Why adolescents with ADHD take risks

*Biological, cognitive and social mechanisms*

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General introduction
Scientist-practitioner
The current dissertation is the product of a 6-year scientist-practitioner project, a collaboration between the University of Amsterdam and De Bascule, Academic Center for Child and Adolescent Psychiatry. Training for “GZ-psychologist” took place parallel to research. Scientist-practitioner projects have many advantages, for both science and clinical practice. Scientist practitioners are able to translate relevant issues that arise in clinical practice into research questions on the one hand, and are able to implement scientific findings in the routine of clinical practice on the other hand (Kazdin, 2008).

Several of the questions investigated in this dissertation were rooted in, or inspired by children and adolescents from de Bascule. Examples are provided in separate “from practice to science” boxes throughout this introduction.

Attention-Deficit/Hyperactivity Disorder (ADHD)
The Diagnostic and Statistical Manual of Mental Disorders (DSM-5; American Psychiatric Association, 2013) describes Attention-Deficit/Hyperactivity Disorder (ADHD) as a neurodevelopmental disorder characterized by excessive levels of inattention and/or hyperactivity and impulsivity. These symptoms lead to impairment across multiple settings (e.g., at home and in school, see Illustration 1), are not explained by another disorder, and some symptoms were already manifest before 12 years of age (but see Caye et al., 2016; Franke et al., 2018; Sibley et al., 2018).

The prevalence of ADHD is estimated at 5-7% in children and adolescents, and at 2.5-5% in adults (Thomas, Sanders, Doust, Beller, & Glasziou, 2015; Willcutt, 2012). Although symptoms usually decline in adulthood, the majority of children with ADHD still experience related impairment in adulthood. For example, about half of the children with ADHD still meets criteria for the disorder in adulthood (Faraone, Biederman, & Mick, 2006).

Moreover, childhood ADHD is a risk factor for myriad negative current and future outcomes. In childhood, ADHD is associated with increased levels of learning problems (Daley & Birchwood, 2010), conflicting interactions with parents (Cunningham & Barkley, 1979) and problems with peers (Nijmeijer et al., 2008). As a consequence, children with ADHD report less self-esteem and lower quality of life relative to their peers without ADHD (Danckaerts et al., 2010; Harpin, Mazzone, Raynaud, Kahle, & Hodgkins, 2013). Later in life, ADHD is associated with a higher risk for a plethora of negative outcomes
such as educational and occupational problems, substance abuse, criminal behavior, traffic incidents, social dysfunctioning, personality problems, and even life expectancy (Franke et al., 2018; Nigg, 2013; Young, 2000). Next to these personal consequences—which obviously impair individuals with ADHD and their near relatives—ADHD puts a high financial burden on society (Birnbaum et al., 2005; Hakkaart-van Roijen et al., 2007; Robb et al., 2011).

Illustration 1. Drawing by Silvan, a 13-year old boy diagnosed with ADHD at the outpatient department of De Bascule, illustrating the constant stream of thoughts and associations in his head, which cause significant impairment (printed with permission).

A large proportion of the behavior that impairs people with ADHD is risk-taking behavior (RTB). RTB is defined as “engagement in behaviors that are associated with some probability of undesirable results” (Boyer, 2006), and often refers to behaviors like substance abuse, risky traffic conduct, criminal/antisocial behavior, risky sexual behavior and gambling.
Aim of this dissertation
The main aim of this dissertation is to better understand why adolescents with ADHD demonstrate higher levels of RTB relative to their peers without ADHD. In the remainder of section one (“introduction”) of this dissertation (Chapter 2), the current state of the literature on the relation between ADHD and RTB is summarized, and potential underlying mechanisms are proposed. In the second section (“experimental approaches to risk-taking behavior in ADHD”, chapters 3-5), gambling tasks—rooted in decision theory—were used to study RTB, and to assess strategies used by adolescents during the process of decision making. In the third section (“biological and social influences on risk-taking behavior”, chapters 6-9), the association between ADHD and RTB is investigated from a biopsychosocial perspective (Engel, 1977). In section four (“personality traits related to risk-taking behavior”, chapters 10 and 11), two different constructs from personality literature – sensation seeking and need for cognition – were investigated, both potentially associated with ADHD and RTB. In the fifth section (“executive functioning in children with ADHD”, chapters 12 and 13) the focus is moved to executive functioning deficits in children with ADHD (instead of adolescents). Executive functioning deficits in children with ADHD are consistently reported (Kasper, Alderson, & Hudec, 2012; Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005) and executive dysfunctioning is predictive of RTB in adolescence (Lahat et al., 2012; Peeters et al., 2015). In the remainder of this general introduction, all parts of the dissertation are introduced in more detail.

Experimental approaches to risk-taking behavior in ADHD
In the second section of this dissertation, the link between ADHD and RTB was studied using a decision-theory framework. Early foundations of decision theory—a theoretical framework to understand how humans make decisions—were laid in the 18th century by the Swiss mathematician Daniel Bernoulli. He defined the construct of Expected Value (EV): the amount of gains multiplied by the probability of gains, minus the amount of loss multiplied by the probability of loss that a certain decision encompasses (Bernoulli, 1738, 1954). The most rational/objective choice would be the choice with the highest expected value. Bernoulli however directly questioned the validity of this EV theory of decision making by providing the following example (Bernoulli, 1954). A very poor man finds a lottery ticket. The ticket either results in winning 20,000 ducats or winning nothing, at equal probabilities. Bernoulli states that selling the ticket for 9,000 ducats would be considered a rational decision for the poor man – which goes against the EV theory. With this example, Bernoulli introduced the
General introduction

concept of Expected Utility (EU), which is defined by a similar formula as EV. However, gains and losses are now considered subjective constructs, which implies that different individuals could arrive at different decisions given the same choice.

Later theories expanded these early observations. The tendency that most people are risk averse, but some people may be risk seeking, is inspired by EU theories (Von Neumann & Morgenstern, 1944). Financial models further disentangled the EV of an option from the riskiness of an option, the latter being defined as the range of potential outcomes (Markowitz, 1952; Schonberg, Fox, & Poldrack, 2011). Decision theory was further developed by Kahneman & Tversky’s Prospect Theory (Kahneman & Tversky, 1979). Prospect Theory introduces different functions for the subjective evaluation of gains and losses, stressing that for most people losses weigh stronger than gains, and that high gain and loss amounts are underweighted.

A different line of research into decision making is aimed at heuristics people may use while making decisions. A heuristic is a rule-of-thumb, which makes the decision-making process faster and more efficient, but could also lead to the ignorance of potentially relevant characteristics involved in the decision (Gigerenzer & Gaissmaier, 2011; Tversky & Kahneman, 1974). An example of a heuristic is the so-called lexicographic decision-making strategy, in which several aspects of a decision are considered sequentially (Luce, 1956). Only if choice alternatives do not differ on the first considered aspect, the second aspect is considered.

There is a large literature on decision making in ADHD populations inspired by decision theory, and decision theory can be a helpful framework to understand decision-making deficits that potentially explain RTB in real life. In Chapter 2, literature on RTB and ADHD is reviewed in terms of decision theory. In individuals with ADHD, for example, RTB could be a consequence of underweighting of losses, overweignting of gains, perceiving certain behavior as less risky, or having a bias towards certain characteristics.

Risky decision making is often investigated with gambling tasks: experimental tasks in which participants have to choose between several alternatives that differ in terms of riskiness. In Chapter 3, a meta-analysis is presented on all 37 studies that compared an ADHD group with a control group on a gambling task. Using meta-analytic (34 studies, 48 effect sizes) and new experimental gambling task evidence from adults with (N = 40) and without (N = 40) ADHD, Chapter 4 tries to answer the question whether decision-making
deficits in individuals with ADHD reflect *suboptimal decision making* (i.e., choosing the 
option with the lowest EV more often) or *risk seeking* (i.e., choosing the option with the 
highest variance of outcomes more often). Gambling tasks have the additional advantage 
that they allow for disentanglement of different pieces of information people consider 
when making a decision. In *Chapter 5*, several versions of the Gambling Machine Task 
(GMT; Jansen, van Duijvenvoorde, & Huizenga, 2012) were used to investigate which 
mechanisms may be implicated in decision making in adolescents with ADHD (N = 81), 
relative to typically developing adolescents (N = 100). First, suboptimal decision making 
and risk seeking were again (as in *Chapter 4*) disentangled, this time in adolescents 
instead of adults, using a gambling task that is better able to answer this question than 
previous studies. Second, using Bayesian latent mixture analysis, it was investigated 
whether adolescents with ADHD used less complex decision-making strategies (i.e., 
heuristics) relative to their peers without ADHD. Third, the influence of experiencing 
outcomes on decision-making performance was investigated. Specifically, it was 
investigated whether only experiencing positive outcomes of decisions yielded larger 
differences between adolescents with and without ADHD than experiencing both positive 
and negative outcomes simultaneously. In real life, RTB like substance use and unsafe 
sex may have predominantly positive consequences on the short term, and therefore 
involve mostly positive outcomes at first. Stronger delay discounting (i.e., valuing small 
immediate rewards over larger delayed rewards; Jackson & MacKillop, 2016) associated 
with ADHD may therefore lead to more RTB in adolescents with ADHD, especially with 
regard to behaviors that involve no direct negative consequences at first sight.

**FROM PRACTICE TO SCIENCE**

A. is a 16-year old boy with ADHD. In therapy, he seems quite motivated to 
get his school diploma. However, his grades are poor; his parents complain 
that he always decides to do other things than preparing for tests, such 
as hanging out with his girlfriend, smoking cannabis with his friends or 
watching Netflix-series until late. A.’s parents are surprised that he never 
seems to anticipate the potential risks that are involved with his behavior. 

Are adolescents with ADHD less capable of integrating potential benefits 
and losses when deciding whether or not to engage in certain behavior? Do 
they use suboptimal decision-making strategies?
**Biological and social influences on risk-taking behavior**

Biopsychosocial models combine biological insights with social influences to better understand mechanisms involved in psychiatric disorders (Engel, 1977). In the *third section* of this dissertation, biological mechanisms (testosterone-by-cortisol interactions), social influences (peers and parents), and biosocial interactions (physiological reactivity to peers) were studied that may be particularly relevant in understanding the link between ADHD and RTB.

**Testosterone-by-cortisol interactions**

Psychoneuroendocrinological theories have long focused on the influence of single hormones on human behavior. In animals, for example, the association between testosterone and aggression is relatively large and firmly established (Archer, 1991). However, in humans, hormone-behavior associations are usually much smaller: $r = .08$ (testosterone and aggression; Archer, Graham-Kevan, & Davies, 2005), $r = .12$ (testosterone and risk taking; Kurath & Mata, 2018), $r = -.05$ (cortisol and externalizing behavior; Alink et al., 2008). The focus of psychoneuroendocrinological research has more recently shifted towards the interplay of different hormones, and their interactive influence on human behavior. The *dual-hormone hypothesis* posits that testosterone positively affects status-relevant behavior like aggression, dominance and risk taking, and that this effect is more pronounced when cortisol is low than when cortisol is high (Mehta & Josephs, 2010). Before investigating the potential relevance of this theory in understanding the link between ADHD and RTB, a much broader meta-analytical evaluation of the dual-hormone hypothesis is described in Chapter 6. This meta-regression analysis aggregates all 33 studies investigating the testosterone-by-cortisol interaction on status-relevant behavior, which was defined as status itself, dominance, risk taking, aggression and psychopathy.

It was notable that only two of these 33 studies were performed in groups with psychiatric disorders (both in delinquents), especially as many psychiatric disorders are characterized by problems with status-relevant behaviors like aggression, dominance and risk-taking. Therefore, in Chapter 7 it was investigated whether the dual-hormone hypothesis provides a useful framework to understand the link between ADHD and RTB. Although the literature on hormones in relation to ADHD is in its infancy, some tentative evidence suggests that ADHD may be characterized by increased testosterone as well as decreased cortisol levels, relative to populations without ADHD (Blomqvist et al., 2007;
Chance, Brown, Dabbs, & Casey, 2000; Isaksson, Nilsson, Nyberg, Hogmark, & Lindblad, 2012; Martel, Gobrogge, Breedlove, & Nigg, 2008). Salivary measurements of testosterone and cortisol, as well as behavioral measures of risk taking, aggression and sensation seeking were obtained in adolescents with (N = 80) and without (N = 100) ADHD to test the hypothesis that the dual-hormone theory explains the link between ADHD and RTB.

**Behavioral and physiological measures of susceptibility to peer influence**

During adolescence, the influence of peers on behavior increases (Somerville, 2013). Different lines of experimental research as well as real-life traffic data demonstrate that adolescents take more risks in situations with peers than alone (Chen, Baker, Braver, & Li, 2000; Gardner & Steinberg, 2005; Weigard, Chein, Albert, Smith, & Steinberg, 2014). Chapter 8 tests the hypothesis that adolescents with ADHD are particularly susceptible to peer influences on RTB, and that this may explain the pronounced levels of RTB that are observed in this group. Increased susceptibility to peer influence in adolescents with ADHD is likely because of three reasons. First, cognitive control systems may be less developed in this group, resulting in a dominance of social-emotional brain systems which are triggered by peers (Shaw et al., 2007; Sonuga-Barke, 2002). Second, adolescents with ADHD experience several social problems (Nijmeijer et al., 2008), and may be more susceptible to peer influence to gain status or avoid rejection (Brechwald & Prinstein, 2011). Third, adolescents with ADHD potentially engage in higher levels of risk taking in peer settings because they are less susceptible to the stress that the peer influence may evoke relative to adolescents without ADHD (Crowell et al., 2006; King, Barkley, & Barrett, 1998), as operationalized by lower autonomic nervous system (ANS) reactivity.

To investigate whether adolescents with ADHD are more susceptible to peer influence, a risk-taking task was administered twice in adolescents with (N = 81) and without (N = 99) ADHD: once while adolescents were alone, and once with a virtual peer pressure manipulation (cf. Weigard et al., 2014). During these tasks, ANS reactivity was also monitored.
**FROM PRACTICE TO SCIENCE**

B. is a 15-year old boy diagnosed with ADHD and a generalized anxiety disorder. He lives in a poor neighborhood in Amsterdam, and his school is often in the newspapers regarding issues of criminality. During therapy, B. speaks about his dilemmas. On the one hand, he wants to do the good things in life, get his diploma, and continue his studies. On the other hand, he wants to belong to his peer-group, he says all his friends carry weapons. One day in therapy, he shows his new knife, he impulsively bought it with a friend. He says he felt pressured by his friend and doesn’t know what to do now, although he admits that carrying the knife gives him a sense of safety.

*Are adolescents with ADHD particularly susceptible to peer influence?*

**Parental monitoring**

Although peer influence increases during adolescence, the role of parents should not be underestimated. Parenting is challenging, especially when children experience psychiatric disorders. Parents of children with ADHD experience higher levels of stress relative to parents of children without ADHD (Theule, Wiener, Tannock, & Jenkins, 2013), and parent-child relationships more often involve negativity (Johnston, Mash, Miller, & Ninowski, 2012). Parental knowledge (i.e., “knowing where, how and with whom children spend their time”; Stattin & Kerr, 2000) is considered relevant in relation to RTB in adolescence: Parental knowledge was lower in children with ADHD, and consequently predicted RTB later in development (Salari & Thorell, 2015; Stattin & Kerr, 2000; Walther et al., 2012), and a recent study suggested that parental knowledge mediated the link between ADHD symptoms and RTB (Pollak, Poni, Gershy, & Aran, 2017). Chapter 9 describes three studies: study 1 aimed to replicate this finding on the mediating role of parental knowledge in the link between ADHD symptoms and RTB, study 2 added peer influence as additional factor into this mediation and investigated whether parental monitoring and resistance to peer influence jointly predicted RTB, and study 3 investigated whether parental knowledge also mediated the link between ADHD and homework problems. All these studies used large and independent community samples of adolescents (N’s > 200), and ADHD symptomatology was measured dimensionally, which aligns recent developments in psychiatric science that recommend to take dimensionality more into account (RDoC; Cuthbert & Insel, 2013; Insel et al., 2010).
Personality traits related to risk-taking behavior

In the fourth section of this dissertation, two personality traits are investigated that may be related to both ADHD and RTB: sensation seeking and need for cognition. Sensation seeking is “a trait defined by the seeking of varied, novel, complex and intense sensations and experiences, and the willingness to take physical, social, legal and financial risks for the sake of such experience” (Zuckerman, 1994). Sensation seeking is related to several forms of RTB like substance abuse (Cohen & Fromme, 2002; Read, Wood, Kahler, Maddock, & Palfai, 2003), gambling (McDaniel, 2002), perilous driving (Arnett, 1996), sexual RTB (Arnold, Fletcher, & Farrow, 2010) and aggression (Arnett, 1996). Furthermore, sensation seeking is associated with several forms of psychopathology, among which ADHD. Sensation seeking was found to mediate the relationship between ADHD symptoms and health-related RTB in college students (Graziano et al., 2015). Compared to adolescence and adulthood, studies on sensation seeking in children are scarce. As sensation seeking in childhood predicts deviant behavior in adolescence/adulthood (Newcomb & McGee, 1991), measurement of sensation seeking early in life is important. Therefore, Chapter 10 describes a study in which the Brief Sensation Seeking Scale for Children (BSSS-C; Jensen et al., 2011) was translated to Dutch and was administered in a community sample of 158 children (M<sub>age</sub> = 11 years): Internal consistency, split-half reliability, test-retest reliability, factor structure, construct validity and convergent validity with attention problems and aggressive behavior were investigated.
Another personality trait that may be relevant in relation to ADHD and RTB is need for cognition. Need for cognition reflects the extent to which one tends towards, and enjoys, analytical thought (Cacioppo & Petty, 1982; Cacioppo, Petty, & Feng Kao, 1984). Need for cognition is presumably lower in ADHD populations, which is for example reflected in the DSM-5 ADHD symptom “a reluctance to engage in activities that require mental effort” (American Psychiatric Association, 2013). As need for cognition is related to the depth of information processing (Chatterjee, Heath, Milberg, & France, 2000; Simon, Fagley, & Halleran, 2004), lower complexity decision-making strategies are expected in individuals with low levels of need for cognition, which in turn could be related to increased RTB. In Chapter 11, in a large sample of young adults (N = 463), it was investigated whether need for cognition mediated the link between ADHD symptoms on the one hand and decision-making complexity and RTB on the other hand.

Executive functioning in children with ADHD

In the fifth section of this dissertation, two studies on executive functioning in children with ADHD and typically developing children are described. Executive functioning is an umbrella-like construct that encompasses several functions necessary for goal-oriented behavior, such as inhibition, working memory, processing speed, planning, organization, and attention (Barkley, 2012). Especially inhibition and working memory are studied in detail in relation to ADHD, with meta-analyses demonstrating consistent ADHD-related impairments on both functions (Alderson, Rapport, & Kofler, 2007; Kasper et al., 2012; Martinussen et al., 2005; Willcutt et al., 2005). Although not directly investigated in this dissertation, executive functioning deficits are potentially relevant in relation to RTB. Executive dysfunctioning in early childhood, for example, predicted risk-taking
propensity later in life (Lahat et al., 2012) and working memory functioning predicted alcohol-related problems in adolescence (Peeters et al., 2015).

**Time-on-task effects**

Time-on-task effects are often reported in children with ADHD when performing cognitively demanding tasks: performance deteriorates over time, and in a disproportionate manner relative to children without ADHD (Dovis, Van der Oord, Wiers, & Prins, 2012; Johnson et al., 2007; Swaab-Barneveld et al., 2000). A likely explanation for this pattern is that children with ADHD are more susceptible to effects of depletion than unaffected children. Depletion theories state that time-on-task effects can originate from two sources: either executive resources are limited and therefore performance declines over time (like a muscle that gets tired), or motivation declines over time and performance declines accordingly (Hagger, Wood, Stiff, & Chatzisarantis, 2010; Huizenga, van der Molen, Bexkens, Bos, & van den Wildenberg, 2012; Muraven & Baumeister, 2000; Muraven & Slessareva, 2003). These two competing hypotheses are investigated in Chapter 12: in children with \((N = 42)\) and without \((N = 54)\) ADHD, it is tested whether time-on-task effects on inhibition and attention appear regardless of manipulating motivation, or whether these effects can be remedied by increasing motivation.

**FROM PRACTICE TO SCIENCE**

E. is an 11-year old boy with ADHD, and ADHD-symptoms especially impede him during academic activities. His teacher noticed that E. is very capable to start his tasks, but his performance quickly drops over time. Together with the therapist, the teacher makes a reward program for E., which yields positive effects: E. is now better able to continue his learning activities for a longer time period.

Are children with ADHD particularly susceptible for time-on-task effects? And can this be counteracted by offering reward?
The relationship between motor activity and cognitive processing

Working memory is hypothesized to consist of a higher-level central executive, which is supported by lower-level short-term memory subsystems that are involved in maintenance/storage of information (Baddeley, 2007). Evidence thus far indicates that it is especially the central executive that is impaired in children with ADHD, which consequently predicts several real-life problems (Alderson, Hudec, Patros, & Kasper, 2013; Dovis, Van Der Oord, Wiers, & Prins, 2013; Kofler, Rapport, Bolden, Sarver, & Raiker, 2010).

In Chapter 13, it is investigated to what extent central executive demands are related to one of the core symptom clusters of ADHD: motor activity. Motor activity is often considered ubiquitous in children with ADHD (i.e., independent of contextual influences), but recent studies demonstrate that motor activity increases when cognitive demands increase (Rapport et al., 2009; Sarver, Rapport, Kofler, Raiker, & Friedman, 2015). Motor activity is proposed to have a functional role by increasing arousal levels necessary for the task (Sarver et al., 2015). However, it is yet unknown whether the relationship between cognitive processing demands and motor activity is linear (i.e., motor activity increases when cognitive processing demands increase) or whether there is an absolute threshold in cognitive processing demands after which motor activity stabilizes. Chapter 13 describes a study in which these two juxtaposed hypotheses were tested in children with (N = 36) and without (N = 24) ADHD.

FROM PRACTICE TO SCIENCE

F. is a 10-year old girl with ADHD. Her parents, as well as many other parents with children with ADHD, describe that F. can sit perfectly still while playing video games or watching movies. However, when she has to make homework, her activity level is much higher.

Is activity level higher during cognitively demanding tasks than during undemanding tasks? Is this something specific in children with ADHD?