The Function of Reward Sensitivity and Temporal Discounting in the Relationship between Risk and ADHD in Adults

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Objective: To explore risk behaviors in adults with ADHD, testing the possible mediating role of reward sensitivity and temporal discounting. Method: 66 adults (43 men, 23 women; 18-65 years) completed clinical interviews and self-report measures of ADHD symptoms, risk-taking behaviours/risky experiences and experimental measures of temporal discounting and reward sensitivity. Results: ADHD symptom severity in adults was significantly associated with self-reported life-time histories of risk-taking behaviours, including alcohol abuse, nicotine abuse, illicit drug abuse, and perpetration of violence; as well as experience of risky sexual situations and violence victimisation (all p values <0.05). The relationships between violence, nicotine use and ADHD symptom severity were significantly and differentially mediated by motivational variances (p values < .05), including temporal discounting and reward sensitivity. Conclusions: The results of this study suggest that motivational variances (reward sensitivity; temporal discounting) may provide a mechanism for understanding the greater risk of harm to adults with ADHD.

Keywords: ADHD; risk-taking; violence; motivation; reward, temporal discounting

Introduction

Attention-Deficit/Hyperactivity Disorder (ADHD) is a developmental disorder that often persists into adulthood (Biederman et al, 2006), and is associated with a range of neurobehavioural difficulties including response inhibition and poor executive functioning (Nigg, 2005; Barkley et al., 2001; Sergeant et al., 2002). One focus of research in this area has been on adverse outcomes associated with ADHD, in particular high-risk behaviour. Research suggests that children and adolescents with ADHD engage in more high-risk behaviours such as dangerous alcohol and drug use (Biederman et al., 1998) and that they are at an increased risk of accidental injuries, such as burn injuries and traumatic brain injuries (Mangus et al., 2004; Merrill et al., 2009). However, significant research gaps exist regarding the extent to which individuals with ADHD are exposed to greater risk of injury or harm in adulthood. A limited number of studies have indicated that adults with ADHD may engage in a higher frequency of substance abuse, smoking (Pomerleau et al., 2003; Biederman et al., 2006), sexual risk taking (Barkley and Gordon, 2002) dangerous driving (Barkley et al., 2005) and suicide and self-harm (James et al., 2004; Taylor, Boden, & Rucklidge, 2014). A key question arising from the literature is the extent to which neurobehavioural features of ADHD may contribute to increasing levels of risky behaviour.

A Neurobehavioural Model of ADHD

Sonuga-Barke et al (2003) present a theoretical model of neurobehavioural factors in ADHD. In this model, there are two pathways by which neuroanatomical differences amongst persons with ADHD result in ADHD typical behaviour; executive dysfunction; and motivational variance (failure of response inhibition). The implications of this model is that while there may be two different pathways, these pathways result in similar behaviour

In terms of empirical support for the executive dysfunction pathway, significant associations between ADHD and executive functioning domains have been repeatedly found (Sergeant et al., 2002) and are often implicated as playing a role in the formation and maintenance of ADHD-typical behaviours. In this way executive dysfunction is one neurobehavioural factor that serves as an etiological pathway between genetic, environmental, neurochemical and neuroanatomical factors and the behavioural phenotypes of ADHD (Tripp & Wickens, 2009). Sonuga-Barke and colleagues (2003) argue that executive dysfunction amongst individuals with ADHD leads to behavioural disinhibition, which in turn leads to ADHD-typical behaviours.

Failure of response inhibition is a second area of neurobehavioural functioning (parallel to executive functioning) thought to affect individuals with ADHD (Nigg, 2005). Sonuga-Barke et al (2003) have hypothesized that as a result of functional differences in the reward circuits of the amygdala and the ventral striatum, individuals with ADHD tend to have steepened delay of reinforcement gradient. The behavioural effects of this steepened gradient may include: a) a higher preference for immediate gratification; and/ or b) a tendency towards temporal discounting. The authors also suggested that these

reward circuits may have a differential effect on those with ADHD resulting in two related but distinct subtypes: one in which there is a greater difficulty with behavioural disinhibition and another subtype characterised by difficulty with temporal discounting.

Reward Sensitivity

A consistent research finding is that individuals with ADHD tend to show a greater preference for immediate gratification than controls (Tripp & Wickens, 2009). For example, Tripp and Alsop (2001), in a study comparing children with ADHD with controls, found that children with ADHD demonstrated a bias toward an immediate reward rather than a delayed reward, whereas this pattern was not observed in controls. Luman et al (2012), in a questionnaire validation study, reported similar findings, with children with ADHD preferring immediate to delayed rewards.

On the basis of these findings, it could be argued that individuals who tend towards immediate gratification may be more likely to engage in behaviours that have an immediate, tangible reward (such as drug use) but higher levels of negative consequences over time. Unsurprisingly, behaviours that are associated with preference for immediate gratification or behavioural disinhibition, such as gambling and drug use, are also more likely to occur among individuals with ADHD (Breyer et al., 2009; Barkley et al., 2001; Dai et al., in press).

Temporal Discounting

A related consequence of the association between ADHD and a shortened delay gradient is a greater tendency towards temporal discounting (Sonuga-Barke et al, 2003), defined as a tendency to disregard distal rewards and overvalue more immediate rewards (Barkley et al, 2001). For example, an individual may discount the larger long-term rewards associated with investing money, preferring instead to focus on the lesser but immediate reward of spending the money in the present. It has been suggested that individuals with ADHD may correspondingly exhibit a kind of 'temporal blindness' regarding the significance of negative consequences (de Wit, 2009), which may unrealistically seem as though they will occur a very long time in the future, if at all.

Preference for immediate gratification and temporal discounting are often referred to as functionally equivalent to behavioural impulsivity (Sonuga-Barke et al., 2003; Barkley et al., 2001), a core characteristic of ADHD. Impulsivity has in turn been repeatedly suggested as an underlying mechanism of risk-taking behaviours such as drug abuse (e.g. de Wit, 2009), problematic drinking (e.g. Vuchinich & Simpson, 1998), violence and aggression (DeWall et al, 2007) and sexual risk-taking (Tapert et al., 2001).

The present study

A largely unexamined question in the literature relates to the possible neurobehavioural mechanisms of the relationship between ADHD symptomatology and risk. For example, it could be argued that the associations between ADHD and risk may be due to intervening variables such as level of impulsivity. A model of a deficit in response inhibition, comprised of executive and motivational dysfunction, may serve to explain some of the behavioural characteristics of ADHD (in particular, impulsivity, inattention and reward seeking). These behaviours may result in a higher rate of risk-taking behaviours among individuals with ADHD.

Against this background, the aims of the present exploratory study were to examine linkages between ADHD symptomatology and exposure to increased harm, using data from a case-control study of ADHD and outcomes in a sample of adults. It was hypothesized that higher levels of ADHD symptomatology would predict increased risk-taking behaviour and victimisation. We hypothesized that there would be both direct and indirect relationships from ADHD to risky behaviour/outcomes, via motivational variances including temporal discounting and reward sensitivity tendencies.

Method

Sample and Procedure

Sixty-six participants were recruited as part of a wide-ranging study of adult ADHD via a participant pool from existing studies at the University of Canterbury (New Zealand); advertisements on campus, in local media; and referral from community mental health treatment services. Exclusion criteria for the study were (a) IQ under 70; (b) a history of psychotic illness; (c) a history of significant traumatic brain injury; (d) diagnoses of pervasive developmental disorder; or (e) being unable to provide corroborating information for the ADHD assessment (e.g. parent or partner completed measures and/or recent clinical diagnosis of ADHD by a trained mental health professional).

Initial telephone interviews were used as a preliminary screen for inclusion/ exclusion criteria followed by a mailed participant pack, containing an information sheet, consent form and self-report screening tools. Those who met inclusion criteria were then invited to take part in face-to-face assessment interviews at the University of Canterbury. All participant interviews were conducted by senior postgraduate students or registered clinical psychologists in a postgraduate research block at the University Of Canterbury Department of Psychology. All participants received grocery or petrol vouchers as reimbursement for their time ($30). Interviewers completed the measures described below in two face-to-face interviews, lasting approximately roughly 2.5 hours per session. All participants (ADHD and control group) who completed the research received a complete psychological assessment report. The purpose of this report was for the outcome of the psychological assessment to be communicated to the participants' general practitioners and other health care providers, if so desired.

Of the participants, 26% were university students. Participants' mean age was 31.9 years (SD = 1.6). The research methods used in this study were approved by both the host university and regional Health and Disability ethics boards. Written consent was obtained from participants and parents/partners prior to interview, and reviewed to ensure that participants were fully informed. Parent/partner responses were obtained either by face-to-face interview, or were completed at home and mailed to the researchers.

Although the study consisted of two groups (those meeting criteria for adult

ADHD [n = 35; 23 males, 12 females] and those not meeting criteria [n = 31; 20 males, 11 females]), for the purposes of the present investigation the two groups were combined to form a single sample. Tests of group membership (ADHD/no ADHD) x covariate interactions were performed to ensure that the strength of association between covariates and outcomes did not differ across the two groups. In no case was a statistically significant interaction observed (all p values > .05).

Measures

ADHD Symptomatology

All participants were administered structured interviews using Conners' Adult ADHD Diagnostic Interview for DSM-IV (CAADID: Epstein et al. 2001) in order to assess ADHD symptomatology, as well as inclusion/exclusion criteria (via assessment of prior mental and physical health history). In addition, the Conners Adult ADHD Rating Scales (CAARS: Conners et al. 1999) was administered to both participants and an independent observer (usually a partner or friend) and used to screen for the presence of attentional difficulties as well as to assess severity (α = .86 to .92). In this study, a continuous predictor variable of ADHD symptomatology was derived from the severity scores of the CAARS Index G T-scores (ADHD DSM-IV Symptom Total). The average of the self-report and observer report scores was obtained to form an overall continuous measure of ADHD symptoms. As expected, this continuous variable is consistent with our dichotomous group variable as demonstrated by the high point biserial correlation between group membership and ADHD severity scores on the CAARS (r_(pb(64))=.85, p<.001). Participants were then grouped into a four-group independent variable (ADHD Severity) based on quartile ranking of the above score of ADHD symptomatology severity (<25%, 26-50%, 51-75%, 76%>). These quartiles were used as the independent variable in the analyses reported below for the purposes of reporting clarity (as noted below, parallel analyses using the continuous measure of ADHD produced analogous results).

Risk-Taking behaviours

The dependent variable of risk-taking comprised of five index scores from the Adult Risk Taking Questionnaire (ART-Q; personal safety, social violence, alcohol use, nicotine use and drug use) and one from the Sexual History Questionnaire (SH-Q: Cupitt, 1998). The ART-Q is a novel self-report questionnaire developed by the author that includes questions from the Youth Risk Behaviour Survey (YRBS; CDC, 2007). The YRBS is a questionnaire that is part of the Youth Risk Behaviour Surveillance System undertaken by the Centre for Disease Control and Prevention (U.S.A Government). All questions from the ART-Q used a Likert scale response format. As the YRBS is in the public domain, the CDC give permission for questions in the YRBS to be used and modified without condition. Questions from the YRBS was adapted for this study in two ways: firstly, the questions were expanded and modified to reflect risk-taking behaviours in *adulthood*: for example, the introduction to each question was changed from "During the last 12 months…" as used in the YRBS, to "From the time you turned 18…" in the ARTQ. Secondly, as the YRBS was developed for use with a North American sample, some changes were made to represent risk taking behaviour in a New Zealand context. For example, idiomatic language was removed or modified. The complete modified questionnaire used in this study contained 37 questions and took approximately 15 minutes to complete. The ART-Q results were divided into five Index (mean) scores: Personal Safety (questions address driving behaviour, dating violence, and self-harm; α=.70); Social Violence (α=.70); Alcohol use (α= .70); Nicotine use (α= .63); and Drug Use (α=.80). The overall internal consistency reliability of the ART-Q was found to be high (α= .89).

The Sexual History Questionnaire (Cupitt, 1998) is a self-administered 20-item questionnaire that assesses the degree to which an individual has engaged in recent sexual activity that increases the risk of contracting a sexually transmitted infection (STI), answered in a response format of "Yes", "No", or "N/A". The questionnaire includes questions regarding; the number of sexual partners within the past 6 months, the proportion of times that participants had unprotected sex, and whether participants had engaged in sexual activity with a partner that they believed may have been infected with an STI. Scores were calculated based on a sum of "Yes" responses. Cupitt (1998) measured the test-retest reliability of the test at 0.80 indicating a high level of reliability.

While Cupitt's (1998) original questionnaire referred to a time-frame of sexual activity within "the previous month" it was felt that this time frame was too short for this study, given the older average age of participants and the potentially lower frequency of sexual activity in general (Seidman & Rieder, 1994). For the purposes of the present investigation the time frame for the questionnaire was altered to "the past six months".

Potential Confounding Factors

Demographic Information

Demographic variables including age, gender, ethnicity, educational achievement, household income level and occupation were assessed. The occupational responses from all participants were converted into SES scores using the New Zealand Socio-Economic Index(NZSEI; Davis, McLeod, Ransom, & Ongley, 1997); a measure which involves the assignation of a score based on one of 97 coded occupational groups, which range from 10 to 90 (10 being the lowest and 90 representing the highest occupational group).

Intellectual Functioning

The Wechsler Abbreviated Scales of Intelligence (WASI: Wechsler, 1999) were administered to gauge general levels of intellectual functioning, in addition to highlighting any fundamental learning or cognitive deficits. The WASI includes the administration of the Vocabulary, Similarities, Matrix Reasoning and Block Design subtests of the WAIS-III and takes approximately 30 minutes to administer. The WASI has been found to have good levels of reliability and validity, and at the time, was found to correlate highly with full scale IQ scores on the comprehensive Wechsler scales (Sparrow & Davis, 2000).

History of Child Abuse

The Childhood Trauma Questionnaire (CTQ: Bernstein and Fink 1998), a 70-item measure using a Likert scale response format, was administered to all participants, covering the period of childhood and adolescence. The CTQ assesses the occurrence of childhood trauma, differentiating between emotional, physical and sexual abuse while excluding experiences of non-abuse related traumatic events such as death of a parent. For the purposes of reducing the number of variables in the present investigation, the measures of emotional, physical and sexual abuse were combined (as directed by the test manual) to form a composite measure of abuse exposure ranging from 0 to 5 (m = 1.71; sd = 1.51).

History of Conduct Problems

A history of conduct problems from childhood to early adulthood was assessed using questions from the CAADID to assess delinquent and conduct-disordered behavior. On the basis of this questioning, 25.8% of the sample reported a history of conduct problems (indicating at least one conduct problem).

Potential Mediating Factors

Temporal Discounting

Temporal discounting was measured by a computer-generated task, derived from the Reward Discounting Task (RDT; Barkley et al., 2001; Green et al., 1994). In this experiment, participants were choose one of two options (Option A or Option B) based on fictional amounts of money presented to them on the screen. The assumption was that individuals with greater difficulty with delaying gratification in their lives were more likely to prefer the option of more immediate gains (option A) versus the delayed option (option B).

The task was presented visually on the computer screen ("please choose between option A and option B. Press the 'A' key for option A or the 'B' key for option B"). The program presented a series of screens (96 in total) with various conditions to the choice task (employing different amounts of money and different time delays). The speed of the rotation through conditions was controlled by the response time of each participant (a new screen emerged once either the A or B key was pressed).

In the first condition, participants were presented with a choice between a static option A: ($100 *in one month*) versus option B: *ascending* amounts of money that were immediately available (ranging from *$1 now* to *$100 now*). This condition was then presented in reverse order (the option B values *descended* from $100 to $1 whilst paired with the same option A: *$100 in one month*). In the second condition, Option A was set at *$100 in one year* and was paired with the same ascending immediate rewards and then descending rewards as in the first condition. In the third condition, the time delay of option B was set at 5 years; and in the fourth condition, the delay was 10 years. This was followed by a second trial which used larger amounts of money for option A (*$1000 in one month*) and option B: (ranging from *$10 now* to *$1000 now*). These larger amounts were similarly followed by the same conditions in reverse, descending order. In total, there were 8 conditions measured, with an associated total of 12 responses per condition. The participants' scores were the immediate reward values at which the participant switched from a preference for the delayed sum of money (option A) for the immediate sum (option B) and the same in reverse for the descending trials (score at which they switched from option B to option A).

Reward Sensitivity

Reward sensitivity was measured through the use of a computer generated passive avoidance learning (PAL) experiment (Farmer and Rucklidge, 2006). The PAL task involves trial and error learning of a go/no-go task with contingent reinforcement; participants received positive visual feedback ("*correct*") and a small reward (ten cent coin) for each correct response and negative feedback ("*wrong*") and a withdrawal of a reward (ten cent coin) for each incorrect response. All participants were introduced to the task by a pre-treatment trial in which a series of six target numbers appears on the computer screen, interspersed with non-target numbers. In the pre-treatment trial, target numbers and non-target numbers were set at a ratio of presentation of 1:3; in order to increase learning success. Participants learned via reinforcement (visual feedback "*correct*" or "*wrong*") which of the numbers presented were target numbers, and which were not. This was followed by the treatment trials in which 32 numbers were presented, including the 6 target numbers which were presented at a 1:1 ratio with random non-target numbers. Participant responses (pressing the space bar) were recorded, in addition to response time. Learning performance on this task was measured by the rate of *passive avoidance errors* (PAE); specifically, errors of commission (responding incorrectly or failing to abstain) or omission (failing to respond).

Statistical Analyses

The data were analysed over several steps. In the first step of the analyses, the bivariate associations between the predictor (the quartile measure of ADHD) and the outcomes (risk-taking behaviours: personal safety; violence risk; alcohol use; nicotine use; drug use; and sexual risk taking) were modelled using ordinary least squares (OLS) regression. In order to examine the extent to which these associations could be explained by potential confounding factors, these variables (demographic factors, measures of IQ and conduct disorder symptomatology, and exposure to child abuse) were entered into each of the models individually.

In the second step of the analyses, the associations between the two potential mediating factors (reward sensitivity; temporal discounting) and the outcome measures that were found to have a statistically significant ($p < .05$) bivariate association with the quartile measure of ADHD in the first step of the analysis (violence risk; alcohol use; nicotine use; drug use; and sexual risk taking) were also modelled using OLS regression.

In the third step of the analyses, potential mediating pathways between ADHD and risk-taking behaviours was tested using bootstrapping of indirect effects via ordinary least squares (OLS) regression (Preacher & Hayes, 2008). An issue arising from many common meditational approaches (such as the Sobel test: Sobel, 1982) is that these approaches assume a normal distribution amongst both predictors and outcomes (see Hayes, 2009, for a discussion of these issues), whereas bootstrapping of indirect effects via latent variable

structural equation modelling or OLS regression (e.g. Muthen & Muthen, 2007; Preacher & Hayes, 2008) does not make assumptions of normality. In these approaches, bootstrapping is used to estimate bias-corrected confidence intervals for each direct and indirect effect in the model, thereby reducing the risk of Type II error and increasing the power of the model to detect effects. Furthermore, these approaches allow the specification of more complex models with multiple mediating pathways (see below). The bootstrapping approach is particularly appropriate for the present analyses as they employ a mixture of variable scales, including continuous outcomes and ordinal and continuous predictors, and the models employ two intervening variables simultaneously.

In the current models, both the ordinal reward sensitivity and temporal discounting variables were employed as potential mediating variables in the association between ADHD and each of the three risk-taking outcomes (violence risk; nicotine use; drug use) that had been found to have a statistically significant ($p < .05$) association with the mediating factors in the second step of the analyses (above). Bootstrapping latent variable models were fitted using the mediation macro developed for SPSS Statistics 19 (Preacher & Hayes, 2008). In this model, effects were estimated for the direct pathway between ADHD and each outcome, as well as the indirect pathways via mediators/moderators, using or Ordinary Least Squares (Preacher & Hayes, 2008). The model also provided tests of statistical significance for each direct and indirect pathway in the model. Final path models were restricted to no more than four variables due to small sample size.

Finally, to ensure the robustness of the conclusions, the analyses above were repeated using the continuous measure of ADHD symptomatology in place of the quartile measure.

Results

Sample Characteristics

Table 1 shows the sample classified into four ADHD severity score quartiles. For each quartile, the mean ADHD severity score, the number of participants meeting criteria for ADHD, and the number of participants in the quartile is provided. The data clearly show that the ADHD quartile scores represent increasing levels of ADHD.

Table 1: Characteristics of sample

	ADHD Score Quartiles			
Characteristics	1-25%	26-50%	51-75%	76-100%
Mean (SD) ADHD severity score[1]	40.68 (3.71)	52.41 (3.33)	66.26 (5.33)	81.50 (3.61)
% met criteria for ADHD	0.0	18.8	94.1	100.0
n	17	16	17	16

[1] "ADHD severity score" indicates an average of ADHD symptom scores derived from self-report and observer report. Scores ranged from 34.5 to 88.5

Associations Between ADHD and Outcomes

Table 2 also shows the sample divided into quartiles on ADHD severity score. For each quartile, the Table displays the mean scores and standard deviations for each outcome measure. The Table also displays tests of significance for linear trend derived from the OLS regression models for the associations between ADHD quartile and outcomes. The Table shows that increasing levels of ADHD symptoms were significantly ($p < .05$) associated with increased scores on the measures of: violence risk; alcohol use; nicotine use; drug use and sexual risk taking (there was no evidence of statistically significant non-linear trend for any outcome; all p values > .05). However, increasing levels of ADHD symptoms were not significantly associated ($p > .20$) with the measure of personal safety, which was dropped from subsequent analyses.

Table 2. Bivariate Associations between ADHD and Risk-Taking Behaviors

	ADHD Score Quartiles					
	1-25%	26-50%	51-75%	76-100%	Total sample	p
Personal Safety						
Mean (sd)	48.27 (8.50)	50.11 (9.35)	48.00 (10.90)	53.69 (10.73)	50.02 (9.97)	.22
Violence risk						
Mean (sd)	45.93 (9.04)	46.56 (7.53)	51.00 (7.11)	57.06 (14.35)	50.14 (10.58)	.001
Alcohol Use						
Mean (sd)	47.27 (8.17)	51.06 (9.30)	46.18 (8.90)	55.56 (11.37)	50.02 (9.99)	.048
Nicotine Use						
Mean (sd)	46.00 (7.66)	48.50 (9.05)	49.82 (9.79)	56.00 (10.88)	50.08 (9.91)	.002
Drug Use						
Mean (sd)	49.00 (11.77)	47.17 (5.18)	48.88 (11.89)	54.69 (9.93)	49.98 (10.12)	.030
Sexual Risk Taking						
Mean (sd)	46.87 (7.50)	47.83 (11.82)	49.35 (6.72)	55.81 (10.70)	49.94 (9.91)	.001

Testing for Potential Confounding (Gender; Ethnicity; IQ; Socioeconomic Status; History of Child Abuse; Conduct Disorder) in the Associations Between ADHD and Outcome Measures

In order to examine the possibility that the associations between ADHD and outcomes could be explained by confounding factors, the models described above were extended to include the following variables gender, ethnicity, IQ, socioeconomic status, history of child abuse, and conduct disorder symptomatology. In no case was a potentially confounding factor statistically significant (all p values > .05).

Associations Between Potential Mediating Factors (Reward Sensitivity; Temporal Discounting) and Outcomes

As noted in Methods, two variables were chosen as potential mediating factors in the analyses (temporal discounting; reward sensitivity). The Pearson product moment correlations for each of these with the quartile measure of ADHD were 0.33 ($p < .05$) and -0.32 ($p < .01$), respectively, while the two mediating factors had a Pearson product moment correlation of 0.09 (*ns*). Table 3 shows the sample divided into quartiles on the measures of temporal discounting and reward sensitivity, and displays the associations between these two mediating factors and the outcomes. The Tables shows that:

1. Total error scores on the RDT (temporal discounting) task was significantly ($p < .05$) negatively associated with three outcome measures: violence risk; nicotine use; and drug

use, suggesting that higher levels of performance on the measure were associated with lower scores on the outcome measure. However, the measure of reward sensitivity was not significantly associated with: alcohol use; and sexual risk (both p values > .05).

2. Participant scores on the PAL task (the measure of reward sensitivity) were significantly ($p < .05$) negatively associated with the measure of violence risk, again suggesting that higher levels of performance on the measure were associated with lower scores on the outcome measure. However, the measure of temporal discounting was not significantly associated with alcohol use; nicotine use; drug use; and sexual risk.

On the basis of these results, the two outcomes that were not associated with the mediating factors, alcohol use and sexual risk taking, were dropped from further analyses.

Testing Mediation for ADHD and Violence Risk

As noted above, the extent to which temporal discounting (RDT task) and reward sensitivity (PAL task) mediated the associations between ADHD and violence risk was examined using bootstrapping of indirect effects via an SPSS macro developed by Preacher & Hayes (2008). In this procedure, the data were modelled with a single direct pathway between ADHD and violence risk, and two indirect pathways between ADHD and violence risk, the first via the temporal discounting variable, and the second via the reward sensitivity variable (see Figure 1). The results of these meditational analyses showed that there was evidence of a statistically significant direct pathway from ADHD to violence risk (path *a*; β = .20, SE = .08, p = .02). Tests of the total mediating pathways via temporal discounting and via reward sensitivity was found to be statistically significant (path *d*: β = .26, SE = .08, p = .001). A test of the specific indirect effects of each mediator was found to be significant for reward sensitivity (path *c*: point estimate = .06, p <.05, 95% CI [.01, .04]) but not temporal discounting (path *b*: point estimate = .21, p = *n.s*).

Figure 1. Mediation model showing the single direct pathway between ADHD and violence risk (a), and two indirect pathways between ADHD and violence risk, the first via the temporal discounting variable (b), the second via the reward sensitivity variable (c). The total indirect effect via both mediating factors is also shown (d).

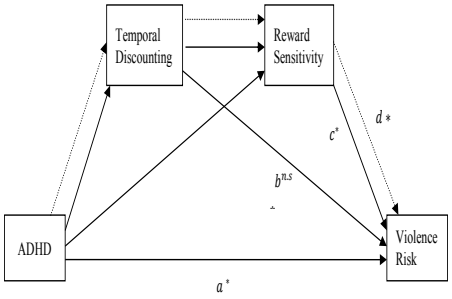


Table 3. Bivariate Associations between Mediating Variables and Risk-taking Behaviors

		Mediating Variables						
		Temporal Discounting (RDT Task) quartiles						
		1-25%	26-50%	51-75%	76-100%	n	Total	*p*
Personal Safety								
	Mean (sd)	51.50 (10.66)	50.93 (10.55)	49.00 (9.53)	49.53 (10.04)	63	50.24 (10.02)	.36
Violence risk								
	Mean (sd)	55.33 (14.82)	50.43 (8.46)	47.00 (7.76)	47.27 (7.87)	63	50.01 (10.78)	.01
Alcohol Use								
	Mean (sd)	52.28 (9.29)	51.64 (11.69)	47.00 (8.48)	50.53 (10.98)	63	50.36 (10.06)	.16
Nicotine Use								
	Mean (sd)	56.11 (9.73)	49.36 (8.63)	44.50 (8.27)	49.13 (9.30)	63	49.78 (9.83)	.002
Drug Use								
	Mean (sd)	54.28 (11.68)	47.57 (5.57)	45.50 (3.74)	51.73 (13.83)	63	49.77 (10.15)	.035
Sexual Risk Taking								
	Mean (sd)	50.06 (7.15)	52.47 (15.24)	48.88 (7.71)	47.13 (7.87)	63	49.63 (9.88)	.257

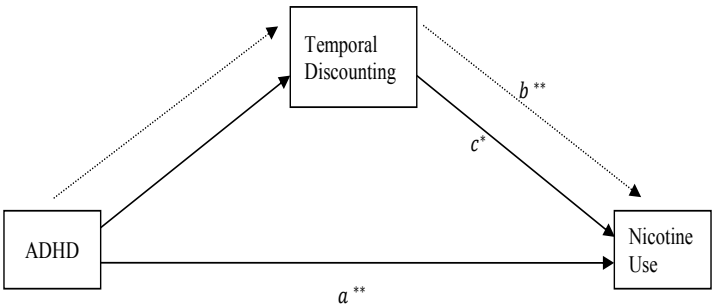
		Reward Sensitivity (PAL Task) quartiles						
		1-25%	26-50%	51-75%	76-100%	n	Total	*p*
Personal Safety								
	Mean (sd)	51.55 (9.69)	49.31 (11.73)	50.80 (10.20)	48.17 (9.21)	66	49.96 (9.97)	.284
Violence risk								
	Mean (sd)	46.95 (8.34)	51.15 (11.66)	51.47 (10.66)	51.72 (12.00)	66	50.32 (10.58)	.020
Alcohol Use								
	Mean (sd)	51.75 (10.85)	49.08 (8.80)	51.07 (11.14)	47.94 (9.12)	66	49.96 (9.99)	.345
Nicotine Use								
	Mean (sd)	49.90 (10.00)	48.62 (9.61)	48.93 (9.28)	52.33 (10.91)	66	49.95 (9.91)	.157
Drug Use								
	Mean (sd)	50.05 (11.45)	50.31 (8.17)	52.27 (13.40)	47.44 (6.24)	66	50.02 (10.12)	.438
Sexual Risk Taking								
	Mean (sd)	47.60 (8.06)	53.69 (12.65)	47.93 (6.71)	51.50 (11.39)	66	50.18 (9.91)	.162

The results of these analyses suggest that the linkages between ADHD and violence risk were mediated by reward sensitivity, but not by temporal discounting. Those individuals with higher ADHD scores were at greater risk of violence (perpetration or victimisation), and this risk could be largely explained by a greater sensitivity to reward, and a lower sensitivity to punishment amongst those with higher ADHD scores.

Testing Mediation for ADHD and Nicotine Use

The extent to which temporal discounting (RDT task) mediated the association between ADHD and nicotine use was also examined using bootstrapping of indirect effects via an SPSS macro (Preacher & Hayes, 2008). In this procedure, the data were modelled with a single direct pathway between ADHD and nicotine use, and a single indirect pathway between ADHD and nicotine use, via the temporal discounting variable (see Figure 2). The results of these meditational analyses showed that there was evidence of a statistically significant direct pathway from ADHD to Nicotine use (path *a*: β = .20, SE = .07, *p* = .008). A test of the total mediating pathways via temporal discounting was found to be statistically significant (path *b*: β = .23, SE = .07, *p* = .002). A test of the total indirect effect via the mediating factor was also found to be statistically significant (path c: point estimate = .04, *p* < .05, 95% CI [.006, .09]).

Figure 2. Mediation model showing the single direct pathway between ADHD and nicotine use (a), the total pathway between ADHD and nicotine use, and a single indirect pathway between ADHD and nicotine use, via the temporal discounting variable (c).



Notes: p-values use a modified Michelin scale by adding marginal significance: * =significant (p<.05), **= highly significant (p<.01), m= marginally significant

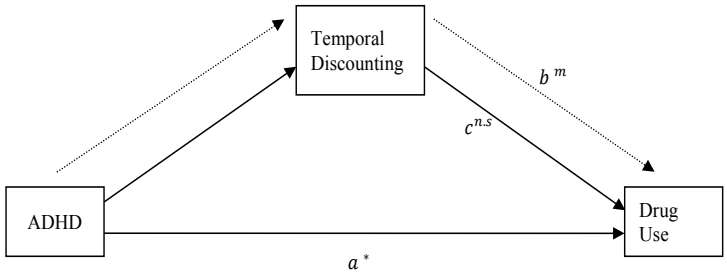
Testing Mediation for ADHD and Drug Use

The extent to which temporal discounting (RDT task) mediated the association between ADHD and drug use was also examined using bootstrapping of indirect effects via an SPSS macro (Preacher & Hayes, 2008). In this procedure, the data were modelled with a single direct pathway between ADHD and drug use, and a single indirect pathway between ADHD and drug use, via the temporal discounting variable (see Figure 3).

The results of these meditational analyses showed:

There was evidence of a statistically significant direct pathway from ADHD to Drug use (path *a*: β = .15, SE = .07, *p* = .04). Testing the total mediating pathways via temporal discounting (path *b*) was not found to be statistically significant. However, a test of the total indirect effect via the mediating factor was found to be marginally statistically significant (path *c*: point estimate =.168, *p* =.05, 95% CI [.016, .335]).

Figure 3. Mediation model showing the single direct pathway between ADHD and drug use (a), the total pathway between ADHD and drug use, and a single indirect pathway between ADHD and drug use, via the temporal discounting variable (c).



Notes: p-values use a modified Michelin scale by adding marginal significance: * =significant (p<.05), **= highly significant (p<.01), m= marginally significant

In summary, the meditational models above demonstrate that adults with higher levels of ADHD symptomatology are at a greater risk of a range of risk-taking behaviours, including violence perpetration and also victimisation; nicotine, alcohol and drug use, and sexual risk taking. Furthermore, for at least two behaviours (violence risk and nicotine use) a significant amount of this increased risk may be differentially explained by either a higher rate of temporal discounting or variances in reward and punishment sensitivity.

Supplementary analyses

As noted in Methods, the analyses reported above were repeated using the continuous ADHD symptom score in place of the quartile measure. The results of these analyses were congruent with those reported above, suggesting that the findings were robust

to the operationalization of the ADHD measure.

Discussion

In this study, ADHD in adulthood was found to be significantly associated with risk variables including violence risk (both perpetration and victimisation); alcohol abuse, nicotine abuse, illicit drug abuse and sexual risk-taking (including number of partners, casual sex encounters, sexually transmitted diseases). Risk-taking measures associated with personal safety indicators (such as seatbelt use, safety helmet use, dangerous driving) were not found to be significantly associated with ADHD in adulthood, although it should be noted that, as this study was exploratory in nature, it may have been underpowered to detect some differences. Understanding the behavioural drivers of these associations may assist in reducing the risk of disability and mortality in this population. Furthermore, a seemingly overlooked area of risk in ADHD (risk of violence) has not been extensively explored in non-offending populations with ADHD, despite indicators that both perpetration and victimization of violence may be associated with childhood ADHD (Goodman et al., 2008) and impulsivity in adults with ADHD (Dowson and Blackwell, 2010).

The findings of the current study concerning substance abuse were consistent with a number of studies that repeatedly found an association between ADHD in adulthood and drug and alcohol abuse (e.g. Biederman et al., 2006; Barkley, 2008). The significant association between ADHD and sexual risk taking was also consistent with previous findings (e.g. Woodward & Fergusson, 1999; Barkley, 2002). The findings regarding risk of violence perpetration (adults with ADHD were more likely to self-report more frequent engagement in physical fights and carrying a weapon to social encounters) were also consistent with previous findings, such as the association between ADHD-consistent traits such as impulsivity and fighting (Stanford et al.; 1996), and linkages between ADHD and impulsive aggressive behaviours (Dowson and Blackwell, 2009).

A key question in the present study was to examine possible pathways (motivational variances) that may explain the linkages between ADHD and risky behaviour. Specifically, this study explored two such potential mechanisms; reward sensitivity and temporal discounting. Both factors in this study were found to be significantly associated with ADHD severity in adulthood, results that were comparable with a number of findings regarding an association between ADHD and motivational differences (e.g. Tripp & Wickens, 2009; Sonuga-Barke et al., 2003). Given the likely functional overlap between reward/punishment sensitivity and temporal discounting, these variables were explored both as single direct mediators as well as combined mediators of the risk-taking outcomes mentioned above. The findings from this study suggest that reward sensitivity and temporal discounting may have a differential effect on risk-taking behaviours. Whilst reward sensitivity significantly mediated the relationship between ADHD and violence risk, temporal discounting was found to significantly mediate the relationship between ADHD and nicotine use. This differential effect of the two motivational variables is logical. One of the key differences between the reward sensitivity and temporal discounting paradigms is the tangibility of the contingent reward. While the positive and negative reinforcement involved in the reward sensitivity variable were real and tangible (as measured by the Passive Avoidance Learning task, [PAL; Farmer and Rucklidge, 2006]), the reinforcement was hypothetical in the temporal discounting variable (as measured by the Reward Discounting task [RDT; Barkley et al., 2001]). These differences in tangibility seem to be consistent with any 'real-life' reinforcement involved with violence risk (more immediate/ tangible) versus nicotine use (more hypothetical/ delayed risk). This is supported by the findings of Scheres and Sumiya (2007) regarding the differential effect of tangibility on reinforcement.

Alternatively, the differential findings regarding the impact of reward sensitivity/temporal discounting mechanisms, may have highlighted a potential difference between two neurocognitive 'subtypes' of ADHD, one that is characterised by a greater tendency to discount delayed rewards and another subtype that is less sensitive to punishment and more sensitive to reward. This hypothesis relating to the findings in this study are consistent with the subtypes of ADHD posited by Sonuga-Barke et al., (2002) and Winstanley et al., (2006): in which ADHD symptoms are influenced by two related but distinct behavioural pathways, delay aversion and behavioural disinhibition. Such a distinction between the differential effects of delay aversion and disinhibition/ insensitivity to punishment, may be important in understanding the effects of different neural variances on ADHD (Sonuga-Barke, 2002) and in turn, the effect of ADHD on adult risk-taking outcomes. For example, DeWall et al. (2007) provide evidence to suggest that the inability to delay gratification (such as that displayed with the reward sensitivity task in the present study) is related to impulsivity (low self-control), which is in turn associated with increased tendencies to violence and aggression.

In this study, the nonsignificant association between ADHD and personal safety measures (e.g. such as seatbelt and helmet use) were not consistent with research of Barkley (2008) or Jonah et al. (2001). As there is a dearth of research that explores such behaviours in adults ADHD, it may be that such an association between adult ADHD and such behaviours does not exist. Conversely, the nonsignificant association between ADHD and safety behaviours may be due to a possible limitation of this study, such as the smaller sample size. Conversely, the majority of the studies that have found an association between ADHD and lower rates of self-protective behaviours have been completed with younger samples (Jonah et al., 2001), whereas the average age of this study was 35 years of age (compared with an average of 25 [Jonah et al., 2001]). Given the association between age and risk-taking behaviours in general (Laurence, 2008), the older age range of this study may have negated any potential association between ADHD and these risk outcomes.

Limitations

A possible limitation of this study is the measure on which the dependent risk-taking variables are based, the

ART-Q. As this is a new measure with only preliminary demonstrated levels of reliability and validity, the measure may not have been sensitive enough to gauge all possible effects of associations between ADHD and risk-taking outcomes. The reliance on such a new measure demonstrates the lack of a selection of reliable measures of adult risk-taking that were available at the time that this study was conducted. Since this study was completed, a number of promising measures have been found which specifically assess susceptibility to risk taking, such as the Sensitivity to Punishment and Sensitivity to Reward Questionnaire (SPSRQ; Torrubia et al., 2001), which was validated for use with children with ADHD by Luman and colleagues (2012). In hindsight, such measures would have been helpful additions to the measurement of risk taking in this study.

A further limitation of this study is the reliance on the grouped variable of 'violence risk'. This grouping (of perpetration and victimisation) was employed for greater statistical power (too many intervening variables would have resulted in a significant loss of power) and also for logical reasons (almost all of the participants involved in relationship violence were both perpetrators and victims). However, such a grouping of 'victims' and 'perpetrators' of violence while methodologically sound, was ethically more difficult to rationalize. In future research (ideally with ideally larger sample sizes) it is hoped that clearer distinctions would be made between victimisation and perpetration of violence.

In addition, although discussion of possible neurocognitive subtypes is of interest, a limitation of this study is the small number of experimental tasks that were used to represent delay aversion and behavioural inhibition. Further exploration of the responses of adults with ADHD to a number of such tasks (such as the stop signal, Go/no-go tasks) may provide more in-depth findings regarding any possible neurocognitive subtype differentiation.

General limitations of this study may largely be related to the small sample size. As a result, whilst power levels were adequate for two-step mediation models in each of the studies reported, more in-depth exploration was not possible without increasing type II error levels significantly. Importantly, a lack of power may have led to a failure to detect associations between ADHD and some of the outcomes shown in Table 2. In addition, a further limitation of this study was the retrospective design of the data that was utilized to assess both ADHD symptomatology and the dependent variables of self-destructive behaviours. An ideal research design would involve the longitudinal follow-up of individuals with ADHD. An additional limitation of this reported study is the reliance on self-reported data. Whilst ADHD diagnosis was conditional on corroborated information, many of the risk-taking outcomes were based on self-report in this study. Although this retrospective design was a necessity as a result of the time-limited and scope-limited nature of single-investigator research, these methodological limitations warrant caution regarding the reliability of this data.

Conclusions

In conclusion, this exploratory research project into the association between ADHD symptomatology in adulthood and risk outcomes in a New Zealand sample found significant associations between adult ADHD and risk-taking outcomes that measured risk of both the perpetration and victimisation of violent behaviours. These findings illustrate that ADHD symptomatology may contribute an additional element of risk in adulthood that has received very little attention to-date, as rates of domestic or sexual violence among this population have not been extensively explored. Considering the worryingly high self-reported rate of intimate violence among participants with ADHD in this current study (46% compared with 23% among controls), this research highlights the importance of considering the many domains in which the safety of adults with ADHD may be compromised, including the risk of harm from intimate partners.

In addition, this research helped to highlight the possible fundamental influence of ADHD on a range of other risk-taking behaviours in adulthood, including drug and alcohol abuse, nicotine use and sexual risk taking. The fact that some of these behaviours were differentially mediated by two motivational variances; reward sensitivity and temporal discounting; supports the hypothesis that individuals with ADHD may differentially respond to reinforcement (based on factors such as the tangibility of the reinforcement or the delay of the reward). This evidence of differential mediators is consistent with a dual neural pathway model of ADHD which may result in two phenotypes; characterised by either behavioural disinhibition (higher reward sensitivity, lower punishment sensitivity) or delay aversion (greater temporal discounting) (Sonuga-Barke et al., 2002).

The clinical implications of a dual pathway/ differential reward response, model of ADHD are manifold. Primarily, if clinicians have a better understanding of a more specific reinforcement model for subtypes of ADHD, then treatment can be better tailored for each individual. Similarly, this research has helped to elucidate the hypothesis that specific reinforcement models may operate for different behaviours. For example, whilst there appears to be an on-going assumption that sensation seeking is characteristic of ADHD due to a generalized increased sensitivity to reward, it may be more accurate to suggest that a subset of individuals with ADHD are likely to engage in sensation seeking such as smoking, more because they have a greater difficulty with seeing the negative consequences of their actions through a kind of 'temporal near-sightedness' associated with temporal discounting (Barkley, 1998). The current research certainly supports this heterogeneous reinforcement model. Therefore, within a clinical setting, to develop a behavioural treatment plan without catering for this differential response to reinforcement would likely lead to ineffective treatment.

Finally, this research study has highlighted a potentially high degree of risk associated with adult ADHD. As this is a relatively new finding, few clinicians may be aware of the importance of a very thorough risk assessment with all individuals, but especially those with ADHD. There are a number of 'hidden' risk behaviours such as low seatbelt use or unprotected sex which occur at a greater frequency among this population.

Clinicians need to be thorough in our assessment of the myriad of ways in which this pervasive neurobehavioural disorder may influence an individual's life.

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Conflicts of Interest

The authors declare no conflicts of interest.

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