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Are ADHD Symptoms Associated with Delay Aversion or Choice Impulsivity? A General Population Study

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Abstract

Objective—The term *delay aversion* has been used both to describe a behavioural tendency of greater preference for smaller-immediate over larger-delayed rewards (choice impulsivity), and to refer to a secondary explanatory construct put forward by delay aversion theory. In this study we examined the association of ADHD symptoms with choice impulsivity and tested the specific hypothesis derived from delay aversion theory.

Method—1062 children aged 7.90-10.90 years (49% female) made a fixed number of repeated choices between a smaller reward delivered immediately and a larger reward delivered after a delay (choice-delay task), under two conditions (including and excluding a post-reward delay). We assessed the unique contribution of each ADHD symptom dimension to the prediction of choice impulsivity and delay aversion, controlling for age (or age and IQ). Gender effects were examined.

Results—Inattention ratings uniquely predicted preference for smaller-immediate rewards under both task conditions for both genders. An index of delay aversion was associated with inattention only in boys; the effect size was small yet significant. Hyperactivity-impulsivity ratings were negatively associated with choice impulsivity in girls in the post-reward delay condition, whereas no significant association with hyperactivity-impulsivity ratings was observed in boys. Categorical analyses using groups with high ADHD symptoms yielded similar results.

Conclusions—This is the first study to report a unique association between inattention symptoms and behavioural measures of choice impulsivity and delay aversion. The findings indicate the importance of the primary constitutional processes that underlie choice impulsivity and their potential role in behavioural inattention. Understanding the behavioural and brain processes underlying choice impulsivity may lead to the improved targeting of behavioural and pharmacological interventions.

Keywords

ADHD; inattention; hyperactivity-impulsivity; delay aversion; choice impulsivity

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Delay aversion theory1,2 has been influential in ADHD research, rekindling interest in motivational processes as explanatory factors for symptoms of inattention and hyperactivity-

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impulsivity. Defined as a motivational style characterised by a "negative emotional reaction to the imposition of delay",[3] the concept of delay aversion is used to denote an independent, complementary developmental route that may contribute to the emergence of ADHD behaviours, alongside a more cognitive/executive dysfunction pathway, as proposed in a dual pathway model.[1,3]

The choice-delay paradigm has provided an experimental platform for the development of delay aversion theory. Participants are offered a fixed number of repeated choices between a smaller-immediate or a larger-delayed reward (a secondary reinforcer). Preference for smaller-immediate rewards (henceforth called c*hoice impulsivity*) denotes lack of self-control, assuming that maximisation of rewards is of greater importance for the organism.[4,5]

The initial formulation of delay aversion theory[2] proposed an alternative to the traditional inability-for-self-control interpretation of choice impulsivity in children with "pervasive hyperactivity". A stronger preference for smaller-immediate rewards was observed when this response style also shortened task length, but not when choice did not impact on task duration. An impulsive behavioural style, rather than reflecting an inhibitory deficit, was seen as a functional, adaptive strategy to reduce *overall* delay by people who are averse to it. Two direct predictions were derived. First, hyperactive children should be sensitive to *overall* task length, irrespective of whether the delay precedes or follows the delivery of rewards. Secondly, children with ADHD will be *able* to restrain "impulsive" behaviour when it does not reduce overall task length but will *prefer* not to do so when it shortens task length, despite the economic cost of this behaviour. A study using 3 year old preschoolers with ADHD-typical behaviour provided support for the initial delay aversion theory[6] (although caution is required in extrapolating to school-aged children given the potential role of verbal ability in self control[7]), but other studies challenged it. Controlling for level of reward, Tripp and Alsop[8] showed that children with ADHD are unusually sensitive to pre-reward (rather than post-reward) delays, suggesting that they have a stronger need to seek immediate rewards rather than be delay-averse. Schweitzer and Sulzer-Azaroff[9] found that children with ADHD had a higher preference for smaller-immediate rewards compared to controls even though task length was kept constant.

Later formulations of delay aversion theory[3,10] embrace impulsivity-as-lack-of-self-control as the necessary substrate for the development of an acquired motivational tendency to avoid/escape delays, i.e. delay aversion. It is postulated that the interaction between a primary constitutional dysfunction of the mesolimbic dopaminergic system (presenting as behavioural impulsivity) and specific familial-societal demands, which clash with an impulsive behavioural style, lead to failure and consequently the development of negative affect for periods of delay.[10] The developmental aspect to this model is yet to be tested empirically.

Children with a clinical or research diagnosis of ADHD have demonstrated increased choice impulsivity both when this reduces overall task length[11-15] and when it does not.[9] Choice impulsivity has also been associated with ADHD symptoms in studies using community samples[16,17] and in a study with young adults.[18] Other studies, using the same[19,20] or a different paradigm,[21] have failed to replicate this finding. Studies using hypothetical rewards suggest that the nature and magnitude of rewards may be important factors.[18,22]

The prediction that children with ADHD prefer smaller-immediate over larger-delayed rewards is not specific to delay aversion theory, but shared with other theories too.[23,24] What sets delay aversion theory apart is the prediction that children with ADHD should show a *differential* increase in choice impulsivity under conditions where delay can be escaped compared to conditions where delay cannot be avoided. So far, apart from the original study,2 three studies have obtained data that enable a direct test of the hypothesis specific to delay aversion theory. These studies compared the two conditions: choice of the smaller-immediate reward followed by no post-reward delay, with a post-reward delay condition such that task length remains constant irrespective of one's pattern of responses. The association between delay aversion and ADHD has been tested in two ways: as the statistical interaction between diagnostic group and delay condition,25 or as the differential increase in choice impulsivity for children with ADHD in the no post-reward delay condition.6,25

The first study was reviewed above.6 The second study,25 on a large European sample of 360 combined type ADHD probands and 112 controls found, first, that probands with ADHD selected the larger-delayed reward less often than healthy controls in both the post- and no post-reward delay conditions (effect sizes *partial* η^2=0.029 and 0.056 respectively). Second, the interaction between group and condition was significant, corresponding to an effect size of *partial* η^2=0.027 (all effects uncorrected for age or IQ).25 *Partial* η^2 does not express the *total* amount of explained variance, but the *maximum possible* amount of variance the corresponding term can explain.26,27 We therefore conclude from this study that a maximum of 2.7% of the variance in the change in choice impulsivity between the two test conditions (reflecting delay aversion) is accounted for by ADHD group status. Finally, a third study21 failed to support the delay aversion theory as children with ADHD were indistinguishable from typically developing children under both conditions. This study showed that, across diagnostic status, children (6-11 years old) had a steeper discounting of delayed rewards compared to adolescents (12-17 years old) under both conditions, suggesting that choice is influenced by reward immediacy rather than delay aversion in the younger group.

Evidence from quantitative genetic and epidemiological studies supports the idea that individuals with ADHD represent the extreme of continuously distributed ADHD symptoms in the general population and the validity of making inferences from population data to clinical cases (see[28] for a summary). Given the selection biases that may be associated with clinic-referred samples, it is important to complement studies that have focused on clinical samples with studies that focus on unselected, population-based samples. Population samples also enable an investigation of the two ADHD symptom dimensions separately, as well as an investigation of gender effects. Some previous studies have showed an association between choice impulsivity and both inattention and hyperactivity-impulsivity, 17 while others only with hyperactivity-impulsivity.12,18 In general population samples, boys have higher inattention and hyperactivity/impulsivity scores than girls,16,29 while no gender differences in choice impulsivity16,25 or discounting rate30 have been reported.

The present study focuses on a large, general population sample of children, using a task identical to that used by Marco et al.25 We predicted that the behavioural symptoms of inattention and hyperactivity-impulsivity would be positively associated with choice impulsivity under both the post-reward delay and no post-reward delay conditions. The original delay aversion formulation predicted an association with ADHD only in the no post-reward delay condition, yet more recent theoretical arguments and empirical data lead to the prediction of an association with ADHD symptoms under both conditions. According to recent formulations of the delay aversion hypothesis, we further predicted that ADHD symptom scores would be positively correlated with an index of delay aversion, expressing the relative increase in preference for smaller-immediate rewards in the no post-reward compared to the post-reward delay condition.

Second, we adopted a categorical approach to defining extreme groups based on the inattention, hyperactivity-impulsivity or combined symptom dimensions, and used the 95th

percentile on each scale, based on the whole sample, as a cut-off point. The comparison of a quantitative and a categorical approach in the same general population sample allows us to examine whether ADHD symptoms are associated with choice impulsivity and/or delay aversion below the clinical threshold levels and not only in clinical cases of ADHD. Assuming that ADHD is the extreme of a quantitative trait normally distributed in the population, we predicted that the association between extreme group membership, choice impulsivity and delay aversion would be comparable to that observed using the quantitative symptom scores. The categorical analyses were restricted to boys due to the very small number of girls with high symptom ratings.

METHOD

Sample and procedure

Participants are members of the Study of Activity and Impulsivity Levels (SAIL) in children,31 a general population sample of twins aged 7.9 to 10.9 years, recruited from the Twins' Early Development Study (TEDS),32 a birth cohort study which had invited parents of all twins born in England and Wales during 1994-1996 to enrol.

Of the 1,230 suitable families contacted, 672 families (55%) agreed to participate. Children with an IQ below 70, on neuropsychiatric medication or with specific medical, neurological or psychiatric conditions were excluded (for details on inclusion and exclusion criteria, see[31]). For the current analyses, we only included participants with ADHD ratings from both parents and teachers, who completed both conditions of the Maudsley Index of Childhood Delay Aversion task, reflecting 79% of the total available SAIL sample, or 1,062 children. The mean age was 8.80 (SD=0.66) and children's IQs ranged from 70 to 158 (M=109.74, SD=14.95). Parents of all participants gave informed consent following procedures approved by the Institute of Psychiatry Ethical Committee.

Two testers assessed the twins simultaneously in separate testing rooms at the Research Centre. The tasks were administered in a fixed order as part of a more extensive test session, which in total lasted approximately 2.5 hours.

Measures

Wechsler Intelligence Scales for Children, Third Edition (WISC-III)33—The vocabulary, similarities, picture completion and block design subtests from the WISC were used to obtain an estimate of the child's IQ.

The Maudsley Index of Childhood Delay Aversion14 (MIDA; see31 for a description of task presentation)—Two conditions, each with 20 trials, were administered. In each trial the child had a choice between a smaller-immediate reward (one point involving a 2 second pre-reward delay) and a larger-delayed reward (two points involving a 30 second pre-reward delay). In the no post-reward delay condition, choosing the small reward led immediately to the next trial, reducing the overall length of the condition. In the post-reward delay condition, choosing the small reward led to a delay period of 30 seconds and choosing the large reward to a delay period of 2 seconds before the next trial; therefore the overall delay was constant and independent of choice made. The order of the two conditions was randomly chosen for each twin.

Two measures were extracted from this task: (a) number of times the smaller-immediate reward was selected in each condition, controlling for total number of trials attempted (see Data analyses); (b) a quantitative index of delay aversion (IDA), calculated as the difference in the percentage of times the smaller-immediate reward was selected between the two

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conditions. A higher score reflected increased preference for smaller-immediate rewards in the no post-reward delay condition and thus a greater degree of delay aversion.

Ratings of inattention and hyperactivity-impulsivity—Parents and teachers were asked to complete the Long Versions of the Conners' Parent and Teacher Rating Scales. 34,35 From both scales, we used the 9-item hyperactive-impulsive and 9-item inattentive DSM-IV symptoms sub-scales. A total DSM-IV ADHD symptoms subscale was formed by adding up items from the two subscales. In a few cases, missing data in Conners' scales were pro-rated: a summary score based on the mean of individual questions on the rest of the subscale was used if there was more than 75% completion for each subscale. Of those with MIDA data (N=1210), 1208 had Conners' Parent Rating Scale data available, and 1064 had Conners' Teacher Rating Scale data. Parent and teacher ratings on each subscale were combined by summating scores.

Data analyses

Details regarding data analysis can be found in the supplementary digital content (online only) materials at http://links.lww.com/admin/xxx. Negative binomial regression (NBREG) models were used to assess the unique contribution of each ADHD symptom dimension (including the other dimension as a covariate) or extreme group membership in predicting the number of times participants selected smaller-immediate rewards, after controlling for age (model I) or age and IQ (model II). To facilitate comparisons between predictors we used standardised scores for ADHD symptoms. The incident rate ratio (IRR) expresses the factor by which the expected number of smaller-immediate reward choices changes for a change of 1 SD in the predictor (dimensional analyses), or with membership in one of the extreme groups.36 To facilitate interpretation, we calculated the discrete change in the percentage of times the smaller-immediate reward was selected per 1 SD change in symptom scores (or with extreme group membership), holding all other variables at their means. As a further aid, discrete change is also expressed as the raw number by which the smaller-immediate reward choices were expected to change for a typical participant who completed 20 trials. To test the delay aversion specific hypothesis, we used IDA scores, which were normally distributed, in linear regression models. All analyses were conducted using STATA (release 9.2, STATA Corporation, College Station, TX, USA), and corrections were applied for the cluster-correlated nature of our data (twin pairs).

For the categorical analyses (male participants), we used the 95th percentile on each symptom dimension as our threshold (it is close to the estimated prevalence rates of ADHD in the UK37, 38) to define three extreme groups: (i) ADHD-IN (N=32), including participants who scored in the top 5% on inattention ratings, but below the top 5% on hyperactivity-impulsivity ratings; (ii) ADHD-H/I (N=25), consisting of participants who scored in the top 5% on hyperactivity-impulsivity ratings but below the top 5% on inattention ratings; (iii) ADHD-CO (N=19), comprising participants who scored in the top 5% on both inattention and hyperactivity-impulsivity ratings. These groups resemble the DSM-IV inattentive, hyperactive/impulsive and combined ADHD subtypes respectively, but only in terms of presence of symptoms, as information regarding the age of onset, pervasiveness, duration and impact of ADHD symptoms needs additionally to be taken into account for a clinical diagnosis.

RESULTS

Subgroup characteristics

Boys and girls did not differ in age or IQ, but girls had lower ratings on both ADHD symptom dimensions. Additional information can be found in the supplementary digital content (online only) materials at http://links.lww.com/admin/xxx. There were no significant differences in age or IQ between the extreme groups and the rest of the sample in the categorical analyses. Table A can be found in the supplementary digital content (online only) materials at http://links.lww.com/admin/xxx.

Gender differences in choice impulsivity and delay aversion

Girls showed a higher percentage of smaller-immediate reward choices both in the post-reward delay (boys: M=13.25, SD=18.28; girls: M=17.3, SD=18.89; F(1, 568)=10.49, p=.001, R^2=.01) and the no post-reward delay (boys: M=27.94, SD=29.71; girls: M=32.65, SD=26.21; F(1, 568)=7.24, p=.007, R^2=.01) conditions, but did not differ from boys on the IDA (F(1, 568)=0.21, p=.65).

Dimensional analyses

Choice impulsivity—Inattention significantly predicted preference for smaller-immediate rewards after controlling for hyperactivity-impulsivity and age in both task conditions and for both gender groups (Table 1, model I). An increase of one SD in inattention increased the expected percentage of times a smaller-immediate reward was selected by 2.41-5.46 points in boys and 4.35-7.01 points in girls, in the post- and no post-reward delay conditions respectively. This translated to an expected increase of 0.48-1.40 in the number of times a typical participant selected the smaller-immediate reward per one SD increase in inattention scores. Controlling for IQ attenuated this effect but it remained significant, except for boys in the post-reward delay condition (Table 1, model II).

Hyperactivity-impulsivity did not significantly predict choice impulsivity after controlling for inattention symptoms and age, except for girls in the post-reward delay condition (Table 1). This effect was similar in size, but *opposite* in direction, to that of inattention, and was maintained after controlling for IQ.

Total ADHD symptom scores showed a significant but attenuated association with choice impulsivity relative to inattention scores in boys, but no association in girls (Table 1). This reflects the opposite in direction association of inattention and hyperactivity-impulsivity symptoms with choice impulsivity.

Index of delay aversion—Inattention (but not hyperactivity-impulsivity) ratings uniquely predicted IDA scores in boys, after controlling for age and hyperactivity-impulsivity symptoms, increasing R^2 by 0.013, a small yet significant effect (Table 2, top). The association was attenuated but still significant after controlling for IQ. Neither symptom dimension significantly predicted IDA scores in girls.

Total ADHD symptom scores showed a significant but attenuated association with IDA relative to inattention scores in boys (Table 2, bottom). A similar association was observed in girls, although the model was not significant. This reflects the fact that both inattention and hyperactivity-impulsivity scores showed a non-significant but positive association with IDA in girls.

Categorical analyses (male participants)

Choice impulsivity—Membership in the group defined in terms of extreme inattention ratings (ADHD-IN) predicted a significant increase in choice impulsivity in the no post-reward delay condition. Membership in any of the other groups did not predict choice impulsivity in either condition (Table 3).

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Index of delay aversion—Only membership in the ADHD-IN group was positively associated with IDA scores, accounting for 0.9% of the variance (Table 4).

DISCUSSION

Currently, some ambiguity surrounds the term "delay aversion". It has been used both in a descriptive capacity, to denote the preference for smaller-immediate over larger-delayed rewards (or the steeper discounting of rewards as a function of time to delivery), which we named *choice impulsivity* to avoid confusion, and to refer to an acquired motivational tendency postulated by delay aversion theory as an explanatory construct contributing to choice impulsivity.

This is the first study to examine choice impulsivity and the delay aversion construct in relation to ADHD symptoms using a large population sample. Choice impulsivity showed a small yet significant association with inattention (controlling for hyperactivity-impulsivity and age). This association was observed in both task conditions, was similar across genders, and remained significant but was attenuated after controlling for IQ (except for boys in the post-reward delay condition). In the categorical analyses, boys with high inattention ratings chose more smaller-immediate rewards when this reduced overall task length.

Unexpectedly, the association between hyperactivity-impulsivity and choice impulsivity was context- and gender-specific. For girls in the post-reward delay condition, higher levels of hyperactivity-impulsivity were associated with *reduced* smaller-immediate reward choices. This association was similar in size but *opposite* in direction compared to inattention ratings. In boys there was no association between hyperactivity-impulsivity and choice impulsivity.

Turning to the predictions stemming from the revised delay aversion theory,10,25 we observed a small yet significant association between inattention ratings and the index of delay aversion in boys only (controlling for hyperactivity-impulsivity and age). Adding inattention ratings in the model increased the explained variance by 1.3% (0.9% after controlling for IQ). The categorical analyses yielded similar results; boys in the inattentive subgroup showed an increase in IDA scores, accounting for 0.9% of the explained variance.

This is the first study to show that, in a large general population sample of school-aged children, choice impulsivity and a derivative measure reflecting the motivational construct of "delay aversion" (IDA) may be associated with inattention rather than hyperactivity-impulsivity ratings. This is not entirely unexpected since delay aversion theory makes no prediction for a preferential association with either symptom dimension3 and existing research, while scant, does not point to a clear direction. A previous study with similarly aged children with combined subtype ADHD found a moderate correlation between choice impulsivity and teacher hyperactivity-impulsivity ratings,12 while a study with pre-school children reported similar correlations between both inattentive and hyperactive-impulsive symptom dimensions and choice impulsivity.17 Another study using a young adult population sample has reported an association between a measure of temporal discounting and hyperactivity-impulsivity only.18 At the behavioural level, choice impulsivity has been positively associated with gross motor behaviour in children with ADHD,12,13 but dissociated from hyperactivity in rodents.39

Future research needs to clarify the extent to which the stronger association of behavioural measures of choice impulsivity and delay aversion with inattention rather than hyperactivity-impulsivity ratings reflects true relations between underlying processes, or an artefact resulting from different levels, or inadequate methods, of measurement. The DSM-IV diagnostic criteria are not operational definitions of precise cognitive processes such as inattention and impulsivity. For instance, DSM-IV "inattention" symptoms may also capture aspects of impulsivity40 and data-driven approaches to subtype definition have identified an inattentive-impulsive class.41 Moreover, questionnaire- and laboratory-based measures of impulsivity do not necessarily associate well, reflecting different levels of analysis.42,43

The observed association between inattention symptoms and a measure of delay aversion (IDA) in the current general population study is consistent with recent evidence from a large sample of clinically ascertained probands with DSM-IV combined subtype ADHD and controls which used the same task.25 The current study further suggests that the association between ADHD and delay aversion may be stronger in boys, and driven by a stronger association with inattention symptoms; a finding that is yet to be confirmed with a clinically ascertained sample. The differential association of inattention and hyperactivity-impulsivity ratings with choice impulsivity/delay aversion in the current study is consistent with research in other areas44 which suggests a possible separation of underlying processes. Our results encourage the separate examination of the two ADHD symptom dimensions, for which purpose general population samples are ideal. The lack of a threshold effect demarcating the top 5% groups is consistent with the idea that ADHD symptoms are quantitative traits distributed continuously in the population and that ADHD represents the tail of this distribution.

The use of secondary reinforcers may be a limitation of the choice-delay paradigm as it has been used to date, reducing its sensitivity to capture the full range of individual differences in choice impulsivity. This may particularly apply in the post-reward delay condition: the lack of a truly immediate effect for the smaller-immediate reward might deprive it from its single advantage in this condition, namely, the gratification of the impulsive drive for an immediate effect. This could also affect the measurement of delay aversion, as the IDA is a relative measure based on the score difference between the two conditions. Given the inherent difficulties in the use of primary reinforcers, these issues could be addressed in future research through the direct assessment of delay aversion *independently* from choice impulsivity, by obtaining some physiological index of emotional reactivity to delays (e.g. reactivity of the amygdala, see[45]).This would allow the independent assessment of primary (choice impulsivity) and secondary (delay aversion) manifestations of the underlying aetiology, as well as of their association to ADHD symptoms and to each other. Delay aversion is a developmental concept; it has been thought to emerge over time, progressively leading to "an elaboration of symptoms from impulsiveness to inattentiveness and overactivity".3 Choice impulsivity and delay aversion are interrelated, as the latter is proposed to be the product of the interaction of environmental factors with the former.3 Their relation will likely be a complex one, with reciprocal, feed-forward and feedback pathways, and to be assessed it will require independent measures of each variable and longitudinal data.

Based on existing data, the acquired motivational tendency to avoid delays (delay aversion) contributes only minimally to ADHD, perhaps in a gender specific-manner; it explains no more than 0.9-2.7% of the variance, depending on the nature of the sample. Therefore, a reappraisal of ADHD symptoms and choice impulsivity as instances of *adaptive* behaviour, or *preferences*, which aim to reduce delays or their psychological impact2, might be necessary.

Choice impulsivity is a commonly observed behavioural phenomenon5,46 which is neurobiologically and behaviourally dissociable from other impulsivity facets (e.g. impulsive disinhibition, measured with the stop signal paradigm) in both animals and humans.39,43,47-50 The association of choice impulsivity with ADHD is more consistent and robust, reflecting moderate effect sizes reported to range from d=0.57 to d=0.7110; a formal meta-analysis with explicit criteria is yet to be published. These estimates are comparable to those reported for executive function measures, ranging from Cohen's d=0.46 to d=1.16.51,52 These findings warrant focusing research interest on the primary, constitutional processes which manifest as choice impulsivity (and eventually may lead to the secondary acquisition of aversion to delays), as a possible aetiological factor contributing to ADHD. Existing theoretical models link the development of ADHD symptoms to a constitutional dysfunction in the dopamine-based brain circuitry which underpins reinforcement learning and reward processing.23,24,53 Choice impulsivity has been directly linked to dopamine function54, and associated with activation in the mesolimbic reward processing circuitry (e.g.[55,56]) which is dysfunctional in ADHD (e.g.[57]). The constitutional nature of this dysfunction is consistent with the high heritability of ADHD,58 but lends itself to early behavioural interventions (e.g.[53]) and pharmacological treatment which may positively influence an organism's developmental pathway and hinder or subdue the development of ADHD symptoms and associated behaviours.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Table 1

Unique contribution of inattention and hyperactivity-impulsivity scores and total ADHD scores to the prediction of choice impulsivity in the MIDA tesk.

	Model I Controlling for other symptom dimension and age					Model II Controlling for other symptom dimension, age & IQ				
	IRR[1]	SE[2]	p	IRR 95% CI[3]	Discrete change %points (rewards)[4]	IRR[1]	SE[2]	p	IRR 95% CI[3]	Discrete change %points (rewards)[4]
Post-Reward Delay condition										
Males										
Inattention[5]	1.21	0.086	.008	(1.05, 1.39)	2.41 (0.48)	1.11	0.080	.16	(0.96, 1.28)	1.19 (0.24)
Hyperactivity/impulsivity[5]	0.99	0.067	.83	(0.86, 1.13)	−0.18 (−0.04)	1.03	0.071	.70	(0.90, 1.18)	0.31 (0.06)
Total ADHD symptoms[5]	1.16	0.067	.006	(1.05, 1.31)	2.00 (0.40)	1.12	0.064	0.44	(1.00, 1.26)	1.34 (0.27)
Females										
Inattention[5]	1.25	0.104	.007	(1.06, 1.47)	4.35 (0.87)	1.18	0.093	.036	(1.01, 1.38)	2.99 (0.60)
Hyperactivity/impulsivity[5]	0.79	0.075	.013	(0.66, 0.95)	−3.23 (−0.65)	0.77	0.069	.004	(0.65, 0.92)	−3.37 (−0.67)
Total ADHD symptoms[5]	1.01	0.070	.84	(0.89, 1.16)	0.00 (0.00)	0.94	0.065	.37	(0.82, 1.08)	−0.94 (−0.19)
No post-Reward Delay condition										
Males										
Inattention[5]	1.22	0.063	< .001	(1.10, 1.35)	5.46 (1.09)	1.18	0.061	.002	(1.06, 1.30)	4.27 (0.85)
Hyperactivity/impulsivity[5]	0.97	0.052	.57	(0.87, 1.08)	−0.80 (−0.16)	0.97	0.053	.63	(0.88, 1.08)	−0.67 (−0.13)
Total ADHD symptoms[5]	1.17	0.050	<.001	(1.08, 1.27)	4.28 (0.86)	1.13	0.049	.003	(1.04, 1.23)	3.31 (0.66)
Females										
Inattention[5]	1.21	0.075	.002	(1.07, 1.36)	7.01 (1.40)	1.16	0.070	.011	(1.04, 1.31)	5.43 (1.09)

	Model I Controlling for other symptom dimension and age					Model II Controlling for other symptom dimension, age & IQ				
	IRR[1]	SE[2]	p	IRR 95% CI[3]	Discrete change %points (rewards)[4]	IRR[1]	SE[2]	p	IRR 95% CI[3]	Discrete change %points (rewards)[4]
Hyperactivity/impulsivity[5]	0.91	0.060	.16	(0.80, 1.04)	−2.81 (−0.56)	0.90	0.058	.10	(0.79, 1.02)	−3.08 (−0.62)
Total ADHD symptoms[5]	1.10	0.055	.059	(1.00, 1.21)	3.31 (0.66)	1.05	0.053	.32	(0.95, 1.16)	1.68 (0.34)

Note: Negative binomial regression models have been used to examine the unique contribution of each symptom dimension or total ADHD scores to choice impulsivity under each task condition, controlling for age (model I) or age and IQ (model II).

[1]Incidence rate ratio.

[2]Robust standard error.

[3]Confidence intervals.

[4]Expected change in preference for smaller-immediate rewards per 1 SD change in symptom scores, holding all other variables at their means, in terms of either percentage points or raw rewards for a typical participant.

[5]Standardised scores. MIDA: Maudsley Index of Childhood Delay Aversion.

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Table 2

Unique contribution of inattention and hyperactivity-impulsivity scores and total ADHD scores to the prediction of IDA scores.

	Model I. Predictors: Age, Inattention, Hyperactivity/impulsivity					Model II. Predictors: IQ, Age, Inattention, Hyperactivity/impulsivity				
	b	SE[1]	p	95% CI[2]	ΔR^2 [3]	b	SE[1]	p	95% CI[2]	ΔR^2 [3]
Males										
Inattention [4]	3.30	1.23	.008	(0.87, 5.73)	.013	2.93	1.23	.018	(0.51, 5.35)	.009
Hyperactivity/impulsivity [4]	−1.10	1.06	.30	(−3.18, 0.98)	.001	−0.99	1.05	.35	(−3.05, 1.07)	.001
	Model I R^2=.029, F(3,371)=5.47, p=.001					Model II R^2=.037, F(4,371)=5.44, p<.001				
Females										
Inattention [4]	1.86	1.49	.21	(−1.07, 4.79)	.003	1.71	1.52	.26	(−1.27, 4.69)	.003
Hyperactivity/impulsivity [4]	1.23	1.44	.39	(−1.59, 4.05)	.001	1.23	1.44	.39	(−1.60, 4.05)	.001
	Model I R^2=.010, F(3,364)=1.65, p=.18					Model II R^2=.011, F(4,364)=1.28, p=.28				

	Model I. Predictors: Age, total ADHD symptoms					Model II. Predictors: IQ, Age, total ADHD symptoms				
	b	SE [1]	p	95% CI [2]	ΔR^2 [3]	b	SE [1]	p	95% CI [2]	ΔR^2 [3]
Males										
Total ADHD symptoms [4]	2.01	0.90	.025	(0.25, 3.78)	.008	1.77	0.88	.046	(0.03, 3.50)	.006
	Model I R^2=.029, F(2,371)=6.90, p=.001					Model I R^2=.032, F(3,371)=6.45, p<.001				
Females										
Total ADHD symptoms [4]	2.80	1.33	.036	(0.18, 5.42)	.009	2.66	1.32	.046	(0.06, 5.27)	.008
	Model I R^2=.010, F(2,364)=2.49, p=.084					Model I R^2=.011, F(3,364)=1.71, p=.17				

Note: Linear regression has been used to examine the unique contributions of each symptom dimension or total ADHD scores to the prediction of index of delay aversion (IDA) scores, controlling for age (Model I) or age and IQ (Model II).

[1] Robust standard error.

[2] Confidence intervals

[3] R^2 change after adding the specific predictor in a model containing the remaining predictors.

[4] Standardised scores.

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Table 3

Using extreme group membership to predict choice impulsivity in the MIDA task (boys only).

Extreme group (top 5%)	n (total)	IRR[1]	SE[2]	p	IRR 95% CI[3]	Discrete change %points (rewards)[4]
Post-reward delay condition						
ADHD-IN[5]	32(542)	1.15	0.28	.57	(0.71, 1.84)	1.94 (0.39)
ADHD-H/I[6]	25(542)	1.05	0.30	.87	(0.60, 1.84)	0.64 (0.13)
ADHD-CO[7]	19(542)	1.37	0.35	.21	(0.83, 2.26)	4.88 (0.98)
No post-reward delay condition						
ADHD-IN[5]	32(542)	1.45	0.22	.015	(1.07, 1.97)	12.33 (2.47)
ADHD-H/I[6]	25(542)	0.99	0.21	.98	(0.66, 1.51)	−0.14 (−0.03)
ADHD-CO[7]	19(542)	1.32	0.24	.12	(0.93, 1.88)	8.95 (1.79)

Note: Negative binomial regression models have been used to examine whether extreme group membership can predict choice impulsivity under each task condition.

[1] Incidence rate ratio.

[2] Robust standard error.

[3] Confidence intervals.

[4] Expected change in preference for smaller-immediate rewards with extreme group membership expressed in percentage points or raw rewards for a typical participant.

[5] ADHD-Inattentive extreme group.

[6] ADHD-Hyperactive/impulsive extreme group.

[7] ADHD-Combined subtype extreme group. MIDA: Maudsley Index of Childhood Delay Aversion.

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Table 4

Using extreme group membership to predict IDA scores

Extreme group (top 5%)	n (total)	b	SE[1]	p	95% CI[2]	R^2
ADHD-IN[3]	32(542)	10.39	4.94	.036	(0.68, 20.10)	0.009
ADHD-H/I[4]	25(542)	−0.81	3.76	.83	(−8.20, 6.58)	0.000
ADHD-CO[5]	19(542)	4.08	5.46	.46	(−6.65, 14.81)	0.001

Note: Linear regression has been used to examine whether extreme group membership can predict index of delay aversion (IDA) scores.

[1]Robust standard error.

[2]Confidence intervals.

[3]ADHD-Inattentive extreme group.

[4]ADHD-Hyperactive/impulsive extreme group.

[5]ADHD-Combined subtype extreme group.