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Dissociation of Cognitive Effort–Based Decision Making and Its Associations With Symptoms, Cognition, and Everyday Life Function Across Schizophrenia, Bipolar Disorder, and Depression

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ABSTRACT

BACKGROUND: Anhedonia and amotivation are symptoms of many different mental health disorders that are frequently associated with functional disability, but it is not clear whether the same processes contribute to motivational impairments across disorders. This study focused on one possible factor, the willingness to exert cognitive effort, referred to as cognitive effort–cost decision making.

METHODS: We examined performance on the deck choice task as a measure of cognitive effort–cost decision making, in which people choose to complete an easy task for a small monetary reward or a harder task for larger rewards, in 5 groups: healthy control (n = 80), schizophrenia/schizoaffective disorder (n = 50), bipolar disorder with psychosis (n = 58), current major depression (n = 60), and past major depression (n = 51). We examined cognitive effort–cost decision making in relation to clinician and self-reported motivation symptoms, working memory and cognitive control performance, and life function measured by ecological momentary assessment and passive sensing.

RESULTS: We found a significant diagnostic group × reward interaction ($F_{8,588}$ = 4.37, $p < .001$, η_p^2 = 0.056). Compared with the healthy control group, the schizophrenia/schizoaffective and bipolar disorder groups, but not the current or past major depressive disorder groups, showed a reduced willingness to exert effort at the higher reward values. In the schizophrenia/schizoaffective and bipolar disorder groups, but not the major depressive disorder groups, reduced willingness to exert cognitive effort for higher rewards was associated with greater clinician-rated motivation impairments, worse working memory and cognitive control performance, and less engagement in goal-directed activities measured by ecological momentary assessment.

CONCLUSIONS: These findings suggest that the mechanisms contributing to motivational impairments differ among individuals with psychosis spectrum disorders versus depression.

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Anhedonia and amotivation are clinical symptoms of many different mental health disorders that are frequently associated with distress, impairment, and functional disability (1). As an example, individuals with schizophrenia often report difficulties with motivation and anticipated pleasure/reward in the domains of social, occupational, and educational function that are associated with life impairment. In addition, individuals with major depression often report anhedonia (a reduction in the ability to experience pleasure) and a lack of motivation, again often associated with functional impairment (2–4). Furthermore, individuals with bipolar disorder can also experience anhedonia and amotivation, though they can experience hyper-reward responsivity in the manic phase (2). One hypothesis in the literature is that there are mechanisms contributing to anhedonia/amotivation that cut across putative diagnostic boundaries (5–9), though some work has begun to suggest that such mechanisms may not be fully transdiagnostic (5,10–13). The goal of the current work was to test the hypothesis that transdiagnostic mechanisms contribute to motivational impairments, with a specific focus on the role of willingness to expend cognitive effort, a component of reward valuation in the positive valence systems component of the Research Domain Criteria (14–16).

There have been a number of different frameworks used to try to understand the pathways that lead individuals to experience anhedonia or amotivation (17). These frameworks include examining the experience of pleasure or reward in the moment, the anticipation of reward or pleasure in the future, and/or the ability to learn about cues and actions in the environment that might lead to reward or pleasure. One additional approach that may help integrate these different components of motivation and parse the source of impairments is the

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concept of willingness to exert effort, or effort-cost decision making (ECDM). ECDM refers to choices that a person makes about how much effort to expend as a function of factors such as the amount or type of reward that one would receive, the likelihood of receiving that reward should one expend the effort, or the amount of time it would take to obtain the reward. Such effort can be either physical (e.g., finger tapping or grip exertion) or cognitive (e.g., willingness to perform a more difficult vs. less difficult cognitive task). There is now robust evidence that individuals with schizophrenia or other psychosis spectrum conditions display a reduced willingness to expend effort to obtain reward under certain conditions (high reward and high probability of obtaining the reward) that would typically lead people to allocate effort, both cognitive (18–22) and physical (20,21,23–32).

Studies investigating ECDM in depression have shown some evidence of reduced willingness to expend physical effort with increasing reward (25,33–37), consistent with the possibility that ECDM deficits represent a transdiagnostic mechanism contributing to amotivation and anhedonia. However, as with schizophrenia, there are mixed results, with some studies not finding impairments, even among those with current depression (23,24,38–40). A few studies have also examined cognitive effort allocation. Both Ang *et al.* (41) and Westbrook *et al.* (42) found that individuals with current depression discounted reward as a function of greater cognitive effort more so than healthy control participants (HCs), though Westbrook *et al.* found that those with remitted depression did not. In contrast, Vinckier *et al.* did not find that individuals with depression were less willing to allocate cognitive effort as a function of reward (38). Studies of ECDM in bipolar disorder have focused exclusively on physical effort, with evidence for reduced allocation of effort as a function of reward in depressed bipolar individuals in one study (37), but not in two other studies (24,43), in bipolar individuals with unspecified phase of illness (23,25), and in bipolar individuals during the manic phase of illness (24).

Several studies have also examined deficits in physical ECDM in transdiagnostic samples that include individuals with schizophrenia/schizoaffective disorder, major depressive disorder (MDD), and bipolar disorder. All 4 of these studies found that both individuals with schizophrenia/schizoaffective disorder and those with bipolar disorder (though with some variation for depressed vs. manic phase) demonstrated reduced willingness to allocate greater physical effort as a function of greater reward amount or probability (23–25,44), and Yang *et al.* and Zou *et al.* also found this to be true of individuals with current major depression (23,25). However, both Yang *et al.* (24) and Moran *et al.* (45) found that individuals with current major depression did not differ from HCs in their willingness to exert physical effort as a function of reward, and Yang *et al.* also did not see differences in patients with bipolar depression in a depressed episode. Furthermore, none of these studies examined cognitive effort allocation. Given that difficulties with concentration are a cardinal symptom of depression, it is possible that deficits in cognitive effort allocation might be more robust among individuals with current major depression.

Even if deficits in cognitive ECDM are present transdiagnostically, it is still possible that the mechanisms contributing to cognitive ECDM deficits differ across putative diagnostic boundaries. For example, among individuals with schizophrenia, degree of working memory impairment was associated with effort discounting for cognitive effort (19). However, associations with cognitive function have not been examined in depression and bipolar disorder. Interestingly, there seems to be shared neural substrates of cognitive and physical ECDM in valuation regions that include parts of the dorsal frontal cortex, insula, and ventral striatum (46,47), but these different aspects of ECDM may dissociate in terms of their associations with more task-specific effector brain systems, such as frontal-parietal networks for cognitive function and motor/sensory regions for physical effort (46,47). As such, it is possible that the known disruptions in frontal-parietal systems found in psychosis (48) may also contribute to differential correlates of cognitive ECDM in psychosis versus mood disorders.

Furthermore, in schizophrenia, motivation and pleasure symptoms (e.g., anhedonia and amotivation) are associated with reduced effort allocation as a function of reward (either cognitive or physical) (19,21,24,27,28,31,49), though not in every study (26,30,39,50). In depression, reductions in anticipated pleasure have been associated with reduced effort allocation as a function of reward (33). In the physical effort transdiagnostic studies described above, Yang *et al.* (24) reported relationships of self-reported amotivation and effort allocation in schizophrenia, but not in depression or bipolar disorder. Neither Zou *et al.* (25) or Yang *et al.* found relationships of effort allocation with clinically assessed or self-reported symptoms. However, Moran *et al.* found relationships between self-reported amotivation/anhedonia that cut across schizophrenia, bipolar disorder, and major depression (44). Thus, whether associations with symptoms are transdiagnostic is still unclear. Furthermore, most studies examine relationships to clinician or self-reported symptoms, but not to everyday life experience measures with tools such as ecological momentary assessment (EMA) and passive sensing. In schizophrenia, greater willingness to exert physical and cognitive effort for reward was associated with fewer motivation and pleasure symptoms assessed via EMA (19,49,51). As such, determining whether laboratory-based measures of cognitive effort relate to everyday life experiences as assessed via EMA in patient populations is critical to understanding whether or not ECDM deficits are important in understanding functional impairment transdiagnostically. In theory, one could use traditional assessment measures (semistructured interviews and questionnaires) to gauge real-world function. However, there is evidence that these measures may be confounded by deficits in memory and associated cognitive processes in people with schizophrenia (49). EMA is an important tool for assessing daily experiences of motivation and pleasure in the moment, which might provide a more accurate assessment.

Current Study

The goal of the current study was to examine whether there are transdiagnostic deficits in cognitive ECDM, a component of effort allocation that has not yet been examined in this way.

Cognitive effort could be particularly relevant to understanding life function because it may relate to ability to engage in educational and occupational endeavors, and it is not clear whether the transdiagnostic patterns of impairment in cognitive effort parallel those seen in physical effort. In addition, we wished to examine whether the symptom correlates of cognitive ECDM were the same or different across diagnostic categories to address whether deficits arising in the context of different forms of mental illness might reflect the same mechanisms. We further sought to determine whether there were relationships between cognitive effort allocation and cognitive function that were transdiagnostic, again relevant to the question of whether such effort allocation impairments reflect common mechanisms across disorders. We also examined the degree to which performance on a cognitive effort task in the laboratory is related to everyday life function using EMA and passive sensing.

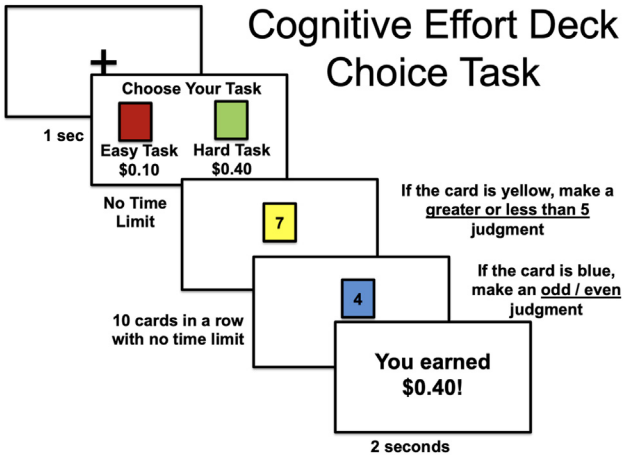

Figure 1. Illustration of the deck choice task.

METHODS AND MATERIALS

Participants

Study participants included 50 people with schizophrenia or schizoaffective disorder (SZ), 58 with bipolar I disorder (BD) with a history of psychosis in any current phase of illness, 60 with MDD as defined by the DSM-5 in a current major depressive episode (C-MDD), and 51 with a past history of a major depressive episode (P-MDD). We included both current and past depression groups to examine trait versus state associations with major depression. Additionally, there were 80 HCs. All participants provided written informed consent to the protocol approved by the Washington University Institutional Review Board. One hundred sixty-three of these individuals completed the tasks in person (40 SZ group, 44 BD group, 49 C-MDD group, and 51 HC group), and 87 (including all of the P-MDD group) completed them remotely via Zoom during COVID-19 in response to the temporary cessation of in-person testing. None of the results below differed as a function of mode of assessment (no interactions with assessment mode) (see the Supplement). Thus, all the data presented below used the entire sample. See the Supplement for inclusion/exclusion and additional study details.

Diagnostic and Symptom Assessment

Diagnostic status, including history of psychosis in the individuals with BD, was confirmed using the Structured Clinical Interview for DSM-5 conducted by master's- or Ph.D.-level clinicians. These clinicians also assessed symptoms using the Structured Clinical Interview for DSM-4-TR Axis I disorders (52), the 24-item Brief Psychiatric Rating Scale (53–55), the Young Mania Rating Scale (56), the Bipolar Depression Rating Scale (57), and the Clinical Assessment Interview for Negative Symptoms (58–60). To assess motivation and pleasure negative symptoms, participants completed the Motivation and Pleasure Self-Report Scale (61) with higher scores indicating more motivation and pleasure across the week (i.e., lower motivation and pleasure negative symptoms). Self-reported depression symptoms were assessed using the Center for Epidemiological Studies Depression Scale (62), and mania symptoms were assessed using the Altman Self-Rating Mania Scale (45).

Deck Choice Task. We used the same cognitive effort–based decision-making task—the deck choice effort task—used previously in studies by Reddy *et al.* (20) and Horan *et al.* (21). In this task (Figure 1), participants make choices from one of two decks of cards. One deck of cards is all the same color (easy deck), and the participant does the same mental task for each card— deciding whether the number on the card is 1) odd or even or 2) above or below 5. The other deck of cards (hard deck) alternates between two colors, one of which has the individual do one mental task (odd/even) and the other a different task (above or below 5). Thus, modulation of cognitive effort in this paradigm is achieved via the amount of mental task switching a participant must perform during each deck. Participants complete practice rounds until they learn which color is associated with which task and achieve 70% accuracy. Participants earn a $0.10 reward for successful completion of an easy deck choice, but hard deck choices can be associated with a $0.10, $0.20, or $0.40 reward. There are 12 choices between easy and hard decks for each of the values of the hard deck (36 total), and participants do the easy or hard task 10 times for each choice. Successful completion is defined as at least 70% accuracy. Outcome measures are the percentage of hard tasks chosen at each of the 3 different reward amounts ($0.10, $0.20, and $0.40). This task has reasonable reliability [intraclass correlation coefficient = 0.63 for change from low to high reward (20)].

Dot Probe Expectancy Task. This task is a measure of the goal representation component of cognitive control (63). See the Supplement for details.

Running Span Task. This task is a measure of working memory (64). See the Supplement for details.

EMA and Passive Sensing

For the 163 individuals who completed the tasks in person, we used the Crosscheck (40) platform to conduct 2 weeks of EMA, along with passive sensing measures of movement during the

day. Crosscheck runs in the background on Android phones and passively collects data. The 87 virtual participants completed the exact same EMA component with the same timing and questions using Qualtrics surveys. Participants using Crosscheck also wore a Garmin Vivosmart 4 fitness watch on their nondominant arm to track steps, heart rate, and sleep throughout the 2-week EMA assessment period. We focused on daily step count as a measure of effort allocation for physical activity in the current analyses, though this measure was not available in the virtual participants.

For EMA, participants were prompted pseudorandomly 4 times a day between 9:30 AM and 8:30 PM and asked to answer questions about what they were currently doing and their current enjoyment and interest level and the same set of questions was asked about anticipated activities in the next 2 hours. We focused on the degree to which participants were currently engaged in putatively goal-directed activities as a measure potentially related to cognitive effort exertion. Goal directed was defined as choosing one or more of the following activities that required them to actively engage in an activity that accomplished some sort of occupational, work, or social task: 1) entertainment away from home, 2) exercising, 3) work/school, 4) running an errand, 5) cleaning/hygiene/chores/cooking, or 6) therapy/doctor's appointment. Nongoal directed was defined as choosing one or more of the following activities that could be passive: 1) eating or drinking, 2) television/radio/reading/computer, 3) socializing, 4) smoking, 5) sleeping, or 6) nothing in particular. Only EMA survey responses that were completed within 20 minutes of survey notification were included in the analyses. Mean response rates were 84% (SD = 18%) and did not differ by group (81%–86.5%; $F_{4,295} = 0.833$, $p = .51$). Consistent with previous EMA research (65), participants were only included in the analyses if they completed at least 33% of the surveys.

Data Analysis

The deck choice task data were analyzed using a repeated-measures analysis of variance in SPSS version 27 that included diagnostic group (HC, SZ, BD, C-MDD, or P-MDD) as a between-subject factor and reward level ($0.10, $0.20, or $0.40) as a within-subject factor. Significant diagnostic group × reward level interactions were followed up by planned comparisons at each reward level. We computed correlations between the percentage of hard task choices in the high reward level ($0.40) and performance on the working memory and cognitive control tasks, as well as the clinician-reported and self-report symptoms. Diagnostic group differences in correlations were compared using a Fisher *r*-to-*z* transformation. The EMA and movement data were analyzed using linear mixed models in R version 4.03 using the lmer function in the package lme4 version 1.1.25. Because engagement in goal-directed activity was a binary outcome (1 or −1), we used a binary logistic linear mixed model for this analysis, using the glmer function in lme4. For these models, we used the percent choice of hard task in the $0.40 reward condition and dummy codes for diagnostic group to predict either being engaged in a goal-directed activity when prompted, or steps taken, with the repeated estimates of the outcome variables across days nested as random effects within participants.

RESULTS

Demographic and Symptom Characteristics

There were no significant group differences in sex or age (Table 1). As expected, there were significant differences in education, with the SZ group having the lowest education; the HC, BD, and C-MDD groups having similar levels of education; and the P-MDD group having the highest level of education. There were also group differences in parental education, with HC having the lowest parental education, significantly lower than BD, C-MDD, and P-MDD, but not different from that of SZ.

Group Differences

As shown in Figure 2, we observed a significant main effect of reward magnitude ($F_{2,588} = 219.86$, $p < .001$, $\eta_p^2 = 0.48$), suggesting that people were more willing to expend cognitive effort as reward value increased. There was also a significant main effect of group ($F_{4,294} = 3.82$, $p = .005$, $\eta_p^2 = 0.049$) that was modified by a significant group × reward interaction ($F_{8,588} = 4.37$, $p < .001$, $\eta_p^2 = 0.056$). Follow-up analyses revealed significant between group differences in hard cognitive task choice in the $0.40 ($F_{4,294} = 6.88$, $p < .001$, $\eta_p^2 = 0.086$) and $0.20 reward conditions ($F_{4,294} = 5.37$, $p < .001$, $\eta_p^2 = 0.068$), but no group differences in the $0.10 reward condition ($F_{4,294} = 1.05$, $p = .383$, $\eta_p^2 = 0.014$). For both the $0.20 and $0.40 reward conditions, these group differences reflected the SZ and BD groups making significantly fewer cognitive hard task choices than the HC, P-MDD, and C-MDD groups. The C-MDD and P-MDD groups did not make fewer cognitive hard task choices than HC in any condition.

Relationships to Cognitive Task Difficulty

One reason that individuals with SZ or BD might be less likely to choose the hard cognitive task is that they could be less capable of performing that task. There were significant group differences in hard cognitive task success ($F_{4,284} = 11.34$, $p < .001$, $\eta_p^2 = 0.138$). However, while individuals with SZ (mean = 48%, SD = 3.0%) were less able to complete the hard cognitive task than HCs (mean = 83%, SD = 2.4%) and those with BD (mean = 75%, SD = 3.3%), C-MDD (mean = 77%, SD = 3.0%), and P-MDD (mean = 79%, SD = 2.8%), the individuals with BD did not differ from those in the HC, C-MDD, or P-MDD groups in their ability to complete the hard cognitive task. Furthermore, when we included hard accuracy as a covariate in the analysis of variance, we still saw a significant group × reward interaction ($F_{8,566} = 2.15$, $p < .05$, $\eta_p^2 = 0.029$). We also found that the significant group × reward interaction remained for both education ($F_{8,586} = 2.32$, $p < .05$, $\eta_p^2 = 0.031$) and reading level ($F_{8,584} = 2.99$, $p = .003$, $\eta_p^2 = 0.039$) as covariates. Thus, the deficits in willingness to exert effort for reward among the individuals with SZ and BD were not secondary to difficulties in performing the task or lower education or reading levels.

Relationship to Working Memory and Cognitive Control

Because the SZ and BD groups performed similarly on the deck choice task, as did the C- and P-MDD groups, we combined each of these to create 3 groups (SZ/BD, C-/P-

Table 1. Participant Demographics and Clinical Measures

	HC, *n* = 80	SZ, *n* = 50	BD, *n* = 58	C-MDD, *n* = 60	P-MDD, *n* = 51	Group Differences, *p* Value	Pattern
Sex, Female:Male	47:33	28:22	37:21	37:23	29:22	.75	–
Race							
African American	39	31	10	22	10	<.001	–
Caucasian	37	19	45	37	39	<.001	–
Additional races	4	0	3	1	2	<.001	–
Age, Years	36.39 (9.19)	35.83 (8.51)	37.56 (8.78)	33.63 (8.71)	36.45 (8.44)	.16	–
Education, Years	15.58 (2.38)	13.58 (2.30)	15.09 (2.51)	15.07 (2.24)	16.49 (2.43)	<.001	P-MDD > HC = BD = C-MDD > SZ
Parental Education, Years	13.58 (2.75)	14.28 (3.02)	14.79 (3.09)	15.17 (2.69)	16.06 (2.98)	<.001	P-MDD > HC = SZ = BD; BD = C-MDD > HC
WTAR	37.04 (9.26)	31.04 (12.06)	39.67 (8.76)	37.17 (9.56)	41.72 (7.42)	<.001	P-MDD > HC, BD, C-MDD > SZ
Unmedicated	100%	20%	16%	29%	50%	–	–
Antidepressant	0	52%	71%	68%	48%	–	–
Mood Stabilizer	0	14%	59%	7%	6%	–	–
Antipsychotic	0	80%	36%	10%	4%	–	–
CPZ	–	481.2 (263.0)	342.7 (212.5)	167.7 (111.7)	175.0 (35.4)	–	–
Dot Probe Expectancy d′-Context	2.62 (1.25)	1.58 (1.09)	2.27 (1.16)	2.52 (0.97)	2.37 (1.26)	<.001	HC = BD = C-MDD = P-MDD > SZ
Running Span Total Correct	47.83 (15.4)	34.43 (15.9)	44.36 (17.2)	43.82 (14.8)	–	.002	HC = BD = C-MDD > SZ
CAINS—Motivation and Pleasure Deficits	–	14.50 (7.74)	10.98 (6.35)	14.32 (5.59)	9.45 (5.42)	<.001	SZ = C-MDD > BD = P-MDD
BPRS Depression	–	10.06 (4.03)	9.81 (4.39)	13.48 (3.20)	9.37 (3.57)	<.001	C-MDD > SZ = BD = P-MDD
BPRS Mania	–	7.58 (2.79)	7.76 (4.30)	5.53 (0.91)	6.00 (1.15)	<.001	SZ = BD > C-MDD = P-MDD
BPRS Negative	–	8.04 (2.79)	6.05 (2.38)	6.62 (2.27)	6.16 (2.17)	<.001	SZ > BD = C-MDD = P-MDD
BPRS Positive	–	9.56 (4.31)	4.21 (2.25)	3.55 (1.10)	3.35 (0.96)	<.001	SZ > BD = C-MDD = P-MDD
CES-D	5.48 (3.46)	12.06 (6.66)	11.64 (6.34)	16.08 (5.04)	9.63 (5.33)	<.001	C = MDD > SZ = BD > P-MDD > HC
MAP-SR	41.95 (9.86)	33.57 (12.46)	36.28 (9.74)	28.85 (9.59)	36.80 (8.87)	<.001	C-MDD < SZ < BD = P-MDD < HC
ASRM	4.72 (4.18)	4.60 (3.12)	4.72 (4.13)	2.80 (2.87)	2.76 (2.96)	.001	HC = SZ = BD > C-MDD = P-MDD

Values are provided as *n*, mean (SD), or %. Higher MAP-SR scores indicate more motivation and pleasure across the week (i.e., lower motivation and pleasure negative symptoms).

ASRM, Altman Self-Rating Mania Scale; BD, bipolar disorder; BPRS, Brief Psychiatric Rating Scale; CAINS, Clinical Assessment Interview for Negative Symptoms; CES-D, Center for Epidemiological Studies Depression Scale; C-MDD, current major depressive disorder; CPZ, chlorpromazine-equivalent dose; HC, healthy control participant; MAP-SR, Motivation and Pleasure Self-Report; MDD, major depressive disorder; P-MDD, past major depressive disorder; SZ, schizophrenia; WTAR, Wechsler Test of Adult Reading.

MDD, and HC) for the correlational analyses. As shown in Table 2, running span task performance as a measure of working memory was significantly positively associated with the percentage of hard task choices in the highest reward conditions in SZ/BD, but not in HC or C-/P-MDD groups, though the magnitude of these correlations did not differ significantly across groups. d′-context on the dot probe expectancy task as a measure of cognitive control was significantly positively associated with the percentage of hard task choices in the highest reward conditions in both the HC and SZ/BD groups, but not in the MDD group. Furthermore, the magnitude of the association was significantly stronger in the SZ/BD group compared with the MDD group (Table 2).

Relationships With Symptoms

As shown in Table 2, among the SZ/BD group, clinician-rated motivation and pleasure symptoms were negatively associated

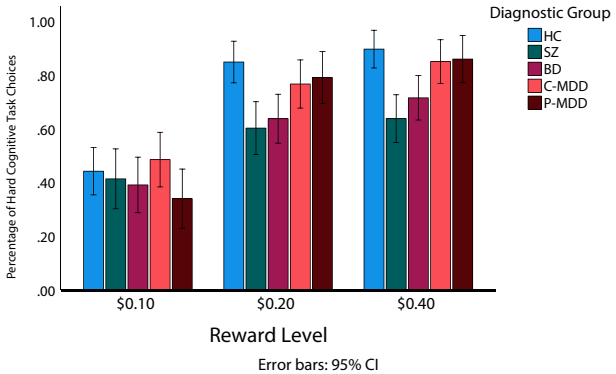

Figure 2. Percentage of hard cognitive task choices across groups. Error bars reflect 95% CIs. BD, bipolar disorder; C-MDD, current major depressive disorder; HC, healthy control participant; P-MDD, past major depressive disorder; SZ, schizophrenia.

Table 2. Correlations With Percentage or Hard Task Choices in the Highest Reward Condition ($0.40)

	Correlations			Fisher's *r*-to-*z* Transformations Comparing Correlations Across Groups		
Measure	HC	SZ and BD	C-MDD and P-MDD	HC vs. SZ/BD	HC vs. C-MDD/P-MDD	SZ/BD vs. C-MDD/P-MDD
Running Span Percent Correct	0.22	0.26[a]	0.15	$Z = 0.22$	$Z = 0.34$	$Z = 0.60$
Dot Probe Expectancy d′-Context	0.26[a]	0.37[b]	0.18	$Z = 0.77$	$Z = 1.24$	$Z = 2.19$[a]
CAINS Motivation and Pleasure	NA	−0.29[a]	−0.06	NA	NA	$Z = -1.74$[a]
BPRS Depression	NA	−0.09	0.08	NA	NA	$Z = -1.24$
Motivation and Pleasure Self-Report	0.14	0.10	0.001	$Z = -0.33$	$Z = 1.00$	$Z = 0.72$
Center for Epidemiological Studies Depression Scale	0.03	0.05	0.07	$Z = 0.13$	$Z = -0.26$	$Z = -0.15$

Higher scores on the Motivation and Pleasure Self-Report Scale indicate more motivation and pleasure across the week (i.e., lower motivation and pleasure negative symptoms).

BD, bipolar disorder; BPRS, Brief Psychiatric Rating Scale; CAINS, Clinical Assessment Interview for Negative Symptoms; C-MDD, current major depressive disorder; HC, healthy control participant; NA, not applicable; P-MDD, past major depressive disorder; SZ, schizophrenia.

[a]$p < .05$.

[b]$p < .01$.

with the percentage of hard task choices in SZ/BD, but not in C-/P-MDD. This relationship was significantly stronger in the SZ/BD compared with the MDD group. Clinician-rated depression symptoms were not related to the percentage of hard task choices in either group. Self-reported motivation and pleasure symptoms and depression were also not related to cognitive hard task choice in any group (Table 2).

Relationships to Engagement in Goal-Directed Activities or Locomotion

The binary logistic linear mixed effect model predicting the likelihood of being engaged in a goal-directed activity when questioned via EMA indicated a significant positive relationship to the percent of hard task choices at the $0.40 reward level (standardized coefficient [SDCoef.] = 0.19, $z = 3.54$, $p = .0004$). When we added the 3 group factor (HC, SZ/BD, C-/P-MDD) to the glmer model, the relationship of percent of hard task choices at the $0.40 reward level to likelihood of being engaged in goal-directed activities remained significant (SDCoef. = 0.11, $z = 2.11$, $p = .035$). Interestingly, both patient groups were less likely to be engaged in goal-directed activities than HCs, though the magnitude of this difference was larger for the SZ/BD (SDCoef. = −0.33, $z = -5.27$, $p < .0001$) than the MDD (SDCoef. = −0.14, $t_{289} = -2.29$, $p = .022$) group. A model that included interactions between the group factor and percent hard task choices in predicting goal-directed activity fit the data worse (Bayesian information criterion = 17,876.3 for interaction model vs. 17,859.9 without), and neither interaction term was significant ($p > .50$). When we examined this relationship within each group, it was only significant in the SZ/BD group (SDCoef. = 0.19, $z = 2.618$, $p < .009$) and not in the HC (SDCoef. = 0.06, $z = .71$, $p = .479$) or MDD groups (SDCoef. = −0.01, $z = -0.135$, $p = .893$). Thus, task performance and diagnostic group status demonstrated independent relationships with engagement in goal-directed activities, with some evidence of stronger relations in SZ/BD.

There was also a significant positive relationship between percent of hard task choices and number of steps taken during the day (SDCoef. = 0.22, $z = 2.45$, $p = .0155$). This effect remained significant (SDCoef. = 0.20, $z = 2.10$, $p = .0369$) in a model that included the group factor, and neither group differed from the HC group in the number of steps taken per day. There were, again, no significant interactions between group and percent hard task choices in relationship to steps taken ($ps > .80$), and, in this case, none of the within-group associations was significant, though the closest was the SZ/BD group (SDCoef. = 0.22, $z = 1.68$, $p = .0974$).

DISCUSSION

We found evidence of reduced willingness to exert cognitive effort compared with HCs among individuals with SZ and BD with psychosis, but not among those with C- or P-MDD. We also found that reduced cognitive ECDM was related to impaired working memory and cognitive control and to clinician-rated symptoms of reduced motivation and pleasure in individuals with SZ and BD, but not among those with C- or P-MDD. Furthermore, willingness to exert cognitive effort in the laboratory-based task was related to the likelihood of being engaged in goal-directed activities in everyday life via EMA in the SZ/BD group, but not in the C-/P-MDD group, though the average number of steps taken during the day was related across all groups. There was also a significant reduction in goal-directed activities among all diagnostic groups compared with the HC group, with the largest differences among individuals with SZ and BD. Together, these findings challenge the hypothesis that the same mechanisms contribute to motivational impairments across SZ, BD, and MDD, instead suggesting commonalities across SZ and BD with psychosis that may not extend to MDD.

Our findings demonstrate that both individuals with SZ and those with BD with psychosis show a reduced willingness to exert cognitive effort as a function of reward compared with HCs, with the largest group differences in the highest reward condition. This pattern in SZ replicates many previous findings with both cognitive (18–22) and physical (20,21,23–32) effort allocation. However, no previous research has examined cognitive effort allocation in a BD group. Our findings in BD are consistent with several previous studies that found reduced willingness to exert physical effort as a function of reward (23–25,37) but contrast with 2 other studies that did not find

such a reduction (24,43). One intriguing potential cause of the variability across studies is whether the individuals with BD had psychosis. All the individuals with BD in the current study had a history of psychosis. Hershenberg *et al.* (37), Wang *et al.* (23), and Zou *et al.* (25) did not specify whether the individuals with BD in their studies had psychosis, and they all observed deficits in willingness to exert physical effort. Yang *et al.* (24) found deficits in individuals with BD in a manic phase, 10 of whom had psychosis. However, all individuals with BD in the Whitton *et al.* (43) study had psychosis but did not show physical effort allocation deficits. Notably, however, Whitton *et al.* never presented demographic or clinical information separately as a function of diagnostic group, so it is difficult to know whether there may have been confounding factors that might have affected the findings. Nonetheless, the fact that the individuals with SZ and BD with psychosis showed very similar patterns of cognitive ECDM deficits is consistent with a large body of literature, suggesting commonalities across these putatively different disorders in terms of genetics, neurobiology, and cognitive function (64,66–71) and providing evidence consistent with the idea that BD with psychosis may be part of a spectrum of psychotic disorders.

In striking contrast to the findings in SZ and BD with psychosis, neither the individuals with current depression nor those with past depression showed any evidence of a reduced willingness to exert cognitive effort. It is difficult to say whether this is consistent with the prior literature on either physical or cognitive effort allocation in depression because the previous work in this area has been mixed, with several studies finding physical ECDM deficits in depression (25,33–37) but others not finding such deficits (23,24,38,39). Work on cognitive ECDM has been similarly mixed, with 2 studies finding greater discounting of reward as a function of cognitive effort in depression (41,42), but other work (38) finding no differences in willingness to exert cognitive effort as a function of reward. As with the mixed findings in BD, it is not clear what drives the variability in findings across studies of depression. One possibility is that it could have something to do with an aspect of depressive disorder severity that has not yet been systematically examined, such as age of onset, number of prior episodes, or comorbid anxiety, hypotheses that could be tested in future studies.

In the current study, the individuals with current depression showed similar levels of clinician-rated symptoms of reduced motivation and pleasure to those of individuals with SZ and more symptoms than individuals with BD. Furthermore, they self-reported worse symptoms of motivation and pleasure than individuals with either SZ or BD (who did not differ). Thus, the differences at the group level between individuals with SZ/BD and MDD in the current study cannot easily be explained by less severe symptoms of impaired motivation in C-MDD compared with the other groups. Furthermore, when we examined the relationship of clinician-rated motivation and pleasure symptoms to ECDM, there was a relationship in the SZ/BD group, but not the C-/P-MDD group, and this relationship was significantly greater in SZ/BD than in MDD. We also found that cognitive ECDM performance was related to working memory and cognitive control performance in the SZ/BD, but not in the MDD group, again with significantly stronger associations in the SZ/BD group (at least for cognitive control). Together these results are consistent with the idea that the mechanisms contributing to deficits in motivation differ across individuals in the psychosis spectrum versus MDD. Furthermore, they suggest that ECDM deficits play a more important role in motivational impairments in the psychosis spectrum than in depression, with potential contributions from cognitive impairment. The latter hypothesis is consistent with the fact that there tends to be associations between negative symptoms in psychosis (which include motivation impairments) and cognitive dysfunction (72).

The data hint that the relationship of cognitive ECDM to everyday life function as measured by EMA differed between the psychosis spectrum and depression groups. We found that the number of hard task choices in the highest reward value predicted greater likelihood of being engaged in goal-directed activities at the time of EMA prompts. While the diagnostic group also predicted reduced engagement in goal-directed activities, particularly among the SZ/BD group, the relation of cognitive effort exertion remained independent of group status. There was no significant modulation of this relationship by group, but the association of cognitive ECDM performance and engagement in goal-directed activities was only significant in the SZ/BD group and nonexistent in the MDD group. We also found that better ECDM task performance predicted more daily steps taken on average. This association was again independent of group status, with no group differences in steps taken, though, again, data hinted at a stronger relationship in the SZ/BD group. Taken together, these findings provide support for a link between cognitive ECDM and function in everyday life, for both engagement in goal-directed activities and steps taken, which are intriguingly likely to involve both cognitive and physical effort exertion. These findings also provide some evidence consistent with this relationship's being different in the SZ/BD than the MDD group, at least for goal-directed activities. In future work, it will be important to provide even more detailed examination of the nature of goal-directed activities (what kinds of work, what type of schooling, etc.) being performed in everyday life, as this may reveal even stronger evidence for diagnostic group differences in the relationship between willingness to exert cognitive effort and function in everyday life.

These findings must be interpreted in the context of several limitations. The data are cross-sectional, and longitudinal analyses of the variation in laboratory-based assessments and function in everyday life would help to establish the robustness of such relationships. In addition, we did not have a BD group without a history of psychosis or an MDD group with psychosis. Thus, we cannot fully assess the degree to which the presence of psychosis is critical in determining the presence of relationships between cognitive ECDM and symptoms of motivational impairment and measures of function in everyday life. Furthermore, a subset of the participants completed the tasks virtually (including all the individuals with P-MDD), though we did not find that the results differed meaningfully as a function of in-person versus virtual assessment, and the individuals with C- and P-MDD performed almost identically. Finally, we found relationships to clinician-rated motivation and pleasure symptoms, but not to the same domain of self-report symptoms. Further work will be needed to determine why results differ across clinician versus self-report, and whether one or the other might be more predictive of different domains of motivation-relevant behaviors.

In summary, the current study provides strong evidence for the differential presence of deficits in cognitive ECDM among individuals with psychosis spectrum disorders (but not among individuals with current or past depression). Furthermore, we found evidence for differential relationships of cognitive ECDM to symptoms, cognitive function, and everyday life function as measured by EMA among individuals with psychosis spectrum disorders, but not among those with depression. These differential relationships suggest that the mechanisms contributing to motivational impairments are not fully transdiagnostic and differ across the psychosis versus nonpsychosis divide.

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