Empirical Validation of Effort Measures in Children and Adults: Divergent Validity, Familial Similarity, and Predictive Validity for Psychopathology

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Research Article

Keywords: EEfRT, effort, psychopathology, RDoC, reward

Posted Date: April 27th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1443111/v1

Abstract

Background: Aberrant reward behavior is known to associate with various forms of psychopathology. ‘Effort’, as one component of reward, is defined as the perception of the value of the prospective outcome as a function of its magnitude and the perceived costs of the physical or cognitive labor required to obtain it. This study sought to empirically validate the ‘effort’ construct via behavioral assessments and self-reports.

Methods: Participants were 1536 children and 1270 of their parents. ‘Effort’ was assessed *via* the Effort Expenditure for Rewards Task (EEfRT). Child psychopathology was measured using the Child Behavior Checklist; adult psychopathology was measured using the Adult Self Report. Multitrait-multimethod matrices were used to demonstrate the divergent validity of ‘effort’ measures from other measures of reward behavior. We used linear regression models to assess familial transmission of ‘effort’, and zero-inflated negative binomial regression models to analyze the relationship between ‘effort’ and psychopathology and the moderating effects of sex.

Results: For adults and their children, measures of ‘effort’ did not correlate with any other measures of reward constructs, suggesting divergent validity. Measures of ‘effort’ were positively correlated between siblings, while correlations between children and adults were not significant. In children, significant interactions were observed between sex and ‘effort’ valuation, in association with anxiety and thought problems, consistent with previous work. The moderating effects of sex had the greatest effect at low ‘effort’, with females having higher severity of psychopathology than males on average.

Conclusions: This study identified the ‘effort’ component of reward behavior as a significant correlate of multiple psychopathologies, moderated by sex. These findings provide further evidence supporting ‘effort’ as a relevant construct for understanding psychopathology. The results consistently demonstrate aberrant ‘effort’ is associated with greater anxiety and thought problems. The *presence* of sibling-sibling correlations accompanied by the *absence* of parent-child correlations suggests a lack of continuity between child and parent measures and suggests that further evaluation and refinement of age-appropriate measures of effort is warranted.

Background

Reward processing encompasses human behavioral and neurobiological responses to positive motivational situations, and alterations in this processing is a known feature of multiple forms of psychopathology (Zald & Treadway, 2017). Given that symptoms of altered reward processing are specifically referred to as diagnostic criteria for multiple psychiatric disorders in the DSM-V, the study of reward processing is a key component to understanding human psychopathology (American Psychiatric Association, 2013). Reward processing can be broken down further into components such as reward responsiveness, reward learning, and reward valuation, each of which may be related to and impacted to different degrees in particular psychiatric disorders (Insel et al., 2010). Reward valuation, as an example,

typically refers to the processes by which the probability and benefits of a prospective outcome are computed by reference to external information, social context, and/or prior experience. Within this reward valuation component are further sub-elements that have been studied via multiple varying approaches. The ‘reward’ sub-construct specifically refers to perception of the magnitude, valence, and predictability of the prospective outcome. The ‘delay’ sub-element refers to the perception of the expected time interval prior to attainment of the prospective outcome. Each of these elements has been examined from both a neurobiological perspective, via the measured activity of dopaminergic neurons or through neuroimaging, and a behavioral perspective, via task-based experiments or self-reports (Klein-Flügge, Kennerley, Saraiva, Penny, & Bestmann, 2015; Kobayashi & Schultz, 2008; Schultz, Carelli, & Wightman, 2015). The focus of the current study is the less-studied third sub-element of reward valuation: ‘effort’. The ‘effort’ sub-element refers to perception of the value of the prospective outcome as a function of its magnitude and the perceived costs of the physical or cognitive labor required to obtain it (NIMH, 2016). Our chosen method for assessing ‘effort’ is the Effort Expenditure for Rewards Task (EEfRT), an NIMH-endorsed behavioral task that has been used previously to study ‘effort’ in adults with anhedonia, major depressive disorder, and schizophrenia (MDD) (Barch, Treadway, & Schoen, 2014; NIMH, 2016; Treadway, Bossaller, Shelton, & Zald, 2012; Treadway, Buckholtz, Schwartzman, Lambert, & Zald, 2009).

Previous research relating ‘effort’ and/or motivation with psychopathology has consistently found significant differences in effort-based decision-making between persons with psychiatric disorders and healthy comparison subjects. Prominent disorders featuring effort-related motivational dysfunction include MDD, autism spectrum disorder (ASD), and schizophrenia. The components of reward behavior that are affected range from decreased sensitivity to reward parameters in ASD, to decreased overall ‘effort’ expenditure in MDD, to inefficient ‘effort’ allocation in ASD, MDD, and schizophrenia (Damiano, Aloi, Treadway, Bodfish, & Dichter, 2012; McCarthy, Treadway, Bennett, & Blanchard, 2016; Mosner et al., 2017; Treadway et al., 2012; Treadway, Peterman, Zald, & Park, 2015). In MDD in particular, decreased motivation is a key symptom most strongly correlated with negative impacts on social functioning and employment-related factors such as days in bed, days of lost work, and low work productivity (Salamone, Yohn, López-Cruz, San Miguel, & Correa, 2016; Stahl, 2002; Tylee, Gastpar, Lépine, & Mendlewicz, 1999). Research on schizophrenia and ‘effort’ found that individuals with schizophrenia demonstrated fundamental problems with engaging in effortful behavior that was independent of difficulties with experiencing pleasure or setting pleasure-based goals, and that individuals with schizophrenia showed reduced selection of high-effort alternatives on a novel decision-making task (Gard et al., 2014; Gold et al., 2013).

Two other disorders with links to abnormal reward behavior are attention-deficit/hyperactivity disorder (ADHD) (Marx, Hacker, Yu, Cortese, & Sonuga-Barke, 2018) and substance use disorders (SUDs) (García-García et al., 2014). People with these disorders are more likely than unaffected individuals to find it difficult to optimally process immediate versus delayed rewards during decision-making, opting for immediate rewards over much larger/more valuable delayed rewards. Current research seeks to determine the neurobiological roots of this behavior by studying elements known to be involved in the reward system at the molecular level (adenosine, dopamine, and GABA), and at the brain circuitry level (ventral

tegmental area and nucleus accumbens). While this research is ongoing, it is already clear that aberrant reward processing is a central component to the impulsivity that characterizes these disorders (Rosch, Mostofsky, & Nebel, 2018). Collectively, this work has demonstrated the wide variety of psychiatric disorders in which 'effort'-related reward behavior is affected. Therefore, assessing 'effort' in a broader context rather than on a disorder-specific basis may be valuable in understanding the core impairments that are common across psychopathologies.

Many of the disorders previously linked to dysfunctional reward behavior also show skewed sex ratios in prevalence; *e.g.*, ADHD shows a 3:1 male:female ratio, while anxiety and depression are two times more common in females (Staller & Faraone, 2006). Regarding symptoms, previous research found that externalizing problems, such as aggressive behavior and hyperactivity, were more prominent in males with ASD, whereas internalizing problems, such as emotional issues, have greater prevalence in females with anxiety and depression (Dorfman, Rosen, Pine, & Ernst, 2016; Werling & Geschwind, 2013). Different patterns have also been found between men and women for determinants of functional disability in MDD, as well as notable sex differences in clinical features, cognitive impairment, and their respective associations among schizophrenia patients (Carmona et al., 2018; Mu et al., 2020). Since research has been conducted thus far into sex-specific symptom differences within various psychiatric disorders, and 'effort' impairment has been identified as a common feature of psychopathology, it follows that investigation into the possible sex- differences in 'effort' behavior may be important to delineate. A recent study of sex differences in psychopathology among children aged nine and ten revealed that males had higher scores and greater frequency of clinically meaningful levels of psychopathology than females (Loso et al., 2021). It is therefore highly relevant to study domains of function, such as reward, that are impacted by psychopathology as early as childhood, and to determine how this effect differs among males versus females.

Familiality is another key dimension of reward behavior whose evaluation may provide important context for its association with psychopathology. Many psychiatric disorders have been identified as familial or as having familial risk factors, including each of the disorders mentioned above (Díaz-Castro, Hoffman, Cabello-Rangel, Arredondo, & Herrera-Estrella, 2021; Grant & Chamberlain, 2020; Thapar, Cooper, Eyre, & Langley, 2013; Xie et al., 2019; Zalar, Blatnik, Maver, Klemenc-Ketiš, & Peterlin, 2018). Assessing the familiality of measures of impairment in 'effort' and/or reward processing is important to understanding what degree of risk these aberrations pose towards the development of psychopathology. One study used a biomarker of reward sensitivity (frontal EEG asymmetry) along with family history of MDD and/or panic disorder (PD) to determine if an association between biomarker and risk factor existed *independent* of DSM-IV diagnosis. This study found that frontal EEG asymmetry was associated with a family history of MDD even after controlling for DSM-IV diagnosis, indicating that reduced sensitivity to reward indexed risk for depression over and above the variance explained by the diagnosis (Nelson et al., 2013). In light of this, research on associations between psychopathology and impairments in 'effort' in a family-based context may be particularly useful, as familiality can be analyzed via direct comparison of measures between parents and their children.

The present study sought to empirically validate ‘effort’ as a construct of human reward processing via multiple different behavioral tasks and self-report measures of psychopathology. To our knowledge, this study would be the first to attempt this validation in a population that included children. We hypothesized that the ‘effort’ construct would show divergent validity from other constructs of reward behavior in children as well as adults. Additionally, we assessed sex differences in the relationship between ‘effort’ and psychopathology in both adults and children to determine whether these differences would show patterns similar to common findings in the literature regarding sex-specificity in psychopathologies. Because many psychiatric disorders feature impaired ‘effort’ behavior *and* also are familial, we hypothesized that measures of ‘effort’ would also correlate within families. We also hypothesized that, in both adults and children, measures of ‘effort’ would be associated with self-report scales related to psychopathology that had previously been linked to abnormal reward behavior, but not scales associated with other forms of psychopathology. In particular, we expected that ‘effort’ would show its strongest association with measures linked to ADHD, ASD, schizophrenia, depression, and anxiety across both children and adults.

Methods

Procedure

Participants were recruited from a variety of sources within the Syracuse, NY and surrounding areas, including the Child and Adolescent Psychiatry Clinic at SUNY Upstate Medical University, child psychiatrists and mental health clinicians working in private practice, and community events (local fairs, festivals, etc.). Children meeting the following criteria were excluded from the study: adopted, sensorimotor disability, a diagnosed neurological condition, a history of head injury with documented loss of consciousness lasting more than 10 minutes, an uncontrolled medical condition, use of psychotropic medications, or an inability to understand the English language. For adults, the same exclusion criteria were applied, except adoption. Two additional exclusion criteria were also added to the adult exclusion list: people who did not have the ability to independently complete study tasks, and women who were pregnant or gave birth within 6 months prior to the study visit. An estimate of intelligence quotient (IQ) was obtained from scores on the vocabulary and abstraction subtests of the Shipley-2 (a validated, age-appropriate instrument for subjects between the ages of 7 and 89 years). This was applied to both adults and children within the recommended age range. As the mean of these two tests correlates 0.90 with full-scale IQ, subjects with an estimated IQ below 80 were excluded from this study. Informed consent was obtained from all parents and assent was given by all children upon arrival for their study visit and the study was approved by the Upstate Medical University Institutional Review Board.

Participants

A total of 2806 participants (1536 children and 1270 parents) took part in this study. The study required parents to report both for themselves and for their children whether they had ever sought mental health

care for emotional or behavioral problems, and it was reported that 52% of children and 52% of parents had such psychiatric history. Our study population was drawn from a convenience sample that was purposely enriched for psychopathology *via* recruitment in local clinics to ensure a broad range of psychopathology into both the clinical and normal ends of the distribution. Psychiatric participants were not selected based on any particular form of psychopathology, as our study was designed to employ an agnostic ascertainment scheme. All children were between the ages of 6 and 12 years (mean age = 9, S.D. = 3.1), and their parents were between the ages of 23 and 59 years (mean age = 37, S.D. = 6.9). Parental age was capped at 59 years of age to avoid the possibility of age-related cognitive decline. While there were approximately equal numbers of female and male children (49% *vs.* 51%), significantly more of the participating parents were female than male (69% *vs*. 31%). Participants were diverse in race, with 65% of parents identifying as White, 24% Black, and 11% other or multiple races, and 55% of children identifying as White, 25% Black, and 20% other or multiple races. Additionally, 6% of parents and 11% of children were Hispanic. The dataset includes 1215 different families, with an average size of 2.94. Detailed demographic information is available in in **Supplementary Table 1**.

Measures

Study visits were approximately 3 hours in length and involved the completion of a variety of computerized inventories and behavioral paradigms.

Effort Expenditure for Rewards Task

The Effort Expenditure for Rewards Task (EEfRT) was developed by Treadway and colleagues to measure effort-based decision-making (Treadway et al., 2009). The EEfRT consisted of a multi-trial game in which participants attempt to maximize their monetary rewards. The rules of the game were explained to each subject as follows: 1) They were instructed to choose between two types of tasks for each trial: ‘Easy Task’ or ‘Hard Task’, where the ‘Hard Task’ provided the opportunity for much greater monetary gain relative to the ‘Easy Task’; 2) The ‘Easy Task’ required 30 button presses with the dominant index finger within 7 seconds with a fixed reward value of $1.00; 3) The ‘Hard Task’ required 100 button presses with the non-dominant fifth finger within 21 seconds with a varying assigned reward value between $1.24 and $4.30; 4) Subjects were expected to complete multiple trials and were given a 20 minute time limit to complete as many trials as they could; 5) For the adult trials, three levels of probability were presented for obtaining a reward upon successful trial completion: ‘high’ (88%), ‘medium’ (50%), and ‘low’ (12%). This means that some adult trials did not result in a reward, even if the subject successfully completed the task, to ensure that participants could not default to choosing only easy or hard options to optimize their performance (Treadway et al., 2009). Because this component requires an understanding of probability, this was not applied in the child trials. If participants did not choose between the hard or easy task, the trial was marked as a ‘time-out’ and was not included in the calculation of summary variables.

All subjects received trials presented in the same randomized order. At the beginning of each trial, in the adult version of the EEfRT task only, subjects are provided with one of the three winning probability levels (88%, 50%, or 12%), which applied equally regardless of whether the hard or easy task was picked. This

probability component is designed to add complexity to the decision-making aspect of selecting the task difficulty, to ensure that neither a strategy of choosing only the easy or hard options would lead to 'optimal' performance. With this safeguard in place, subjects' decisions better reflect individual differences in willingness to expend 'effort' for a given level of reward (Treadway et al., 2009). However, since this component required the subjects to have a complete understanding of the concept of probability and its effect on the reward outcome to properly impact the decision-making process, it was not practical to apply to child participants given their young age. As a result, the probability component is not present in the child version of the EEfRT task.

Our outcome variables for the EEfRT task were hard-task choice percentage and reward sensitivity. The hard-task choice percentage was calculated as the percentage of trials for which that participant chose the hard task. We categorized individuals as having relatively "high" or "low" hard-task choice percentage based on a median split of hard task choice percentage. To derive reward sensitivity, a logistic beta weight was calculated on a per-participant basis *via* logistic regression with an individual's hard task choice as the outcome (dependent) variable and reward magnitude (monetary amount; dollars) as the predictor (independent) variable. Therefore, the reward sensitivity variable is a measure of the degree to which the reward amount influences an individual's choice between hard and easy tasks.

Adult Self Report

The Adult Self Report (ASR) was used to measure psychopathology in adult participants. This 126-item self-report measure is well validated and widely used in clinical practice to assess symptoms of psychopathology and adaptive functioning in individuals aged 18–59 years (Rescorla & Achenbach, 2004). Participants were asked to respond to each item on a three-point scale: from *not true, often true*, or *very true*. The ASR provides T-scores for seven syndrome scales (anxious/depressed, withdrawn, somatic complaints, thought problems, attention problems, aggressive behavior, rule-breaking behavior), three composite scores (internalizing composite, externalizing composite, total problems composite), and four scales assessing substance use (tobacco, alcohol, recreational drugs, substance use composite). Due to the nature of the ASR assessment, the minimum possible T-score generated is 50, which would represent a participant whose level of self-reported psychopathology is that of a typically developing, psychiatrically unaffected individual (no psychopathology). A T-score of 50 then represented a 'zero-value' in our study. More detailed information is available in **Supplementary Table 2**.

Child Behavior Checklist

The Child Behavior Checklist (CBCL) was used to measure psychopathology in children. This 113-item parent-report measure is well validated and widely used in clinical practice to assess emotional and behavioral functioning in children ages 6–18 years (Achenbach, 1991). Parents were asked to respond to each item on a three-point scale: from *not true, often true*, or *very true*, which indicated how true the item is for their child. The CBCL provides T-scores for eight syndrome scales (anxious/depressed, withdrawn/depressed, somatic complaints, social problems, thought problems, attention problems, rule-breaking behavior, aggressive behavior), and three composite scores (internalizing composite,

externalizing composite, total problems composite). The CBCL shares the same minimum T-score as the ASR (50), so our outcome variables follow the same logic described in the section above. More detailed information is available in **Supplementary Table 2**.

Additional Behavioral Measures

The Delay Discounting Task (DDT) and Probability Discounting Task (PDT) assess choice behaviors in the form of preferences and thresholds for selecting instantaneous versus delayed rewards. Briefly, in a series of delay trials, subjects choose between receiving a large reward ($10) after a delay (1-365 days) or a smaller amount (*e.g.*, $2) immediately or a probabilistic amount (*e.g.*, with a 25% chance). For each delay, the immediate reward amount is changed based on previous responses until an indifference value is reached. The indifference value is defined as the smallest amount of money chosen for immediate receipt instead of waiting the specified delay in order to receive the maximum (Richards, Zhang, Mitchell, & de Wit, 1999). Values used in the analysis and results refer to the area under the curve (AUC) from the indifference point plots from the delay discounting and probability discounting tasks. The DDT is an NIMH-endorsed method for the study of the 'delay' subconstruct of Reward Valuation (National Institute of Mental Health, 2018).

The Iowa Gambling Task (IGT) has been extensively used to probe expectancy and reward prediction error in both adults and children. Briefly, participants are presented with four options (decks of cards for adults, pirate chests for children), each of which contains cards that reward or punish the player by adding or subtracting money from their account. Two of the options led to net increases over the course of repeated play (advantageous options) while the other two lead to net decreases (disadvantageous options). The player is instructed to maximize winnings, which requires learning to determine which options will lead to long-term gains and which to long-term losses. The net difference between the number of draws from advantageous versus disadvantageous options over time indexes performance, and the latency value indexes the time taken for an individual to learn the characteristics of each option (Bechara, Tranel, & Damasio, 2000; Cauffman et al., 2010; Garon & Moore, 2004). The IGT is an NIMH-endorsed method for the study of Reward Learning (National Institute of Mental Health, 2018).

The Temporal Experience of Pleasure Scale (TEPS) is a validated, self-administered, 18-item questionnaire that measures anticipatory and consummatory experiences of pleasure in adults. The instrument is divided into a ten-item assessment of anticipatory experiences of pleasure and an eight-item assessment of consummatory experiences of pleasure. The response format is a six-point Likert scale, with possible responses ranging from (1) very false for me to (6) very true for me. The analogous Pleasure Scale for Children (PSC) is a validated, self-administered, 39-item questionnaire that measures expectance and reward in school-age children. The instrument was created to assess anhedonia in children. Subjects rate their anticipated level of 'happiness' on the occurrence of 39 different events and activities on a three-point Likert scale with possible responses including: (1) wouldn't matter; (2) happy; (3) very happy (Gard, Gard, Kring, & John, 2006; KAZDIN, 1989). A modified version of the Pleasure Scale for Children termed the Experienced Pleasure Scale for Children (ePSC) was also administered, which differs from the original PSC in that it asks subjects to rate only the events and activities which they have

experienced. The TEPS and PSC are NIMH-endorsed methods for the study of Reward Responsiveness (National Institute of Mental Health, 2018).

Statistical Analyses

Statistical analyses were conducted in R version 3.4.1.

Analytical Models Assessing the Divergent Validity of the ‘effort’ Construct

Campbell and Fiske’s multitrait-multimethod matrix was used to examine the divergent validity of the ‘effort’ construct from other PVS constructs. EEfRT measurements were compared to five other methods for assessing reward behavior constructs such as Reward Responsiveness, Reward Learning, and Reward Probability. For adults, these three other methods included the DDT/PDT, IGT, and the TEPS. For children, the PSC/ePSC was used in place of the TEPS.

Analytical Models Assessing Familial Correlations for EEfRT Performance

The degree of sibling-sibling similarity was tested by paired-sample correlations using intraclass correlations as well as Spearman’s ρ. For parent-child correlations, a linear regression model was used with child hard task choice percentage as the outcome (dependent) variable and mother and father hard task choice percentage as the predictor (independent) variables. Benjamini-Hochberg False Discovery Rate (FDR) correction was applied to correct for multiple comparisons, and *p*-values reported in the results are FDR-adjusted. This procedure is a recommended alternative to Bonferroni-type corrections, which are often criticized for increasing the likelihood of type-II errors, particularly when a large number of tests are conducted (Perneger, 1998).

Analytical Models Assessing the Relationship between EEfRT and Psychopathology

A series of zero-inflated negative binomial regression models examined ‘effort’ expenditure and reward sensitivity as predictors of psychopathology in adults. Zero-inflated negative binomial regression was used to account for non-normal distribution of the outcome variables, which were T-scores. The main effects of hard task choice percentage, reward sensitivity, and sex were tested. It also included the testing of interactions of sex with hard task choice percentage, and sex with reward sensitivity. All adult models covaried for demographic variables including age, education, employment, income, race, and marital status.

As with the adults, zero-inflated negative binomial regression was used to account for non-normal distribution of outcome variables in children. Main effects of hard task choice percentage, reward sensitivity, and sex were tested. Additionally, interactions between hard task choice percentage and sex as well as reward sensitivity and sex were tested. All child models covaried for parent income and education,

but not age, as the range was limited and there was no association between child's age and EEfRT scores.

Robust standard errors were used across all models to account for non-independence in the data due to familial relationships. The Benjamini-Hochberg False Discovery Rate method (Benjamini & Hochberg, 1995) was used to correct for multiple testing. A 5% false discovery rate was utilized for determining the significance of findings across both groups. For the regression models, the total number of tests conducted was 12 for adults and 8 for children. *P*-values reported in the results are false-discovery-rate adjusted.

Data Imputation

Since 25% of participants chose not to report their household income, multiple imputation was utilized to handle missing adult income data. In total, ten iterations of imputation were conducted. IQ and demographic information including self-reported levels of education, employment, marital status, age, race, and sex were used to predict income in the imputation procedure. When modeled together, these variables explained a large proportion of the variance in income (R^2 = 0.698), which was consistent with the variance observed in the discovery sample. Since missing data was not a problem for the other demographic variables (education, employment, age, marital status, IQ, race, and sex), multiple imputation for those variables was not necessary and was not performed.

Results

EEfRT Task Statistics

For children, the average proportion of hard task choices was 56.7%, and the average reward sensitivity was 0.11. Hard task choice is represented by the proportion of total trials in which the participant chose the hard task rather than the easy task. Reward sensitivity is an indicator of the degree to which reward magnitude (dollar amount) influences choosing the hard task *vs*. the easy task, where higher values indicated stronger influence. The minimum reward sensitivity was − 3.3, and the maximum was 6.8. The inter-quartile range of reward sensitivity was − 0.004 to 0.027. Mean percent completion rate among children was 86.6%. On average, child participants timed out in their choice of the hard *vs*. easy task in just 1.3% of trials.

For the adult participant sample, the average proportion of hard task choices was 36.4%, and the average reward sensitivity was 0.73. The minimum reward sensitivity was − 2.0, and the maximum was 7.9. The inter-quartile range of reward sensitivity was 0.17 to 1.18. Mean percent completion rate among adults was 93.4%. If participants did not choose between the hard or easy task, that trial was marked as a 'time-out' and was not included in calculation of summary variables. For adults, 0.7% chose only easy tasks, and none chose only hard tasks. For children, 0.9% chose only easy tasks, and 3.1% chose only hard tasks. On average, adult participants timed out in their choice of the hard vs. easy task in 6.9% of trials.

In comparing EEfRT statistics between adults and children, we found that the average proportion of hard task choices was higher among children relative to adults (56.7% vs. 35.4%) and the average reward sensitivity value was lower among children relative to adults (0.11 vs. 0.73).

Effort Construct Validity

In adults, the EEfRT outcome variables of hard task choice and reward sensitivity were correlated with one another (r = 0.33, p = 0.00). In children, the EEfRT outcome variables of hard task choice and reward sensitivity were also correlated (r = 0.31, p = 0.00). For both adults and children, neither EEfRT outcome variable was significantly correlated with any other reward behavior measure items. In adults, the 'effort' hard task choice was not significantly correlated with PDT area under the curve (r = -0.09, p = 0.70), DDT area under the curve (r = 0.08, p = 0.70), IGT totals (Latency: r = -0.02, p = 0.70; Net Gain: r = 0.09, p = 0.70), and TEPS subscales (Anticipatory: r = 0.12, p = 0.10; Consummatory: r = 0.05, p = 0.10). Similarly, the EEfRT outcome variable of reward sensitivity had very weak and non-significant correlations with PDT area under the curve (r = -0.04, p = 0.70), DDT area under the curve (r = 0.00, p = 0.70), IGT totals (Latency: r = 0.03, p = 0.70; Net Gain: r = 0.05, p = 0.70), and TEPS subscales (Anticipatory: r = 0.10, p = 0.10; Consummatory: r = 0.02, p = 0.10) (Fig. 1A). In children, the 'effort' hard task choice was not significantly correlated with PDT area under the curve (r = 0.00, p = 0.70), DDT area under the curve (r = -0.03, p = 0.70), Pleasure subscales (Consummatory: r = 0.05, p = 0.10; Anticipatory: r = 0.02, p = 0.10), and IGT totals (Latency: r = -0.01, p = 0.70; Net Gain: r = -0.05, p = 0.70). Similarly, the EEfRT outcome variable of reward sensitivity had no significant correlations with PDT area under the curve (r = 0.00, p = 0.70), DDT area under the curve (r = 0.03, p = 0.70), Pleasure subscales (Consummatory: r = 0.07, p = 0.10; Anticipatory: r = 0.08, p = 0.10), and IGT totals (Latency: r = 0.03, p = 0.70, Net Gain: r = 0.03, p = 0.70) (Fig. 1B).

Familial Correlations

Small, but significant positive correlations were observed between siblings for hard task choice percentage (r = 0.11, p = 0.001). The father-child (r = -0.087, p = 0.072) and mother-child correlations (r = -0.012, p = 0.71) were not significant (Fig. 2). For reward sensitivity, no significant correlations were found between siblings (r = 0.012, p = 0.72) or between father-child pairs (r = 0.063, p = 0.054) or mother-child pairs (r = 0.011, p = 0.62). No significant results were found when regressing child values on parent values for either hard task choice nor reward sensitivity.

Child Psychopathology

A main effect of hard task choice was observed in child models predicting attention problems, social problems, and withdrawn depression. Increased attention problems were observed among children who primarily chose the easy task over the hard task (β = -1.51, FDR-adjusted p = 0.01). Similarly, increased social problems were observed among children who primarily chose the easy task over the hard task (β = -1.34, FDR-adjusted p = 0.03). In addition, increased severity of withdrawn depression was observed among children who primarily chose the easy task over the hard task (β = -0.95, FDR-adjusted p = 0.05).

The interaction between sex and hard task choice was significant in the model predicting anxious depression. Among children who primarily chose the easy task over the hard task, males reported more anxious depression than females (β = 0.92, FDR-adjusted *p* = 0.05). Severity of anxious depression did not differ between males who preferred the easy task and males who preferred the hard task (High Hard Task % CBCL Score = 56.1; Low Hard Task % CBCL Score = 56.3); in contrast, severity of anxious depression was lower in females who preferred the easy task in comparison to females who preferred the hard task (High Hard Task % CBCL Score = 56.6; Low Hard Task % CBCL Score = 54.4). (Fig. 3A).

We found a significant interaction between reward sensitivity and sex in the model predicting thought problems as follows: among children who primarily chose the easy task over the hard task, males reported more increased thought problems than did females (β = -0.84, FDR-adjusted *p* = 0.004). Similar to the model predicting anxious depression, severity of thought problems did not differ between males who preferred the easy task and males who preferred the hard task (High Reward Sensitivity CBCL Score = 56.8; Low Reward Sensitivity CBCL Score 57.1), whereas severity of thought problems was lower in females who preferred the easy task in comparison to females who preferred the hard task (High Reward Sensitivity CBCL Score = 56.7; Low Reward Sensitivity CBCL Score = 55.3). (Fig. 3B).

Adult Psychopathology

Models predicting adult psychopathology found variable results based on the reward probability level. At medium reward probability (50%), we observed a significant interaction between hard task choice and sex (β = 1.249, FDR-adjusted *p* = 0.008). At this probability level, among adults who primarily chose the hard task, females had greater severity of somatic complaints compared with males (Female ASR Somatic Complaints Score = 56.7; Male ASR Somatic Complaints Score = 55.2). At high reward probability (88%), we observed a significant interaction between hard task choice and sex (β = 1.140, FDR-adjusted *p* = 0.007). At this probability level, among adults who primarily chose the easy task over the hard task, males had greater severity of thought problems relative to females (Female ASR Thought Problems Score = 56.9; Male ASR Thought Problems Score = 58.0).

In models predicting reward sensitivity, a significant interaction between reward sensitivity and sex was observed in the model predicting tobacco problems (β = -0.637, FDR-adjusted *p* = 0.008). Among adults who primarily chose the hard task, females had greater severity of tobacco problems compared with males (Female ASR Tobacco Problems Score = 52.5; Male ASR Tobacco Problems Score = 51.7). For adults who primarily chose the easy task, severity of tobacco problems across the sexes was not significantly different (Female ASR Tobacco Problems Score = 53.0; Male ASR Tobacco Problems Score = 53.3).

Discussion

The current study sought to empirically validate the ‘effort’ construct of the Reward Valuation *via* behavioral assessments and self-reports, and to determine if it diverged from other constructs/constructs of reward behavior. We found that both measures of ‘effort’ (hard task choice and reward sensitivity) did

not correlate with other measures of reward behavior. This divergence indicates that the ‘effort’ construct captures a distinct and specific element of human reward behavior. Our study is the first to demonstrate this divergence.

Based on evidence from the literature, we hypothesized that psychopathology scales linked to anxiety or depression would show significant associations with ‘effort’ measures. Additionally, we expected that such associations would present differently between males and females in effort-based decision making. In concordance with these hypotheses, hard task choice percentage was a significant predictor of both anxiety and thought problems in children and was moderated by sex. The consistency of these findings for anxiety and thought problems indicate that aberrant ‘effort’ valuation may be a reliable predictor of psychopathologies associated with those problems, such as anxiety and depression. The additional consistency of the moderating effects of sex underscores the importance of incorporating sex-specificity in any research aimed at understanding dimensions of psychopathology, including diagnosis, biological mechanisms, and treatment. These findings serve to further support the validity of the ‘effort’ construct.

Our analysis also found differences in effort-based decision-making between male and female children regarding severity of psychopathology, based on associations with low ‘effort’ and reward sensitivity. At high ‘effort’ levels and reward sensitivity, males and females did not have a significant difference in CBCL Thought Problem T-score. However, at low ‘effort’ levels, males had significantly higher CBCL Thought Problem T-scores than females, though the underlying reason for this divergence is not currently clear. According to the CBCL scale, Thought Problems include seeing or hearing things, repeating acts, and strange ideas/behavior. In children, this has been linked with relatively high sensitivity and specificity to behavior on the autism spectrum (Mazefsky, Anderson, Conner, & Minshew, 2011). Previous research investigating diagnostic differences has shown that males are more likely to be diagnosed with ASD, with a male-to-female ratio of 3:1 (Loomes, Hull, & Mandy, 2017). However, previous research has also demonstrated that there are clear differences in clinical manifestation between males and females with ASD (Rynkiew Icz & Łu Ck A, 2018). The CBCL does not have an ASD-specific subscale, so our finding may in part be capturing this ASD-specific difference. However, our study found significant sex differences only at **low** ‘effort’ levels/reward sensitivity (impaired reward processing) but **not high** ‘effort’ levels/reward sensitivity (normal reward processing). This seems to indicate that there is some interaction specific to impaired reward processing that is worthy of further investigation. It is important to have a deeper understanding of how and why sex impacts reward processing, which could provide greater insight into ASDs, as well as other disorders where sex differences are present.

Previous work on ‘effort’ in children has demonstrated that ‘effort’ expenditure had a significant relationship with anxiety and thought problems that was moderated by sex. At low levels of ‘effort’ and reward sensitivity, male children had greater anxiety and thought problems than female children. There was also significant positive correlations between siblings’ ‘effort’ valuation, but no correlations between parents and their children (Nguyen et al., 2019). While these results may seem at odds with the familial nature of these types of psychopathology, previous research in child behavior has found that developmental shifts occur in decision-making during adolescence (Hartley & Somerville, 2015).

Specifically, the increase in risk-taking behavior is often attributed to extensive structural and functional brain development. Although risk-taking encompasses more than solely reward-based behavior, a previous study found evidence for increased limbic responses to reward stimuli which peaked at mid-adolescence, indicating that reward behavior *is* an affected component of adolescent development (Crone & Dahl, 2012). While our child participants were primarily in the pre-adolescent age range, previous research has found that adolescents and children take equal levels of risk (Defoe, Dubas, Figner, & Van Aken, 2015). Additionally, there are distinct methodological differences between child and adult tasks which cannot be discounted as a confounding source.

The current work faced particular constraints, including the use of parent-reports as measures for both child and parent psychopathology, and a disproportionate number of (adult) female participants. In addition, because of our sampling strategy that was agnostic to disorders, few participants displayed clinically elevated symptoms for some of the dimensions of psychopathology examined in this study. Future studies designed around collecting information from individuals who experience particular problems may help to discover new or clearer relationships between 'effort' valuation and specific forms of psychopathology.

While the current work demonstrated the applicability of construct-based validation and assessment towards 'effort' and its relationship to multiple types of psychopathology, it also highlights areas of possible improvement. To our knowledge there has been no previous study of the relationship between 'effort' and *child* psychopathology. Many of the reward behavioral measurement tasks were developed and intended for adults, including Treadway's EEfRT task. Because of this, it is not clear whether applying such tasks across both adults and children is fully equivalent. We found significant sibling-sibling correlations but no significant parent-child correlation. This suggests that the child and adult EEfRT tasks do not measure the same *familial* construct. Additionally, the psychopathology models that were significant in children and the trends observed within those models differed from those found in adults. Given that our sample size is large and the mother-child and father-child correlations are negligible (Mother-Child: $r = -0.037$, 95% CI = [-0.188, 0.115]; Father-Child: $r = -0.142$, 95% CI = [-0.288, 0.004]), it is unlikely that our finding of non-significance was due to low power. Ideally, a longitudinal study would compare a child's behavior to their parent's historical behavior at a similar age. As such, we believe that longitudinal studies are essential to investigate the stability of 'effort' valuation and reward processing behavior over time, especially in children, who may exhibit differences as they pass through stages of their development. Our findings support longitudinal research as an important component to the goals of research-based validation of constructs and revision of current diagnostic systems. Modern day conceptualizations of psychiatric disorders may be more accurately reflected along spectra of illness severity, which more closely resemble dimensions of underlying behavioral and biological processes, rather than simply discrete phenomena, a direction consistent with the premise of the Research Domain Criteria (RDoC) initiative put forth by the U.S. National Institute of Mental Health.

The current findings show that 'effort' is a psychological construct that is both empirically valid and worthy of further study in the context of child psychopathology, with differing profiles of effect between

sexes. Based on the observed associations between low ‘effort’ expenditure, low reward sensitivity, anxiety, and thought problems, we identified aberrant reward processing as a potentially important indicator of specific dimensions of psychopathology. Additionally, the reward processing deficits’ greater impact on male children indicate that ‘effort’ expenditure and reward sensitivity may be important risk factors to assess and address in males and may be a critical target for mitigating symptom severity. It is possible that these are key to understanding the biological mechanisms behind psychopathological manifestations. Furthermore, to our knowledge, our work was the first application of EEfRT in children. In summary, our current study provided credible evidence supporting the further use of EEfRT to understand ‘effort’ valuation in children, especially if applied in a longitudinal approach, to determine the stability of the construct over time as children progress through development to adulthood.

Declarations

Ethics approval and consent to participate

Informed written consent was obtained from all parents and assent was given by all children upon arrival for their study visit and the study was approved by the Upstate Medical University Institutional Review Board.

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare they have no competing interests.

Funding

NIH grants and supplements (R01MH101519-01A1 and R01MH101519-01A1S1)

Authors’ contributions

SVO, PF, SDB, and WPF were critical in the collection, acquisition, and interpretation of behavioral data. SVF and SJG were responsible for the conception and design of the study, in addition to making significant contributions to the analysis, writing, and revision of the manuscript. JLH was a major contributor in the analysis, writing, and revision of the manuscript. NHN was responsible for and made significant contributions to data interpretation and data analysis, and was a major contributor in the writing and revision of the manuscript.

Acknowledgements

Not applicable

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Figures

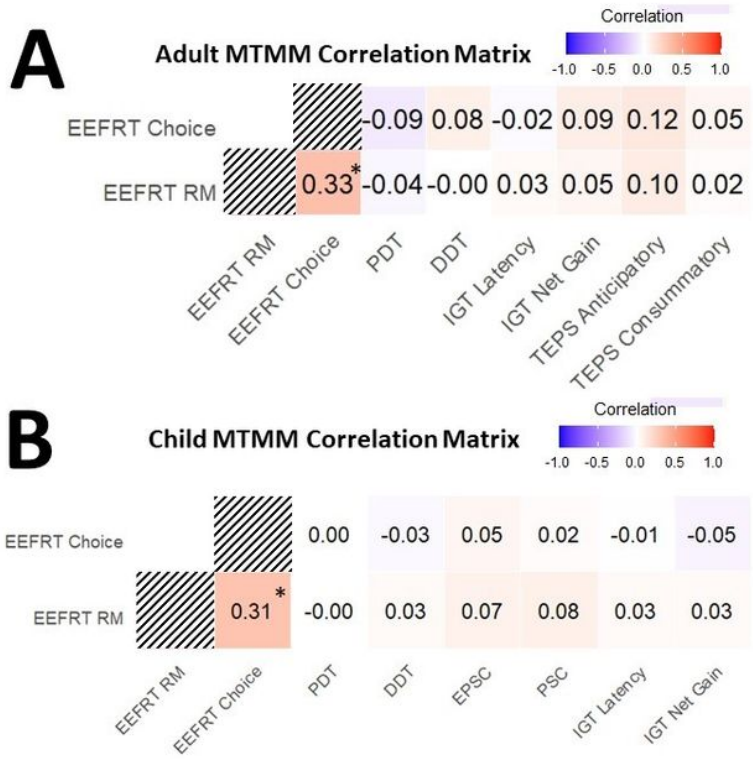

Figure 1

Correlation matrices from multitrait-multimethod matrix analysis of divergent validity for behavioral measures of PVS constructs in adults (**A**) and children (**B**). For **Figure 1A**, *DDT* and *PDT* refer to the area under the curve (AUC) from the indifference point plots from the delay discounting and probability discounting tasks, *EEFRT RM* and *EEFRT Choice* refer to the reward sensitivity value and hard-task choice percentage metrics from the EEfRT, *IGT Latency* and *IGT Net Gain* refer to the deck learning latency and overall net point gain in the Iowa Gambling Task, and *TEPS Anticipatory* and *TEPS Consummatory* refer to the score totals from the anticipatory and consummatory subscales of the TEPS. For **Figure 1B**, shared labels with **Figure 1A** have the same meanings, and *EPSC* and *PSC* refer to the score totals from the experienced Pleasure Scale for Children and the standard Pleasure Scale for Children. (*) indicate correlations that were found to be significant with $p < 0.05$.

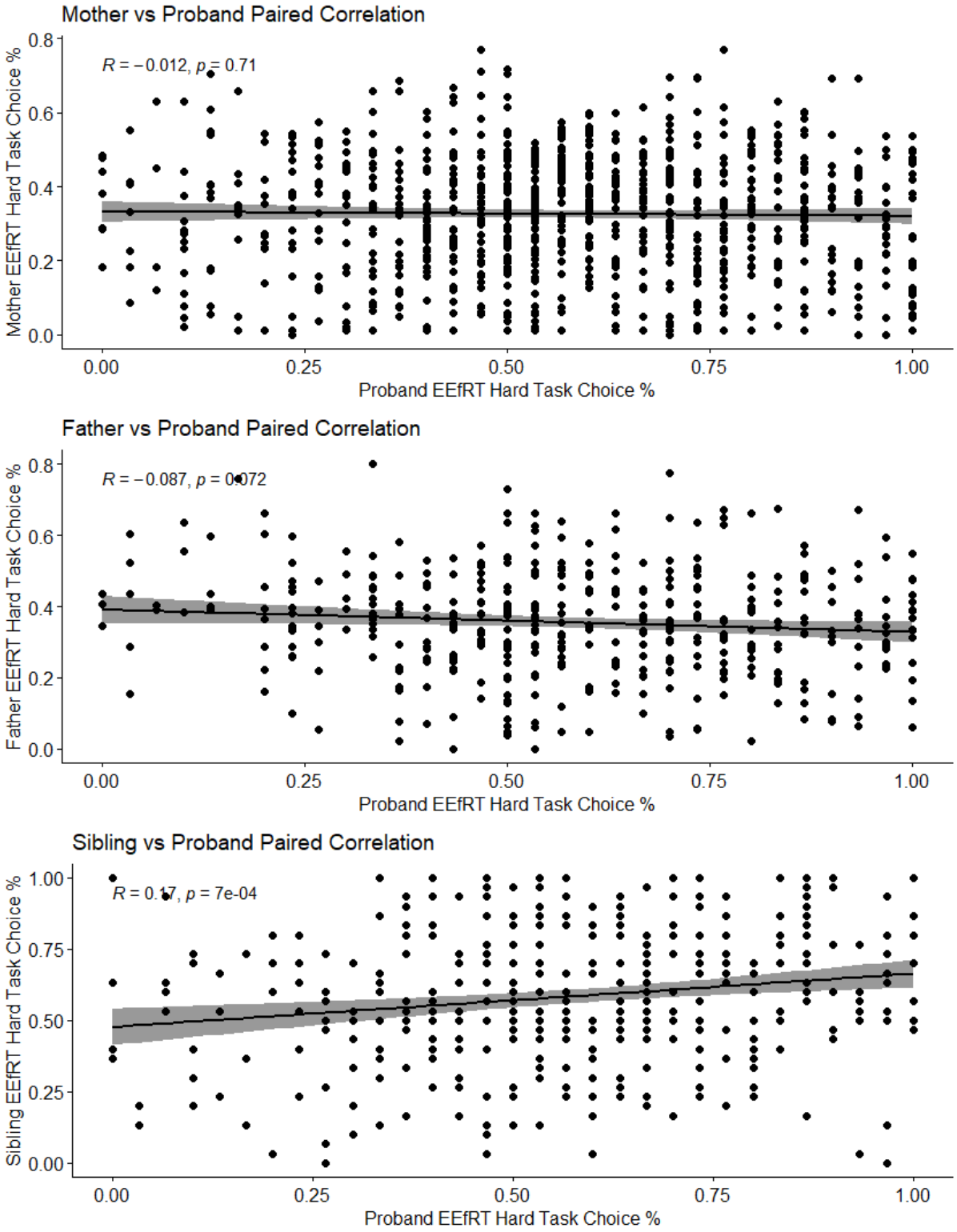

Figure 2

Paired correlations for EEfRT Hard Task Choice percentage between parents and their children, and between siblings.

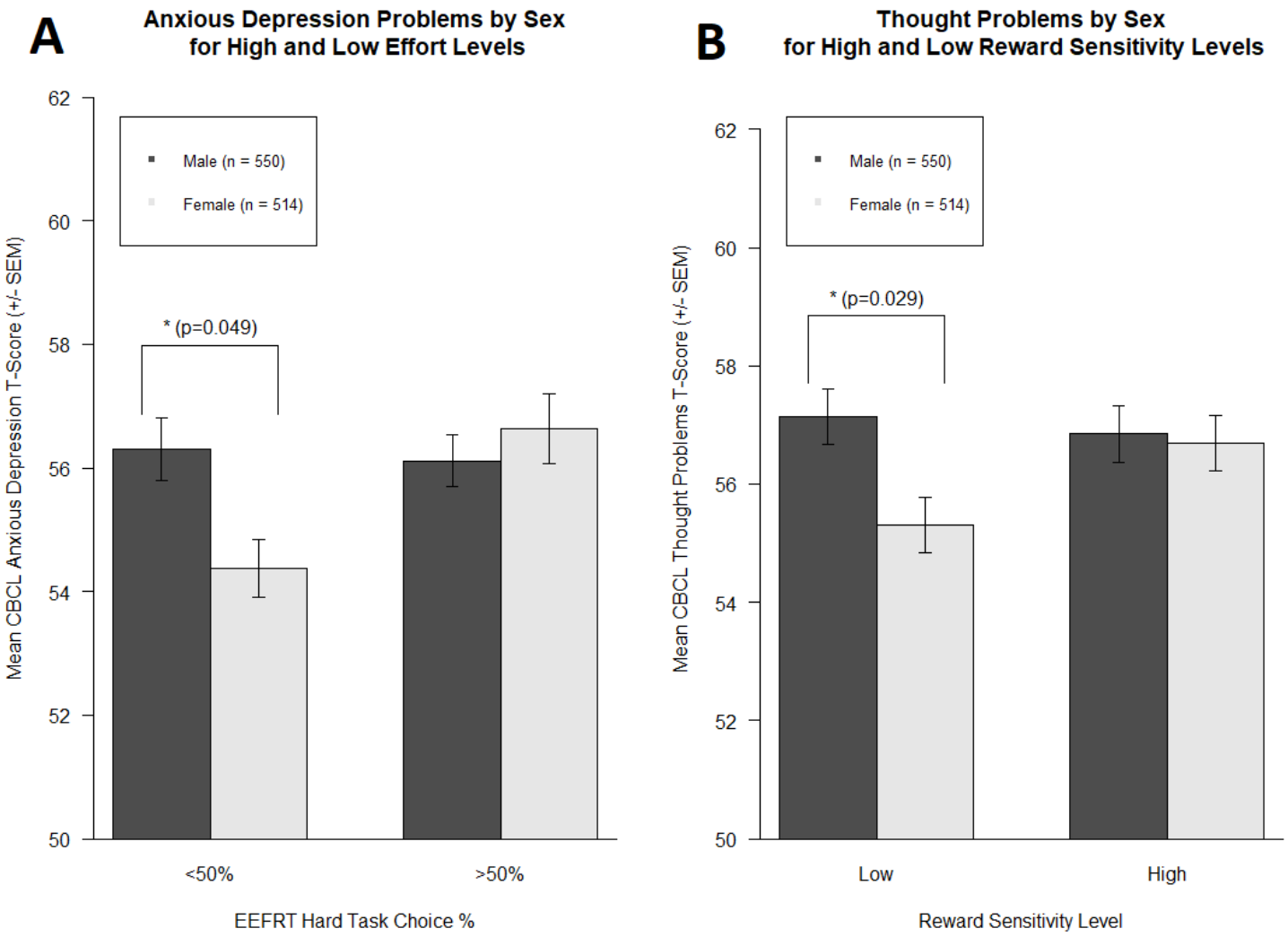

Figure 3

EEfRT Hard Task Choice percentage and sex in CBCL Anxious Depression (left, **A**). EEfRT Reward Sensitivity and sex in CBCL Thought Problems (right, **B**). Error bars shown are SEM.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementaryTable1FINAL.docx
- SupplementaryTable2.docx