Archival Report

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Associations Between Cognitive and Physical Effort–Based Decision Making in People With Schizophrenia and Healthy Control Subjects

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ABSTRACT

BACKGROUND: Effort can take a variety of forms including physical (e.g., button pressing) and cognitive (e.g., working memory tasks). Few studies have examined whether individual differences in willingness to expend effort are similar or different across modalities.

METHODS: We recruited 30 individuals with schizophrenia and 44 healthy control subjects to complete 2 effort-cost decision-making tasks: the Effort Expenditure for Rewards Task (physical effort) and the cognitive effort discounting task (cognitive effort).

RESULTS: Willingness to expend cognitive and physical effort was positively associated for both individuals with schizophrenia and control subjects. Further, we found that individual differences in motivation and pleasure dimension of negative symptoms modulated the association between physical and cognitive effort. Specifically, participants with lower motivation and pleasure scores, irrespective of group status, showed stronger associations between task measures of cognitive and physical effort-cost decision making.

CONCLUSIONS: These results suggest a generalized deficit across effort modalities in individuals with schizophrenia. Further, reductions in motivation and pleasure may impact effort-cost decision making in a domain-general manner.

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Daily decision making involves choices about exerting cognitive or physical effort. For example, a student may decide to study an additional hour (cognitive effort), hoping to achieve a higher grade on an upcoming examination. Similarly, Texas Longhorns athletes may decide to complete an additional workout (physical effort), hoping to defeat their rival, the Oklahoma Sooners. In the current study, we were interested in determining the extent to which people's willingness to expend cognitive and physical effort is related.

Recently, experimental tasks have been developed that assess individual differences in willingness to exert physical (1–3) or cognitive (4,5) effort for monetary rewards. In the basic science literature, these tasks have been instrumental in quantifying individual differences in the subjective cost of effort (1–4). Further, in the clinical literature, recent work using these tasks has suggested that physical and cognitive effort-cost decision making (ECDM) may be a potential contributor to the motivation and pleasure (MAP) dimension of negative symptoms in schizophrenia (6–8). Specifically, research has shown that people with schizophrenia are less willing than control subjects to exert physical and cognitive effort to obtain rewards on experimental tasks (8–20). Further, many studies show relationships between effort and MAP, such that schizophrenia patients with the highest MAP symptoms show the least willingness to expend effort for rewards (9,14,21–23). However, few studies have collected both physical and cognitive ECDM tasks in the same participants. Such data are imperative for determining the extent to which aspects of ECDM are domain general versus modality specific, a key question for existing models. Similarly, the extent to which aspects of psychopathology (e.g., MAP, cognitive deficits) modulate ECDM in a domain-general versus modality-specific manner is unknown, a key question for the clinical literature. For example, avolition, a cardinal negative symptom, is frequently described in the schizophrenia literature as a general reduction in purposeful behavior (24). However, there is little empirical work supporting the claim that avolition acts as a domain-general process. Work attempting to parse domain-general versus modality-specific motivational processes may help clarify the nature of avolition.

A small number of studies have collected data from cognitive and physical ECDM tasks in the same subjects. Lopez-Gamundi and Wardle (25) conducted both physical and cognitive variants of an ECDM task in healthy individuals and found that willingness to expend effort on these task variants was positively correlated. Further, work in a community sample (N = 144) found that parameter estimates from effort discounting models fit to cognitive and physical ECDM tasks were positively correlated, suggesting similar discounting during decision making (26). Tran *et al.* (27) administered both

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cognitive and physical ECDM tasks to people with major depressive disorder and control participants, finding that severity of anhedonia predicted lower motivation for physical, but not cognitive, effort. However, no association analyses between tasks were reported. Finally, Horan *et al.* (11) compared performance across multiple ECDM tasks (including a cognitive variant and 2 physical variants) in people with schizophrenia and control subjects. A factor analysis across tasks revealed a single factor explaining approximately 53% of the variance, suggesting that these task measures might be reflecting, in part, a single unitary construct (11). Thus, a small literature suggests a positive association between willingness to expend cognitive and physical effort. However, replication of these results is needed. Further, it is currently unknown whether the magnitude of this association is similar across diagnostic groups and whether aspects of psychopathology (e.g., MAP, cognitive deficits) impact cognitive and physical ECDM in a similar manner.

While the above-mentioned work suggests the presence of domain-general components of ECDM, several recent studies have emphasized domain-specific effects. For example, Horan *et al.* (11) finding that a single factor explained approximately 53% of the variance across ECDM tasks suggests that approximately 47% of the variance is explained by either measurement noise or domain-specific effects. Further, while some authors have demonstrated similar discounting rates for physical and cognitive effort in gain and loss contexts (28), others have shown differences (29). Chong *et al.* (30) have shown that the shape of cognitive effort discounting curves is different in elite athletes compared with nonathletic control subjects, suggesting that greater physical motivation may accompany a fundamentally different pattern of cognitive ECDM. Finally, researchers have shown that individuals with premanifest Huntington's disease show reduced cognitive, but not physical, ECDM compared with control subjects, indicating a domain-specific motivational impairment early in the course of illness (31). Thus, while the literature does suggest the presence of domain-general components, many studies also point to the importance of domain-specific effects.

Current Study

In the current study, individuals with schizophrenia and control subjects completed both cognitive and physical ECDM tasks. Our primary research aim was to determine the degree to which an individual's willingness to expend cognitive and physical effort is related. Given previous work, we hypothesized that willingness to expend cognitive and physical effort would be positively correlated (26,32). Further, we aimed to extend this work by showing associations between cognitive and physical ECDM in control subjects and people with schizophrenia. We did not have strong predictions as to whether the magnitude of this association would differ by diagnostic group. Our second aim was exploratory. Specifically, we analyzed whether factors known to be important for ECDM (i.e., cognitive performance and MAP) modulate the association (i.e., bivariate correlation) between physical and cognitive ECDM. Here, we hypothesized that individuals with lower MAP may show stronger associations between cognitive and physical ECDM task indices, suggesting a domain-general impairment in willingness to exert effort in individuals with lower MAP. In addition, we hypothesized that individuals with higher levels of cognitive ability may show stronger associations between cognitive and physical effort, given that higher-order cognitive functions are thought to be necessary for both types of ECDM.

METHODS AND MATERIALS

Participants

The current analyses were performed using data collected across 2 separate studies. Task effects and group difference analyses for the cognitive effort discounting (COGED) task paradigm have been described in prior publications. The analyses reported in this article are original and have not been reported elsewhere (22,33).

Study participants included 30 individuals meeting DSM-IV criteria for schizophrenia or schizoaffective disorder and 44 demographically matched control participants with no personal or family history of psychosis. Our primary aim was to determine the extent to which cognitive and physical ECDM are associated. Our sample provided >75% power to observe effects of $r = 0.4$ or greater for this association analysis at a type I error rate of $\alpha < 0.05$ in either group. This effect size is similar to a previous report (25). While we were adequately powered to examine our primary aim, our sample size was modest to examine differences and potential modifiers of this association. Thus, results from our exploratory, secondary aim must be interpreted as preliminary and will need to be replicated in a larger sample.

Participants were recruited from the St. Louis, Missouri, community. Exclusion criteria included DSM-IV diagnosis of substance abuse or dependence in the last year, DSM-IV diagnosis of a current major depressive episode, changes in medication dosage 2 weeks before consent, past head injury with documented neurological sequelae and/or loss of consciousness, and Wechsler Test of Adult Reading (WTAR) Estimated Full-Scale IQ <70 (34). All participants were required to pass a urine drug screen. There were no significant group differences in terms of age, biological sex, racial identity, or parental education (Table 1). The Washington University Institutional Review Board approved the study, and participants provided written, informed consent in accordance with the Washington University Human Subject Committee criteria.

Diagnostic and Symptom Assessment

Diagnoses were determined by the Structured Clinical Interview for DSM-IV-TR (35). To assess individual differences in MAP symptoms, all participants completed the Motivation and Pleasure Scale–Self-Report (MAP-SR) (36). The MAP-SR includes a total score with higher scores equaling more MAP across the week. We also collected the Brief Psychiatric Rating Scale (37), Beck Depression Inventory, Second Edition (38), and Clinical Assessment for Negative Symptoms (39) in participants with schizophrenia to assess positive, depressive, and negative symptoms, respectively.

ECDM Tasks

Effort Expenditure for Rewards Task. Participants performed a modified version of the Effort Expenditure for

Table 1. Participant Demographics, Clinical Measures, and Cognitive Task Performance

	Control Group, n = 44	Schizophrenia Group, n = 30	Statistical Test	
			Test Statistic	p Value
Age, Years, Mean (SD)	36.2 (11.2)	38.3 (12.6)	$t = -0.7$	.5
Gender, Female, %	32%	30%	$\chi^2 = 0.03$	.9
Racial Identity, %			$\chi^2 = 2.2$	.3
Asian	13.60%	3%		
Black	50%	57%		
White	36.40%	40%		
Education, Years, Mean (SD)				
Parental	14.4 (2.8)	14.3 (3.7)	$t = 0.2$	.9
Participant	15.6 (2.3)	12.8 (2.9)	$t = 4.7$	<.001
Cognitive Score, Mean (SD)				
WTAR Standard Score	96.9 (19.9)	92.7 (19.9)	$t = 0.89$	.4
n-back performance				
1-back d'	2.9 (1.3)	2.0 (1.3)	$t = 2.8$	.007
2-back d'	1.6 (1.0)	1.1 (0.8)	$t = 2.4$	.02
3-back d'	1.2 (0.8)	0.7 (0.9)	$t = 2.6$	.01
4-back d'	1.0 (0.6)	0.5 (0.8)	$t = 3.1$	.002
Average d'	1.7 (0.8)	1.1 (0.8)	$t = 3.1$	.003
Clinical Characterization Score, Mean (SD)				
MAP-SR	41.7 (9.6)	36.7 (9.4)	$t = 2.2$	.03
CAINS total		22.2 (7.4)		
BPRS total		38.1 (8.0)		
BPRS reality distortion subscale		7.8 (4.2)		
BDI-II total		13.7 (9.1)		

BDI-II, Beck Depression Inventory, Second Edition; BPRS, Brief Psychiatric Rating Scale; CAINS, Clinical Assessment Interview for Negative Symptoms; MAP-SR, Motivation and Pleasure–Self-Report; WTAR, Wechsler Test of Adult Reading.

Rewards Task (EEfRT) (11) developed by Treadway *et al.* (1). In the task, participants make repeated choices between completing an easy or hard button-pressing task for varying amounts of reward. The easy task involves making 20 dominant index finger button presses in a 7-second window for the opportunity to win $1. The hard task involves making 100 nondominant pinky finger button presses in a 21-second window for the opportunity to win between $1.24 and $4.30. At the beginning of each trial, participants are told the amount of money they could earn for each task as well as the probability of reward receipt (50% or 88%). Participants completed a total of 54 trials. For each participant, the percentage of hard task choice across all trials was calculated (EEfRT average) and used as a trait measure of global willingness to expend physical effort.

COGED Task. Participants completed a modified version of the COGED task (10), originally developed by Westbrook *et al.* (4). In this task, participants first practiced increasingly difficult versions of a cognitively demanding working memory task, the n-back (1–4 back) task. Specifically, the participants completed two 64-trial runs of each n-back level; each run consists of 16 target trials and 48 nontargets. Next, they made a series of choices about repeating one task up to 10 more times for cash rewards. Participants are instructed that they need to perform only as well on the n-back tasks as they performed during the practice phase to receive payment. Specifically, each decision trial involved a two-alternative forced choice between completing a more demanding level of the n-back (2–4 back) task for a greater reward or a less demanding level (1-back) for a smaller reward. Critically, after each choice the reward amount for the 1-back was titrated until participants were indifferent between the base offer for the harder task and the offer for the 1-back. This indifference point was then divided by the base offer amount for the hard task to quantify a subjective value for each hard task-base amount pair. In the current study, 3 high-demand n-back levels (n = 2–4) and 2 base reward amounts ($2 and $4) were used. Finally, one of the participant's choices was selected at random to determine the task that they were required to repeat and the amount they were paid. For each participant, the estimated subjective values were averaged across the 6 across task-amount pairs (COGED task average) and used as a trait measure of global willingness to expend cognitive effort.

n-Back Performance. For each level of the n-back, the sensitivity index, d', was used to quantify performance, controlling for target or nontarget response biases. Raw d' values were adjusted by the log linear transformation to address extreme false-alarm and hit proportions (40). For each participant, the 4 n-back levels were averaged to obtain a single measure of cognitive task performance, d' average.

Data Analysis

ECDM Task Performance. For the EEfRT, trials were first grouped into quartile categories based on hard task offer value (low: <$1.96; medium: $1.96 to <$2.77; high: $2.77 to

<\$3.58; highest ≥\$3.58) (9). Next, we conducted a repeated measures analysis of variance where the dependent measure was percentage of hard task choices, and reward probability (50% or 88%) and hard task reward value quartile were within-subjects factors. Diagnosis (coded: −0.5 = control, 0.5 = schizophrenia) was a between-subjects factor.

For the COGED task, subjective effort costs were quantified as the subjective value of discounted rewards. Specifically, the indifference point for a given task-amount pair was divided by the base amount to yield a subjective value. For example, if a participant was indifferent between \$1.43 for the 1-back and \$2 for the 2-back, then the subjective value for the \$2, 2-back pair would be \$1.43/\$2 = 0.715. Greater subjective value estimates equal a greater willingness to choose the high-effort option. A hierarchical linear model was used to account for the hierarchical nesting of indifference points within participants (4,10). Specifically, task level (2-back–4-back), diagnostic group (coded: −0.5 = control, 0.5 = schizophrenia), and their interaction were included as predictors of subjective value. Models were fit in R using the lmer4 package, version 1.1-7 (R Foundation for Statistical Computing).

Associations Between Cognitive and Physical ECDM. Given the non-normal distribution of task measures, Spearman rank-order correlations were conducted within each group to assess associations between willingness to engage in cognitive (COGED task average) and physical (EEfRT average) effort. This analysis was performed across groups as well as within each group separately. To examine group differences in the Spearman correlations, a *z*-transformation was performed on the rho values for each group, and the *z* scores were compared.

Factors That Modulated the Association Between Cognitive and Physical ECDM. As an exploratory aim, we examined whether factors that have been previously related to ECDM, cognitive performance (d' average) and MAP (MAP-SR), modulated the association between physical and cognitive ECDM. To this end, we ran 2 regression models across groups. In the first model, EEfRT average was the dependent variable, and COGED task average, MAP-SR, their interaction, and group status (coded: −0.5 = control, 0.5 = schizophrenia) were entered as predictors. This model was implemented to determine if individual differences in MAP modulated the association between physical and cognitive effort. In the second model, EEfRT average was the dependent variable, and COGED task average, d' average, their interaction, and group (coded: −0.5 = control, 0.5 = schizophrenia) were entered as predictors. This model was implemented to determine if cognitive performance modulated the association between physical and cognitive effort.

RESULTS

MAP-SR and n-Back Performance

Similar to previous reports, individuals with schizophrenia performed significantly worse than control subjects on every level of the n-back (Table 1) (41,42). People with schizophrenia self-reported significantly less MAP than control subjects (Table 1).

ECDM Task Behavior

Effort Expenditure for Rewards Task. We found significant main effects of probability ($F_{3,72}$ = 42.6, $p < .001$) and reward level ($F_{3,72}$ = 89.3, $p < .001$) with a greater chance of the participants choosing the hard task as the reward probability and hard task reward value increased (Figure 1A, B). In contrast to previous reports (9,13), we did not find a significant main effect of group or interactions between group and reward or probability levels ($ps > .12$). Given that effects of effort aversion in the schizophrenia literature have been most notable

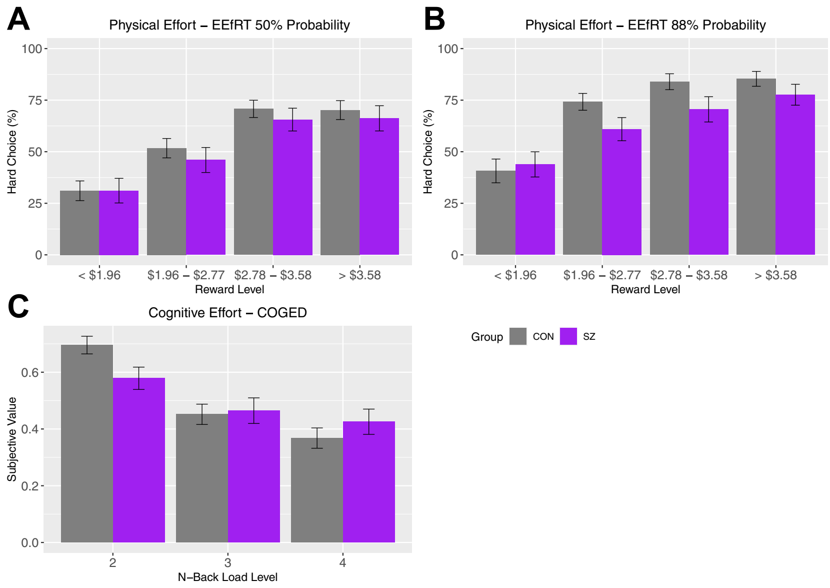

Figure 1. Effort-cost decision-making task performance by group. **(A)** Physical effort, Effort Expenditure for Rewards Task (EEfRT) 50% probability. **(B)** Physical effort, EEfRT 88% probability. **(C)** Cognitive effort, cognitive effort discounting (COGED) task. CON, control group; SZ, schizophrenia group.

Table 2. COGED Task: Hierarchical Linear Model Predicting Subjective Value

	Estimate	Standard Error	*t* Value	*p* Value
Intercept	0.74	0.04	17.60	>.001
n-Back Level	−0.12	0.02	−6.39	>.001
Diagnostic Group	−0.19	0.08	−2.27	.02
Group × n-Back Level	0.09	0.04	2.32	.02

COGED, cognitive effort discounting.

at the highest reward probability levels (9,13), we conducted a supplementary repeated measures analysis of variance including only 88% reward probability choices. Here, we observed a significant effect of reward value ($F_{3,72} = 56.0$, $p < .001$) and a significant reward × group interaction ($F_{3,72} = 2.7$, $p = .04$), such that people with schizophrenia showed a reduced willingness to choose the hard task as the reward value for the hard task increased. In contrast, the group × reward interaction was not significant in a model including only the 50% reward probability choices ($p = .88$) These effects are similar to previous reports (9,13).

COGED Task. Both participants with schizophrenia and control subjects discounted reward offers for higher levels of the n-back task and did so in a mostly monotonic fashion (Figure 1C, Table 2). Thus, participant discounting was sensitive to cognitive task load, and subjective costs of effort increased with objective demands. There was a trend-level effect of group and a significant group × n-back level interaction (Table 2). Here, the control group less steeply discounted reward offers as the n-back task difficulty increased. Consistent with prior literature (10,22), this interaction appeared to be driven by steep discounting of rewards by individuals with schizophrenia compared with control subjects at the 2-back load level (Figure 1C).

Associations Between Cognitive and Physical ECDM

Figure 2 illustrates the positive association between cognitive (COGED task average) and physical (EEfRT average) ECDM. The association was significant when conducted across groups (Spearman's $\rho = 0.43$, $p < .001$) as well as within each group separately (control: Spearman's $\rho = 0.37$, $p = .01$; schizophrenia: Spearman's $\rho = 0.51$, $p = .004$). The magnitude of the correlation was not significantly different between groups (z score = 0.7, $p = .48$). Finally, we examined whether the effect of reward magnitude on ECDM was associated across the COGED task and EEfRT. Surprisingly, reward magnitude effects were not significantly associated across tasks (Figure S1).

Factors That Modulated the Association Between Cognitive and Physical ECDM

Next, we examined our exploratory aim—whether 2 factors known to be important for ECDM, MAP and cognitive performance, modulated the strength of the association between cognitive and physical effort (Table 3). See Table S1 for bivariate correlations between study variables.

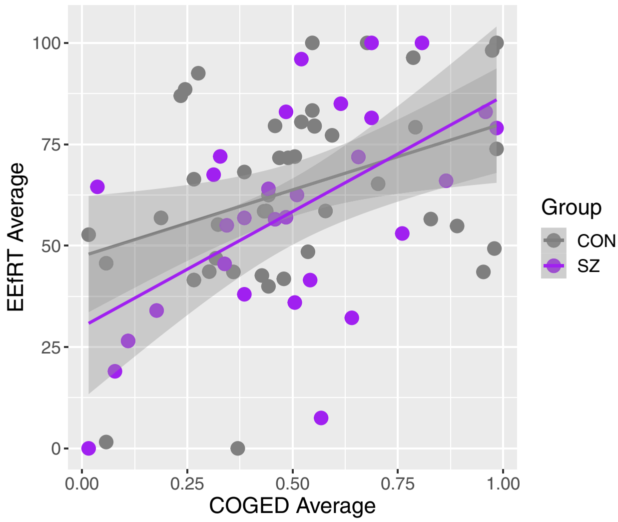

Figure 2. Positive association between physical and cognitive effort-cost decision making. COGED, cognitive effort discounting (task); CON, control group; EEfRT, Effort Expenditure for Rewards Task; SZ, schizophrenia group.

In the first regression model, we included COGED task average, MAP-SR, their interaction, and group as predictors of EEfRT average (Table 3). Here, as expected, COGED task average and MAP-SR were positively associated with EEfRT average, although the beta coefficient for MAP-SR did not reach statistical significance. However, there was a COGED task average × MAP-SR interaction, such that the association between cognitive and physical effort was strengthened for participants with lower levels of MAP (Table 3). Critically, this interaction remained significant in a model that included diagnostic group as a covariate, suggesting that individual differences in MAP may be important to this association irrespective of group status. Finally, to determine whether the MAP-SR × COGED task average interaction differed between groups, we conducted a hierarchical regression (Table S2). Specifically, the aforementioned model was used as a base model. Next, we entered interaction terms for MAP-SR × group, COGED task average × group, and MAP-SR × COGED task average × group in the base model to determine if including these interaction terms accounted for more of the variability in EEfRT average. Importantly, this model did not account for significantly more variability in EEfRT average than the null model (R^2 change = 0.006, $p = .96$). Taken together, while MAP scores modulated the association between cognitive and physical ECDM, this effect did not differ by group (see Table S3 for similar analyses using the Clinical Assessment for Negative Symptoms MAP score in participants with schizophrenia only).

In a second regression model, we included COGED task average, d' average, their interaction, and group as predictors of EEfRT average (Table 3). Here, as expected, COGED task average and d' were positively associated with EEfRT average. However, the COGED task average × d' interaction was not significant. Results were similar when using the WTAR as a measure of cognition instead of d' (Table S4). Thus, while

Table 3. Modulators of the Association Between Physical and Cognitive Effort

Predictor Variable	Unstandardized Beta	Standard Error	*t* Value	*p* Value
First Regression Model: Dependent Variable EEfRT Average				
Intercept	−0.003	0.11	−0.03	.98
COGED Task Average	0.49	0.11	4.55	<.001
MAP-SR	−0.06	0.11	−0.54	.59
Group	−0.25	0.22	−1.13	.26
COGED Task Average × MAP-SR	−0.22	0.11	−2.09	.04
Second Regression Model: Dependent Variable EEfRT Average				
Intercept	0.01	0.10	0.12	.91
COGED Task Average	0.38	0.11	3.60	<.001
Average d'	0.33	0.11	3.06	<.001
Group	0.01	0.22	0.03	.98
COGED Task Average × d'	−0.12	0.11	−1.18	.24

COGED, cognitive effort discounting; EEfRT, Effort Expenditure for Rewards Task; MAP-SR, Motivation and Pleasure–Self-Report.

cognitive performance was positively associated with physical ECDM, individual differences in cognitive performance were not robust modulators of the association between physical and cognitive effort.

DISCUSSION

Our primary goal was to determine the degree to which cognitive and physical ECDM are related. As an exploratory aim, we examined whether aspects of psychopathology (e.g., MAP, cognitive deficits) modulate the association between physical and cognitive ECDM. We found a positive association between willingness to expend cognitive and physical effort. Further, we found that individual differences in MAP modulated the association between physical and cognitive effort. Specifically, we found that participants with lower MAP scores, irrespective of group status, showed stronger associations of cognitive and physical ECDM. Contrary to our hypotheses, cognitive performance did not significantly modulate the association between cognitive and physical ECDM. We discuss these findings and their implications below.

Our finding of a positive association between cognitive and physical ECDM is consistent with several previous reports (11,25,26). For example, Horan *et al.* (11) conducted a factor analysis of 5 ECDM paradigms in participants with schizophrenia and control subjects and found a clear one-factor solution explaining approximately 53% of the variance. Taken together, the current study and previous literature suggest that aspects of ECDM may be similar for different types of demands across both control subjects and people with schizophrenia. The current study further generalizes these findings through the use of different experimental paradigms, showing a previously unreported association between the EEfRT and COGED task. Further, our study provides evidence that a factor relevant to psychopathology (MAP) modulates the strength of this association.

While behavioral, our findings of domain-general ECDM processes are analogous to older literature on common neural representations of reward valuation as well as common influences of reward value on cognitive and physical effortful exertion in control subjects (43,44). Specifically, Chib *et al.* found that ventromedial prefrontal cortex activation was positively correlated with subjective value for different types of reward (e.g., food, money), suggesting that the brain encodes “a common currency that allows for a shared valuation for different categories of goods” (43). Schmidt *et al.* (44) found that a valuation region, ventral striatum, represented expected reward from effort exertion and switched its effective connectivity with motor and cognitive subregions of the dorsal striatum based on whether exertion of physical or cognitive effort was necessary to obtain rewards. It will be important for future work to determine if valuation regions encode a common representation of effort cost across modalities and to observe how reward value may interact with that representation to facilitate decision making.

While the current study points to domain-general components of ECDM, the shared variance between cognitive and physical ECDM was only approximately 25%. Thus, a question emerges as to what the other approximately 75% of the variability represents. A portion may represent noise in the data. However, the current results likely also point to a considerable amount of modality-specific variability, which has been described in several previous reports (29–31). It will be imperative for future work to attempt to understand such modality-specific variability.

Future Directions

One key interpretative limitation of our results involves the associative nature of the experimental design. Future work will need to manipulate within-person variables that might influence cognitive and physical ECDM. For example, one piece of evidence for the hypothesis that cognitive and physical ECDM may, at least in part, reflect a unitary underlying construct could come from designs incorporating fatigue. Specifically, researchers could tax one system through physical or cognitive fatigue and observe whether willingness to expend effort in the other domain is unaffected or diminished. Second, the EEfRT and COGED task paradigms both involve participants making an assessment of success, should they choose to engage with an effortful option, given that reward is contingent on successful completion of the required effortful task. Measures of defeatist performance beliefs, which could be conceptualized generally as diminished assessments of potential success of effort expenditure, were not collected in the current study. However, such measures have been associated with both cognitive and physical ECDM (45,46). It will be important for future work to determine whether such beliefs modulate the association between physical and cognitive ECDM.

Limitations

We examined potential group differences in the correlations between cognitive and physical effort as well as potential modulators of this association (e.g., MAP-SR). However, our statistical power was limited for these analyses. Thus, results must be interpreted as preliminary and will require replication in larger samples. Second, the majority of patients were on a variety of psychotropic medications including antipsychotics. D_2 antagonists such as haloperidol have been shown to reduce effort expenditure in rodent models (47). Replication of results in medication-naïve samples is an important avenue for future research. Third, in the current analyses, individual differences in cognitive performance (d') were not robust modulators of the association between physical and cognitive effort; however, this performance measure was taken from our cognitive ECDM task, potentially confounding results. While we supplemented this finding with evidence that performance on an independent cognitive measure (WTAR) also did not modulate the association between physical and cognitive effort, the WTAR is not a measure of working memory or cognitive control. Thus, it will be important for ECDM studies to collect independent measures of working memory or cognitive control.

Conclusions

Willingness to expend cognitive and physical effort was positively associated for both people with schizophrenia and control subjects. Further, individual differences in MAP modulated the association between physical and cognitive effort. Taken together, these results suggest a generalized deficit across effort modalities in people with schizophrenia and that reductions in MAP may impact ECDM in a domain-general manner.

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AJC, EKM, and DMB contributed to conceptualization. AJC, EKM, DMB, and SDD contributed to methodology. AJC, EKM, DMB, and SDD performed formal analysis. AJC, EKM, DMB, and SDD carried out investigations. AJC, EKM, DMB, and SDD contributed to writing and preparation of the original draft. AJC, EKM, DMB, and SDD reviewed and edited the manuscript.

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The current analyses were performed using data collected across 2 separate studies (22,33). Task effects and group difference analyses for the cognitive effort discounting task paradigm have been described in prior publications. The analyses reported in this manuscript are original and have not been reported elsewhere.

The authors report no biomedical financial interests or potential conflicts of interest.

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