts (US$ 10, 20, 50, 100, 200, 500, 1000) on a scale from 0 (not at all valuable) to 10 (extremely valuable). The rating for $10 was subtracted from the rating for $1000 to represent subjective sensitivity to gradations in monetary value; the lower the value, the less the sensitivity (i.e., more similar value ratings from highest and lowest amounts).

Statistical Analyses

Following preliminary analyses that compared demographic and other characteristics between the groups, the primary analyses were conducted in four stages. The first stage evaluated whether there were qualitative differences in the orderliness and shape of the DD data for both groups.

Orderliness was assessed using established criteria (M. W. Johnson & Bickel, 2008): starting with the second delay value (1 day for the hypothetical task; 5 sec for the QDOT), no indifference point value could exceed the immediately preceding indifference point value by more than 0.2. If the data for a discounting task for a particular individual violated this criterion, the discounting task was flagged as being relatively less orderly for that participant. Passing the criterion indicates a relatively orderly pattern of stable and/or decreasing value across all increases in delay.

Shape of the discounting curves was analyzed by using the Akaike information criterion (Akaike, 1974; Bozdogan, 1987; Burnham & Anderson, 2003) to determine whether the hyperbolic model expressed in Equation 1 (Mazur, 1987) or an exponential model traditionally assumed in economics and expressed in Equation 2, was more likely to be the correct model.

$$IND = 1/(1+kD) \quad (1)$$

$$IND = e^{-kD} \quad (2)$$

In each model, IND is the indifference point expressed as a proportion of the delayed reward amount, D is the delay to receipt of the reward, and *k*, a free parameter, is the discounting rate. In Equation 2 *e* represents the constant Euler’s number. The hyperbolic model accounts for dynamic inconsistency or “irrationality” in the form of empirically-observed preference reversals over time that are not accounted for by the exponential model (L. Green et al., 1994).

The second stage evaluated quantitative differences between the groups on the DD tasks. The extent of discounting was determined using area under the curve (AUC) (Myerson,

Green., & Warusawitharana, 2001); AUC values can range from 0–1, with greater values indicating less DD, or greater preference for larger-later rewards. The AUC data were normally distributed and parametric statistical tests were used. Group comparisons were done with a repeated-measures ANOVA using task as the within-subject variable and group as the between-subjects variable.

The third stage evaluated whether DD (i.e., AUC for each task) was associated with symptoms, neurocognition, antipsychotic dose equivalents, and subjective valuation of money using Pearson correlation coefficients. Schizophrenia subgroups based on nicotine, alcohol, cannabis, and other substance use status were compared with paired t-tests.

The fourth stage examined test-retest reliability within the schizophrenia group with Pearson correlations and paired-samples t-tests between DD performance at times 1 and 2.

Results

Demographic, neurocognitive, and clinical data

Descriptive data is presented in Table 1. The groups did not differ in age, sex, ethnicity, or parental education. As expected, the schizophrenia had significantly lower education and neurocognitive functioning than controls. The schizophrenia group showed mild to moderate levels of symptoms on the PANSS and CAINS.

Regarding substance use, the schizophrenia group had a higher proportion of cigarette smokers than controls, X^2 (1,201) = 45.95, $p < .001$. Since the exclusion criteria for other types of substances differed across groups, between-group comparisons were not conducted. Finally, the schizophrenia showed significantly smaller scores than controls on the subjective value of money index; this reflected the schizophrenia group assigning relatively higher values than controls for the small amount ($10) while the group ratings were virtually identical for the high amount ($1000).

Between-group comparisons

Discounting Data Orderliness and Shape—The large majority of participant data sets for both tasks provided data that was orderly across all delay indifference points. For the QDOT, 85.5% of the schizophrenia group and 92.9% of controls passed the criterion. For the hypothetical discounting task, 84.0% of the schizophrenia group and 95.8% of controls passed the criterion. The proportion of participants with less-orderly data did not significantly differ between group for the QDOT, $X^2(1,201) = 2.35$, $p = .17$, but was higher in the schizophrenia than the control group for the hypothetical task, $X^2(1,201) = 6.13$, $p = .01$.

Regarding the shape of discounting functions, Akaike information criterion analysis showed that in all 4 conditions examined (both tasks × both groups), the hyperbolic model had >99.99% probability of being the correct model over the exponential model. Thus, the DD data were qualitatively similar across groups in terms of shape, demonstrating a hyperbolic discounting function on both tasks.

Discounting rates—Figure 1 shows median indifference points with best-fitting hyperbolic curves. The upper panel shows data from the QDOT and the lower panel shows data from the hypothetical discounting task (descriptive statistics are presented in Supplemental Table 1). Comparisons using AUC indicated that there was a significant main effect for task, $F(1,199) = 163.01$, $p < .001$, $\eta_p^2 = .450$, a non-significant main effect for group, $F(1,199) = 1.26$, $p = .26$, $\eta_p^2 = .006$, and a significant task × group interaction, $F(1,199) = 4.95$, $p = .03$, $\eta_p^2 = .024$. Follow-up comparisons for the QDOT indicated that the schizophrenia group (M = .49, SD = .22) showed significantly greater discounting than controls (M = .57, SD = .22), $t(199) = 2.39$, $p = .02$, $d = .34$. However, for the hypothetical DD task, the schizophrenia group (M = .27, SD = .25) did not significantly differ from controls (M = .25, SD = .23), $t(199) = -.60$, $p = .54$, $d = .09$. Correlations between the experiential and hypothetical DD tasks (using AUC) were relatively small in both the schizophrenia ($r = .24$, $p = .005$) and control ($r = .19$, $p = .11$) groups.

The results of between-group comparisons for the AUC were unchanged after excluding participants with less-orderly data for either task: a significant task × group interaction, $F(1,157) = 4.06$, $p = .04$, $\eta_p^2 = .025$, reflected greater discounting in the schizophrenia group than controls on the QDOT, $t(157) = 2.04$, $p = .04$, $d = .33$, and a non-significant group difference on the hypothetical task, $t(157) = -.46$, $p = .65$, $d = -.07$.

Associations with other variables within the schizophrenia group

Results are shown in Table 2. Contrary to predictions, DD was not associated with negative symptoms; there were only non-significant trend level correlations between the QDOT and MAP negative symptoms, and between the hypothetical DD task expressive negative symptoms. There were no significant correlations with other types of symptoms or neurocognitive composite scores, or with CPZ equivalents or the monetary valuation index. A supplemental analysis also revealed no significant correlations with any of the MCCB subdomain scores (Supplemental Table 2).

Regarding substances, within the schizophrenia group, smokers (M = .22, SD = .19) showed significantly greater discounting than non-smokers (M = .33, SD = .31) on the hypothetical DD task, $t(129) = -2.44$, $p = .01$, $d = -.43$, but these subgroups did not significantly differ on the QDOT, $t(129) = -.24$, $p = .83$, $d = -.04$. Among controls, the small subgroup of smokers did not significantly differ from non-smokers on either DD task (t's < 1.67, p's > .05). For the QDOT, when the schizophrenia vs. control comparison was restricted only to non-smokers, the schizophrenia group continued to show significantly greater DD than controls, $t(118) = 2.00$, $p = .04$, $d = .37$. Similarly, for the hypothetical DD task, the groups still did not significantly differ, $t(118) = -1.43$, $p = .16$, $d = -.26$.

For other substances, within the schizophrenia group, there were no significant differences among subgroups with versus without alcohol, cannabis, or other substance use disorders, (t's < −1.13, p's > .05; see Supplemental Table 3).

Test-retest reliability within the schizophrenia group

The DD functions for the schizophrenia group at the one-month retest are displayed in Figure 2. The mean AUC for the schizophrenia group at retest for the QDOT (M = .49, SD = .24) and the hypothetical DD task (M = .30, SD = .30) were very similar to their baseline means reported above. The test-rest correlations were large and significant for the QDOT, r = .70, p < .001, and the hypothetical DD task, r = .67, p < .001. Further, mean differences across testing occasions were non-significant with small effect sizes for both the QDOT, t(121) = −.15, p = .75, d = .01, and the hypothetical DD task, t(121) = −1.22, p = .21, d = −.11.

Discussion

The schizophrenia and control groups had qualitatively similar DD functions, but quantitatively, the schizophrenia group showed a significantly greater DD than controls on the experiential task, and normal DD on the hypothetical task. The schizophrenia group's performance on the DD tasks was generally not associated with a range of potential confounds. In addition, test-retest reliability was examined for the schizophrenia group and was good on both tasks. These findings provide the first evidence of impaired DD in schizophrenia using an experiential paradigm that parallels tasks used in animal research much more closely than conventional human paradigms. While not all aspects of reward processing are impaired in schizophrenia (e.g., Horan, Foti, Hajcak, Wynn, & Green, 2012; Llerena, Wynn, Hajcak, Green, & Horan, 2016), these findings suggest alterations do extend to a delay discounting context that involves real rewards and real delay periods. As described below, the schizophrenia group's pattern of altered experiential and normal hypothetical DD likely reflects the fact the these tasks differed on several key dimensions, including reward type (real vs. unreal), reward magnitude (cents vs. hundreds of dollars), and delay time frame (minutes with actual waiting periods vs. decades with no waiting periods).

Regarding qualitative analyses, the shape and orderliness of the DD data were generally similar across groups. In line with a prior report (Ahn et al., 2011), the schizophrenia group showed typical hyperbolic discounting functions across tasks. Further, a large majority (> 84%) demonstrated orderly data for both DD tasks. The proportion with less-orderly data on the hypothetical, though not the experiential, task was significantly larger than controls (similar to (Weller et al., 2014)). However, the main study findings were unchanged after removing the subset of participants from both groups with less-orderly data.

In this first study of experiential DD in schizophrenia, the schizophrenia group showed quantitatively greater discounting than controls for actual monetary rewards delivered in real time. Diminished discounting on this and similar experiential tasks has been reported in other clinical populations, including cocaine dependence, ADHD, and smokers (M. W. Johnson, 2012; Reynolds, 2006a; Rosch & Mostofsky, 2016). Experiential tasks appear to tap into a rather different aspect of DD than hypothetical tasks. For example, the correlation between hypothetical and experiential DD tasks was relatively small in both groups. Several studies have also reported relatively low convergence between these tasks (M. W. Johnson, 2012; Krishnan-Sarin et al., 2007; Melanko et al., 2009) and one found altered experiential but not hypothetical discounting in ADHD (Rosch & Mostofsky, 2016).

There were no quantitative group differences for the hypothetical DD task and this study included the largest schizophrenia and control samples examined to date. Our finding on this task is consistent with two prior studies (including the second largest study (MacKillop & Tidey, 2011; Wing et al., 2012), but inconsistent with four others that found greater hypothetical DD in schizophrenia (Ahn et al., 2011; Heerey et al., 2011; Heerey et al., 2007a; Weller et al., 2014). The rather substantial methodological differences across the few DD studies make it difficult to pinpoint why three studies found normal DD but four did not. Since all prior studies included chronically ill samples, and all except one (Ahn et al., 2011) examined outpatients, the discrepancies across studies are not attributable to these participant characteristics. However, the tasks and data analytic approaches varied widely. For example, across the seven studies, the maximum delayed reward magnitude ranged from $86 to $1000, and the maximum delayed reward duration ranged from a few months up to 50 years. Further research will want to systematically assess the impact of these parameters on hypothetical DD in schizophrenia. For example, it could be informative to examine how individuals with schizophrenia perform on a hypothetical task with reward magnitudes and delay intervals that correspond to those in the experiential task.

The current study considered a wide range of potentially confounding factors on DD and found that their impact was small. The only relevant factor was smoking status. Smokers showed greater hypothetical DD than non-smokers, which converges with prior findings from the general population (MacKillop et al., 2011) and schizophrenia (MacKillop & Tidey, 2011; Wing et al., 2012). However, we still found the pattern of altered experiential and normal hypothetical DD in schizophrenia when we limited our analyses to non-smokers. There were no significant associations between DD and other substances, symptoms, or antipsychotic medication dosages. Given the conceptual link between reward processing and negative symptoms (Reddy, Horan, et al., 2016), it is somewhat puzzling that alterations in DD, particularly on the experiential task, did not significantly correlate with higher clinically rated negative symptoms. Although some studies have found that neuroscience-based reward and decision making tasks are associated with negative symptoms (e.g., Barch, Treadway, & Schoen, 2014; Gold et al., 2013; Strauss et al., 2014) a number of studies by our group and others failed to detect such relationships (see Green, Horan, Barch, & Gold, 2015; Horan et al., 2015). The reason for these discrepancies is not year clear. We have suggested that there are complex intervening steps on the causal pathway between the relatively discrete processes measured by decision-making tasks and the broad aspects of experience and behavior that are captured by clinical rating scales, which may substantially diminish direct correlations (Green et al, 2015). DD also showed no significant associations with global or particular domains (e.g., working memory) of neurocognition. This does not support prior suggestions that DD disturbances in schizophrenia reflect problems in the representation and maintenance of reward value (Heerey et al., 2007a).

The schizophrenia group's pattern of altered experiential but normal hypothetical DD was also not attributable to differences in the test-retest reliabilities of the tasks. The test-retest correlations of approximately .70 for both tasks are similar to prior reports in healthy samples (Matusiewicz, Carter, Landes, & Yi, 2013; Smits, Stein, Johnson, Odum, & Madden, 2013; Weafer, Baggott, & de Wit, 2013) and the group means showed good stability across occasions. These findings, in conjunction with the lack of associations with

symptoms, suggest the DD tasks are measuring relatively stable traits among individuals with schizophrenia. These properties support the use of the experiential DD task as a performance measure of decision-making impairment in clinical trials for schizophrenia (see (M. F. Green et al., 2015). Its potential usefulness for clinical trials is bolstered by evidence that it is sensitive to state-related changes, such as sleep deprivation, dopamine agonist administration in Parkinson's disease, alcohol administration, and methylphenidate administration in ADHD (Reynolds et al., 2006; Reynolds & Schiffbauer, 2004; Shiels et al., 2009; Voon et al., 2010).

One might have expected the schizophrenia group to show greater difficulties for hypothetical, distant rewards in light impaired abstract thinking and longer-term prospection associated with this disorder (Eack & Keshavan, 2008; Fioravanti, Carlone, Vitale, Cinti, & Clare, 2005; Goodby & MacLeod, 2016). However, the pattern found in the current study may relate to participant and task characteristics. Regarding participant characteristics, since schizophrenia is associated with decreased SES (Werner, Malaspina, & Rabinowitz, 2007) and many in the schizophrenia group were receiving limited fixed incomes, the schizophrenia group may have valued immediately available, real (albeit small) rewards more than controls. This possibility is bolstered by our finding that the schizophrenia group assigned higher value ratings than controls for the lowest value ($10) but similar ratings for the highest value ($1000) on the subjective valuation of money index, and with previous research showing greater discounting in lower income adults (L. Green, Myerson, Lichtman, Rosen, & Fry, 1996). Although individual differences in subjective valuation ratings did not significantly correlate with performance on the DD tasks, this factor remains a possible contributor (Reimers, Maylor, Stewart, & Chater, 2009).

Regarding task characteristics, Paglieri (2013) postulated key differences between hypothetical tasks and experiential tasks, beyond reward magnitude and delay length. Whereas hypothetical tasks merely involve postponing receipt of a reward with no constraints on how subjects spend their time during the intervening delay, the waiting period in experiential tasks comes with associated costs. These include direct costs, such as boredom or discomfort, and opportunity costs, such as valuable activities that the participant could be engaged in if not forced to wait. The relevance of such costs was demonstrated in a recent study that found DD rates increased as an orderly function of the constraints on what people could do (e.g., freely surf the net on the computer vs. sit at the computer and do nothing) during the delay interval on a hypothetical task (P. S. Johnson et al., 2015). Perhaps the individuals with schizophrenia in our study were hyper-responsive to the associated costs of doing nothing in the delay period and experienced alterations in their cost/benefit calculations. For example, schizophrenia is associated with an elevated tendency to experience negative affect/arousal and boredom (Cohen & Minor, 2010; Gerritsen, Goldberg, & Eastwood, 2015), as well as altered decision-making on tasks that involve weighing the relative effort expenditure costs against monetary rewards (M. F. Green et al., 2015). Studies that manipulate the constraints, or obtain subjective ratings/ psychophysiological measures, during delay intervals could shed light on the possible impact of these costs in DD in schizophrenia.

Strengths of the current study include the large clinical sample, use of two different types of DD tasks, rigorous evaluation of data integrity, examination of many potential confounds, and evaluation of test-retest reliability. However, the study has some limitations and highlights areas in need of further study. First, participants with schizophrenia were taking medications at clinical dosages. Although dosage equivalents were not related to DD, the impact of medications remains unclear. Second, the schizophrenia sample was chronically ill and it is unknown whether similar DD patterns would be evident in younger or high-risk samples. Third, the order of delay discounting task administration was not counterbalanced, so we are unable to examine potential order effects. Fourth, although performance on the tasks was not related to subjective valuation of money, we did not obtain objective measures to evaluate whether income or socio-economic status was associated with DD task performance. Fifth, this study only assessed monetary rewards and it is unknown whether similar patterns would be found for other primary (e.g., food) or secondary (e.g., social, health) reinforcers. Sixth, although the schizophrenia group showed normal performance on the hypothetical DD task, we cannot tell if the normal choice patterns were achieved through abnormal neural processes. For example, a small fMRI study reported that individuals with schizophrenia showed an abnormal hypo-activation in some regions (e.g., inferior frontal cortex, dorsal anterior cingulate cortex, ventral striatum) and hyper-activation in others (insula, precuneus) while making DD decisions (Avsar et al., 2013). Further attention to these issues can help clarify the nature of impaired reward processing and decision-making in schizophrenia.

General Scientific Summary: Delay discounting (DD) refers to whether one is willing to forego a smaller, sooner reward for the sake of a larger, later reward. This study found that people with schizophrenia showed a greater preference for smaller, sooner rewards than healthy comparison participants on a DD task that involved making choices about actual monetary rewards provided in real time. In contrast, both groups showed comparable performance on a DD task that that involved making choices about hypothetical rewards provided in the more distant future. These findings point to key alterations in how people with schizophrenia value different types of rewards.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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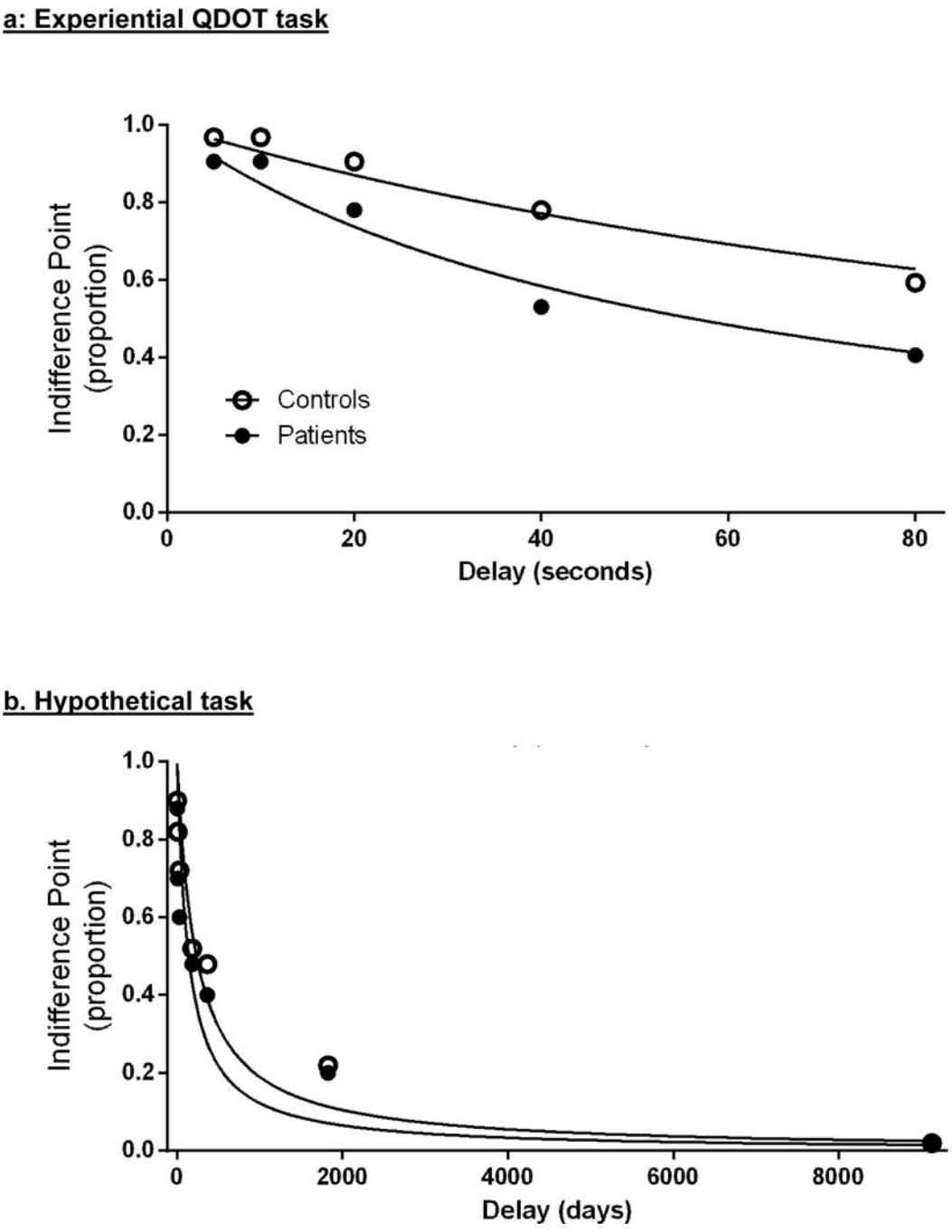

Figure 1.

Delay discounting functions for the schizophrenia and control groups for the experiential (panel a) and hypothetical (panel b) delay discounting tasks

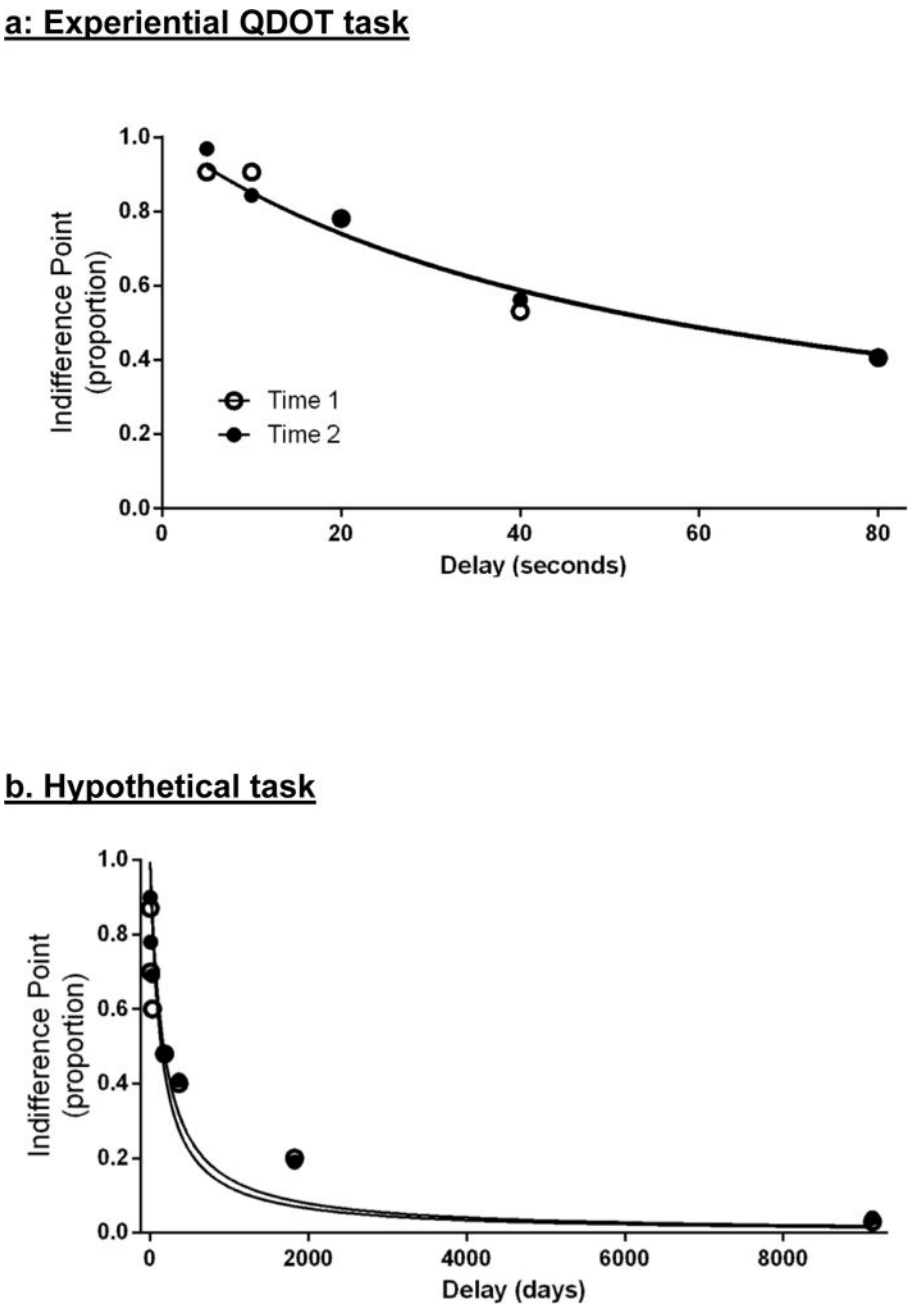

Figure 2.

Delay discounting functions within the schizophrenia group at times 1 and 2 for the experiential (panel a) and hypothetical (panel b) delay discounting tasks

Table 1

Demographic and Clinical Data for Schizophrenia (n = 131) and Control (n = 70) Groups

	Schizophrenia	Controls	Group comparisons
Age	48.7 (11.3)	48.0 (8.6)	t(199) = .45, p = .66
Sex (% Male)	68%	59%	$X^2(1,201) = 1.75$, p = .22
Education	13.1 (1.9)	14.6 (1.8)	t(199) = − 5.30, p < .001
Parental Education	12.8 (3.0)	13.1 (3.2)	t(199)= −.66, p = .52
Ethnicity (% Hispanic)	19%	21%	$X^2(1,201) = .21$, p = .71
Race (%)			$X^2(5,201) = 1.75$, p = .35
American Indian/Alaskan	1%	0%	
Asian	6%	4%	
Hawaiian/Pac. Islander	1%	6%	
Black/African American	32%	33%	
White	55%	51%	
More than one race	5%	6%	
MCCB Overall Composite	33.1 (12.2)	45.8 (10.3)	t(199) = − 7.32, p < .001
Symptoms			
CAINS Motivation and Pleasure	16.0 (7.3)		
CAINS Expressive	5.0 (4.1)		
PANSS Positive	18.5 (7.7)		
PANSS Disorganized	12.5 (4.5)		
PANSS Excitement	5.4 (6.9)		
PANSS Depression/Anxiety	7.2 (2.8)		
Lifetime substance use disorder status[a,b]			
Lifetime alcohol abuse or dependence (%)	30%	7%	
Lifetime cannabis abuse or dependence (%)	30%	3%	
Lifetime other substance abuse or dependence (%)	37%	2%	
Current cigarette smoker (%)	59%	7%	
Subjective value of money index	3.3 (2.9)	4.1 (2.7)	t(199) = 2.01, p = .04

Notes: Standard deviations appear in parentheses.

[a]Exclusion criteria for alcohol, cannabis, and other use disorder differed across groups: control participants were excluded for any current or past substance dependence disorders whereas participants with schizophrenia were only excluded for current substance dependence disorders (past substance dependence disorders were allowed). Regarding substance abuse disorders, participants in both groups were excluded for current substance abuse disorders (past substance abuse disorders were allowed for both groups).

[b]For substance use disorders among patients, breakdowns (% of patient sample) for substance abuse vs. dependence are: Alcohol abuse (7%), dependence (27%); Cannabis abuse (17%), dependence (13%); Other abuse (9%), dependence (28%).

Table 2

Correlations Between Delay Discounting Tasks and Symptoms, Neurocognition, Antipsychotic Dosage Equivalents, and Subjective Valuation of Money Within The Schizophrenia Group (n = 131)

	QDOT Experiential Delay Discounting Task	Hypothetical Delay Discounting Task
CAINS Motivation and Pleasure	.16†	.10
CAINS Experiential	.12	.16†
PANSS Positive symptoms	.02	.10
PANSS Disorganization symptoms	.01	−.07
PANSS Excited symptoms	.01	−.01
PANSS Depression/Anxiety	−.03	.01
MCCB Overall Composite	−.05	.11
CPZ equivalents	−.10	−.05
Subjective Value of Money	−.07	−.11

Notes:

† p = .07. QDOT = Quick Discounting Operant Task; CAINS = Clinical Assessment Interview for Negative Symptoms; PANSS = Positive and Negative Symptoms Scale; MCCB = Matrics Consensus Neurocognitive Battery. CPZ = Chlorpromazine.