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A meta-regression analysis

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Risky decision making in Attention-Deficit/Hyperactivity Disorder: A meta-regression analysis

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HIGHLIGHTS

- A meta-analysis shows that ADHD is related to risk taking in laboratory settings.
- Co-morbid Disruptive Behavior Disorders enhance risk taking in ADHD.
- Risk taking deserves more attention in the assessment and treatment of ADHD.
- Underlying neuropsychological and -biological mechanisms are yet unclear.

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ABSTRACT

ADHD has been associated with various forms of risky real life decision making, for example risky driving, unsafe sex and substance abuse. However, results from laboratory studies on decision making deficits in ADHD have been inconsistent, probably because of between study differences. We therefore performed a meta-regression analysis in which 37 studies (n ADHD = 1175; n Control = 1222) were included, containing 52 effect sizes. The overall analysis yielded a small to medium effect size (standardized mean difference = .36, $p < .001$, 95% CI [.22, .51]), indicating that groups with ADHD showed more risky decision making than control groups. There was a trend for a moderating influence of co-morbid Disruptive Behavior Disorders (DBD): studies including more participants with co-morbid DBD had larger effect sizes. No moderating influence of co-morbid internalizing disorders, age or task explicitness was found. These results indicate that ADHD is related to increased risky decision making in laboratory settings, which tended to be more pronounced if ADHD is accompanied by DBD. We therefore argue that risky decision making should have a more prominent role in research on the neuropsychological and -biological mechanisms of ADHD, which can be useful in ADHD assessment and intervention.

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Contents

1.	Introduction	2
2.	Methods and materials	4
2.1.	In- and exclusion criteria	4
2.2.	Meta-regression	4
2.3.	Moderator variables	4
2.4.	Handling of multiple effect sizes	4
2.5.	Publication bias	5

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3.	Results	5
3.1.	Literature search	5
3.2.	ADHD and risky decision making	5
3.3.	Robustness of the overall result	5
3.4.	Moderating variables	5
3.4.1.	Co-morbid DBD/APD in ADHD samples	5
3.4.2.	Co-morbid ADHD in DBD/APD samples	10
3.4.3.	Co-morbid internalizing disorders	10
3.4.4.	Age	10
3.4.5.	Explicitness of the task	10
3.4.6.	Exploratory analyses	10
4.	Discussion	10
	Role of funding sources	13
	Contributors	13
	Conflict of interest	13
	Acknowledgments	13
	Appendix A. Supplementary data	13
	References	13

1. Introduction

People with Attention-Deficit/Hyperactivity Disorder (ADHD) engage in more risk taking in daily life than people without ADHD. For example, several meta-analyses report ADHD related elevated rates of risky driving (Jerome, Segal, & Habinski, 2006), substance abuse (Lee, Humphreys, Flory, Liu, & Glass, 2011) and criminal activities (Pratt, Cullen, & Blevins, 2002). Furthermore, childhood ADHD is associated with more risky sexual behavior in adulthood (Flory, Molina, & Pelham, 2006) and adults with ADHD are at increased risk for developing gambling problems (Faregh, & Derevensky, 2011). This risky behavior not only affects the patient and its immediate environment, but also results in high healthcare costs for society (Hakkaart-van Roijen et al., 2007).

Several characteristics are assumed to contribute to this enhanced risk taking in ADHD. First, ADHD is characterized by altered reward sensitivity, which potentially contributes to risk taking by an enhanced focus on gains and consequently, an ignorance of possible losses (Scheres, Milham, Knutson, & Castellanos, 2007; Ströhle, Stoy, Wrase, Schwarzer, Schlagenhauf, Huss, et al., 2008). Second, impulsivity, one of the core symptom clusters of ADHD, is related to behavioral disinhibition, aversion to the delay of rewards and rushed decision making without consideration (Winstanley, Eagle, & Robbins, 2006). These characteristics potentially contribute to risk taking, as delay aversion can lead to the avoidance of choice alternatives that are merely beneficial on the longer term, and as behavioral disinhibition can easily lead to ignorance of possibly more advantageous choice alternatives.

The study of laboratory instead of real life decision making is very informative, as it offers the opportunity to investigate these underlying mechanisms experimentally. Laboratory risk taking is typically operationalized by gambling tasks, in which participants have to choose between options that may differ in the magnitude and probability of gains or losses (see Table 1 for an extensive description of all gambling tasks that were used in this meta-regression analysis). However, contrary to real life risky decision making studies, laboratory studies report inconsistent findings in ADHD (for a narrative review, see Groen, Gastra, Lewis-Evans, and Tucha, 2013). Therefore, to test our hypothesis that ADHD is related to enhanced risk taking on gambling tasks, the first goal of the current study is to perform a meta-analysis on laboratory studies that assessed risk taking in participants with and without ADHD. The second goal of this study is to identify relevant moderating variables, both related to characteristics of the population under study, as well as characteristics related to the gambling task.

Several participant characteristics will be investigated as moderators. First, the presence of antisocial behavior is included as moderator, as comorbidity between ADHD and antisocial behavior is high (e.g.

Jensen, Martin, & Cantwell, 1997). In the current study, antisocial behavior is operationalized by DSM diagnoses of Disruptive Behavior Disorders (DBDs), i.e. Oppositional Defiant Disorder (ODD) and Conduct Disorder (CD) in childhood and adolescence, and Antisocial Personality Disorder (APD) in adulthood. At the behavioral level, co-morbid DBD is associated with heightened levels of risky driving (Barkley, Guevremont, Anastopoulos, DuPaul, & Shelton, 1993), and among children with ADHD, those with co-morbid DBD show most risk taking as adults (Ramos Olazagasti, Klein, Mannuzza, Belsky, Hutchison, Lashua-Shriftman, et al., 2013). In a longitudinal study on ADHD, co-morbid CD was linked to the highest risk for substance dependence 10 years later (Biederman, Petty, Dolan, Hughes, Mick, Monuteaux, et al., 2008). Also, in the laboratory, studies investigating ADHD and a co-morbid DBD or APD more often demonstrate deficits on gambling tasks than studies investigating ADHD only (Groen et al., 2013). At the neural level, CD is associated with abnormalities in the paralimbic system (e.g. ventromedial orbitofrontal cortex) linked to affect and motivational control, which might be required in gambling tasks (Hobson, Scott, & Rubia, 2011; Rubia, 2011). In sum, based on real-life, laboratory and neural findings, larger effect sizes are expected in studies investigating ADHD samples with larger proportions of co-morbid antisocial behavior. In order to make a precise distinction between the different disorders, we included also studies with participants characterized by antisocial behavior without ADHD.

Second, the presence of co-morbid internalizing disorders, also occurring frequently in the ADHD population (Schatz, & Rostain, 2006), is included as a moderator. Co-morbid internalizing disorders are associated with a higher functioning behavioral inhibition system (Garon, Moore, & Waschbusch, 2006; Quay, 1988), which has been linked to avoidance of options characterized by high losses (Peters, & Slovic, 2000), possibly leading to better performance on gambling tasks (Garon et al., 2006). Related to this behavioral inhibition, co-morbid anxiety in ADHD, as compared to ADHD only, can be linked to heightened epinephrine excretion (Pliszka, Maas, Javors, Rogeness, & Baker, 1994), more physiological arousal and fear expression (Mezzacappa, Katkin, & Palmer, 1999), and elevated cortisol reactivity (Hastings, Fortier, Utendale, Simard, & Robaey, 2009). Therefore, based on real-life, laboratory and hormonal findings, smaller effect sizes are expected in studies investigating ADHD samples with larger proportions of co-morbid internalizing disorders.

Third, to investigate age differences on risky decision making in ADHD, we included age as a moderator. With age, symptoms of hyperactivity and impulsivity typically decrease (Biederman, Mick, & Faraone, 2000; Ingram, Hechtman, & Morgenstern, 1999), possibly because of age-related improvements in executive functioning (Groen et al., 2013). In line with these results, at the neural level, cortical maturation

is found to be delayed in children with ADHD, with a most prominent delay in prefrontal cortical regions responsible for executive functioning (Shaw, Eckstrand, Sharp, Blumenthal, Lerch, Greenstein, et al., 2007). Therefore, effect sizes are expected to decrease with age.

With regard to task characteristics, a potential moderator is the explicitness of the task. Some of the gambling tasks have explicit characteristics, meaning all characteristics of the different options are given to the participants (e.g. Game of Dice Task; Brand, Labudda, Kalbe, Hilker, Emmans, Fuchs, et al., 2004) and others have implicit characteristics, meaning that characteristics of options have to be learned by experiencing gains and losses (e.g. Iowa Gambling Task; Bechara, Damasio,

Damasio, & Anderson, 1994). Accordingly, implicit tasks seem to put a higher demand on participants' executive functioning. For example, working memory might be needed to remember previous experiences, and to update characteristics of options given these experiences. Several meta-analyses show impaired executive functions like working memory in ADHD (Wilcutt, Doyle, Nigg, Faraone, & Pennington, 2005; Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005), and at the neural level, these impairments are linked to alterations in the ventrolateral and dorsolateral prefrontal cortex (Rubia, Halari, Smith, Mohammad, Scott & Brammer, 2009; Sonuga-Barke, & Fairchild, 2012). Because of these differential working memory demands and related deficits in

Table 1
Characteristics of gambling tasks included in meta-regression analysis.

Task	Short description	Outcome measure(s), higher scores indicate more risky decision making
Iowa Gambling Task (IGT) (Bechara et al., 1994)	In this implicit task, participants can pick a card from one out of four decks. Two decks have large gains, the other two have small gains. However, because of infrequent large losses, the decks with large gains are disadvantageous on the long term. Adaptations of this task are frequently used, for example in which participants are asked about their strategies during the task (Mellentin, Skot, Teasdale, & Habekost, 2013; Miranda, MacKillop, Meyerson, Justus & Lovallo, 2009) or with values reduced with a fixed factor (Toplak, Jain, & Tannock, 2005). Other studies reduced values so participants could earn real instead of imaginary money (e.g. Vaurio, 2011), or adapted characteristics to make the task more appealing for children (Garon et al., 2006).	Choices of disadvantageous minus advantageous decks, also referred to as 'net score'. Sometimes, only the amount of choices for either advantageous or disadvantageous decks is reported. See IGT.
Hungry Donkey Task (HDT) (Crone, & van der Molen, 2004)	In this implicit task, participants have to collect apples behind doors (instead of money/points on cards) to feed a hungry donkey. Similar to IGT but adapted for children.	Proportion of choices from disadvantageous decks.
Foregone Payoff Gambling Task (FPGT) (Agay, Yechiam, Carmel, & Levkovitz, 2010)	This implicit task is almost similar to the IGT, with a slightly different payoff structure. The main difference is that after the choice of a card, participants also get to see the outcomes of the other decks, providing more information but arguably also more distraction.	Mean number of cards played.
Card Playing Task (CPT) (Newman, Patterson, & Kosson, 1987)	In this implicit task, participants can pick cards from a 110 (or sometimes 100) card deck, every card comes with a gain or a loss. The probability of losing increases with 10% in every block of 10 cards, which was unknown to the participant. The participant has to decide the optimal moment to stop.	Mean number of doors opened.
Door Opening Task (DOT) (Daugherty & Quay, 1991)	In this implicit task, participants have to open a door instead of picking a card. Identical principle as CPT.	Mean number of cards played/doors opened/boxes opened/poles thrown.
Reward Dominance Task (RDT) (Daugherty & Quay, 1991)	In this implicit task, cards, doors, boxes and persons with fishing poles were used as stimuli. Identical principle as CPT and DOT.	Mean number of pumps on unexploded balloons (also referred to as average adjusted pumps). Sometimes, the total amount of pumps is reported.
Balloon Analogue Risk Task (BART) (Lejuez et al., 2002)	In this implicit task, participants have to inflate a balloon, every pump delivers money (or points). However, when the balloon explodes, all money/points is/are lost.	Mean number of inflating responses.
Colorado Balloon Game (CBG) (Crowley et al., 2010)	In this implicit task, similar to the BART, participants have to choose between inflating a balloon or cashing money to bank account. Contrary to the BART, in this task probabilities of exploding increase as the task progresses. ^a	Mean number of risky choices.
Game of Dice Task (GDT) (Brand et al., 2004)	In this explicit task, participants can gain or lose play money by betting on a number of a dice. Subsequently, they can choose to throw one or more dices (4 possibilities). Betting on 1 or 2 dices is risky, betting on 3 or 4 dices is safe.	Risk taking (the amount of money/points the participant puts at risk). ^b
Cambridge Gambling Task (CGT) (Rogers et al., 1999)	In this explicit task, participants have to discover a hidden symbol behind 1 out of 10 red or blue squares; 1 color is in majority. They have to decide on which color they bet and how much of their account they will bet. Betting possibilities are presented in varying ascending or descending order.	Area Under the Curve (the higher, the more risk-seeking). Inaccuracy of decision making score (scores with the highest expected value are considered most accurate). Percentage choices of disadvantageous jackpots. ^c
Probabilistic Discounting Task (PDT) (e.g. Scheres et al., 2006)	In this explicit task, participants have to choose between 1 option with a certain gain and 1 option with a varying probability of a larger gain.	
Gambling Machine Task (GMT) (van Duijvenvoorde, Jansen, Visser, & Huizenga, 2010)	In this explicit task, participants have to choose between 2 gambling machines with 3 dimensions (gain, loss, probability of loss), differing in expected value. This was the only task in which participants did not receive immediate feedback after a trial.	
Jackpot Task (Luman, Oosterlaan, Knol, & Sergeant, 2008)	In this implicit task, participants have to choose between 3 jackpots. One jackpot delivers small gains and infrequent small losses and is advantageous over time. The other 2 jackpots are disadvantageous, delivering either large (magnitude condition) or frequent (frequency condition) losses as well as small to moderate gains.	
Rational Decision Making Under Risk (RDMUR) Task (Ibanez et al., 2012)	In this implicit task, participants have to draw cards from a deck of 10 cards. Nine out of 10 cards add a gain to the account, but if the 'bad card' is drawn, everything on the account is lost. Participants can choose whenever they would like to stop and cash their account. In reality, the bad card always appeared ninth.	Amount of cards drawn from the deck.

^a In this task, the decision balloons were followed by directed balloons, in which participants were directed to a certain response. These trials were used as baseline for fMRI analyses. Participants were told that the these trials had no effect on their earnings and these trials were not taken into account in the current analyses.

^b The CGT offers multiple outcome measures. For this meta-regression study we chose the Risk Taking measure.

^c The original studies (Luman et al., 2008; Luman, Sergeant, Knol, & Oosterlaan, 2010) do not report this outcome measure, but focus on probabilities of advantageous choices given the amount of trials the participant has performed.

ADHD, higher effect sizes are expected at implicit than at explicit gambling tasks.

In sum, this meta-regression study investigates whether participants with ADHD, as compared to typically developing participants, engage in more risky decision making on gambling tasks. An overall group difference is expected: people with ADHD are expected to make more risky decisions than people without ADHD, since, as described above, this is found in several real life situations and as several characteristics of ADHD (altered reward sensitivity, delay aversion, behavioral disinhibition) can be theoretically linked to risk taking. With regard to moderating variables, we expect (a) higher effect sizes in case of co-morbid DBDs/APD, since these disorders are associated with risky decision making themselves; (b) lower effect sizes in case of co-morbid internalizing disorders, because of higher rates of behavioral inhibition; (c) effect sizes that decrease with age, as a result of delayed cortical maturation in ADHD; (d) higher effect sizes on implicit tasks, imposing higher demands on executive functioning than explicit tasks.

2. Methods and materials

2.1. In- and exclusion criteria

A systematic literature search was conducted using Web of Science, PubMed, PsycInfo and Google Scholar until December 2014, using key words ADHD, behavioral disorders and gambling tasks, or variants thereof (see Appendix A for the complete search syntax). The literature search was independently performed by two researchers (TJD and a research assistant). Studies were included when meeting the following criteria: a) comparison of a clinical group diagnosed with either Attention Deficit/Hyperactivity Disorder (ADHD), Oppositional Defiant Disorder (ODD), Conduct Disorder (CD) and/or Antisocial Personality Disorder (APD) according to DSM-IV-TR (American Psychiatric Association, 2000) or previous editions, with a typically developing (TD) control group; b) participants performed a gambling task with probabilities of gains or losses (see Table 1 for included tasks and corresponding outcome measures); c) group means and standard deviations on outcome measures were provided, either in the paper or by correspondence with the authors; d) average IQ at group level was above 80.

Studies were excluded if, a) on explicit tasks, the probability of experienced gains or losses did not equal the explicitly presented probability (therefore we excluded Drechsler, Rizzo, and Steinhausen, 2010)¹; b) administration of the task did not take place under neutral or motivating circumstances, i.e. studies inducing boredom (e.g. second task in Matthies, Philippen, and Svaldi, 2012) or stress (e.g. second task in Fairchild, van Goozen, Stollery, Aitken, Savage, Moore, et al., 2009) were excluded.

Missing data, when relevant for the main analyses, were requested from the authors. In some cases, the data received from the authors differed from the published data.² In these cases, the data provided by the authors were included.

All studies were coded by one author (TJD) and checked by another (AP, JAAvR, HMM).

2.2. Meta-regression

All effect sizes were calculated in terms of standardized mean difference (Hedges' g), reflecting the mean difference between clinical and control groups on the outcome measure for risky decision making, divided by the pooled standard deviation and corrected for a slight positive bias (Hedges, & Olkin, 1985; Viechtbauer, 2010).

¹ We decided on this inclusion criterion as manipulating probabilities unknown to the participants may have had a confounding influence in explicit tasks.

² In most of these cases, number of participants differed because larger samples were investigated than reported, for example because participants were excluded based on measures irrelevant for this meta-analysis.

Study characteristics, moderators, means and standard deviations, as well as corresponding effect sizes, are provided in Table 2. Some outcome measures were recoded to ensure that higher values indicated more risky decision making. In interpreting the standardized mean differences, we follow Cohen's guidelines (1992), with values of 0.2 indicating small, values of 0.5 indicating medium, and values of 0.8 indicating large effect sizes.³ We report $\bar{\mu}$ in the analysis of the main effect, denoting the standardized mean difference, and $\hat{\beta}$ coefficients in the moderator analyses, denoting the change ($\hat{\beta}_1$) in standardized mean difference with a one unit increase in the value of the moderator and the intercept ($\hat{\beta}_0$), which is the standardized mean difference for a specific value of the moderator.

In order to account for expected between study variance, we performed a random effects meta-regression. Because some studies contributed multiple effect sizes, our random effects meta-regression concerned three levels, with the effect size level nested within the study level. The methods for this analysis have only recently been developed, but have shown to be more valid than conventional methods for this type of three level data (Konstantopoulos, 2011; cf. van den Noortgate, Lopez-Lopez, Marin-Martinez, & Sanchez-Meca, 2013; Cheung, 2014).⁴ First, we fitted a model without moderators to test the overall effect size. For the moderator analyses, we included each potential moderator separately. All analyses were performed using the metafor package in R (Viechtbauer, 2010).

2.3. Moderator variables

Relevant participant characteristics were: 1) DSM diagnosis of DBD or APD (continuously coded as % of participants in the clinical group diagnosed with a DBD or APD); 2) DSM diagnosis of internalizing disorders (continuously coded as the % of participants in the clinical group diagnosed with a DSM mood or anxiety disorder); 3) average age of the ADHD and TD control participants in the study, both continuously and categorically coded [<12 , $12-18$, $18+$]. The relevant task characteristic was defined as: Type of task (categorically coded: implicit or explicit).

Exploratory analyses on intelligence differences, gender, medication use, substance use disorders and the presence of an actual reward are reported in Appendix A. Although theoretically interesting, it was not possible to perform moderator analyses on ADHD subtypes, because very few studies reported detailed outcome information for ADHD subtypes.

2.4. Handling of multiple effect sizes

Several studies contained multiple effect sizes, either because multiple tasks were administered or because multiple groups were investigated. Below we outline how we handled these effect sizes.

In five studies, multiple tasks were administered to the same participants. To control for the potential correlation between these tasks, the 'multiple endpoints' method by Gleser and Olkin (2009)⁵ was used. In order to adopt this procedure, correlations between tasks should be provided. When correlations were not reported in the paper, they were estimated from relevant literature. Note furthermore that when the design was longitudinal (e.g. Skogli, Andersen, Hovik, & Øie, 2014), only the first assessment was included into the analyses, to rule out possible confounding developmental effects.

³ Although Bosco, Aguinis, Singh, Field and Pierce (2015) show that revision of this terminology might be necessary, we follow these guidelines because of their familiarity to both clinicians and researchers.

⁴ These methods are included in the metafor R package: (<http://www.metafor-project.org/doku.php/analyses:konstantopoulos2011>).

⁵ These methods are included in the metafor R package: (<http://www.metafor-project.org/doku.php/analyses:gleser2009>).

Nine studies compared multiple relevant groups to one control group. The control group thus contributed to multiple effect sizes, thereby violating the assumption of independency. We controlled for this dependency using the ‘multiple treatments’ procedure by [Gleser and Olkin \(2009\)](#).

In one study ([Agay et al., 2010](#)), both scenarios described above occurred. Therefore, we integrated both the ‘multiple endpoints’ and the ‘multiple treatments’ method of [Gleser and Olkin \(2009\)](#).

2.5. Publication bias

Studies with positive significant effects might be more likely to be published than studies with null results ([Easterbrook, Gopalan, Berlin, & Matthews, 1991](#)). In case of such a publication bias, the average effect size will be an overestimation. By contacting authors and searching for unpublished papers, we aimed to minimize publication bias. A funnel plot was made to examine potential publication bias, which was tested by a regression test of asymmetry ([Egger, Smith, Schneider, & Minder, 1997](#)). We further investigated funnel plot asymmetry with the trim and fill method ([Duval, & Tweedie, 2000](#)), which is used to check how many (hypothetical) studies need to be imputed to arrive at a symmetrical funnel plot.

3. Results

3.1. Literature search

Using aforementioned criteria, we found 37 eligible studies with clinical ADHD samples, together containing 52 effect sizes (see [Table 2](#)). When studies on DBD/APD were also included (no longer requiring an inclusion criterion of an ADHD proportion of 1), we found 16 additional studies. This sums up to 53 eligible studies, together containing 75 effect sizes. For the corresponding PRISMA flowchart ([Moher, Liberati, Tetzlaff, & Altman, 2009](#)), see [Fig. 1](#).

3.2. ADHD and risky decision making

Demographic characteristics, effect sizes and moderators are shown in [Table 2](#). Including only studies with a clinical group of 100% ADHD diagnoses ($k = 52$, n ADHD = 1175, n TD = 1222) yielded a significant, small to medium effect size: $\hat{\mu} = .36$, $p < .001$, 95% CI [.22, .51]. This indicates that, overall, risky decision making in laboratory gambling tasks is higher in ADHD groups than in control groups (see [Fig. 2](#)). Furthermore, variation between studies was significant (see [Table 3](#) for statistics).

3.3. Robustness of the overall result

The robustness of the overall results was investigated in different ways. First, Egger's test ([Egger, Smith, Schneider, & Minder, 1997](#)) indicated no funnel plot asymmetry ($z = .94$, $p = .35$) and the trim and fill method ([Duval, & Tweedie, 2000](#)) estimated that 0 studies are missing on the left side of the funnel (see [Fig. 3](#)).⁶ These results therefore do not suggest publication bias.

Second, it was checked whether the overall effect size was overly dependent on any single effect size by using the ‘leave one out’ method,

redoing the main analyses as many times as there were effect sizes, each time leaving out a single effect size. With a minimum of $\hat{\mu} = .34$, $p < .001$, 95% CI [.20, .49] and a maximum of $\hat{\mu} = .39$, $p < .001$, 95% CI [.24, .53], influences of single effect sizes seemed small.

Third, an alternative method to account for multiple effect sizes is to aggregate multiple (dependent) effect sizes from a single study into weighted averages ([Borenstein, & Rothstein, 1999](#)). This method did not lead to different results: $\hat{\mu} = .37$, $p < .001$, 95% CI [.26, .48].

Fourth, the ‘multiple endpoints’ method ([Gleser, & Olkin, 2009](#)) requires a correlation coefficient between tasks. These correlations were reported in the case of [Dai, Harrow, Song, Rucklidge and Grace \(2013\)](#); correlation between CPT and PDT is $-.14$ and [Mäntylä, Still, Gullberg and Del Missier \(2012\)](#); correlation between IGT and BART is $-.04$. In other cases, when correlations were not provided, correlations were estimated from the relevant literature. However, to investigate the robustness of the data, in these five cases, we also reanalyzed the data with alternative correlation estimates.

For [Baker \(2011\)](#), we assumed the correlation between the IGT and the GDT to be .47 (based on [Brand, Recknor, Grabenhorst, & Bechara, 2007](#)), the correlation between the BART and the GDT to be .07 (based on [Goudriaan et al., 2010](#)), and the correlation between the IGT and the BART to be $-.04$ (based on [Mäntylä et al., 2012](#)). If the correlation between the IGT and the BART is assumed to be .67 (based on [Goudriaan et al., 2010](#)), the SMD remained the same: $\hat{\mu} = .36$, $p < .001$, 95% CI [.21, .51].

For [Ibanez et al. \(2012\)](#), we assumed the correlation to be 0, because of large differences between the IGT and the RDMURT. If the correlation between the IGT and the RDMURT ([Ibanez et al., 2012](#)) was assumed to be .5 instead of 0, the SMD remained the same: $\hat{\mu} = .36$, $p < .001$, 95% CI [.22, .51].

For [Luman et al. \(2008\)](#), the correlation between the two different versions of the Jackpot task was assumed to be 0.5, because of the similarity of the tasks. If the correlation between the two different versions of the Jackpot task was assumed to be 0 instead of .5, the SMD is slightly higher: $\hat{\mu} = .37$, $p < .001$, 95% CI [.22, .51].

The study of [DeVito et al. \(2008\)](#), in which the same group of ADHD participants was tested twice (with medication and with placebo) and was compared with a control group without medication, was also analyzed using the ‘multiple endpoint’ procedure. As there is no information available about the test–retest correlation of the CGT, we used the test–retest correlation of the BART (i.e., .77; [White, Lejuez, & de Wit, 2008](#)). This high correlation is theoretically plausible, as the same test is administered twice in the same participants. However, when using an alternative lower correlation estimate of .25, the SMD remained the same: $\hat{\mu} = .36$, $p < .001$, 95% CI [.21, .51].

Finally, for [Agay et al. \(2010\)](#), the correlation between the IGT and FPGT was assumed to be .5, as the tasks were highly similar. Alternatively, if the correlation between the IGT and the FPGT was assumed to be 0 instead of .5, the SMD remained the same: $\hat{\mu} = .36$, $p < .001$, 95% CI [.23, .50].

To sum up, using several methods of analysis, the result of the main analyses seems to be quite robust.

3.4. Moderating variables

3.4.1. Co-morbid DBD/APD in ADHD samples

As expected, there was a moderating influence of the percentage of co-morbid DBD/APD, although two sided only at trend level (significant at one-sided testing): $\hat{\beta}_1 = .42$, $p = .07$, 95% CI [$-.04$, .89], indicating that effect sizes tended to increase with the rate of co-morbid DBD/APD. Follow-up analyses indicated that effect sizes at both 0% and 100% co-morbid DBD/APD differed significantly from zero (see [Table 4](#)). These results are depicted in the left panel of [Fig. 4](#).

⁶ It is currently not possible to perform Egger's test and the trim and fill method on the data while modeling dependency of effect sizes. Therefore, we performed these methods assuming independence of effect sizes. However, given the results from the analysis not modeling for dependency ($k = 52$, $\hat{\mu} = .37$, $p < .001$, 95% CI [.22, .51], 95% PI [$-.47$, 1.20], $\tau^2 = 0.18$, $I^2 = 69\%$, $QE(51) = 153.5$, $p < .001$), differences resulting from dependency seem small.

Table 2
Demographic characteristics, moderators and effect sizes of included studies.

Study	Group comparison	Clinical group						Typically developing control group			Task (Impl./expl.)	Outcome measure	M CI Gr (SD)	M TD (SD)	SMD (SE)
		n (% men)	M age (SD)	M IQ (SD)	% ADHD	% DBD/APD	% ID	n (% men)	M age (SD)	M IQ (SD)					
Agay, Yechiam, Carmel and Levkovitz (2010)	ADHD + MPH vs TD + placebo	13 (38)	31.7 (7.9)	7.9 (1.7)	100	0	0	16 (63)	32.4 (7.7)	6.8 (2.6)	IGT (I)	Proportion choices disadv. decks	0.40 (0.03)	0.42 (0.03)	−0.65 (0.38)
	ADHD + Placebo vs TD + placebo	13 (46)	33.2 (8.6)	7.6 (2.2)	100	0	0						0.40 (0.03)	0.42 (0.03)	−0.65 (0.38)
	ADHD + MPH vs TD + placebo	13 (38)	31.7 (7.9)	7.9 (1.7)	100	0	0				FPGT (I)	Proportion choices disadv. decks	0.31 (0.06)	0.24 (0.03)	1.49 (0.42)
	ADHD + placebo vs TD + placebo	13 (46)	33.2 (8.6)	7.6 (2.2)	100	0	0						0.35 (0.06)	0.24 (0.03)	2.33 (0.48)
	ADHD vs TD	18 (67)	11.6 (2.5)	108.3 (13)	100	NA	NA	18 (67)	11.6 (2.3)	111.1 (11.7)	IGT (I)	Proportion choices of adv. decks – final block (rescored)	−0.44 (0.15)	−0.61 (0.19)	0.97 (0.35)
Baker (2011)											GDT (E)	Risky choices	6.7 (5.3)	6.8 (4.8)	−0.02 (0.33)
											BART (I)	Pumps on unexploded balloons	26.5 (10.3)	28.7 (12.4)	−0.19 (0.33)
Bartgis (2005)*	ADHD vs TD	58 (67)	9.0 (2.0)	100.6 (13.3)	100	39	NA	36 (47)	9.6 (1.8)	109.5 (12.6)	DOT (I)	Doors opened	75.48 (24.31)	65.72 (26.69)	0.38 (0.21)
Bekkens, Jansen, van der Molen and Huizenga (2015)*	ADHD vs TD	35 (77)	14.9 (1.1)	99.0 (9.4)	100	0	NA	106 (52)	14.3 (1.4)	NA	GMT (E)	Accuracy (rescored)	−0.64 (0.14)	−0.69 (0.12)	0.43 (0.20)
	DBD vs TD	62 (60)	14.7 (1.6)	96.6 (8.6)	0	100	NA						−0.64 (0.15)		0.4 (0.16)
	ADHD + DBD vs TD	6 (33)	14.3 (1.2)	92.2 (5.9)	100	100	NA						−0.71 (0.15)		−0.17 (0.42)
Bekkens, Huizenga, Neville, Bredman, Collot d'Escury-Koenigs and van der Molen (2013)*	ADHD vs TD	6 (100)	15.0 (0.6)	93.0 (11.5)	100	0	NA	44 (100)	14.6 (1.4)	95.8 (11.8)	BART (I)	Pumps on unexploded balloons	34.61 (12.73)	29.56 (10.05)	0.48 (0.44)
	DBD vs TD	25 (100)	14.8 (1.4)	93.8 (9.4)	0	100	NA						30.18 (8.85)		0.06 (0.25)
	ADHD + DBD vs TD	6 (100)	14.7 (0.8)	90.4 (5.8)	100	100	NA						23.93 (9.26)		−0.56 (0.44)
Coghill, Seth and Matthews (2013)	ADHD vs TD	83 (100)	8.9 (1.7)	96.0 (12.3)	100	60.7	23.8	66 (100)	9.0 (1.7)	106.0 (10.6)	CGT (E)	Risk taking	0.56 (0.14)	0.51 (0.14)	0.34 (0.17)
Crowley, Raymond, Mikulich-Gilbertson, Thompson and Lejuez (2006) ^a	CD + SU vs TD	13 (100)	16.0 (1.2)	101.2 (9.3)	0	100	23.1	20 (75)	16.5 (1.1)	102.7 (7.8)	BART (I)	Responses before collect	36.66 (10.19)	24 (8.4)	1.35 (0.39)
Crowley et al. (2010)	CD + SU vs TD	19 (100)	16.5 (1.0)	97.0 (9.0)	0	100	15.8	20 (100)	16.5 (1.6)	104.9 (9.0)	CBG (I)	Risky right presses	51.95 (10.47)	52.4 (1.9)	−0.06 (0.32)
Dai et al. (2013) ^{b,*}	ADHD vs TD	30 (45)	35.3 (13.4)	115.8 (16.1)	100	NA	53	28 (52)	31.0 (12.4)	119.9 (16.0)	CPT (I)	Cards played	35.73 (25.8)	27.45 (23.5)	0.33 (0.26)
											PDT (E)	Area under the curve	0.14 (0.08)	0.11 (0.07)	0.39 (0.27)
De Brito, Viding, Kumari, Blackwood and Hodgins (2013) ^c	APD vs TD	45 (100)	37.3 (6.8)	90.7 (8.0)	0	100	NA	21 (100)	35.0 (8.2)	95.1 (11)	CGT (E)	Risk taking	0.64 (0.11)	0.6 (0.11)	0.38 (0.27)
DeVito et al. (2008)	ADHD + placebo vs TD	21 (100)	10.0 (2.1)	NA	100	0	0	22 (100)	10.3 (1.6)	NA	CGT (E)	Amount bet	69.8 (14.34)	66.67 (9.85)	0.25 (0.31)
	ADHD + MPH vs TD												60.5 (13.34)		−0.52 (0.31)
Dolan and Lennox (2013)	CD vs TD	72 (100)	16.4 (0.7)	85.6 (8.9)	0	100	0	20 (100)	15.6 (1.5)	100.4 (12.5)	CPT (I)	Payoff (rescored) ^d	−0.89 (0.54)	−1.13 (0.43)	0.46 (0.26)
	CD + ADHD vs TD	35 (100)	16.0 (1.0)	86.5 (9.7)	100	100	0						−0.81 (0.6)		0.58 (0.29)
Drechsler, Rizzo and Steinhausen (2008) ^e	ADHD vs TD	23 (91)	12.2 (0.8)	101.3 (10.7)	100	13	8.7	24 (96)	11.9 (0.6)	108.5 (18.5)	GDT (E)	Risky choices	4.77 (2.45)	3.16 (1.86)	0.73 (0.30)

Ernst et al. (2003)	ADHD vs TD	10 (50)	29.9 (7.3)	108.8 (9.5)	100	0	NA	12 (50)	28.8 (6.6)	105.6 (8.3)	IGT (I)	Adv.–disadv. choices (rescored)	– 4.3 (22.2)	– 6.3 (28.5)	0.07 (0.43)
Fischer, Barkley, Smallish and Fletcher (2005) ^{†*}	ADHD vs TD	68 (90)	20.9 (1.1)	9.6 (2.8)	100	0	NA	70 (93)	20.5 (0.6)	11.7 (2.4)	CPT (I)	Cards played	40.9 (31.4)	40.4 (27.5)	0.02 (0.17)
	CD + Hyperactive vs TD	46 (91)	21.2 (1.4)	9.2 (2.3)	67	100	NA						46.5 (33.2)		0.20 (0.19)
Garon et al. (2006) [§]	ADHD vs TD	21 (81)	9.83 (1.8)	94.9 (16.7)	100	81	NA	21 (81)	9.68 (1.9)	103.4 (14.7)	IGT ^h (I)	Adv. choices (rescored)	– 10.4 (1.3)	– 11.56 (1.28)	0.89 (0.32)
Geurts, van der Oord and Crone (2006)	ADHD vs TD	20 (85)	9.9 (1.1)	106.9 (15.4)	100	60	NA	22 (82)	10.0 (1.3)	108.9 (16.2)	HDT [†] (I)	Adv.–disadv. choices (rescored)	– 46.4 (68.49)	– 43.4 (87.34)	0.04 (0.31)
Gonzalez-Gadea, Baez, Torralva, Castellanos, Rattazzi, Bein, et al. (2013)	ADHD vs TD	22 (64)	35.3 (12.7)	37.0 (3.8)	100	0	0	21 (52)	38.3 (14.4)	37.1 (3.0)	IGT (I)	Adv.–disadv. choices (rescored)	– 4.51 (21.13)	– 12.22 (21.03)	0.36 (0.31)
Henderson (2007)	ADHD vs TD	13 (69)	11.9 (1.2)	113.3 (19.0)	100	NA	NA	14 (57)	12.5 (1.2)	114.3 (5.6)	IGT (I)	Adv.–disadv. choices (rescored)	8.36 (15.87)	0.86 (9.96)	0.55 (0.39)
Hobson, Scott and Rubia (2011)	ADHD +/– DBD vs TD	31 (84)	13.3 (1.8)	95.5 (13.1)	100	67	NA	34 (74)	13.1 (2)	106.5 (12.1)	IGT (I)	Disadv. choices (only 2nd half of task)	27.51 (7.51)	21.59 (9.44)	0.68 (0.26)
	DBD vs TD	28 (68)	12.6 (2.0)	100.7 (14.4)	0	100	NA						27.82 (8.82)		0.67 (0.26)
Humphreys and Lee (2011) ^{h,*}	ADHD vs TD	55 (73)	7.2 (1.2)	98.9 (13.9)	100	0	41	87 (67)	7.5 (1.1)	113.1 (20.7)	BART (I)	Total pumps	731.54 (273)	791.44 (254.3)	– 0.23 (0.17)
	ODD vs TD	13 (64)	7.9 (1.3)	103.1 (16.3)	0	100	29						936.51 (371.80)		0.53 (0.3)
	ADHD + ODD vs TD	48 (76)	7.4 (1.2)	106.1 (13.7)	100	100	56						1001.91 (263.5)		0.81 (0.19)
Ibanez et al. (2012)	ADHD vs TD	12 (92)	31.4 (11.0)	NA	100	0	NA	25 (64)	35.1 (11.2)	NA	IGT (I)	Adv.–disadv. choices (rescored)	– 1571 (635.9)	– 1847.1 (564.1)	0.46 (0.36)
											RDMURT (I)	Number of cards	6.8 (1.1)	6.7 (1.1)	0.09 (0.35)
Karaman (2006)	CD vs TD	16 (0)	15–18	NA	0	100	NA	14 (0)	15–18	NA	IGT (I)	Adv. choices (rescored)	– 51.75 (6.93)	– 53.36 (13.11)	0.15 (0.37)
Luman et al. (2008) ^k	ADHD vs TD	22 [†] (78)	9.7 (1.4)	98.9 (11.3)	100	47.8	NA	20 (75)	9.4 (1.4)	114.7 (14.3)	JP-M (I)	% choices Jackpot A (rescored)	– 31.26 (6.52)	– 46.95 (14.86)	1.37 (0.34)
		23 (78)									JP-F (I)		– 45.95 (10.98)	– 49.78 (12.16)	0.33 (0.31)
Luman et al. (2010)	ODD +/– ADHD vs TD	18 (67)	10.2 (1.3)	93.4 (15.3)	89	100	NA	24 (54)	10 (1.3)	111.4 (13.6)	JP-M (I)	% choices Jackpot A (rescored)	– 34.94 (15.55)	– 39.33 (15.33)	0.28 (0.31)
		17 (67)									JP-F (I)		– 57.71 (24.2)	– 58.96 (23.54)	0.05 (0.32)
Malloy-Diniz, Fuentes, Borges Leite, Correa and Bechara (2007)	ADHD vs TD	50 (56)	33.7 (11.7)	51.0 (6.8)	100	0	28	51 (39)	32.2 (12.9)	49.0 (7.2)	IGT (I)	Adv.–disadv. choices (rescored)	– 5.6 (20.9)	– 22.8 (23)	0.78 (0.21)
Malloy-Diniz, Borges Leite, de Moraes, Correa, Bechara and Fuentes (2008)	ADHD vs TD ^m	25 (60)	31.8 (9.1)	50.6 (4.4)	100	0	0	25 (40)	32.1 (8.5)	50.6 (3.9)	IGT (I)	Adv.–disadv. choices (rescored)	– 5.01 (23.93)	– 21.13 (21.99)	0.69 (0.29)
Mäntylä et al. (2012) ⁿ	ADHD vs TD	31 (55)	30.8 (12.6)	NA	100	NA	NA	32 (53)	29.8 (10.8)	NA	IGT (I)	Money earned (rescored) ^o	342 (619)	– 61 (812)	0.55 (.26)
											BART (I)	Pumps on unexploded balloons	1005.7 (269.4)	981.5 (215.6)	0.1 (0.25)
Masunami, Okazaki and Maekawa (2009) ^p	ADHD vs TD	14 (93)	11.5 (2.2)	102.2 (12.2)	100	0	0	11 (55)	11.7 (1.7)	NA	IGT (I)	Adv. choices (rescored)	– 8.75 (1.32)	– 9.33 (0.85)	0.49 (0.41)

(continued on next page)

Table 2 (continued)

Study	Group comparison	Clinical group						Typically developing control group			Task (Impl./expl.)	Outcome measure	M CI Gr (SD)	M TD (SD)	SMD (SE)
		n (% men)	M age (SD)	M IQ (SD)	% ADHD	% DBD/APD	% ID	n (% men)	M age (SD)	M IQ (SD)					
Matthies et al. (2012)	ADHD vs TD	15 (53)	38.1 (11)	29.7 (4.3)	100	NA	33	16 (50)	32.4 (14.4)	31.4 (3.4)	GDT (E)	Safe–unsafe choices (rescored)	–6.13 (10.29)	–13.88 (5.08)	0.94 (0.38)
Matthys, van Goozen, de Vries, Cohen-Kettenis and van Engeland (1998)	DBD + ADHD vs TD	10 (100)	10.0 (1.2)	90.0 (11.0)	100	100	NA	31 (100)	9.6 (1.1)	98.0 (11.0)	DOT (I)	Doors opened	93.6 (19.4)	57.9 (28.9)	1.3 (0.39)
	DBD vs TD	11 (100)	10.4 (1.0)	96.0 (12.0)	0	100	NA						71.6 (35.9)		0.44 (0.35)
Matthys, van Goozen, Snoek and van Engeland (2004)	DBD +/– ADHD vs TD	19 (100)	9.8 (1.2)	NA	63.2	100	NA	20 (100)	9.7 (1.6)	NA	DOT (I)	Doors opened	89.4 (34.2)	62.8 (36.3)	0.74 (0.33)
Mazas, Finn and Steinmetz (2000)	APD vs TD	8 (75)	23.2 (3.3)	111.0 (6.1)	0	100	NA	32 (44)	22.7 (2.1)	111.2 (6.7)	IGT (I)	Adv.–disadv. choices (rescored)	–5 (13.4)	–25.1 (21.3)	0.98 (0.41)
	APD + AD vs TD	13 (69)	22.7 (2.5)	107.0 (6.7)	0	100	NA						–0.9 (20.2)		1.13 (0.35)
Mellentin et al. (2013)	APD + SUD vs TD	16 (94)	36.8 (8.6)	NA	NA	100	NA	17 (76)	36.7 (10.6)	NA	IGT ^a (I)	Adv.–disadv. choices (rescored)	2.5 (31.91)	–24.17 (20.96)	0.97 (0.37)
Miranda et al. (2009)	APD + AD vs TD	17 (100)	27.1 (6.1)	96.0 (10.2)	NA	100	0	21 (100)	22.6 (4.3)	108.1 (9.4)	IGT ^a (I)	Adv.–disadv. choices (rescored)	–0.47 (21.57)	–16.43 (20.28)	0.75 (0.34)
O'Brien and Frick (1996)	DBD vs TD	9 (NA)	NA	NA	0	100	0	40 (80)	8.9 (1.5)	NA	RDT (I)	Trials played	318.3 (61.03)	247.8 (87.41)	0.83 (0.38)
	DBD + ANX vs TD	25 (NA)	NA	NA	0	100	100						224.7 (72.6)		–0.28 (0.26)
	ADHD vs TD	18 (NA)	NA	NA	100	0	0						252.7 (75.6)		0.06 (0.28)
Ryan, Dube and Potter (2013)	ADHD vs TD	11 (27)	19.6 (2.1)	116.1 (12.2)	100	NA	0	15 (53)	20.1 (1.5)	114.5 (8.1)	BART (I)	Pumps on unexploded balloons	41.09 (4.3)	39.47 (2.6)	0.46 (0.4)
Scheres et al. (2006)	ADHD vs TD (children)	12 (83)	8.8 (1.6)	108.4 (18.6)	100	25	8.3	13 (69)	9.1 (1.7)	105.2 (12.2)	PDT (E)	Area under the curve	0.6 (0.15)	0.59 (0.14)	0.05 (0.4)
	ADHD vs TD (adolescents)	10 (70)	14.4 (1.6)	102.9 (13.1)	100	40	0	11 (73)	14.3 (1.5)	98.0 (14.0)			0.62 (0.09)	0.55 (0.14)	0.51 (0.44)
	DBD vs TD	28 (82)	16.8 (1.5)	78.7 (12.3)	0	100	NA	99 (73)	17.5 (1.9)	88.8 (19.2)	IGT (I)	% disadv. choices	50.57 (13.31)	50.89 (13.31)	–0.02 (0.21)
Schutter, van Bokhoven, Vanderschuren, Lochman and Matthys (2011)	DBD + SUD vs TD	25 (76)	17.5 (1.8)	82.3 (15.2)	0	100	NA						57.44 (13.31)		0.49 (0.23)
Skogli, Andersen, et al. (2014)*	ADHD vs TD (boys)	37 (100)	11.2 (1.9)	94.5 (13.5)	100	5.1	5.2	29 (100)	11.4 (1.9)	102.5 (13.0)	HDT (I)	Adv.–disadv. choices (rescored)	4.16 (36.56)	–15.1 (34.52)	0.53 (0.25)
	ADHD vs TD (girls)	32 (0)	12.0 (2.0)	96.4 (15.7)	100	8.3	27.7	18 (0)	11.6 (1.9)	107.1 (13.1)			–15 (35.27)	11.67 (23.01)	–0.83 (0.31)
Skogli, Egeland, et al. (2014) ^f	ADHD vs TD	75 (56)	12.0 (1.4)	95.4 (9.4)	100	13.6	7.5	50 (64)	12.0 (2.0)	103.8 (12.9)	HDT (I)	Adv.–disadv. choices (rescored)	–4.88 (24.56)	–5.08 (33.05)	0.01 (0.18)
Toplak et al. (2005)	ADHD vs TD	44 (86)	15.6 (1.4)	104.1 (10.1)	100	29.5	15.9	34 (41)	15.4 (1.5)	109.4 (10.2)	IGT (I)	Adv.–disadv. choices (rescored)	4.64 (22.55)	–6.21 (30.48)	0.41 (0.23)

van Goozen, Cohen-Kettenis, Snoek, Matthys, Swaab-Barneveld and van Engeland (2004) Vaurio (2011) ^t	ODD vs TD	15 (88) ^s	10.1 (1.2)	99.4 (17.4)	0	100	NA	36 (39)	9.2 (1.2)	97.4 (8.8)	DOT (I)	Doors opened	97.4 (25.6)	49.6 (28.6)	1.69 (0.35)
	ODD + ADHD vs TD	26 (88)	9.5 (1.6)	94.4 (10.6)	100	100	NA						86.7 (30.4)		1.25 (0.28)
Weafer, Milich and Fillmore (2011) ^{v,*} Wiers, Gunning and Sergeant (1998) Wilbertz, Tebartz van Elst, Delgado, Maier, Feige, Philipsen, et al. (2012) ^w	ADHD vs TD	22 (77)	12.0 (2.1)	102.3 (8.4)	100	NA	NA	21 (65)	12.8 (2.4)	108.3 (8.9)	IGT ^u (I)	Adv.-disadv. choices (rescored)	−0.06 (0.62)	−0.69 (0.64)	0.99 (0.32)
	ADHD vs TD	30 (48)	21.1 (1.6)	105.4 (6.3)	100	NA	NA	21 (57)	22.3 (1.4)	109.1 (5.2)	BART (I)	Pumps on unexploded balloons	46.1 (15.5)	44.1 (13.1)	0.14 (0.28)
	ADHD vs TD	28 (100)	9.0 (1.3)	99.3 (10.3)	100	0	0	34 (100)	9.1 (1.4)	107.5 (11.3)	DOT (I)	Doors after optimum	15.5 (19.1)	12 (18.9)	0.18 (0.26)
	ADHD vs TD	28 (54)	37.1 (9.1)	113.2 (16.4)	100	0	21.4	28 (50)	36.7 (9.3)	105.7 (11.2)	GDT (E)	% risky choices	24.93 (21.39)	28.79 (22.59)	−0.17 (0.27)

Abbreviations: AD, Alcohol Dependence; ADHD, Attention Deficit Hyperactivity Disorder; Adv., advantageous; ANX, anxiety; APD, Antisocial Personality Disorder; BART(–Y), Balloon Analogue Risk Task (–Youth); CBG, Colorado Balloon Game; CD, Conduct Disorder; CGT, Cambridge Gambling Task; CI Gr, clinical group; CPT, Card Playing Task; Disadv., disadvantageous; DBD, Disruptive Behavior Disorder; DOT, Door Opening Task; Expl., explicit; FPGT, Foregone Payoff Gambling Task; GDT, Game of Dice Task; GMT, Gambling Machine Task; HDT, Hungry Donkey Task; ID, Internalizing Disorders; IGT, Iowa Gambling Task; Impl., implicit; JP-F/M, Jackpot Frequency/Magnitude; M, mean; MA, methamphetamine; MPH, methylphenidate; NA, not available; ODD, Oppositional Defiant Disorder; PDT, Probabilistic Discounting Task; RDMURT, Rational Decision Making Under Risk Task; RDT, Reward Dominance Task; SD, standard deviation; SE, standard error; SMD, standardized mean difference; SU(D), Substance Use (Disorder); TD, typically developing control group; WAIS-R, Wechsler Adult Intelligence Scale–Revised; WISC, Wechsler Intelligence Scale for Children.

^a Only participants with current CD diagnoses were taken into our analysis. Data for this subgroups were provided by the authors.

^b Separate data on the PDT (\$50 and \$5000 version) were provided by the authors, these were averaged for both the ADHD and control group.

^c Two APD groups (with and without psychopathy) were investigated: age, IQ and risk taking were averaged to create one APD group.

^d Usual outcome measure (amount of cards played) was not available.

^e Data on two consecutive rounds of the GDT were reported separately. These data were averaged for both the ADHD and control group.

^f IQ data of the CD + Hyperactive group was provided by the authors. WAIS-R Vocabulary and Block Design were averaged to create one IQ score.

^g The authors provided IGT outcome data on four separate blocks; these were averaged for both the ADHD and control group.

^h Adaptation of IGT: instead of numbers, pictures of animals were depicted on the cards.

ⁱ Outcome data are averages of the normal and reversed HDT.

^j Some participants performed on the BART, others on the BART-Y (in which the amount of pumps has to be indicated beforehand); these data were provided by the authors and were averaged for all 4 groups separately.

^k Data on the Jackpot Task were provided separately for two subgroups of participants (one group in which the frequency condition was administered first and one group in which the magnitude condition was administered first); these data were averaged for the ADHD and control group, for both the frequency and magnitude condition.

^l Note that in both Luman et al. (2008) and Luman et al. (2010) 1 participant dropped out. To fit the data of these study into the analyses according to Gleser & Olkin (2009), we set n at 22 and 17 respectively, as these analyses cannot control for dependency if n is different.

^m There were 2 control groups (English and Portuguese); we used the Portuguese control group, as the clinical group was also performing the IGT in Portuguese.

ⁿ Outcome data on the BART were reported for two blocks separately, these data were averaged for both the ADHD and control group.

^o Usual outcome measures in IGT studies were not available.

^p Outcome data on the IGT were provided by the author for five blocks separately, these data were averaged for both the ADHD and control group.

^q Every 20 trials participants were asked about their conscious knowledge about the task.

^r Two ADHD groups (different subtypes) were investigated: age, IQ and HDT outcome scores were averaged to create one ADHD group.

^s % of men not available for ODD and ODD + ADHD groups separately; 88% is for both groups together.

^t Separate WISC IQ scores for Verbal Comprehension and Perceptual Organisation were reported; these were averaged for the ADHD and control group. Also, outcome data on the IGT were provided by the author for five blocks separately, these data were averaged for both the ADHD and control group.

^u A slight adaptation of the IGT was used to make it more suitable for children, see Hooper, Luciana, Conklin, and Yarger (2004).

^v Separate verbal and nonverbal IQ scores were reported; these were averaged for both the ADHD and control group.

^w Data on two consecutive sessions of the GDT were reported separately. These data were averaged for both the ADHD and control group.

* In these cases, demographics, moderators and outcome measure were based on different number of participants. N reported in this table corresponds to number of participants on relevant outcome measure. Overall ES is only reported in case of more than one ES in a study.

Fig. 1. PRISMA flowchart. PRISMA flowchart of the literature search.

3.4.2. Co-morbid ADHD in DBD/APD samples

To further disentangle the effects of DBD/APD, an additional analysis was performed in studies investigating 100% DBD/APD samples, with varying ADHD rates. The percentage co-morbid ADHD in samples with 100% DBD/APD had no significant moderating influence: $\hat{\beta}_1 = -.02$, $p = .88$, 95% CI $[-.35, .30]$. Furthermore, follow-up analyses indicated that effect sizes at both 0% and 100% co-morbid ADHD differed significantly from zero (see Table 4). These results are depicted in the right panel of Fig. 4.

3.4.3. Co-morbid internalizing disorders

Contrary to expectations, there was no moderating influence of the percentage of co-morbid internalizing disorders: $\hat{\beta}_1 = .05$, $p = .93$, 95% CI $[-1.12, 1.22]$.

3.4.4. Age

Contrary to expectations, there was no moderating influence of age: $\hat{\beta}_1 = -.0003$, $p = .97$, 95% CI $[-.0154, .0148]$. This was confirmed by categorical analyses (three groups: <12 years, 12–18 years, >18 years): group comparisons were non-significant, and effect sizes of all groups separately were significant (see Table 4).

3.4.5. Explicitness of the task

Contrary to expectations, there was no significant effect of the explicitness of the task: $\hat{\beta}_1 = -.16$, $p = .38$, 95% CI $[-.51, .20]$. However, follow-up analyses indicated that only implicit tasks yielded a significant effect size (see Table 4).

3.4.6. Exploratory analyses

Exploratory analyses on intelligence differences, gender differences, medication use, substance use disorders and the presence of an actual reward are reported in Appendix A.

4. Discussion

People with ADHD are known to be characterized by increased risk taking in daily life, such as risky driving, substance use, criminal activities, risky sexual behavior and gambling problems (Jerome et al., 2006; Lee et al., 2011; Pratt et al., 2002; Flory et al., 2006; Faregh, & Derevensky, 2011). Our results indicate that ADHD groups are characterized by more risky decision making than typically developing control groups in the laboratory as well, with a small to medium effect size. Moderator analyses indicated a trend for co-morbid DBD/APD, and no effects of co-morbid internalizing disorders, age, and explicitness of the task.

With regard to participant characteristics, the tendency that co-morbid DBD/APD increased effect sizes is in line with studies showing increased daily life risk taking in ADHD groups with co-morbid DBD/APD (Barkley et al., 1993; Ramos Olazagasti et al., 2013; Biederman et al., 2008) and with evidence from recent neuroimaging studies (Bjork, & Pardini, 2014), showing increased risk taking in these groups in particular. Consistent with our additional analysis including 100% DBD/APD samples, in which co-morbid ADHD had no moderating influence, some even argue that the increased prevalence of risk behaviors in ADHD is an artifact of the high overlap between ADHD and antisocial behavior (Lilienfeld, & Waldman, 1990). However, this account is not supported by the main analyses of the current study, as it indicated also heightened risky decision making in ADHD groups without co-morbid DBD/APD. Possibly, no moderating influence of co-morbid ADHD in DBD/APD groups was found because of a ceiling effect.

No moderating effect of co-morbid internalizing disorders was found, suggesting that an overactive behavioral inhibition system has no effect on risky decision making. There are however ample alternative explanations for the absence of this moderating effect. First, ADHD participants with co-morbid internalizing disorders are quite likely to also have a co-morbid DBD (Jensen et al. 2001), which is related to increased risk seeking. Therefore, two opposite mechanisms (inhibited risk aversion and externalizing risk seeking) could potentially counteract each other, explaining the non-significant finding. Second, co-morbid anxiety

Fig. 2. Forest plot of effect sizes. Forest plot of standardized mean differences of studies comparing 100% ADHD samples with typically developing (TD) samples; positive effect sizes indicate more risky decision making in ADHD groups than in TD groups.

in ADHD worsens working memory deficits (Schatz, & Rostain, 2006), which could possibly counteract the effects of enhanced inhibition. Third, the differential role of depression and anxiety was not disentangled in the current study, while some suggest (Raghunathan, & Pham, 1999) that sadness is related to high-risk choices and only anxiety is related to low-risk choices. Fourth, statistical power was low, as only two studies investigated an ADHD group with more than 50% of the participants having an internalizing disorder.

Age did not moderate outcomes, suggesting that cortical maturation (Shaw et al., 2007) and the decrease in ADHD symptoms over lifespan (Biederman et al., 2000; Ingram et al., 1999) may not have been of influence. This is partly in line with a recent meta-analysis on typically developing samples, which also found no differences in risky decision making between studies investigating children and studies investigating adolescents (Defoe, Dubas, Figner, & van Aken, 2015). However, an alternative explanation for the absence of this effect is that ADHD studies in adults

Table 3
Test statistics of overall meta-analysis.

Comparison	k	n ADHD	n TD	$\hat{\mu}$	95% CI	95% PI	$\hat{\sigma}^2_{\text{estimate}}$	$\hat{\sigma}^2_{\text{study}}$	QE (df)
ADHD vs TD	52	1175	1222	.36***	.22, .51	-.50, 1.22	.19	.00	176.4 (51)***

$\hat{\mu}$ is the standardized mean difference (i.e. effect size), CI = 95% confidence interval of mean effect size over studies, PI = 95% prediction interval of effect sizes over studies, $\hat{\sigma}^2_{\text{estimate}}$ is the estimated variance between effect size estimates, $\hat{\sigma}^2_{\text{study}}$ is the estimated variance between studies, and QE is a test for residual heterogeneity.

Abbreviations: k = number of effect sizes, n = number of participants, ADHD = Attention-Deficit/Hyperactivity Disorder, TD = typically developing control group, and df = degrees of freedom.

*** $p < .001$.

Fig. 3. Funnel plot. Funnel plot with black dots indicating standardized mean differences of studies comparing 100% ADHD samples with typically developing samples. Standard errors are depicted on the Y-axis.

only included participants meeting ADHD criteria at that moment, ignoring those with decreased symptomatology.

With regard to task characteristics, a moderating influence of the explicitness of the task was expected, because of differential working memory demands. However, we did not observe such a moderating effect. Since a wealth of studies demonstrated working memory deficits in ADHD (Wilcutt et al., 2005; Martinussen et al., 2005), it is unlikely that the absence of these deficits could explain the absence of this moderating effect. Therefore, alternative explanations are more likely. First,

several studies suggest that decision making and working memory may be independent processes (Toplak et al., 2005; Vaurio, 2011; Drechsler et al., 2008; Skogli, Egeland, Andersen, Hovik, & Øie, 2014; Fairchild et al., 2009). Accordingly, Toplak et al. (2005) conclude that decision making in gambling tasks (both implicit and explicit) mainly relies on the motivational/affective part and not on the executive functioning part of the dual-pathway model in ADHD (Sonuga-Barke, 2003). Therefore, explicitness of the task may not have been of influence. Second, a statistical power problem could also explain this finding. As there were few studies using explicit gambling tasks, and as there was large heterogeneity in effect sizes, existing differences related to the explicitness of the tasks may have been undetectable.

The results of this meta-regression analysis should be considered in light of several limitations. First, multiple moderators showed only limited variation, thereby decreasing the power to detect effects. Therefore, it will be beneficial if future studies on laboratory decision making (a) include more clearly defined subgroups with co-morbid profiles, to disentangle potential decision making differences for co-morbid anxiety, mood and substance use disorders; (b) include explicit gambling tasks in order to compare these tasks with the more frequently used implicit tasks; (c) investigate decision making in ADHD groups with and without medication, to examine potential beneficial effects of medication.

Second, note that in the majority of studies, risk taking was operationalized as a choice for options with low expected value, that is, low mean expected outcomes. However, low expected value does not necessarily imply high risk, which is defined as the standard deviation of expected outcomes (also see Defoe et al., 2015; Schonberg, Fox, & Poldrack, 2011; Weber, Shafir, & Blais, 2004; van Duijvenvoorde et al., 2015). Therefore, it will be beneficial if future studies will assess risk taking in tasks requiring a choice between options which differ in risk, yet which do have equal expected value.

The findings of the current study have several implications for both clinical practice and research. With regard to clinical practice, given the robust findings in real life and laboratory studies, we advise clinicians to

Table 4
Test statistics of moderator analyses.

Moderators (k)	Effects	$\hat{\beta}_1$	$\hat{\beta}_0$	95% CI	$\hat{\sigma}^2_{\text{estimate}}$	$\hat{\sigma}^2_{\text{study}}$	QE (df)
Co-morbid DBD/APD (40) ^a	DBD/APD	.42		-.04, .89	.21	.00	132.5 (38)***
	0% DBD/APD		.22*	.00, .44			
	100% DBD/APD ^c		.65***	.28, 1.02			
Co-morbid ADHD in DBD/APD samples (27)	ADHD	-.02		-.35, .30	.04	.13	81.2 (25)***
	0% ADHD		.53***	.29, .78			
	100% ADHD ^c		.51**	.19, .83			
Co-morbid internalizing disorders (28) ^b	Internalizing disorders	.05		-1.12, 1.22	.25	.00	114.0 (26)***
Age, continuously analyzed (51) ^c	Age in years	-.0003		-.02, .01	.20	.00	175.3 (49)***
Age, categorically analyzed (52) ^d	Children vs adolescents	.07		-.32, .46	.20	.00	175.7 (49)***
	Children vs adults	.01		-.33, .36			
	Adolescents vs adults	-.06		-.46, .35			
	Children (21 effect sizes)		.34**	.11, .58			
	Adolescents (12 effect sizes)		.41**	.10, .72			
Task explicitness (52)	Adults (19 effect sizes)		.36**	.10, .61			175.4 (50)***
	Implicit vs explicit	-.16		-.51, .20	.19	.00	
	Implicit tasks (40 effect sizes)		.40***	.23, .57			
	Explicit tasks (12 effect sizes)		.24	-.07, .55			

$\hat{\beta}_1$ denotes the change in SMD with a one unit increase in the moderator, $\hat{\beta}_0$ denotes the SMD if the moderator equals the level in the Effects column, $\hat{\sigma}^2_{\text{estimate}}$ is the estimated variance between effect size estimates, $\hat{\sigma}^2_{\text{study}}$ is the estimated variance between studies, and QE is a test for residual heterogeneity.

Abbreviations: k = number of effect sizes, df = degrees of freedom, DBD = Disruptive Behavior Disorder, APD = Antisocial Personality Disorder, ADHD = Attention-Deficit/Hyperactivity Disorder, CI = confidence interval, and SMD = standardized mean difference.

^a 12 effect sizes with no data on DBD/APD were omitted.

^b 24 effect sizes with no data on internalizing disorders were omitted.

^c 1 study (O'Brien & Frick, 1996) was omitted because age information was missing.

^d The age information provided by O'Brien and Frick (1996) was sufficient to classify the study for the categorical analyses on age (i.e. children were tested). Hence the difference in k for the continuous and for the categorical analyses.

^e These $\hat{\beta}_0$ statistics are extrapolations of the model, hence the difference in $\hat{\beta}_0$ between 100% ADHD in DBD/APD samples and 100% DBD/APD in ADHD samples.

* $p < .05$.

** $p < .01$.

*** $p < .001$.

Fig. 4. Effects of co-morbid DBD/APD in ADHD and effects of co-morbid ADHD in DBD/APD. Left: meta-regression on the effect of % DBD/APD in studies with 100% ADHD samples. Right: meta-regression on the effect of % ADHD in studies with 100% DBD/APD samples.

pay more attention to risk taking, in the assessment as well as in the treatment of ADHD. For example, in order to target risk taking in a direct way, gambling tasks may be converted into training instruments.

Future research should focus on the mechanisms underlying increased risk taking in ADHD. Two potential mechanisms are of special interest. First, ADHD might be characterized by an enhanced focus on gains (Scheres et al., 2007; Ströhlle et al., 2008), leading to the relative neglect of losses, and therefore resulting in suboptimal decision making. If this would indeed be the case, it might be worthwhile to investigate whether the elevated focus on gains can be retrained using a cognitive bias modification paradigm (Hertel, & Mathews, 2011).

Second, disinhibition, which is also characteristic of ADHD (Barkley, 1997; Rubia, Smith, Brammer, Toone, & Taylor, 2014; Huizenga, van Bers, Plat, van den Wildenberg, & van der Molen, 2009), might be of importance. That is, participants with ADHD may react impulsively to one characteristic of options, neglecting others. In accordance with this explanation, it has been observed that participants with ADHD, as compared to controls, switched more after experiencing losses (Sallum, Mata, Miranda, & Malloy-Diniz, 2013) and after gains on safe choices (Matthies et al., 2012), although this resulted in suboptimal decision making. If impulsivity would indeed be important, it might be worthwhile to investigate whether a training targeting impulsivity will reduce risk taking in ADHD.

Furthermore, potential differences between ADHD subtypes in risk taking need to be studied. Few laboratory studies differentiated between subtypes, and findings are mixed. In one study, the combined subtype showed more risky decision making than the inattentive subtype, but this was only true for adolescents and not for children (Skogli, Egeland, et al., 2014). Another study found no decision making differences comparing inattentive and combined subtypes, but did report increasing risk taking with parent reported symptoms of hyperactivity and impulsivity (Toplak et al., 2005). With regard to real life risk taking, for example substance abuse, symptoms of hyperactivity and impulsivity (and not inattention symptoms) predicted substance abuse 5 years later (Lee & Hinshaw, 2006), but on the other hand a similar study found that next to ODD symptoms, severity of inattention was a strong predictor of substance abuse (Molina, & Pelham, 2003).

Overall, this meta-regression analysis showed that, in accordance with real life findings, ADHD groups engaged in more laboratory risky decision making than typically developing control groups, with a tendency for more pronounced effects in ADHD groups with highly prevalent DBD or APD. This finding has three major implications. First, future research is required into the mechanisms underlying risky decision making in ADHD. Second, emphasis on co-morbid (externalizing) disorders is justified and recommended. Third, the need arises to directly address risky decision making in psychological assessment and interventions, as it turns out to be a robust deficit in ADHD.

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Contributors

HMH & TJD designed the study; TJD and a research assistant searched for literature; TJD coded studies; AP, JAAvR and HMH checked coding; JAAvR and TJD performed analyses; TJD, AP, JAAvR, AB and HMH wrote and revised the manuscript. All authors have approved the final manuscript.

Conflict of interest

The authors reported no biomedical financial interests or potential conflicts of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <http://dx.doi.org/10.1016/j.cpr.2016.03.001>.

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