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Attention-Deficit/Hyperactivity Disorder and Monetary Delay Discounting: A Meta-Analysis of Case-Control Studies

Jacob N.S. Jackson and James MacKillop

ABSTRACT

BACKGROUND: A growing number of studies have investigated delay discounting, a behavioral economic index of impulsivity, and its relevance to attention-deficit/hyperactivity disorder (ADHD), but with mixed findings. The current meta-analysis synthesizes the literature on the relationship between monetary delay discounting and ADHD in studies using case-control designs. Specifically, the objectives were as follows: 1) to characterize the aggregated differences in monetary delay discounting between individuals with ADHD (cases) and control subjects in studies using categorical case-control designs; 2) to examine potential differences based on sample age ($<$18 vs. $>$18), reward outcome (real vs. hypothetical), and prevalence of conduct disorder and oppositional defiant disorder in the sample; and 3) to evaluate potential small-study (publication) bias in the literature.

METHODS: From 567 candidate articles, 21 independent investigations yielded 25 case-control comparisons (total $N =$ 3913). Random effects meta-analysis was conducted using Cohen's d as the common effect size. Publication bias was evaluated using fail-safe N, Begg-Mazumdar and Egger tests, and meta-regression of publication year and effect size.

RESULTS: Across studies, a statistically significant difference of medium magnitude effect size was present for the case-control comparisons ($d = .43$; $p < 10^{-15}$). No significant differences based on sample age, reward outcome, or comorbid status were detected. Minimal heterogeneity and evidence of publication bias were present.

CONCLUSIONS: These findings provide robust evidence that delay discounting is significantly elevated among individuals with ADHD compared with control subjects. Gaps in the literature and the importance of characterizing the neural and genetic bases of this relationship are discussed.

Keywords: Attention-deficit/hyperactivity disorder, Decision making, Delay discounting, Impulsivity, Intertemporal choice, Meta-analysis

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Since the earliest clinical descriptions of attention-deficit/hyperactivity disorder (ADHD), high levels of impulsivity have been described as a cardinal feature of the disorder (1). However, although impulsivity can be broadly defined as a person's capacity to inhibit or regulate arising impulses, it is operationalized in a variety of different ways (2,3), including both self-report questionnaires and behavioral tasks. Importantly, these diverse measures are often not highly intercorrelated, undermining the notion of a single underlying process. A recent meta-analysis of the interrelationships among self-report and behavioral task measures of impulsivity indicated little overlap between the two domains (4). Recent factor analyses suggest that when multiple measures of impulsivity are examined concurrently, latent aggregations of measures emerge (5–7), suggesting that impulsivity appears to be a psychological genus that subsumes a number of species.

One discrete form of impulsivity is delay discounting, reflecting how much a person devalues a reward based on its delay in time. Delay discounting is an index of impulsivity from behavioral economics, a hybrid discipline that integrates principles and methods from psychology and economics to study choice behavior. It is commonly measured using decision-making tasks that pose a variety of decisions, such as "Would you rather have $40 today or $100 in a month?," with systematic variation of smaller immediate rewards and delays in time while keeping the larger delayed reward consistent. Then, across an array of smaller (discounted) immediate rewards and future delays, an individual's overall devaluation of the larger delayed reward can be generated. Often, this is via examination of where an individual switches preferences from smaller-sooner to large-later rewards and then using those points of indifference across delays to model the individual's temporal discounting function. A widely used model uses a hyperbolic function, $v_d = V/(1 + kd)$ (8), where v_d is the discounted value of the delayed reward, V is the objective value of the delayed amount, d is the delay duration, and k is the derived parameter that characterizes the degree of future reward discounting. Alternatively, the switch points can be used to generate an individual's discounting curve, and area under the curve (AUC) can be used as a measure of future

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discounting (9). Of note, larger k values reflect more precipitous devaluation of future rewards (reflecting a larger denominator in the equation), whereas the opposite is true for AUC values (reflecting a smaller space beneath the curve). Common to all methods is that if a delayed reward loses value more rapidly, the individual is considered more impulsive. Of note, delay discounting tasks are related to delay of gratification paradigms (10), such as the marshmallow test (11), but differ insofar as the latter typically have a real-time component in which participants can alter their preference at any point, incorporating an element of in vivo temptation.

There has been longstanding experimental and theoretical interest in steep discounting of delayed rewards as a feature of ADHD. Empirically, early studies used simple choice tasks and found support for intertemporal choice deficits among children with ADHD (12,13). Subsequently, studies using iterative behavioral tasks systematically examining preferences for monetary rewards have revealed similar patterns in children, adolescents, and adults (14–18). Theoretically, steep delay discounting is considered a hallmark deficit of ADHD (19–21), akin to deficits in response inhibition and sustained attention (22,23). The underlying deficit has been theorized to be hypoactivity in mesocortical dopamine neurotransmission based on preclinical and functional magnetic resonance imaging (fMRI) studies (19,24), although characterizing these processes remains an active area of inquiry. In addition, steep temporal discounting may be a cause of the high comorbidity between ADHD and substance use disorders (25,26). For example, individuals with ADHD have, depending on the drug type, a twofold to eightfold higher prevalence of substance use disorder (25). Conversely, in a large recent study of treatment-seeking individuals with substance use disorders, over 40% screened positive for ADHD (27). This substantial overlap suggests some level of common etiological causality, one form of which may be delay discounting. Behavioral studies have found evidence of more precipitous temporal discounting in individuals with alcohol dependence (28), nicotine dependence (29), cocaine dependence (30) and opioid dependence (31) compared with matched control participants. Thus, steep discounting of delayed rewards may be a common risk process in ADHD and addiction.

As a proliferation of studies on delay discounting and ADHD has emerged over the last 5 years, several have not reported significant associations (32,33), suggesting the link may be weaker or more ambiguous than initially believed. Furthermore, the accumulating literature has not been systematically examined to characterize overall patterns of findings and possible bias. This was the focus of the current meta-analysis. Specifically, the present study had three aims: 1) to characterize the relationship between monetary delay discounting and ADHD in previously published case-control comparisons; 2) to examine three potential moderators of effects, namely, sample age ($<$18 vs. $>$18 years), reward outcome (real vs. hypothetical), and prevalence of conduct disorder/oppositional defiant disorder in the sample; and 3) to investigate the presence of small-study bias, reflecting the probability of publication bias.

METHODS AND MATERIALS

Meta-Analysis Sample

The initial inclusion criterion was any peer-reviewed published study or unpublished dissertation reporting comparisons of delay discounting between a group meeting ADHD diagnostic criteria and a control group. To minimize substantial methodological variability, studies were restricted to delay discounting of monetary rewards (e.g., simple choice tasks using golden donkeys, spaceships, etc., were excluded), and studies of probability discounting and social discounting were excluded. Studies were identified via a literature search using the PubMed and PsycINFO databases as of September 25, 2015. The specific Boolean terms entered were (discounting OR delay of gratification) AND (attention OR ADHD). The search term ADHD is automatically expanded to include attention deficit disorder with hyperactivity OR (attention AND deficit AND disorder AND hyperactivity). A total of 567 records were generated, of which 422 were unique after eliminating duplicates from the two databases, and 49 were relevant. Full-text reviews were conducted on the relevant studies, yielding 21 viable studies with 25 distinct comparisons. Records were excluded if they used rodent models, were review papers, or if they did not collect data on either ADHD or delay discounting. Two of the relevant studies reported overlapping data. After contacting the authors, only the more extensive of these two studies was included. The meta-analysis was performed on the 25 viable comparisons of delay discounting and ADHD. Meta-analysis of continuous associations was considered but ultimately not pursued because of a paucity of studies (k = 3). A flow diagram that is consistent with meta-analysis guidelines is provided in Figure 1 (34).

Sample Characteristics

Effect sizes reflecting differences between an ADHD-positive group and a control group were available for 21 of the 422 uniquely identified articles, yielding 25 comparisons. Fifteen of these relevant comparisons reported statistically significant differences in delay discounting performance between ADHD and control groups and 10 reported nonsignificant differences. Three individual articles provided results for delay discounting at multiple magnitudes. All reported comparisons were included to maximize representation of the literature, but a follow-up analysis included a single meta-analysis effect size from studies using multiple measures.

Individual study characteristics are presented in Table 1 and illustrate the wide variation of study protocols. Sample sizes ranged considerably, from $n = 36$ to $n = 1298$ (total $N = 3913$), with an average sample size of 157. The average age within studies ranged from 7.9 to 36.9 years old, with a total sample average age of 21.0 years and median study age of 16.0 years. The delayed rewards for the discounting tasks were primarily for hypothetical outcomes, ranging from \$0.10 to \$5000, with an average of \$380 and a median of \$42.50. The vast majority of studies used k or AUC as the index of discounting. One study reported individual points of indifference, one study reported impulsive choice ratio, and