Disrupted Expected Value Signaling in Youth With Disruptive Behavior Disorders to Environmental Reinforcers

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Objective: Youth with disruptive behavior disorders (DBD), including conduct disorder (CD) and oppositional defiant disorder (ODD), have difficulties in reinforcement-based decision making, the neural basis of which is poorly understood. Studies examining decision making in youth with DBD have revealed reduced reward responses within the ventromedial prefrontal cortex/orbitofrontal cortex (vmPFC/OFC), increased responses to unexpected punishment within the vmPFC and striatum, and reduced use of expected value information in the anterior insula cortex and dorsal anterior cingulate cortex during the avoidance of suboptimal choices. Previous work has used only monetary reinforcement. The current study examined whether dysfunction in youth with DBD during decision making extended to environmental reinforcers. **Method:** A total of 30 youth (15 healthy youth and 15 youth with DBD) completed a novel reinforcement-learning paradigm using environmental reinforcers (physical threat images, e.g., striking snake image; contamination threat images, e.g., rotting food; appetitive images, e.g., puppies) while undergoing functional magnetic resonance imaging (fMRI). **Results:** Behaviorally, healthy youth were significantly more likely to avoid physical threat, but not contamination threat, stimuli than youth with DBD. Imaging results revealed that youth with DBD showed significantly reduced use of expected value information in the bilateral caudate, thalamus, and posterior cingulate cortex during the avoidance of suboptimal responses. **Conclusions:** The current data suggest that youth with DBD show deficits to environmental reinforcers similar to the deficits seen to monetary reinforcers. Importantly, this deficit was unrelated to callous-unemotional (CU) traits, suggesting that caudate impairment may be a common deficit across youth with DBD. J. Am. Acad. Child Adolesc. Psychiatry, 2014;53(5):579–588. **Key Words:** disruptive behavior, conduct disorder, decision making, expected value, environmental reinforcers

Youth with disruptive behavior disorders (DBD), including conduct disorder (CD) and oppositional defiant disorder (ODD), show increased aggression and antisocial behavior.[1] Moreover, prognosis is poor, with approximately half presenting with severe pathology in adulthood.[2,3] In addition to antisocial behavior, youth with DBD have difficulties in reinforcement-based decision making, the neural bases of which are only beginning to be understood.[4-9]

Youth with DBD show reduced reward responses within the ventromedial prefrontal cortex/orbitofrontal cortex (vmPFC/OFC),[5,8,10] and increased responses to unexpected punishment within the vmPFC and striatum.[5,7] A recent model-based functional magnetic resonance imaging (fMRI) study revealed specific neuro-computational impairments.[6] Thus, both prediction error (PE) signaling and the representation of the expected value (EV) of a choice are disturbed in youth with DBD. Typically, healthy individuals show increased striatal responses to positive PE (greater reward than expected).[11] Youth with DBD showed a reduction in this signaling relative to comparison youth.[6] In addition, during response selection, healthy individuals typically show increases in vmPFC activity as a function of EV (i.e., increasing vmPFC activity the more that the choice


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is associated with expected reward).[11,12] Youth with DBD have shown a reduction in this signaling relative to comparison youth.[6] Finally, when attempting to avoid suboptimal choices, healthy individuals typically show increases in the anterior insula cortex (AIC), caudate, and dorsal anterior cingulate cortex (dACC).[13,14] These regions are involved in changing current responding (i.e., if the individual is about to avoid responding to a desirable stimulus), which can occur as a function of EV.[15,16] Youth with DBD showed a reduction in EV signaling within AIC and caudate during avoidance responses.[6]

Previous studies of decision making in youth with DBD have used monetary reinforcement. The goal of the current study was to determine whether dysfunction in PE and EV signaling in youth with DBD would extend to environmental reinforcement. This is an interesting issue, as aversive environmental reinforcement is exposure to a noxious stimulus, whereas aversive reinforcement during monetary reinforcement is the removal of a positive stimulus. This study involved a novel decision-making paradigm in which participants chose whether to enter doors that might lead to rewarding (appetitive images) or aversive consequences (images of physical or contamination threats). Importantly, the current study used computational model-based fMRI, which allows for testing how, not simply where, a function is conducted (i.e., whether EV and PE computations are intact).[17] Regressors for the choice phase were weighted by EV (the degree to which the door previously predicted outcome), and those for the feedback-phase were weighted by PE (the difference between predicted and received outcome), according to learning theory.[18] We predicted that, during decision making (choice phase), youth with DBD relative to healthy youth would show the following: reduced modulation of activity within vmPFC by reward-related EV when making optimal choices (i.e., when choosing the door associated with appetitive images); and reduced modulation of activity within AIC, dACC, and caudate by threat-related EV in youth with DBD when making suboptimal choices (i.e., when not choosing the door associated with appetitive images or when choosing the doors associated with aversive images).

During the feedback phase, we predicted that youth with DBD would show, relative to healthy youth, both reduced positive PE modulation to appetitive outcomes and increased negative PE modulation to aversive outcomes in vmPFC and caudate.

METHOD

Participants

A total of 34 youth participated: 15 youth with DBD and 15 healthy comparison (HC) youth, 10 to 17 years of age (Table 1). Four additional youth underwent scanning (2 youth with DBD and 2 HC youth) but were excluded, as they opened all doors and thus prevented modeling of nonchoice behavior. Youth were recruited from the community through advertising and referrals from area mental health practitioners. A statement of informed assent and consent was obtained from participating children/adolescents and parents. This

TABLE 1 Characteristics of Youth With Disruptive Behavior Disorders (DBD) and Healthy Comparison Youth

	Youth With DBD (n = 15) *DSM-IV* Diagnoses		HC Youth (n = 15)	
Characteristic	**Mean**	**SD**	**Mean**	**SD**
Age (y)	14.36	1.98	14.04	2.30
IQ[a]	93.47*	10.12	106.6*	10.80
ICU	31.71***	11.28	14.53***	6.52
	n	**%**	**n**	**%**
Gender (female)	4	26.67	5	33.33
***DSM-IV* Diagnoses**	**n**	**%**	**n**	**%**
CD	11	73.33	0	0
ODD	4	26.67	0	0
ADHD	7	46.67	0	0

Note: ADHD = attention-deficit/hyperactivity disorder; CD = conduct disorder; HC= healthy comparison; ICU = Inventory of Callous-Unemotional Traits; ODD = oppositional defiant disorder.

[a]*Assessed with the Wechsler Abbreviated Scale of Intelligence (2-subtest form).*

*p < .05; ***p < .001.