Reward sensitivity in ADHD
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CHAPTER 7

General discussion and conclusion
As discussed in the General introduction of this thesis, ADHD is associated with increased risk-taking in daily life and impairments in social and educational or occupational functioning. Although the behavioral and cognitive characteristics of ADHD are likely to contribute to these difficulties, motivational deficiencies may also play a role. Therefore, the current thesis focused on reward sensitivity in individuals with ADHD. The first aim was to create a comprehensive overview of particular neuropsychological aspects of reward sensitivity in ADHD (i.e., sensitivity to probabilistic and social rewards). The second aim was to examine educational aspects of reward sensitivity in ADHD (i.e., the effectiveness of reward-based classroom interventions and teachers’ experiences with these interventions in school practice). These objectives were specified in four research questions and examined in four different studies.

**RESEARCH QUESTION 1**

**Do individuals with ADHD demonstrate altered sensitivity to probabilistic rewards in gambling tasks?**

Research on reward sensitivity in ADHD has predominantly focused on temporal discounting of rewards, indicating that individuals with ADHD often prefer small, immediate rewards over larger, delayed rewards (see meta-analytic review of Jackson & Mackillop, 2016). Chapter 2 of this thesis provided new insights into an underexposed aspect of reward sensitivity in ADHD, i.e., sensitivity to probabilistic rewards in gambling tasks.

The literature was systematically reviewed on risk-taking in gambling tasks in individuals with ADHD. The results showed that half of studies (7 out of 14 studies) indicate increased risk-taking on gambling tasks in children and adolescents with ADHD. Thus, there is inconsistent evidence that children and adolescents with ADHD demonstrate altered sensitivity to probabilistic rewards in gambling tasks. Because of this inconsistency in results, chapter 2 examined potential confounding variables. The results indicated that comorbid externalizing disorders (i.e., oppositional defiant disorder and conduct disorder) are likely to increase risk-taking of individuals with ADHD in gambling tasks. A more recent meta-analytic review, independent from our study, has corroborated this finding (Dekkers, Popma, Agelink van Rentergem, Bexkens, & Huizenga, 2016). Another factor that may influence risky decision-making in children and adolescents with ADHD is the frequency of penalty delivery. Chapter 2 found some evidence that children and adolescents with ADHD do not behave differently from typically developing/developed controls (TDCs) in gambling tasks when penalties are frequent. This finding is in line with previous findings that a high frequency of reinforcement is highly effective for individuals with ADHD (Luman et al., 2005). Furthermore, Chapter 2 provided limited or inconsistent evidence that comorbid internalizing disorders (e.g., anxiety and depression), ADHD subtype, use of methylphenidate, form of reward (i.e., fictive or tangible), and type of gambling task (i.e., explicit or implicit) influence risky decision-making in individuals with ADHD.

Both cognitive and motivational deficits may underlie altered risky decision-making in children
and adolescents with ADHD because the outcomes did not differ between studies using explicit gambling tasks and studies using implicit gambling tasks. With regard to reward sensitivity, theoretical models of ADHD predominantly focus on temporal discounting at which individuals with ADHD prefer small, immediate rewards over larger, delayed rewards. Chapter 2 suggests that children and adolescents with ADHD can be also more likely than TDCs to prefer less probable, large rewards over more probable, smaller rewards. Moreover, they seem to risk higher penalties to obtain these larger rewards. Chapter 2 also revealed that only a minority of studies (3 out of 11 studies) indicate altered sensitivity to probabilistic rewards in gambling tasks in adults with ADHD. Thus, the evidence for increased risk-taking on gambling tasks is weaker for adults with ADHD than for children and adolescents with ADHD. This finding may be associated with the developmental trajectory of ADHD. Symptoms of ADHD, particularly symptoms of hyperactivity-impulsivity, often decrease from childhood into adulthood (Davidson, 2008). According to the prefrontal recovery hypothesis, this remission in ADHD is associated with improvements of cognitive control functions during adolescence (Halperin & Schulz, 2006). To get more insight into the developmental course of risky decision-making in individuals with ADHD, there is a need for well-powered studies, in particular longitudinal studies.

**RESEARCH QUESTION 2**

**Do individuals with ADHD demonstrate altered sensitivity to social rewards?**

Research on reward sensitivity in ADHD is very limited with regard to the type of reward used. Whereas ADHD has been associated with alterations in tangible reward processing (Luman et al., 2005), little is known on processing of social rewards in individuals with ADHD. Therefore, Chapter 3 of this thesis described a systematic literature review on social reward processing in individuals with ADHD.

This review included six studies in children with ADHD, whereas no studies on adults have been available for this review. Overall, the results indicated that, relative to non-reward, social rewards are associated with increased task performance and neural responsiveness (e.g., in the ventral striatum) as well as higher self-reported ‘wanting’ and ‘liking’ in children with ADHD, implying that social rewards can be used to motivate children with ADHD. There was some evidence that the effects of social rewards on task performance (two out of five studies) and neural responsiveness (one out of one study) are larger for children with ADHD than for TDCs. However, no studies indicate altered social reward processing in children with ADHD in terms of temporal discounting (one out of one study) and self-reported ‘wanting’ and ‘liking’ (two out of two studies). With regard to neural responsiveness, stronger activation in the medial prefrontal cortex has been observed during social reward conditions in children with ADHD than in TDCs. This brain area has been primarily associated with the ‘liking’ component of reward (Berridge et al., 2009; Kohls et al., 2012), implying that children with ADHD enjoy social rewards more than TDCs. Kohls et al. (2014) suggest that this neural hyperresponsiveness to social rewards may explain the impulsive and intrusive social behavior of...
children with ADHD, which may serve as a compensatory reaction to frequently experienced peer rejection.

Chapter 3 further examined the specificity of the findings with regard to the type of reward. Overall, like social rewards, monetary rewards have positive effects on the different outcome measures. Like TDCs, children with ADHD seem to benefit somewhat more from monetary rewards than social rewards but the evidence is inconsistent. Furthermore, Chapter 3 revealed that the findings concerning reward-type specificity are rather inconsistent across studies. This finding is not surprising as a previous review study already pointed to mixed results on tangible reward processing in individuals with ADHD (Luman et al., 2005). Knowledge about the underlying reasons for these observed inconsistencies is scarce, but there is some evidence that variables such as comorbidity and the frequency of reward may play a role. Future research may hopefully provide more insight into factors accounting for these inconsistencies.

ADHD shares many characteristics with autism spectrum disorder (ASD) but theories suggest that both disorders may differ with regard to sensitivity to social rewards (Leitner, 2014; Rommelse et al., 2011; Taurines et al., 2012). Therefore, Chapter 3 also compared children with ADHD and children with ASD in social reward processing. Five out of the six studies in the review included a group of children with ASD. No evidence was found for group differences between ADHD and ASD in self-reported ‘wanting’ and ‘liking’ of social rewards (two out of two studies) and social reward effects on task performance (four out of four studies). There was only limited evidence that, relative to children with ASD, children with ADHD demonstrate neural hyperresponsiveness to social rewards (one out of one study) and steeper temporal discounting of social rewards (one out of one study). Remarkably, in comparison to ASD, ADHD is also associated with neural hyperresponsiveness to monetary rewards, although this stronger activation is located in the ventral striatum and not in the medial prefrontal cortex as during social reward conditions. These neurobiological findings imply that children with ADHD like (but not want) social rewards more and want (but not like) money more than children with ASD. Although Chapter 3 provided little direct evidence for differences in social reward processing between ADHD and ASD, there are still indications for differences in social reward processing between both disorders. Whereas Chapter 3 revealed rather social hyper- than hyporesponsiveness in children with ADHD, the literature suggests rather social hypo- than hyperresponsiveness in children with ASD (Bottini, 2018; Chevallier et al., 2012).

The few studies in the area of social reward processing in ADHD point to an intact sensitivity or even hypersensitivity to social rewards in children with ADHD, which is a promising finding. Firstly, children with ADHD may benefit equally or even more from social rewards compared to typically developing children. Parents and teachers therefore may effectively use social rewards (e.g., praise, a smile, cooperation, or competition) to increase motivation and task performance of children with ADHD. In this respect, it may be important to consider individual reward preferences and to alternate between different types of rewards (Zentall, 2005). Secondly, although only few studies directly investigated differences in social reward processing between ADHD and ASD, there are
indications that children with ADHD are hypersensitive to social rewards and children with ASD are hyposensitive to social rewards. Therefore, the difficulties in social functioning in both disorders may derive from different sources and may be a starting point for future research.

**RESEARCH QUESTION 3**

**How effective are classroom interventions (including reward-based interventions) for reducing task-irrelevant behaviors in students with symptoms of ADHD?**

The interim Chapter 4 of this thesis discussed the role of motivation in educational outcomes of students with ADHD. It was pointed out that ADHD is associated with a lower academic motivation and that the relationship between academic motivation and educational outcomes is stronger for students with ADHD than for typically developing students (Gut et al., 2012; Z. R. Smith & Langberg, 2018). Moreover, several studies have demonstrated that academic motivation mediates the relationship between ADHD symptoms and academic achievement (Demaray & Jenkins, 2011; Ogg et al., 2016; Volpe et al., 2006). Considering these motivational deficiencies, it is warranted to implement classroom interventions to increase academic motivation in students with ADHD. These interventions could focus, for example, on increasing intrinsic motivation by making tasks and instructions more interesting but also on extrinsic motivation by providing rewards for desirable behaviors.

Previous research has shown that classroom interventions have positive effects on the academic and behavioral outcomes of students with ADHD (DuPaul & Eckert, 1997; DuPaul et al., 2012). When considering different types of classroom interventions (i.e., antecedent-based, consequence-based, and self-regulation interventions), the picture has been inconsistent and needs further examination. In the classroom, particularly the behavior of students with ADHD may be stressful to teachers and disturb overall classroom functioning. In addition, the behavioral problems are associated with less task engagement and are likely to contribute to underperformance in students with ADHD. Therefore, Chapter 5 of this thesis described a meta-analytic review on the effectiveness of different types of classroom interventions (including reward-based interventions) in order to decrease task-irrelevant classroom behavior in students with symptoms of ADHD.

This meta-analytic review included 100 studies covering a period of over 40 years of research. Two separate meta-analyses were performed; one for within-subjects design (WSD) studies ($k = 24$) and one for single-subject design (SSD) studies ($k = 76$). Besides reward-based interventions, referred to as consequence-based interventions in Chapter 5, three other types of interventions were included, i.e., antecedent-based interventions (i.e., manipulating antecedent conditions, such as environment, task, or instruction), self-regulation interventions (i.e., implemented by the student to develop self-control and problem-solving skills), and combined interventions (i.e., a combination of the other types of interventions).

The results of Chapter 5 revealed that all of the examined types of classroom interventions reduce off-task and disruptive classroom behavior in students with symptoms of ADHD (small to
The WSD studies indicate that reward-based interventions are more effective than antecedent-based, self-regulation, and combined interventions, whereas the SSD studies show the largest effect for self-regulation interventions. For the WSD studies, the effect size for reward-based interventions was large, indicating that rewards may be very useful to improve classroom behavior in students with ADHD symptoms. No statistical guidelines exist for the interpretation of effect sizes for SSD studies. Chapter 5 also found that interventions are more effective in general education classrooms than in other classroom settings (e.g., special education), which could be associated with higher symptom severity of ADHD and already existing behavioral programs in special education classrooms. Unfortunately, it was not possible to formulate reliable conclusions about the moderating effects of type of measure (i.e., direct observations or teacher ratings) and students’ age, sex, intelligence, and medication use.

There was some evidence that classroom interventions for ADHD have positive effects not only on students with symptoms of ADHD themselves but also on classmates. The studies including outcomes of classmates show that both classmates who receive the same intervention as the student with symptoms of ADHD as well as classmates who do not receive any intervention show an improvement in behavioral and academic outcomes. This finding implies that classroom interventions for students with ADHD have both direct effects on classmates (because classmates benefit from the intervention) and indirect effects on classmates (because classmates profit from less classroom disturbance by students with symptoms of ADHD).

The findings of Chapter 5 stress that teachers can use different types of classroom interventions for reducing task-irrelevant classroom behavior in students with symptoms of ADHD. Reward-based interventions show large effects, implying that teachers could effectively use rewards to improve classroom behavior of students with ADHD symptoms. It may be important for teachers to consider the characteristics of the individual student as well as the function of his or her ADHD-related behavior when selecting and implementing an intervention (F. G. Miller & Lee, 2013). This procedure may require the help of a professional, such as a school psychologist. The findings suggest that classroom interventions are also beneficial in general education classrooms, for students with ADHD who already receive medical treatment, and for overall classroom functioning. To effectively implement classroom interventions, it is recommended to offer classroom management trainings for teachers.

**RESEARCH QUESTION 4**

*What are teachers’ experiences with evidence-based classroom interventions (including reward-based interventions) for students with symptoms of ADHD?*

Chapter 5 showed that teachers can implement different types of interventions to reduce task-irrelevant behaviors of students with symptoms of ADHD. However, little has been known about Dutch teachers’ experiences with these evidence-based interventions for ADHD in school practice. Insight into this aspect may be especially relevant for educational policy makers and may contribute
General discussion and conclusion

to an improvement in teacher support and training. Therefore, Chapter 6 of this thesis examined Dutch teachers’ experiences with evidence-based classroom interventions (including reward-based interventions) for students with symptoms of ADHD in school practice.

Chapter 6 described a survey study among 140 general education teachers in the Netherlands. Primary \((n = 89)\) and secondary \((n = 51)\) school teachers rated their frequency of use of different classroom management strategies (CMSs) for students with ADHD symptoms as well as typically developing students. Teachers reported that they use a variety of CMSs for students with ADHD symptoms, but most often apply the CMSs that are easy to implement (e.g., preferential seating, simple instructions, and praise) and least often use the CMSs that are more individualized (e.g., daily report card, individual behavior plan, and teaching self-monitoring skills) or negative-oriented (e.g., time-out and mild punishment). Previous studies also found that teachers predominantly utilize less effortful CMSs (Arcia et al., 2000; Blotnicky-Gallant et al., 2015; Martinussen et al., 2011; Mulligan, 2001) and prefer positive-oriented CMSs (Almog & Shechtman, 2007; Y. Lee & Witruk, 2016; Power et al., 1995). Irrespective of whether a student has ADHD or not, teachers reported that they use antecedent-based CMSs most often and self-regulation CMSs least often, with reward-based CMSs in-between.

With regard to students with symptoms of ADHD, Chapter 6 showed that primary school teachers report using antecedent-based CMSs more often for such students than for typically developing students. This finding may suggest that teachers focus primarily on the academic performance of students with ADHD because meta-analytic studies indicate that antecedent-based interventions have a positive effect particularly on the academic performance of students with ADHD (DuPaul et al., 2012). However, antecedent-based interventions have been shown to be less helpful with regard to the improvement of classroom behavior of students with ADHD symptoms, especially in comparison to reward-based and self-regulation interventions (Gaastra et al., 2016). Another explanation for our finding is that teachers may be more familiar with antecedent-based CMSs and therefore use them more often. Self-regulation and reward-based CMSs may be less known and therefore less favored by teachers. Furthermore, teachers may experience antecedent-based CMSs as easy to implement and less time-consuming. The qualitative analysis of our study indeed revealed that time constraints are an issue in selecting CMSs for students with symptoms of ADHD. Contrary to primary school teachers, secondary school teachers indicated that they do not adapt their frequency of use of CMSs for students with ADHD symptoms. This finding is striking because the educational difficulties of children with ADHD often continue into adolescence (Barkley, 2015; Daley & Birchwood, 2010; Loe & Feldman, 2007).

Besides the frequency of use of CMSs, teachers also rated the perceived effectiveness of CMSs for students with ADHD symptoms. Teachers experienced antecedent-based CMSs as most effective and self-regulation CMSs as least effective for reducing problem behavior of students with ADHD symptoms. This perceived effectiveness is opposite to the evidence base for effectiveness (see Chapter 5 of this thesis), emphasizing the importance of adequate teacher training for classroom
management. Teachers’ perceived effectiveness of CMSs for students with ADHD symptoms was associated with their reported frequency of use of CMSs. Because of the correlational nature of this study, no causal relationship could be concluded between the perceived effectiveness of CMSs and the frequency of use.

Chapter 6 observed important differences between primary and secondary school teachers. As previously mentioned, primary school teachers reported that they adapt their frequency of use of antecedent-based CMSs for students with ADHD symptoms, whereas secondary school teachers did not. Previous studies also indicate that primary school teachers are somewhat more prepared to provide additional support to students with disabilities as compared to secondary school teachers (Hart et al., 2017; Scott et al., 1998). Irrespective of whether a student has ADHD or not, primary school teachers indicated that they use CMSs more often than secondary school teachers, particularly antecedent-based CMSs and self-regulation CMSs, which they also rated as more effective. These differences between primary and secondary school teachers may be explained by variables associated with the teacher (e.g., level of training in managing behavioral problems), educational setting (e.g., number of responsible classes), and the student (e.g., age). Secondary school teachers with a more positive attitude towards ADHD were more likely to use CMSs for students with ADHD symptoms. Other teacher variables (i.e., teaching experience, knowledge about ADHD, teacher efficacy, level of training in managing behavioral problems) were not significantly related to the reported frequency of use of CMSs.

To gain more insight into the obstacles that teachers experience in teaching students with symptoms of ADHD, Chapter 6 examined teachers’ perceived barriers and their support needs. Almost half of teachers reported that large class sizes, class composition that includes multiple students with disabilities, and a lack of time are the main reasons for not using particular CMSs. Accordingly, teachers stated that smaller class sizes with fewer students with disabilities, a teaching assistant, and more time would help them to manage students with ADHD. In addition, about half of teachers indicated that they have a need for training in managing students with ADHD in the classroom and a smaller proportion reported that they would appreciate information in another form (e.g., literature). Some teachers remarked that they adapt their use of CMSs to the individual student and therefore do not use particular CMSs. Research recognizes the importance of tailoring interventions to the individual student (F. G. Miller & Lee, 2013). When asked about the support that teachers receive from school for managing students with ADHD, about one-fifth of teachers indicated that they do not experience any support from school at all. Most teachers, however, perceived that they receive support in form of individual action plans for students, collegial meetings, internal support from a coach, care team, or teaching assistant, the possibility to approach external professionals, or the opportunity to work on professional development.

The findings of Chapter 6 have important implications. There appears to be a discrepancy between teachers’ perceptions of effectiveness and the evidence base for effectiveness of classroom interventions for students with ADHD. This finding emphasizes the importance of providing
adequate teacher training. Current teacher trainings may be adapted as Chapter 6 indicates that the current level of training in managing behavioral problems is not significantly associated with the frequency of use of CMSs. These trainings may also focus on teachers’ attitudes towards ADHD. Teachers experience several barriers with regard to the use of particular CMSs, indicating that regular schools in the Netherlands may be facilitated insufficiently to recently changed policies to include students with special needs. Providing adequate teacher support therefore appears vital.

**METHODOLOGICAL ISSUES**

There are several issues with respect to the methodology of the (reviewed) studies. An important limitation of the chapters focusing on neuropsychology (Chapter 2 and 3) concerns the ecological validity of the tasks and rewards used in the reviewed studies. With regard to risk-taking, there seems to be a discrepancy between experimental and real-life findings, raising the question to which extent gambling task performance reflects risk-taking in daily life. Several studies have indicated that gambling task performance (e.g., Iowa Gambling Task, Probabilistic Discounting Task, and Balloon Analogue Risk Task) is associated with real-life risk-taking in adults (Buelow & Suhr, 2009; Lejuez et al., 2002; Petry, 2012; Takahashi et al., 2009). However, studies on this relationship in children and adolescents are, to our knowledge, still lacking. Concerning social reward sensitivity, studies operationalized a social reward as a symbolic representation of social reward. Because social interaction in real life is complex, the ecological validity of simple, static pictures representing social rewards can be disputed. For future research, therefore, the use of more ecologically valid social rewards (e.g., videos) is recommended. Strengths of the chapters on neuropsychology concern the research designs of the reviewed studies. The majority of studies included adequate, well-matched control groups and used standardized procedures. Moreover, most studies on social reward sensitivity used a non-reward (control) condition as comparison condition to the social reward condition.

Whereas the chapters about the neuropsychological studies may have difficulties with ecological validity and show strengths with regard to experimental control, the chapters on educational approaches (Chapter 5 and 6) show the opposite pattern. Most of the reviewed effectiveness studies were weak in methodological quality. For example, a substantial number of studies did not include a control group (applicable for WSD studies) or had difficulties with experimental control (applicable for SSD studies). The same is true for the survey study of Chapter 6. Although we included a control group of typically developing students, there was little experimental control and we solely relied on teachers’ self-report. On the other hand, these chapters show high ecological validity because most of the reviewed studies were performed in natural classroom settings and the survey study asked about teachers’ behavior in real life. Considering the importance of this topic, there is a need for high-quality studies on classroom interventions for students with ADHD.

Several limitations exist with regard to the included samples in the (reviewed) studies. Generally, the studies had small sample sizes. To increase the power to detect significant effects
and improve the reliability of the findings, larger sample sizes are recommended. Furthermore, the samples consisted mostly of males and rarely of females with ADHD. This is in line with previous observations that girls and women with ADHD are an understudied patient population. Future research on reward sensitivity in females with ADHD is important because ADHD in females, like ADHD in males, is associated with increased risk-taking in daily life and impairments in social and educational functioning (Kok et al., 2016; Quinn & Madhoo, 2014). However, the exact behavioral expressions and underlying mechanisms may be sex-specific. Another underexposed population group in this field is adolescents and adults with ADHD. Little research has been conducted on the effectiveness of classroom interventions for adolescents with ADHD, whereas the educational difficulties often persist in this age group (Barkley, 2015; Daley & Birchwood, 2010; Loe & Feldman, 2007). Furthermore, social reward sensitivity in ADHD is a relatively new field of research that is so far limited to studies in children with ADHD. Future research on social reward sensitivity, preferably longitudinally research, therefore could focus on children, adolescents as well as adults with ADHD. In addition, future research may provide more insight into the specific reward components that may be disrupted or intact in individuals with ADHD.

**CONCLUSION**

Although many studies on ADHD have been performed, a clear and comprehensive overview is often lacking despite the relevance of such an overview for the formulation of evidence-based recommendations for practice. This thesis therefore critically reviewed neuropsychological and educational aspects of reward sensitivity in individuals with ADHD and provides valuable insights. Research had already indicated that individuals with ADHD show an increased delay aversion and are more motivated by tangible rewards in comparison to healthy controls. In addition, this thesis suggests that the probability of rewards may also play a role, especially in children and adolescents with ADHD. Furthermore, this thesis provides the first preliminary evidence that children with ADHD may show an intact sensitivity or hypersensitivity to social rewards. This finding shed light on potential discriminating characteristics between ADHD and ASD.

With regard to the educational setting, reward-based interventions are one of the recommended interventions for students with ADHD. This thesis indicates that reward-based interventions are indeed beneficial for improving behavior of students with symptoms of ADHD. More specifically, they lead to large behavioral improvements in students with symptoms of ADHD and are more effective for reducing task-irrelevant behaviors than antecedent-based interventions. Although research has shown that students with ADHD show difficulties in educational functioning and teachers experience increased stress in teaching a student with ADHD, little was known about Dutch teachers’ classroom management of students with ADHD symptoms in school practice. This thesis provides important insights into Dutch teachers’ experiences with evidence-based classroom interventions for students with ADHD. For example, there appears to be a discrepancy between teachers’ perceived effectiveness and reported frequency of use of classroom interventions for
students with ADHD symptoms and the evidence base for effectiveness. These findings have important implications for the provision of adequate teacher support and highlights the importance of bridging the gap between science and practice.