Delay Aversion in Attention Deficit/Hyperactivity Disorder: An empirical investigation of the broader phenotype

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Abstract

Background: Delay-related motivational processes are impaired in children with Attention Deficit/Hyperactivity Disorder (ADHD). Here we explore the impact of ADHD on the performance of three putative indices of Delay Aversion (DAv): i) the choice for immediate over delayed reward; ii) slower reaction times following delay and; iii) increased delay-related frustration - to see whether these tap into a common DAv construct that differentiates ADHD cases from controls and shows evidence of familiality.

Method: Seventy seven male and female individuals (age range 6 to 17) with a research diagnosis combined type ADHD, 65 of their siblings unaffected by ADHD and 50 non-ADHD controls completed three delay tasks.

Results: As predicted the size of the correlation between tasks was small but a common latent component was apparent. Children with ADHD differed from controls on all tasks (d = .4 - .7) and on an overall DAv index (d = .9): The battery as a whole demonstrated moderate sensitivity and specificity. In general, deficits were equally marked in childhood and adolescence and were independent of comorbid ODD. IQ moderated the effect on the MIDA. Scores on the DAv factor co-segregated within ADHD families.

Discussion: There is value in exploring the broader DAv phenotype in ADHD. The results illustrate the power of multivariate approaches to endophenotypes. By highlighting the significant, but limited, role of DAv in ADHD these results are consistent with recent accounts that emphasize the neuropsychological heterogeneity.

Key words: Delay Aversion, Endophenotypes, Heterogeneity, IQ, Oppositional Defiant Disorder (ODD).

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INTRODUCTION

In recent years the phenotype of childhood disorders, such as Attention Deficit/Hyperactivity Disorder (ADHD), has been extended from observable clinical symptoms (i.e. the exo-phenotype) to neuro-psycho-biological characteristics thought to mark putative causal pathways to the disorder (i.e. endophenotypes; Castellanos & Tannock, 2002). A range of ADHD endophenotypic markers have been proposed. These have typically focused on cognitive processes encompassed by the concept of executive function (Doyle et al., 2005). Researchers are extending this to candidate endophenotypes in the motivational and cognitive-energetic domain (Andreou et al., 2007; Bidwell et al., 2007; Marco et al., submitted).

An altered response to delayed outcomes, first identified as a relevant factor in ADHD by Douglas and Parry (1983), is one such candidate (Sagvolden et al., 2005; Sonuga-Barke, 2002; 2003; 2005). The fact that ADHD children exhibit a preferential response to immediate as compared to delayed outcomes is one of the most consistent findings in the motivational literature (Luman et al., 2005; Sonuga-Barke et al., 2008). For instance, when given the choice, children with ADHD have a stronger preference for smaller sooner (SS) over large later (LL) rewards than controls, even when this leads to less rewards over a testing sessions (Antrop et al., 2006; Dalen et al., 2004; Kuntsi et al., 2001; Luman et al., 2005; Marco et al., submitted; Schweitzer & Sulzer-Azaroff, 1995; Solanto et al., 2001; Sonuga-Barke et al., 1992). A recent review (Sonuga-Barke et al., 2008) of two tasks commonly used to index this tendency (*Maudsley Index of Delay Aversion* - MIDA; Kuntsi et al., 2001; and the *Choice Delay Task* - CDT; Sonuga-Barke et al., 1992) reported pooled effects sizes for case-control differences which compare

favorably with those reported for executive function deficit (Willcut et al., 2005). Data from other paradigms also support altered response to delay as a putative endophenotypic marker for ADHD. Children with ADHD display a bias towards task responses tied to immediate rewards (Tripp & Alsop, 2001); they prefer reward immediacy to high reward rate or task ease (Neef et al., 2005), and they discount future rewards (Barkley et al., 2001; but see Scheres et al., 2006 for a counter case). According to a number of theories these effects are thought to be grounded in the neurobiology of the fronto-striatal reward circuits of the brain (with especially prominent roles for the orbito-frontal cortex and ventral striatum; Cardinal et al., 2001; Sagvolden et al., 2005; Scheres et al., 2007), and are modulated by alterations in catecholamine functioning (especially dopamine; Tripp & Wickens, 2007; Winstanley et al., 2006).

The *Delay Aversion* (DAv) model of ADHD makes a number of specific predictions about the effects of delay in different contexts. These differentiate it from other motivational models (Sagvolden et al., 2005; Sonuga-Barke et al., 2008; Tripp & Wickens, 2007). These predictions are derived from the theory that the constitutionally-based delay-related effects associated with fundamental alterations in the signaling of delayed rewards, discussed above, are compounded by an acquired secondary motivation to escape or avoid delay. This is hypothesized to be conditioned over time in response to repeated exposure to social censure and failure in delay-rich settings experienced by children with altered delay-reward signaling (Sonuga-Barke, 2003), predictions that are yet to be tested empirically.

Furthermore, in the model, this acquired motivational attitude is expressed in different ways as a function of whether or not environmental delay levels can actually be

reduced (i.e. whether there is a choice or not). So for instance, in the choice settings described above the constitutionally-based and acquired elements combine to create a marked preference for immediate over delayed outcomes (Sonuga-Barke et al., 2008). This model of choice behavior is supported by a recent study demonstrating that ADHD children and adolescents chose SS over LL more than controls and this tendency was exacerbated in a condition when this response style reduced total delay across a session (Marco et al., submitted).

While the preference for SS over LL expressed in choice situations is regarded by many as the hallmark of DAv, the DAv theory implicates a broader phenotype marked by a characteristic response to the imposition of delay in situation where escape and avoidance of it is not possible (Sonuga-Barke, 1994; Sonuga-Barke, 2005). Although much less frequently investigated than choice behavior, these putative markers of the DAv endophenotype were described in the earliest theoretical formulation (Sonuga-Barke, 1994). According to the model, the imposition of fixed delay creates frustration and emotional arousal and leads to attempts to modify the experience of waiting and so reduce the aversiveness of delay. In terms of behaviour it is hypothesized that this will be achieved by engaging in patterns of stimulus-seeking behavior that speed up the passage of time (i.e. increased activity and attention) but may reduce the quality of performance especially on long and boring tasks or under slow event rate conditions.

These predictions are supported by data from a number of studies using tasks with a fixed delay component. For instance, children with ADHD are unusually vigilant to environmental delay-related cues (Sonuga-Barke et al., 2003) suggesting an increased emotional salience for delay. They find the imposition of unexpected delay more

frustrating than controls as indexed by an increased rate of responding during the delay period on the Delay Frustration Task (DeFT; Bitsakou et al., 2006). They show more activity and increased responding during fixed periods of delay or the extinction of reinforcers (Sagvolden et al., 1998). Finally, in terms of time on task and event rate effects children with ADHD tend to disengage from long and boring tasks with the passage of time and there is a consistent effect of slow event rate and/or long inter-stimulus interval on ADHD children's performance, reaction times and reaction time variability (Aase & Sagvolden, 2006; Andreou et al., 2007; Wiersema et al., 2006).

According to the DAv model these different expressions of delay-related behaviour in different choice and non-choice settings and on different tasks by children with ADHD are manifestations at least in part of an underlying core latent construct or trait – DAv. This particular prediction of the DAv theory has not been tested to date. The current study therefore set out to explore the relationship between three putative elements of the broader DAv construct by examining the relationship between performance on three different delay tasks (choice between LL and SS; delay-related frustration in non-choice tasks and increased RTs under conditions of low event rate or long inter-stimulus intervals) and their power to discriminate ADHD cases from controls. The prediction, based on the DAv hypothesis is that these delay-related expressions will covary one with another to some degree, with each tapping into a single common latent-factor.

The extent to which this covariation between domains will be observed in the laboratory will depend on the features of the specific tasks employed. This is because, for any particular delay task performance will be determined by a myriad of factors in addition to any common effects of delay that may be present. This means that if different

expression of DAv are measured by similar tasks tapping related psychological processes, in addition to response to delay, then correlation between tasks are likely to be high – however the extent to which this high correlation is due to delay-related elements or other elements shared between the tasks would be difficult to determine. Under such circumstances high correlations between delay tasks may, therefore, be in part spurious. If the tasks are very different and tap different psychological processes, in addition to the delay-related response, then the correlations will be much lower. Adopting this second strategy to testing delay-related domain covariation is more conservative and may underestimate the actual correlation between domains but it allows us to be more confident that manifest correlation between tasks is the product of the common focus on delay across tasks and not a spurious effect of other similarities between the tasks. This latter strategy was adopted in the current paper with the three tasks differing very greatly in their form and their response. One task was a choice task requiring a single choice response, one was a reaction time task and one was button pressing task for which the relevant output was responses per unit of time. For this reason we predicted that in the current study that the correlations between tasks would be low but a common latent factor that captures the variance shared by the tasks would be especially good at differentiating ADHD from control children.

The study also explored the co-segregation of ADHD and DAv within families by comparing DAv as a latent trait in ADHD probands and their unaffected siblings. Such an analysis will start to address the question of whether some pathways between initial causes with a familial component (i.e., genes and shared environments) and ADHD are mediated by DAv (i.e. whether DAv is an endophenotype of ADHD). According to the

DAv theory, the implication of biological (i.e. dopamine function in determining unconditional immediacy preference) and family-based social factors (i.e. punitive parenting) in determining the tendency toward DAv leads to the prediction that performance on these tasks is familial. To date, there is only limited support for this position. Although negative parenting has been implicated in ADHD (Psychogiou et al., 2008), its role in the origins of DAv per se, has not been tested directly. Indirect evidence of family influences comes from twin studies but even here the evidence is mixed. Kuntsi & Stevenson (2001) employed a twin design to demonstrate a significant shared environmental basis for DAv. However, more recent studies have failed to confirm the role of familial factors (Kuntsi et al., 2006; Andreou et al., 2007; Bidwell et al., 2007). One possible reason for this is that the choice-tasks (e.g., MIDA) do not meet the assumptions of the parametric model fitting approaches employed in these studies because of its J-shaped response distribution – most children choose the LL on 50 percent of trials or more. In the current paper by employing a latent DAv index derived from the three tasks tapping the broader phenotype we hope to overcome such problems.

The current paper includes participants ranging in age from 6 to 17 years. Although not a primary goal of the study this allowed us to explore developmental changes in the extent to which DAv is an important characteristic of ADHD across childhood and adolescence. There are competing hypotheses with regard to this. On the one hand, the DAv theory argues that DAv is an emerging feature that occurs over time and compounds pre-existing delay-related deficits. In this sense one might expect DAv to increase with age (at least up to a certain age). One the other hand, it is to be expected that there will be a more general change in patterns of the motivational salience of

outcomes, as individuals mature across the life span with small rewards becoming far less salient in adolescence than in childhood (Wulfert et al., 2002), while at the same time the ability to tolerate delay to rewards grows exponentially (Bjork et al., 2004; Green et al., 1994; Green et al., 1996). This could mean that DAv becomes more difficult to index as individuals grow with longer and longer delay and larger and larger rewards required. It is also possible that the expression of DAv changes with age, as is the case with other symptoms of ADHD (Nutt et al., 2007). So for instance, one might expect a diminution of the behavioural manifestation of DAv accompanied perhaps by an increase in internal agitation during delay as children grow into adolescents. So that even if DAv is increasing overtime ones' ability to measure it may be more limited. Taking all the factors together makes it difficult to make definitive predictions regarding the effects of age on DAv in ADHD.

. We will also explore the possible confounding effects of IQ and comorbid Oppositional Defiant Disorder (ODD) on DAv in ADHD. Kuntsi and colleagues (2001) examined the effect of DAv (choice-task) before and after controlling for IQ. Although the DAv main effect remained significant, the magnitude of the effect was reduced, indicating that IQ could be a mediator of DAv in ADHD. Finally, the two studies (Antrop et al., 2006; van der Meere et al., 2005) investigating the impact of ODD on DAv in ADHD have provided inconclusive results and further research is required.

So, in summary the aims of the current study are:

(i) To explore the covariation of three putative measures of DAv and to examine whether DAv can be conceptualised in terms of a common underlying construct.

(ii) To examine their power to discriminate ADHD cases from controls.

(iii) To test whether DAv is familial and whether it segregates with ADHD within families.

(iv) To explore the extent to which age, IQ and comorbid ODD alter these effects of ADHD on DAv.

Methods

Participants

Initially, 71 families with at least one child with ADHD were recruited to participate in the Southampton arm of the International Multicenter ADHD Genetics study (IMAGE; Brookes et al., 2006). Six siblings of ADHD probands were also affected with ADHD. These cases were included in the analysis of cases vs. control differences but excluded from the familiality analysis as indexed by case, control and unaffected sibling differences. Therefore, 77 ADHD cases with a combined type diagnosis (M = 11.82 years, SD = 2.39 years), 65 unaffected siblings of a subset of these cases (M = 11.46 years, SD = 3.19 years) and 50 non-ADHD controls (M = 12.15 years, SD = 2.25 years) were included in the various analyses. Controls were recruited from local primary and secondary schools. Inclusion criteria for cases was a research diagnosis of ADHD, an IQ of at least 70, age range between 6 to 17 years, and no apparent other major mental health problems, such as autism, epilepsy, brain disorders, or known genetic disorders, such as Downs syndrome or Fragile X syndrome.

Diagnostic Criteria

Probands were recruited after receiving a clinical diagnosis of ADHD combined type following a careful evaluation. Diagnosis was validated to research criteria using the standard procedures of the IMAGE project described fully elsewhere (Brookes et al., 2006). Briefly, screening questionnaires (parent and teacher Conners long-version rating scales (Conners, 1996), parent and teacher versions of the *Strengths and Difficulties Questionnaire* (SDQ; Goodman, 1997), and Social Communication Questionnaire (Berument et al., 1999) were used to quantify ADHD and comorbid symptoms. Probands and their siblings with *T* scores > 63 on the Conners' ADHD subscales were administered the *Parental Account of Childhood Symptoms* (PACS; Taylor et al., 1991). PACS is a semi-structured clinical interview developed to provide a research-based diagnosis of ADHD and related disorders. A trained interviewer administered PACS with parents. Inter-rater reliability was high with product-moment correlations for pairs of interviewers ranging from .79 to .96 (Brookes et al., 2006). A standardized algorithm was applied to PACS data to derive each of the 18 DSM-IV ADHD items. These were combined with items that were scored 2 (pretty much true) or 3 (very much true) in the teacher-rated Conners ADHD subscales to generate the total number of hyperactive-impulsive and inattentive symptoms of the DSM-IV symptom list. Situational pervasiveness was defined as at least one symptom occurring in two or more situations and the age of onset of the symptoms needed to be before seven years. In addition, the PACS interview gave diagnoses of Conduct Disorder (CD), ODD and autistic spectrum disorder.

Control children were recruited from two schools in Southampton (N = 27 children), two churches where families send their children to Sunday school (N = 9 children) and 14 children were recruited from previous studies that took place in

Psychology Department, after they and their parents had given consent to be approached for future studies. The initial recruitment strategy aimed to match controls against ADHD cases for age and gender. Sixty-five children were initially recruited. However, on closer inspection 15 of these scored above the borderline cut-offs on the hyperactivity/impulsivity subscale of the SDQ. Because these 15 cases tended to be younger and male we were left with a preponderance of older children and females in the controls relative to the ADHD cases. This effect was significant for gender but not for age (table 1). The effect of age and gender were explored in subsequent analyses to ensure that these group differences were not biasing the results. None of the control children had any diagnosed mental disorder according to parental reports. Table 1 provides sample and clinical characteristics of ADHD cases and non-ADHD controls.

Insert Table 1 about here

Tasks & Measures

The three delay tasks were part of larger battery of cognitive tests.

The Maudsley's Index of Childhood Delay Aversion (MIDA; Kuntsi et al., 2001): This is a computer-based choice delay task specifically designed to test DAv. The task measures preference towards LL and SS. MIDA has been found to have high reliability (intra-class correlation = .74; Kuntsi et al., 2001) and to distinguish ADHD cases from controls (d = .57; Sonuga-Barke et al., 2008). The task is presented as a space game, in which the child had to 'destroy' an enemy space-craft with their own spaceship, by using the computer mouse. The child chose between two options: either to wait for 2sec in order to destroy

one spaceship and get 1 point as a reward (SS), or to wait for 30sec in order to destroy two spaceships and get 2 points as a reward (LL). The task can be presented under two conditions. One condition has no period of post-reward delay so as soon as the child makes their choice (which ever it is) the next trial is presented. In this condition choosing the small immediate alternative reduces the length of the trial and the session as a whole. The second condition has a post-reward delay period that equalizes the trial length irrespective of which choice is made. Typically case-control differences are larger in no-post than the post reward delay condition (Sonuga-Barke et al., 1992; Marco et al., submitted) with ADHD children more likely to choose the small immediate reward when doing so reduces the length of trials and/or sessions. Only one condition (the no-post reward delay condition) was used in the current study in order minimize, as far as possible, the length of the testing session while maximizing the chance of group differences. There were 15 trials, the passage of each trial was indicated to the child by removing one of 15 stars placed next to the computer. Children had two practice trials with a forced choice of each alternative. After the practice trials the researcher asked the child questions about the options to ensure that they had understood the rules and aims. Depending on the child's final score (max. 30 points) the child received a reward of either 1 pencil or 1 pencil and two extra small stationary items of their choice (e.g. robber, ruler etc). The value of the reward was not revealed to the child until the end of the task. The percentage LL choice is the dependent variable.

Delay Frustration Task (DeFT; Bitsakou et al., 2006): The task has been described fully elsewhere (Bitsakou et al., 2006) and has high test-retest reliability (intra-class correlation

= .89; Bitsakou, 2007, unpublished PhD thesis). Briefly in the Delay Frustration Task (DeFT), the 'primary task' involves a series of simple math questions (55 trials) presented on a computer. Participants were required to select the correct answer by pressing a button on a four-button response box. On most trials (N = 39) as soon as the participant responded the program moved to the next trial (no post-response delay condition). However, on a minority of trials the access to the next question was delayed by 20sec (8 trials; post-delay condition). Moreover, eight distractor trials were provided, where the delay period varied from 3 to 10 seconds. On the post-delay and distractor trials the response button was 'inactive' during the delay period and the responses were therefore ineffective at accessing the subsequent trial although all responses were recorded. At the end of the delay period the response box was 'reactivated' once again and the first response became effective in allowing the participant to move on to the next trial. The sequencing of the post-response delay trials was presented in a pseudo-random order. For the first 10 trials there were no post-response delay trials. After that the placement of delay trials was randomized across the remaining 45 trials. The distractor trials were not included in the analysis because there was only one trial at each delay level and this was deemed to be insufficient to provide a reliable measure of response frustration at any particular level of delay.

This pattern of delay following responses was designed to create delay-related frustration leading to attempts by DAv participants to escape delay by pressing the button to move on to the next question. The participants were 'warned' that the computer has given signs of malfunction and that if the computer appeared not to register their response they may need to respond again before they could move onto the next trial. This

modification was introduced following pilot testing when participants appeared to loose interest in the task following the experience of the unresponsiveness of the task during delay. No information was given about the nature of the length of the delays that might be experienced or how likely they would occur during a particular period in the experiment. The mean total duration (MTD) of responding per second of delay on the delayed trials was the dependent variable. This was the product of the average response frequency (i.e. number of responses per second) and the average duration of each response (i.e. the total time of response per second). The first second was excluded from the analysis, as this indexed reaction to the task and not delay aversion.

Delay Reaction Time task (DRT; Sonuga-Barke & Taylor, 1992): This task is a modified version of the Delay Reaction Time task used by Sonuga-Barke and Taylor (1992), which was developed to measure the impact of event rate on DAv as indicated by an increased RT to a delayed stimulus. The revised task was found to have high test-retest reliability (intra-class correlation = .79; Bitsakou, 2007, unpublished PhD thesis). During this task a stimulus (either a left or a right green arrow) appeared on the centre of the computer screen for either 3000 of 20000 milliseconds period of delay. The screen then turned blank, at which point the participant was required to respond as quickly and accurately as possible to the disappearance of the stimulus, by pressing the left or right button of the mouse according to the direction of the arrow. Each trial was indicated by a fixation tone of 500msec. Participants had four practice trials (2 trials for each delay condition) and then 12 experimental trials (6 trials for each delay condition). The presentation of the left and right arrows was counterbalanced. To calculate the main DRT index (i.e. DRT Delay Sensitivity – DRT DS), a control task was also used (2 Choice Response task; 2CR –

Hogan et al., 2005). The 2CR measure, which had the same structure and visual components as the DRT, essentially had no delay (the arrows were presented for 100 ms) prior to the response being required. This represented a useful control against which to judge sensitivity to delay. The DRT DS index is the mean RT score for the two delay levels of the DRT task minus the RT on the 2CR task (no delay task).

Wechsler Intelligence Scales for Children (WISC-III; Wechsler, 1991): The Vocabulary and Block Design subtests from the Wechsler Intelligence Scales for Children-III (WISC-III; Wechsler, 1991) were used to estimate IQ. In order to convert the scaled scores to deviation IQ scores, the formula by Sattler (1992) was used. According to Sattler (1992) this two-subtest short form IQ has reliability of .95 and validity of .86.

Procedure

Families of children with ADHD were recruited from six clinics around the Hampshire area. Children with ADHD were off-medication for at least 48 hours before testing. Children with ADHD and their siblings were tested in parallel by two different researchers to avoid information exchange. No PACS interview was undertaken with the non-ADHD control children or siblings. Full testing took between 2 to 2 1/2 hours and children rested during short breaks. The experimenter remained with each child throughout the task. At the end of the session all children received a £5 voucher for their participation. Ethical approval was received both from the Southampton University Ethics Committee and the local NHS medical ethics committee and all participants and their parents gave their informed consent.

Analytical Strategy

Tests were run for outliers on all the depended measures of each individual and each task. Reaction times that were less than 100ms were considered as impossible non-processed responses, and were replaced with the mean for the relevant cell for that person. Moreover, any score that lay outside three standard deviations from the group mean was considered an outlier. In those cases, outliers were replaced with the group mean for the relevant cell for that measure.

Case – control analyses: These analyses included 77 ADHD cases and 50 non-ADHD controls. First we examined the covariation between the three putative DAv measures using principal components analysis to test whether a single component could be derived on the basis of covariation between scores on the three tasks. An index of DAv was created using the item-to-factor weights derived from the principal components analysis. Second, we employed ANOVA to examine case-control difference for all key dependent variables separately and for the DAv factor score. Status (ADHD vs. controls) and Age (6-12 years vs. 13-17 years) were the independent between subject variables. Where there were case-control differences in factors such as IQ or conduct problems (ODD and CD) these were introduced as covariates into the above analysis. CD was always found to co-exist with ODD (based on the *PACS*), therefore only the effect of comorbid ODD on neuropsychological performance was investigated. In fact, 19 cases had 'pure' ADHD and 58 cases had ADHD+ODD. Gender was also included in the initial analysis, but since it showed no significant effects, it was removed from the present analysis. Operating characteristics (i.e., sensitivity/specificity) for each measure and for the DAv index are presented. Multiple logistic regression analysis (forward stepwise) was employed to examine the independent contribution of each individual

measure to the prediction of ADHD caseness. In preliminary analysis, non-parametric tests were used for measures that were not normally distributed. However, as the results were the same as those found with the ANOVA, these analyses are not reported (but are available from the authors).

Familiality analyses: These analyses investigated familiality of the DAv index score that combined the three test indices measures by looking at i) proband-sibling correlations and ii) their segregation with ADHD by comparing mean levels of task performance for probands, siblings and controls. Analysis was also carried out to investigate the linear and non-quadratic trend of the data, as was used by Waldman and colleagues (2006). For this stage of analysis, families with affected siblings were removed from the analysis. Therefore, the final sample for this analysis was 65 pairs of ADHD probands and their unaffected sibling and 50 non-ADHD control children. Table 2 provides the characteristics of ADHD probands, their unaffected siblings and non-ADHD controls.

Results

Covariation of DAv measures: As predicted the main indices of the three DAv measures were correlated, although the effect sizes were small. Specifically, DRT DS was significantly associated with the other two measures (MIDA r = -.26, p = .003; DeFT r = -.20, p = .027). The correlation between MIDA and DeFT approached significance (r = .15, p = .097). As suggested by this pattern of correlation a principal component analysis with Varimax rotation, supported the hypothesis that the key dependent variables from the three tasks shared common variance and that a latent variable could be extracted, with

each task score item loading above normal thresholds (eigenvalue = 1.3; 43.8% of variance explained with item to factor loadings of MIDA % LL = -.65, DRT DS = .79, DeFT MTD = .51). A DAv index was derived from this analysis, calculated by using item to factor loadings as weights. This was employed in subsequent analyses.

Insert Table 2 about here

Case-control differences in DAv

MIDA Task: ADHD cases were less likely to wait for the LL reward compared to control cases independent of age group (Table 2; d = .49). IQ was associated with preference on LL reward (r = .21, p = .017) and when controlled for in ANCOVA the group effect was no longer significant ($F(1,121) = 2.51$, p = .11). There was an effect of age which remained significant ($F(1,121) = 9.59$, p = .002) after controlling for IQ; children were less likely to choose LL reward compared to adolescents. The effect of ODD on MIDA performance was marginally significant ($F(2,120) = 3.00$, p = .05). However, Bonferroni post-hoc analysis indicated no significant difference between 'pure' ADHD cases and ADHD cases with comorbid ODD. The task correctly identified 60.3% of cases (sensitivity 54.5%: specificity 69.4% using a 40% cut-off for task performance).

DeFT Task: ADHD cases had increased total response duration during the unexpected delay trials compared to control children (Table 2; d = .63). No age main effect or status x age interaction was found. IQ was not associated with DeFT MTD (r = .11, p = .12). A one-way ANOVA was employed to investigate the effect of comorbid ODD with status (ADHD, ADHD+ODD and controls) and age (6-12 years vs. 13-17 years) as independent factors. The status main effect was significant ($F(2,114) = 3.68$, p = .02). Bonferroni post-hoc analysis indicated no difference between 'pure' ADHD cases

and ADHD cases with comorbid ODD. This task correctly classified 61% of cases (sensitivity 45.1%; specificity 83.7% with a 40% cut-off).

DRT Task: ADHD cases showed slower RTs on trials with longer ISIs compared to control children, as an indication of their delay sensitivity (Table 2; d = .76). The age main effect and status x age interaction were not significant (F(1,119) = 2.55, p > .05; F(1,119) =.19, p > .05 respectively). IQ was negatively associated with responding during delay (r = -.18, p = .045). The effect of status (ADHD vs. control) remained significant when IQ was entered as a covariate (F(1,118) = 9.88, p = .002), whereas the age main effect and status x age interaction remained non-significant (F(1,118) = 3.16, p = .07; F(1,118) = 0.08, p = .77 respectively). A one-way ANOVA was employed to investigate the effect of comorbid ODD with status (ADHD, ADHD+ODD and controls) and age (6-12 years vs. 13-17 years) as independent factors. The status main effect was found to be significant (F(2,117) = 6.22, p = .003). Bonferroni post-hoc analysis indicated no difference between 'pure' ADHD cases and ADHD cases with comorbid ODD. The task correctly classified 67% of cases (sensitivity 59 % and specificity 78% with a 40% cut-off).

DAv Index: For the overall factor score the main effect of status was highly significant (Table 2) and remained significant after controlling for IQ (F(1,111) = 14.27; p < .001). The effect size (d = .95) suggests a large association between ADHD and the DAv according to Cohen's (1992) criteria. The index classified 69% of cases (sensitivity 64.7%; specificity 75% with a 40% cut-off on task performance). Moreover, the effect of ODD on the DAv index was significant (F(2,110) = 8.26, p < .001). Bonferroni post-hoc

analysis indicated no significant difference between 'pure' ADHD cases and ADHD cases with comorbid ODD.

Insert Table 3 and 4 about here

According to the stepwise logistic regression both DRT DS (step 1) and DeFT MTD (added step 2) make independent contributions to predicting ADHD. On its own the DRT DS (OR=.44; CI = .27 - .71) accounted for 15% of the variance of ADHD. DRT DS (OR= .46; CI = .28 - .76) and DeFT MD (OR= .42; CI = .22 - .82) were significant in step 2. Adding DeFT MD to DRT DS significantly increased the predictive power of the model which at step 2 accounted for 25% of the variance. Although having a significant univariate effect MIDA LL did not make a further independent contribution to the model (χ^2 (1) = 2.68, p = .10) and adding it (step 3) did not significantly improve the model (R^2 = .26).

Familiality analysis

Table 3 indicates the sample and clinical characteristics of the three groups included in this analysis. Proband-sibling correlations for the individual DAv measures and overall DAv index were of modest to moderate magnitude, with only the correlation on MIDA task reaching significance (MIDA: r = .35, p = .004; DeFT: r =.26, p = .06; DRT: r = .14, p = .30; DAv index: r = .16, p = .29).

To test differences between probands, siblings and controls a univariate ANOVA was used with two independent factors: status (ADHD, unaffected siblings, and controls)

and age (6-12 years vs. 13-17 years). Table 4 reports ANOVA main and interaction effects. The status main effect was significant for all measures, indicating that there was a difference between the three groups (Figure 1.I-IV). The age main effect was significant on MIDA, DRT DS and DAv index, with children having worse performance than adolescents. No significant status x age interaction was found. Bonferroni post-hoc analysis was used to identify specific difference between groups (Table 4). First, control cases showed significantly better performance compared to ADHD probands on the DeFT (Figure 1.II), DRT (Figue 1.III), and DAv index measures (Figure 1.IV). In the MIDA task the difference, although in the expected direction, was not significant (Figure 1.I). Second, controls demonstrated better performance compared to unaffected siblings on the DRT task (Figure 1.III) and DAV index (Figure 1.IV). Finally, unaffected siblings and their ADHD probands did not show any differences on any DAv measure or on the DAv index.

In order to statistically test whether siblings' neuropsychological performance was intermediate to that of their ADHD probands and control cases, linear and quadratic trends were explored. Results as displayed in Figure 1 indicated that the group means increased proportionally for all DAv measures, with ADHD probands having greater deficits compared to unaffected siblings who had, in turn, worse performance than typical controls. Only performance in MIDA did not show a linear trend, as unaffected siblings had worse performance than ADHD probands (Figure 1.I). This difference did not reach significant levels. Quadratic trend analysis also confirmed the linear trend of all data. Quadratic tests on MIDA performance was significant, indicating that siblings'

neuropsychological performance on that task deviates from being intermediate to performance of ADHD probands and typical controls (Figure 1.I).

Insert Figure 1

Discussion

DAv, a broadly-based motivation to escape or avoid delay expressed in different ways under different settings and circumstances, has been proposed as a possible neuropsychological basis for ADHD (Sonuga-Barke et al., 1992; Sonuga-Barke et al., 2008). In this sense DAv represents an alternative to the executive function models that have dominated the field over the past 10 years or so (Castellanos et al., 2006). Evidence for the role of altered delay-related processes in ADHD comes from a wide range of individual tasks involving both choice and non-choice settings (Sonuga-Barke et al., 2008 and review in the introduction). However, there has been no study of whether performance deficits displayed by children with ADHD on these different delay tasks have a shared element or tap some aspect of a common latent trait. The aim of the current study was to address this question. There were a number of important findings.

First, ADHD cases and controls differed on all three tasks in ways that would be predicted by the DAv hypothesis (i.e. chose SS more than LL, had differentially slower RTs on long ISI trials and responded more when confronted with the unexpected imposition of delay). The effects replicated previous findings from studies employing these three tasks (MIDA: Marco et al., submitted; Kuntsi et al., 2001; DeFT: Bitsakou et al., 2006; DRT Task: Andreou et al., 2007; Soung-Barke & Taylor, 1992). In this study

the effect size was smaller for the preference for SS over LL on the MIDA than the other tasks, and this task failed to make an independent contribution in the logistic regression. Interestingly this task has been regarded as the main index of DAv.

Second, as predicted performance on these tasks was correlated and the effects were small. As described in the introduction in the current study we adopted a 'conservative' test of covariation between delay-related domains by choosing tasks that minimized commonalities in elements other than delay. This was to avoid spurious correlations that might be due to shared task characteristics and associated psychological processes, other than the imposition of, and response to, delay. However, this approach will inevitably produce low correlations between tasks and may in fact underestimate the true covariance between the different delay-related domains – as much of the variation in task performance will be due to other factors not shared across the tasks. However, in keeping with the view that the three tasks tapped some shared underlying process or latent trait the outputs from the three tasks formed a single principle component. This index derived on the basis of the loadings between the individual task items and this common latent factor was a more powerful predictor of ADHD than were any of the three tests individually. This suggests that whatever the common element tapped by the tasks, it was a more important predictor of ADHD group membership than the range of specific processes that each task engaged separately.

This pattern of finding begs the question; Is this common element can be characterised as DAv? This raises two further questions. First, was there some other element common to these tasks that might account for the overlap seen. Second, if the

overlapping element of the three tasks is related to delay specifically (as we propose), how confident can we be sure that this is tapping an aversion to delay rather than some other broadly-based delay-related process. Neither of these questions can be answered definitively on the basis of currently available data. As far as the first question is concerned we can rule out general ability as the common factor on the basis of the analyses showing the effects on the DAv index are independent of IQ (but see discussion of MIDA and IQ below). Other possible candidates, such as reaction time speed or efficiency of decision making, can be ruled out on the basis that only one task (DRT) involved reaction time measures and on only one was a decision between choice alternatives required. Similarly, fine motor control was not required for either the MIDA or the DeFT. There may of course be other factors common to the three tasks but these are not obvious to the authors. Delay related processing appears to be the most obvious element shared by the three tasks.

In response to the second question, a number of different delay-related mechanisms have been demonstrated to be implicated in ADHD and a number of different theories have been formulated to account for these findings. For instance, it has been argued that ADHD children are not delay averse but rather are drawn to immediate rewards (Tripp & Alsop, 2001). This is a fine distinction in some ways but can be tested (Marco et al., submitted). The key task in the current battery in this regard is the MIDA. As described in the introduction there are normally two conditions one with, and one without, a post-reward delay. In the no-post reward delay condition the participant can reduce trial length (i.e., overall delay) by choosing the small immediate reward, while in the post reward delay condition they cannot. Therefore, if the participants continue to

choose the small immediate reward to the same degree even when this does not reduce trial length (i.e., under the post-reward delay condition) then the reward immediacy rather than the delay aversion hypothesis is favoured. Unfortunately, given practical constraints we could not test between these different accounts because we did not include both conditions and could not test between these two accounts. Recent evidence in fact suggests that both of these processes are involved (Marco et al., submitted). A large scale study using both conditions of the MIDA found that while ADHD children choose the small immediate reward under the no-post reward delay condition, this was exacerbated when the post reward delay period was removed. Even accepting this possibility, it is difficult to explain the current findings from the DRT and the DeFT in terms of reward immediacy as (i) rewards were not employed in these tasks and (ii) the delay interval could not be shortened by the participants' responses.

A second, possibility to consider relates to the cognitive energetic models of ADHD that posit state regulation deficits as the core of ADHD (Sergeant, 2005). In these models event rate is a key indicator of energetic state and it is argued that ADHD children have difficulty regulating their state at very high or very low event rates (Wiersema et al., 2006). One could argue that the findings from both the DRT (longer RTs under slower event rates) and the DeFT (more responding on longer trials) are consistent with such an account. However, on the DRT ADHD children performance on the fast event rate was not worse than controls (a key prediction of the state regulation account). Furthermore, the state regulation account has not made explicit predictions about ADHD children's reference for immediate over delayed rewards in choice paradigms. One possibility is that ADHD children choose the small reward in order to

regulate their energetic state be removing delay. In this case you might argue that their delay aversion is caused by state regulation factors. In future, head-to-head studies are required to tease out the different predictions of these closely related models.

In the current study we were also able to investigate the effects of gender, age, IQ and comorbid ODD on the case-control differences in DAv. Gender did not affect the results. With regard to age the evidence is somewhat inconclusive. There were no significant interactions between ADHD status and age, which is in line with finding in the literature (Luman et al., 2005). However, on closer inspection it could be argued that this lack of effect for some measures was the result of the limited statistical power available, perhaps reflecting the smaller number of cases in the young age group. For instance, the effect sizes were markedly smaller for adolescents than for children for the MIDA and the overall DAv index. On the face of it this smaller effect in the older group (although not significant) seems to run counter to the prediction of the DAv theory that DAv emerges during development. However, one needs to be cautious in making this assertion as the current tasks employed may be less sensitive to DAv in the older groups. The MIDA in particular may be too 'childish' and boring for the older participants or just too easy. It is important to recognize that the current study was cross sectional in design and that longitudinal studies are required to examine whether there are individual continuities between childhood and adolescents in DAv. IQ seemed to moderate MIDA performance, with lower IQ leading to less preference for the delayed large reward. This result is in line with findings by Kuntsi and colleagues (2001) and Marco and colleagues (submitted). However, it is still a somewhat surprising finding, especially given that performance on the other two tasks did not seem to implicate IQ. One possible explanation is that the

MIDA involves decision making and that this is closely tied to IQ (Deakin et al., 2004; Mazas et al., 2000). A second possibility is that the delay of gratification required for successful MIDA performance is influenced by socio-economic factors and that IQ is acting as a proxy for these (Freire et al., 1990). Whatever its origins the impact of IQ of MIDA results suggests that performance on this task may have a rather different pattern of associations compared to the other tasks in the battery and therefore may tap a somewhat different process than the DeFT or the DRT.

Approximately 40-70% of children with ADHD (Faraone & Biederman, 1994) and 25-75% of adolescents with ADHD (Barkley, 1998) also have comorbid ODD/CD. However, only a small number of studies have examined the effect of comorbid ODD on delayed reward choice in ADHD (Antrop et al., 2006; Kuntsi et al., 2001). These two studies give mixed results. Antrop et al. (2006) found no effect of ODD/CD on DAv in ADHD, while Kuntsi et al. (2001) found that the effects of ADHD on MIDA performance were reduced to non-significant levels when ODD scores were introduced as a covariate. In the current study we did not have the necessary power to test the effects of the presence of ODD/CD on ADHD children's DAv because of the small numbers of pure ADHD cases in the study. However, we found no evidence that ADHD+ODD had greater DAv than ADHD-ODD. Clearly larger studies are required to test this issue fully.

The case-control effect size for the DAv index was large and exceeded the pooled effect sizes for the majority of neuropsychological test included in recent meta-analysis (Willcutt et al., 2005). Taken together this data appears to provide evidence that DAv, as a latent trait tapped by the three tasks included in the current study, is an important associate of ADHD. However, even for the DAv index these effects are a long way short

of the magnitude required to add diagnostic value (Sergeant et al., 2008) – not all children with ADHD in the current study express DAv to an equal degree. In fact by using the 10th centile cut-off on the controls performance (Nigg et al., 2005) only 40 percent of ADHD cases could be described as displaying DAv. Furthermore, each task and the DAv index as a whole had only moderate operating characteristics identifying between 60 and 70% of cases correctly. In this sense the results are highly consistent with recent studies showing (i) only moderate diagnostic power of individual neuropsychological tests (Riccio & Reynolds, 2001; Romine et al., 2004), (ii) improved performance of multivariate models (Berlin et al., 2004; de Zeeuw, et al., 2008) and (iii) theoretical models that emphasize the neuropsychological heterogeneity of the condition and the possibility of multiple pathways between originating causes and disorder expression (Sonuga-Barke, 2002; 2003; 2005; Nigg, 2006). The current data, clearly encourage the exploration of alternative neuropsychological bases in ADHD such as inhibitory control (Bitsakou, et al., 2008), state regulation (Sergeant, 2005), and temporal processing (Toplak et al., 2006).

There are no definitive and universally agreed approaches to test familial liability to neuropsychological deficits. Some researchers have used proband-sibling correlations as an indication of associated performance (Nigg et al., 2004). In the current study there was little evidence to support this approach as only the correlation for the MIDA was significant. An alternative approach examines the mean differences between probands and unaffected siblings to assess the degree of familial co-segregation of ADHD and neuropsychological performance relative to unrelated and unaffected controls (Doyle et al., 2005; Nigg et al., 2004; Schachar et al., 2005; Slaats-Willemse et al., 2003). While

the pattern of results for the individual tasks was mixed in the current study, the DAv index derived from the factor analysis of these task scores showed the predicted pattern of familiality, indicating that DAv and ADHD co-segregate within families. Previous studies have given mixed results with regard to the familiality of individual DAv related measures (see Bidwell at al., 2007). The current study supports the use of a latent variable modeling approach to address this issue.

The current study had a number of limitations that should be considered when interpreting the results. The first two relate to the sample. First, there were unequal ratios of males and females in the ADHD and the control samples. While this did not appear to bias the results, matching the groups for gender would have allowed a more informative analysis of sex differences, the study was not powered for this. Second, the ADHD group included proportionately younger children than did the control group. Again this affected the power for our cross-sectional developmental analyses. Despite this we are fairly confident that the main effects reported were independent of the effects of age, the one exception to this may be the MIDA. However, a much larger study using this task found significant effects of ADHD on MIDA performance in both middle childhood and adolescence, although the effects were somewhat reduced in the adolescent group (Marco et al., submitted). Third, there was no measure of socio-economic status (SES). This variable has been shown to account for aspects of delay of gratification performance (see above) such as that required in the MIDA. A study of the impact of SES on DAv in ADHD would be of value. Fourth, in order to keep the test battery to a reasonable length we only included one condition of the MIDA. The implications of this are described above. Furthermore each task included only a relatively small number of trials. More trials would have improved reliability. Fifth, in the current study we were limited

to three delay tasks including more tasks would have improve the reliability of measurement and also allowed some finer grain distinctions between sub-elements in the delay-related domain to be assessed. A final aspect of the study that might be considered a limitation is the fact the different tasks did not impose the same levels of delay. In the MIDA the long delay was 30 seconds, in the DeFT it was 20 second while in the DRT it was 3 and 10 seconds. In selecting these delays we adopted an essentially pragmatic approach and used delay levels that had proved valuable in previous studies and pilot work. It may of course be that there is no absolute threshold for delay tolerance and that the extent to which delay affects performance depends on the sort of task that is being carried out: Some tasks being more sensitive than others to the impact of delay.

In sum, the current results support the role of DAv as an associate of ADHD while at the same time highlight the benefits of taking a multivariate approach to testing the broader expression of this phenotype. They also provide evidence for the familial co-segregation of DAv and ADHD and for the value of DAv as an endophenotype of ADHD that might mediate the effects of familial causes on the development of the disorder. Longitudinal studies with larger samples in genetically informative designs are required to adequately test for age-related changes in DAv, for the mediating effect of ODD/CD and IQ and for the moderating effects of family environments.

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Table 1: Sample and clinical characteristics of ADHD cases and typical controls by age.

	ADHD Cases		*Controls*		*Omnibus Test ADHD vs. Controls*	
	6 – 12 years	*13 – 17 years*	*6 – 12 years*	*13 – 17 years*	*Status F*	*p*
	N = 54	N = 23	N = 29	N = 21		
% Males	81	83	58	76	9.37[b]	< .01
Age	10.54 (1.46)	14.81 (1.09)	10.90 (2.12)	13.89 (0.86)	.62	.43
WISC-III	N = 54	N = 23	N = 29	N = 21		
Vocabulary	8.87 (3.05)	8.61 (2.33)	10.31 (3.56)	9.14 (3.30)	3.31	.07
Block Design	9.33 (2.91)	9.13 (1.91)	10.97 (2.32)	9.81 (2.80)	6.45	< .05
Full	94.64 (15.01)	93.21 (9.53)	103.91 (14.31)	96.85 (15.74)	6.80	< .05
Parent SDQ	N = 54	N = 23	N = 29	N = 21		
Hyperactivity	8.20 (1.75)	8.26 (2.05)	2.14 (1.72)	1.76 (1.64)	374.36	< .001
Total	22.83 (6.65)	20.61 (5.68)	6.66 (4.79)	6.00 (3.91)	230.70	< .001
Teacher SDQ	N = 44	N = 18	N = 24	N = 13		
Hyperactivity	6.73 (3.01)	6.94 (2.36)	1.29 (1.51)	1.46 (1.05)	120.30	< .001
Total	14.63 (7.66)	15.56 (7.26)	3.63 (3.62)	3.69 (2.68)	74.38	< .001
Parent Conners	N = 54	N = 23	N/A[a]	N/A[a]	N/A[a]	N/A[a]
Hyperactivity	82.85 (9.36)	83.39 (10.33)				
Inattention	73.28 (8.85)	75.13 (9.14)				
Combined	80.24 (8.22)	82.35 (8.89)				
Teacher Conners	N = 45	N = 19	N/A[a]	N/A[a]	N/A[a]	N/A[a]
Hyperactivity	63.49 (15.06)	68.32 (17.47)				
Inattention	61.13 (13.73)	70.32 (13.35)				
Combined	63.29 (14.76)	71.95 (13.95)				

Note: SDQ = Strengths and Difficulties Questionnaire; WISC = Wechsler Intelligence Scales for Children

a = No parent and teacher Conners' questionnaire for control children.

b = χ^2

Table 2: Delay aversion performance of ADHD vs. control cases and effect sizes of measures

	ADHD Cases		*Controls*					*Effect Sizes (d)*		
	Mean (S.D.)		*Mean (S.D.)*		*ANOVA*			*ADHD vs. Controls*		
	6 – 12 yrs	*13 – 17 yrs*	*6 – 12 yrs*	*13 – 17 yrs*	*Status (S)*	*Age (A)*	*S x A*	*Full Sample*	*6 – 12 yrs*	*13 – 17 yrs*
Maudsley Index of DAv					$F_{(1,122)}$	$F_{(1,122)}$	$F_{(1,122)}$			
LL (%)	60.87 (29.91)	81.34 (24.85)	77.61 (31.43)	87.32 (26.49)	4.21*	7.43**	0.94	.49	.54	.23
Delay Frustration Task					$F_{(1,116)}$	$F_{(1,116)}$	$F_{(1,116)}$			
MTD (ms)	274 (290)	210 (251)	113 (136)	120 (137)	7.56**	0.39	0.59	.63	.71	.44
Delay Reaction Time Task					$F_{(1,119)}$	$F_{(1,119)}$	$F_{(1,119)}$			
DS (ms)	303 (174)	246 (132)	192 (125)	159 (102)	12.16**	2.55	0.19	.76	.73	.73
Delay Aversion index					$F_{(1,111)}$	$F_{(1,111)}$	$F_{(1,111)}$			
DAv index	0.50 (1.08)	-0.11 (0.86)	-0.45 (0.73)	-0.67 (0.76)	16.98**	5.20*	1.24	.95	1.03	.69

Note: DAv = Delay Aversion; DS = Delay Sensitivity; LL = Long Large reward; MTD = Mean Total Duration; S.D. = Standard Deviation; * = $p < .05$; ** = $p < .01$.

Table 3: Sample and clinical characteristics of ADHD probands, their unaffected siblings and typical control cases by age.

	ADHD probands		Unaffected Siblings		Controls			
	6-12 years	13-17 years	6-12 years	13-17 years	6-12 years	13-17 years	Status *F*	*p*
	N = 43	N = 22	N = 40	N = 25	N = 29	N = 21		
Male %	90.69	86.36	55	48	58.62	76.19	21.15[e]	< .001[c]
Age	10.72 (1.32)	14.81 (1.09)	9.45 (2.23)	14.68 (1.22)	10.90 (2.12)	13.89 (0.83)	1.31	.27
WISC-III	N = 43	N = 22	N = 40	N = 25	N = 29	N = 21		
Vocabulary	8.91 (2.80)	8.55 (2.36)	9.00 (2.78)	8.68 (2.61)	10.31 (3.56)	9.14 (3.30)	2.09	.12
Block Design	9.44 (2.51)	9.14 (1.95)	9.85 (3.15)	9.40 (2.21)	10.97 (2.32)	9.81 (2.80)	2.84	.06
Full	95.13 (12.23)	93.04 (9.72)	96.51 (14.42)	94.24 (11.45)	103.91 (14.31)	96.85 (15.74)	3.74	< .05[b]
Parent SDQ	N = 43	N = 22	N = 40	N = 25	N = 29	N = 21		
Hyperactivity	8.49 (1.71)	8.41 (1.96)	3.13 (3.05)	2.20 (2.04)	2.14 (1.72)	1.76 (1.64)	165.02	< .001[c]
Total	23.77 (6.70)	20.95 (5.56)	10.53 (8.71)	8.64 (7.59)	6.66 (4.79)	6.00 (3.91)	100.20	< .001[c,d]
Teacher SDQ	N = 33	N = 17	N = 36	N = 16	N = 24	N = 13		
Hyperactivity	6.55 (2.58)	7.00 (2.42)	3.11 (2.42)	4.50 (2.73)	1.29 (1.51)	1.46 (1.05)	62.17	< .001[c,d]
Total	13.94 (6.87)	15.94 (7.29)	6.64 (5.48)	11.31 (8.17)	3.63 (3.62)	3.69 (2.68)	35.95	< .001[c,d]
Parent Conners	N = 43	N = 22	N = 39	N = 24	N/A[a]	N/A[a]		
Hyperactivity	83.02 (9.39)	84.73 (8.30)	55.59 (14.82)	54.29 (12.57)			174.03	< .001
Inattention	73.58 (8.34)	75.68 (8.95)	53.08 (12.80)	51.13 (8.20)			138.97	< .001
Total	80.30 (7.98)	83.36 (7.61)	54.59 (14.41)	52.58 (10.64)			187.83	< .001
Teacher Conners	N = 35	N = 18	N = 35	N = 18	N/A[a]	N/A[a]		
Hyperactivity	61.83 (13.73)	69.44 (17.25)	49.80 (6.46)	60.17 (14.22)			18.53	< .001
Inattention	59.80 (12.12)	69.89 (13.60)	52.29 (8.90)	59 (8.52)			14.95	< .001
Total	61.86 (13.45)	72.17 (13.91)	51.46 (7.42)	60.61 (10.83)			20.60	< .001

Note: SDQ = Strengths and Difficulties Questionnaire; WISC = Wechsler Intelligence Scales for Children.
a = Typical controls did not complete parent and teacher Conners' questionnaire.
b = ADHD probands were significantly different from Controls
c = ADHD probands were significantly different from Siblings and Controls
d = Siblings were significantly different from Controls
e = χ^2

Table 4: ANOVA main and interaction effects, post-hoc analysis and linear and quadratic trend of data.

	Analysis of Variance					*Trend*	
	df	*Status (F-value)*	*Age (F-value)*	*Status x Age (F-value)*	*Post-hoc*[a] *(p-value)*	*Linear (p-value)*	*Quadratic (p-value)*
MIDA LL (%)	173	5.64**	10.89**	0.39	S>C	.143	.002
DeFT MTD (ms)	158	3.58*	0.09	0.36	A>C	.01	.35
DRT DS (ms)	160	6.32**	6.93**	0.76	A,S>C	.001	.37
DAv index	147	8.60**	10.57**	0.82	A,S>C	.001	.14

Note: A = ADHD; C = Controls; DAV = Delay Aversion; DeFT MTD = Delay Frustration Task Mean Total Duration; DRT DS = Delay Reaction Time Delay Sensitivity; MIDA % LL = Maudsley's Index of Delay Aversion Probability of Long Large reward; S = Siblings.

* $p < .05$; ** $p < .01$;

[a] > indicates that the group(s) on the left of the symbol had worse performance

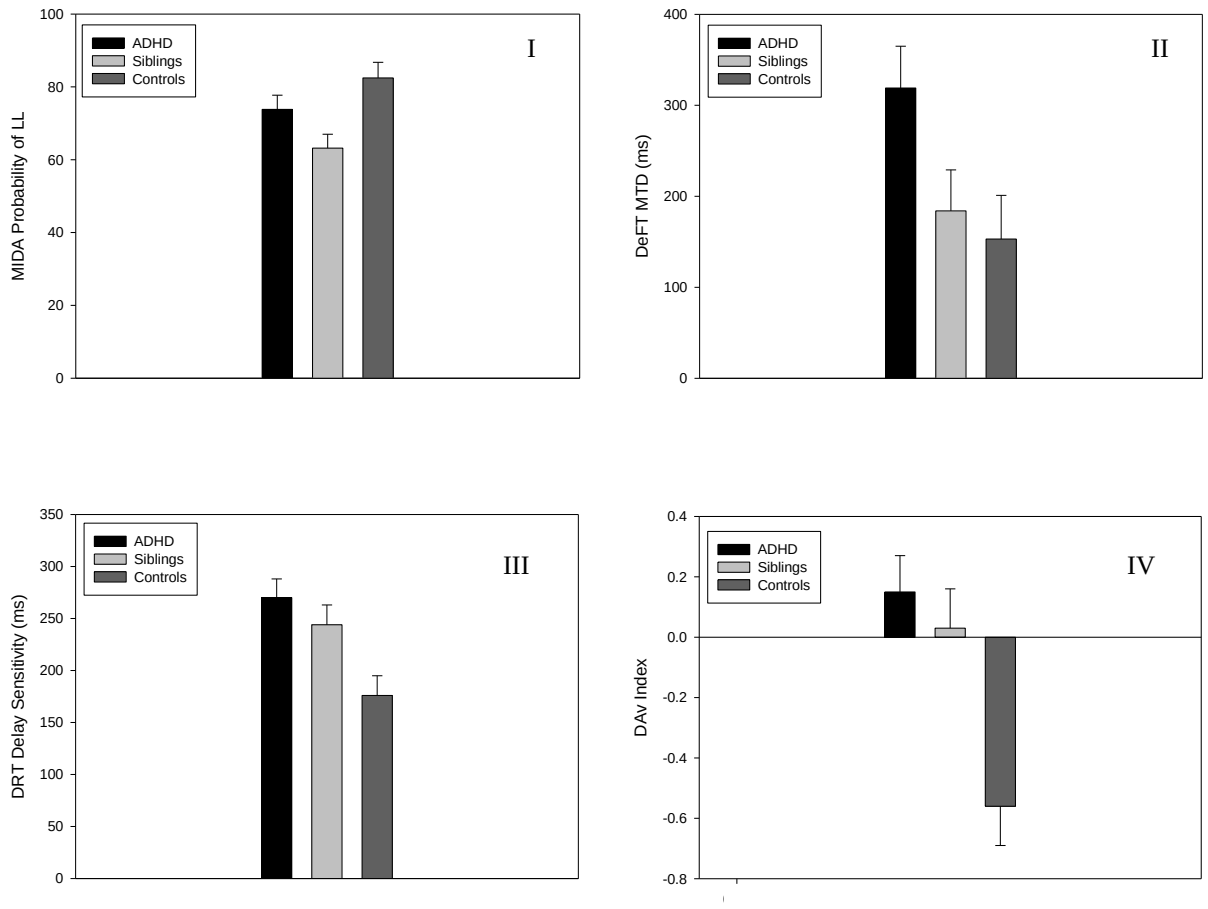

Figure 1: Status performance (ADHD probands, unaffected Siblings, Controls) on neuropsychological measures (error bars indicate SE; age controlled).

I. Maudsley's Index of Delay Aversion Probability of Long Large reward; II. Delay Frustration Mean Total Duration; III. Delay Reaction Time Delay Sensitivity; IV. Delay Aversion index.