Title: Effort-Based Decision-Making in Schizophrenia

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Abstract:

Motivational impairment has long been associated with schizophrenia but the underlying mechanisms are not clearly understood. Recently, a small but growing literature has suggested that aberrant effort-based decision-making may be a potential contributory mechanism for motivational impairments in psychosis. Specifically, multiple studies have consistently shown that individuals with schizophrenia are less willing than healthy controls to expend effort to obtain rewards. Further, this effort-based decision-making deficit has been shown to correlate with severity of negative symptoms and level of functioning, in many but not all studies. In the current review, we summarize this literature and discuss several factors that may underlie aberrant effort-based decision-making in schizophrenia.
Introduction

Many individuals with schizophrenia experience reductions in motivation and goal-directed behavior [1]. These deficits are strongly associated with social and occupational functioning, but treatments are not sufficiently effective at alleviating such symptoms [2], potentially due to a poor mechanistic understanding of the causes of impaired motivation in schizophrenia. Recently, research has suggested that motivational deficits in schizophrenia might arise, in part, due to aberrant effort-based decision-making [3,4].

Effort-based decision-making refers to mental computations individuals perform to estimate the amount of work required to obtain an outcome (see Box 1 for example). Recent work has suggested that individuals with schizophrenia are less willing than healthy controls to exert effort to obtain monetary rewards on experimental tasks [5-15], and that this deficit in effort allocation is related to negative symptoms [5,6,8,9,13-19]. In the current review, we summarize this literature, discuss interpretative challenges, and provide ideas for future directions.

Physical Effort-Based Decision-Making

Many recent studies have been published suggesting a reduced willingness of individuals with schizophrenia compared to healthy controls to exert physical effort for monetary rewards [5,7-14]. Broadly, these studies involve participants making repeated decisions between completing a hard or easy physical task for high or low monetary reward. For example, studies have used button-pressing tasks where individuals select between completing an easy task (i.e., a minimal number of button presses) for a small reward or a hard task (i.e., a large number of button presses) for a larger reward [8,20]. These studies find that individuals with schizophrenia are less likely than controls to select the harder task [5,7-14], although some studies have reported null results [19,21]. Further, these studies typically find that this group difference is largest when the reward amount for completing the hard task is highest and the probability of reward receipt is most certain [5,7,8,11-14].
In regards to relationships with individual differences, many studies have shown that individuals with schizophrenia with the most severe negative symptoms are those least willing to exert effort [5,8,9,13,14,16-19]. Further, work by our group has shown patient behavior on effort-based decision-making tasks is a reliable predictor of motivation and pleasure ratings in daily life (i.e., individuals more willing to exert effort also report more interest and enjoyment with their daily activities) [18]. However, not all studies have observed significant associations between physical effort-based decision-making tasks and negative symptoms [7,10,21,22]. In part, this inconsistency may be due to differences in the methods used to assess negative symptoms with most of the significant associations using newly developed measures of negative symptoms (i.e., the CAINS [23] or BNSS [24]). Indeed, these new measures better reflect the field’s current conceptualization of negative symptoms, differentiating the experience (i.e., motivation and pleasure) from the expression of negative symptoms (i.e., flat affect, alogia). Recent studies using these measures have found that impairments in effort-based decision-making are more robustly related to experiential negative symptoms [6,15,17,19].

**Cognitive Effort-Based Decision-Making**

Similar to physical effort-based decision-making, multiple studies have been published reporting decreased cognitive effort-based decision-making [6,12,15]. For example, our group utilized a cognitive effort-discounting task [25] where individuals first experienced increasingly difficult levels of a cognitively demanding task and subsequently made decisions about repeating an easy or hard level for small or large monetary rewards. We found that individuals with schizophrenia were less willing than healthy controls to select the hard task [6]. Several other studies have reported similar results, using a variety of paradigms [6,12,15], though one study reported null results potentially due to patients’ difficulty detecting effort demands [26]. Further, studies observed that individuals with the greatest negative symptom severity showed the least willingness to exert effort [6,15], although some studies have reported null results [17,26].
Neural Correlates of Effort-Based Decision-Making

While a comprehensive review is beyond the scope of the current manuscript [27-29], work in the basic human and animal sciences has begun to detail aspects of the neural circuitry underlying effort-based decision-making including the anterior cingulate cortex, the ventral striatum, and dopamine systems. Specifically, human functional neuroimaging studies have shown that ventral striatum [10,30,31] and anterior cingulate [30,32] BOLD activation tracks the subjective value of actions, increasing with reward value and decreasing with effort. Further, rodent work has shown that ablation of the anterior cingulate cortex [33] or depletion of ventral striatal dopamine [34] in mice leads to decreases in effort exertion.

In regards to schizophrenia, only a few studies have examined the neural correlates of aberrant effort-based decision-making. In one study, Huang and colleagues found that greater BOLD activation in the ventral striatum during effort-based choice was associated with greater willingness to exert effort across patients and controls [10]. Further, they found that individuals with schizophrenia showed reduced BOLD activation in the ventral striatum, the posterior cingulate gyrus, and the left medial frontal gyrus as a function of reward value and reward probability compared to healthy controls [10]. In a related study, Wolf and colleagues found that increased BOLD activation of the ventral striatum and the dorsolateral prefrontal cortex during reward processing was significantly related to increased willingness to exert effort on a behavioral task [15]. Finally, Park and colleagues showed greater activation of the caudate for individuals with schizophrenia compared to healthy controls as a function of effort [35]. However, this task did not include a choice, but rather required individuals to perform either a hard or easy option. Thus, it is difficult to generalize the results of the Park study to the larger effort-based decision-making literature [35]. In summary, while still preliminary, results suggest roles for the ventral striatum, cingulate gyrus, and the dorsolateral prefrontal cortex in effort-based decision-making deficits in schizophrenia.

Factors That Might Drive Reduced Effort
Although several papers have been published establishing reduced effort expenditure in schizophrenia [3,4], few studies have been conducted to determine the types of factors that might drive this deficit. In Box 1 we provide an example of factors that may increase or decrease the willingness of individuals to expend effort. In the sections below we discuss these factors and the likelihood of their contribution to aberrant effort-based decision-making in schizophrenia.

**Reward Responsivity**

One explanation for reduced effort expenditure is reduced reward responsivity. Put simply, if individuals with schizophrenia do not like rewards as much as healthy individuals they may be less likely to exert effort to obtain them. While reduced liking of rewards was a prominent explanation for motivational impairment in schizophrenia for many years [36,37], a large body of recent work has suggested that individuals with schizophrenia self-report levels of pleasure similar to controls when experiencing pleasurable activities in daily life or in the laboratory [38]. Further, behavioral tasks [39,40], electrophysiological indices [41,42], and neuroimaging markers [43-45] of reward responsivity consistently show similar patterns between controls and those with schizophrenia, suggesting intact reward responsivity. Finally, one study by our group [6] assessed the contribution of reward responsivity to effort-based decision-making by asking patients and controls to self-report factors that influenced decision-making. Specifically, we asked “To what degree were your choices based on the amount of money that you could win?” We found similar responses across groups, and further that group differences in effort allocation remained significant when controlling for responses. Thus, reduced reward responsivity appears to be an unlikely mechanism for impaired effort allocation in schizophrenia.

**Anticipatory Pleasure**

While individuals with schizophrenia report similar levels of pleasure “in the moment”, a large literature suggests reduced anticipatory pleasure in schizophrenia compared to healthy controls [46,47]. Anticipatory pleasure is thought to be an integral aspect of motivated behavior
and effort allocation. For example, individuals who self-report greater trait levels of anticipatory pleasure demonstrate increased willingness to expend effort to obtain rewards [48-50], although not in all studies. In schizophrenia, patients self-reporting higher trait levels of anticipatory pleasure demonstrate increased willingness to expend effort [16], although results are inconsistent. Future work will need to replicate and extend such findings to better understand how state anticipatory pleasure may influence effort allocation in those with schizophrenia.

**Cognitive Control**

Effort-based decision-making requires a variety of functions highly reliant on cognitive control including the integration of decision information and the utilization of internal representations of cost and reward information to drive choice behavior. Schizophrenia is associated with a robust cognitive control deficit [51]. No study has directly assessed the contributions of cognitive control processes to effort expenditure in schizophrenia. However, several studies have found that patients with greater cognitive impairment are less willing to exert effort to obtain rewards [8,16,17,26]. One recent study, also found that increased working memory was related to increased effort expenditure in schizophrenia [16]. However, several studies have also reported non-significant associations between cognition and effort expenditure in schizophrenia [7,9,11,15,19,21,22]. Thus, further research is needed in this area. In particular, studies may benefit from using cutting-edge cognitive control paradigms developed in the basic science literature to discern clear associations between control processes and effort allocation.

**Defeatist Performance Beliefs**

Individuals with schizophrenia may also be less willing to exert effort compared to healthy controls due negative beliefs they may have about their ability to successfully complete actions [52]. Studies have found elevated defeatist performance beliefs in those with schizophrenia compared to healthy controls and linked such beliefs to negative symptoms, cognition, and functioning [52,53]. Granholm and colleagues [54] collected data from individuals
with schizophrenia and healthy controls on a digit span task. They found that effort allocation, as measured through pupillary response, increased in healthy controls and patients with low levels of defeatist performance beliefs as the cognitive demands of the task increased. However, individuals with schizophrenia with high levels of defeatist performance beliefs failed to increase effort allocation as task demands increased, suggesting a potential link between effort allocation and defeatist performance beliefs [54]. While this finding is intriguing further research is needed to replicate this finding using effort-based decision-making tasks.

**Medications Effects**

One limitation to previous work regarding effort-based decision-making in schizophrenia is antipsychotic medication. As stated above, effort-based decision-making has been linked to striatal dopamine [34] and antipsychotics are proposed to work by blocking D2 receptor sites [55]. Thus, antipsychotics may modulate aspects of the effort-based decision-making circuitry. While studies consistently find insignificant correlations between antipsychotic dose equivalents and effort-based decision-making, the utility of such equivalency measures is widely debated [56]. A recent study used an alternative approach, classifying the antipsychotics by D2 receptor affinity, and found that patients prescribed antipsychotics with greater D2 affinity were less willing to expend effort [3]. While this result is intriguing, the sample was small and the patients prescribed antipsychotics with high D2 affinity also had the greatest negative symptom severity, limiting clear interpretations of medication effects. Future research would also benefit from collecting data in unmedicated samples and those at-risk for developing schizophrenia in order to more carefully examine medication effects.

**Summary and Future Directions**

Recent literature has suggested that impaired effort-based decision-making may be a potential contributory mechanism for motivational impairment in schizophrenia. This work includes primarily behavioral studies, but recent studies suggest preliminary neural correlates to this deficit including reduced striatal, cingulate, and dorsolateral prefrontal cortex activation
[10,15]. While recent work has consistently shown reduced effort allocation in schizophrenia, the factors that may give rise to this reduction are less clearly understood and remain important avenues for future research. An understanding of such factors is critical to discerning potential targets for intervention strategies. For example, cognitive-behavioral therapy targeting defeatist performance beliefs [52] may be particularly effective if future research determines contributions of defeatist performance beliefs to effort deficits in schizophrenia. Finally, although not discussed in the current review, studies have suggested that impaired effort allocation is associated with several other psychiatric disorders including major depressive [49,50,57-60] and bipolar disorder [58]. Future work will need to examine whether the mechanisms underlying effort deficits are transdiagnostic or disorder-specific in order to guide targeted treatment of novel intervention strategies across patient groups. In summary, impaired effort-based decision-making appears to be an attractive contributory mechanism for motivational impairment in schizophrenia. Future work examining neural correlates, unmedicated patients, potential psychological mechanisms, and transdiagnostic samples is needed to better characterize these initial findings.

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** Gold et al., 2013: The first study to examine effort-based decision-making in those with schizophrenia. Results showed decreased willingness of patients compared to healthy controls to increase effort as reward value and probability increased. This effect was most robust in the high negative symptom patients.**


* Huang et al., et al., 2016: This study collected data from individuals with schizophrenia and healthy controls using a button-pressing task in the scanner. They found that activation in the ventral striatum significantly predicted choice behavior and further that this activation was significantly blunted in those with schizophrenia compared to healthy controls.


** Reddy et al., 2015: First large sample study to show decreased effort allocation in those with schizophrenia across several commonly used paradigms. Psychometric characteristics of these paradigms and use in patient samples are examined.**


** Wolf et al., 2014: This study examined willingness to expend effort in those with schizophrenia and healthy controls. They found decreased willingness to expend cognitive effort in the patients. Further, they found that, during neuroimaging, BOLD activation of the dorsolateral prefrontal cortex and the ventral striatum during a reward-processing task was related to willingness to expend effort behaviorally.


** Moran et al., 2017: This study showed that willingness to expend effort on an experimental task was associated with self-reports of enjoyment and interest with daily activities measured outside of the laboratory using ecological momentary assessment techniques.


* Treadway et al., 2009: This was the initial study that used the Effort Expenditure for Rewards Task, the most commonly utilized task for assessing individual and diagnostic group differences.


* Salamone et al., 2015: Exceptional review paper that summarizes findings regarding the neurobiological processes underlying motivation in the basic and animal sciences. The review also describes how such processes might come to be disturbed in psychopathology.

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**Box 1:** Factors that may influence effort-based decision-making: A real-world example

Below, we provide a real-world situation to better contextualize the decision-making components individuals utilize to perform effort-based decision-making. We also discuss factors that may influence effort exertion.

**Situation:**

Nicholas is debating whether he should recreate the delicious chocolate-chip cookie that he ate last weekend. In weighing his decision, he considers the reward (i.e., that delicious cookie). Further, he considers the probability of reward receipt (e.g., what if he accidentally burns the whole batch). Next, he considers the effort necessary to bake the cookie, including going to the store and time spent in the kitchen. He also considers the precision of his estimation of effort (e.g., the cookies might be easier or harder to bake than anticipated). Finally, he considers his motivational state (e.g., is he hungry right now?).
Factors That Modulate Effort Exertion:

1. *Reward Responsivity*: If Nicholas does not enjoy cookies, he may be less likely to make them. Alternatively, if Nicholas’ favorite dessert is a cookie he may be more likely to make them.

2. *Anticipatory Pleasure*: Nicholas may think about how good the cookie will taste prior to baking it. If this anticipatory pleasure is strong, Nicholas may use such a representation to drive behavior and expend effort in baking the cookies.

3. *Defeatist Performance Beliefs*: Nicholas may be less likely to attempt to recreate the recipe if he views himself as being a bad cook unable to successfully make complex receipes.

4. *Impaired Cognitive Control*: There are a number of different components of decision information (e.g., reward, cost, and probability information) that Nicholas must integrate to determine whether he is willing to expend effort to bake the cookies. If such information is poorly represented or ineffectively integrated Nicholas may be less likely to bake the cookies.
Figure 1: Model of Factors That Influence Effort-Based Decision-Making and Subsequent Symptoms