Cognitive Control and Motivation in Children with ADHD

How Reinforcement Interacts with the Assessment and Training of Executive Functioning

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Faculteit der Maatschappij- en Gedragswetenschappen

Voor Daniëlle en Madelief

en voor mijn ouders

Contents

Chapter 1

General Introduction

Attention-deficit/hyperactivity disorder (ADHD) is a highly heritable neurodevelopmental disorder (Nikolas & Burt, 2010), which has been estimated to affect 2-9% of children worldwide (Skounti, Philalithis, & Galanakis, 2007). ADHD is characterized by age-inappropriate and impairing symptoms of hyperactivity, impulsivity, and/or inattentiveness (American Psychiatric Association, 2000; 2013). Children with ADHD are at high risk of experiencing negative long-term outcomes such as educational underachievement, occupational problems, financial difficulties, high accident/injury rates and difficulties sustaining social relationships (Barkley, Murphy, & Fisher, 2008). In this thesis we focus on the interaction between two neuropsychological processes that are proposed to play a pivotal role in explaining the problems children with ADHD encounter in daily life: executive functioning and motivation. Understanding these processes is crucial for early detection, adequate psycho-education, and effective treatment and disease management of ADHD.

1.1 Executive functioning

Many of the problems children with ADHD experience in daily life are thought to be the result of deficits in executive functioning (e.g., Barkley, 2006; Nigg, 2006). Via dorsal frontostriatal brain circuits, executive functions (EF) allow individuals to regulate their behavior, thoughts and emotions, and thereby enable self-control (Durston, van Belle, & de Zeeuw, 2011). Evidence indeed suggests that impairments in EF are related to deficits in attention, hyperactivity and impulsivity (e.g., Burgess, Depue, Ruzic, Willcutt, Du, & Banich, 2010; Crosbie et al., 2013; Kofler, Rapport, Bolden, Sarver, & Raiker, 2010; Raiker, Rapport, Kofler, & Sarver, 2012; Rapport, Bolden, Kofler, Sarver, Raiker, & Alderson, 2009; Tillman, Eninger, Forssman, & Bohlin, 2011), and with associated problems such as deficient academic functioning (Biederman et al., 2004; Titz & Karbach, 2014). Meta-analyses (e.g., Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005; Willcutt et al., 2012) demonstrate that children with ADHD show relatively strong impairments in executive functions such as behavioral inhibition, cognitive flexibility and working memory. Visuospatial working memory is considered most impaired in these children, and is described as the ability to maintain, control and manipulate goal-relevant visuospatial information (e.g., Martinussen et al., 2005). Working memory enables skills like reasoning, planning, problem solving, and goal-directed behavior (e.g., see Baddeley, 2007; Conway, Jarrold, Kane, Miyake, & Towse, 2007; Martinussen et al., 2005). Due to an impaired working memory a child has trouble remembering what (s)he was doing, thinking or saying, or to keep in mind what (s)he has to do to reach his or her current goal.

1.2 Motivation

Alternative theories suggest that motivational deficits are a core problem in ADHD (e.g., Haenlein & Caul, 1987; Sergeant, Oosterlaan, & Van der Meere, 1999; also see Sagvolden, Johansen, Aase, & Russell, 2005; Sonuga-Barke, 2003). These theories state that children with ADHD are less stimulated by reinforcement than typically developing children (possibly due to a dopaminergic deficit) and therefore, under normal conditions, are not motivated enough to function on the same level as their typically developing peers. Deficits in executive functioning are thought to be, at least partially, the result of this abnormal reinforcement sensitivity. In typical - mostly low stimulating - test conditions, children with ADHD would be unable to muster the required motivation to perform optimally on executive tasks, resulting in suboptimal EF performance (Sergeant et al., 1999). This is supported by the fact that not all studies find an executive dysfunction in children with ADHD (suggesting state dependency; e.g., see Luman, Oosterlaan, & Sergeant, 2005), and that executive deficits only have moderate sensitivity and specificity (e.g., Nigg, Willcutt, Doyle, & Sonuga-Barke, 2005). Moreover, a study by Slusarek, Velling, Bunk, and Eggers (2001) demonstrated that the abnormal performance of children with ADHD on a measure of behavioral inhibition – an executive function considered to constitute a core problem in ADHD (Barkley, 2006), normalized when these children were motivated with additional incentives. The finding that not an inhibitory deficit, but a motivational deficit was responsible for poor inhibition in these children, suggests that inhibition may not be a core deficit in ADHD and raises the question to what extent this is the case for the executive function that is considered most impaired in these children: visuospatial working memory. Therefore, in chapter 2 we investigate whether the divergent visuospatial working memory performance of children with ADHD (combined subtype; aged 9-12) is the result of deficits in their sensitivity to reinforcement.

1.3 Effects of Reinforcement by Gamification

In research and practice, different types of reinforcement are used to motivate children with ADHD. However, there are indications that a qualitatively different type of reinforcer, like *computer gaming* may influence the performance of children with ADHD differently than a monetary reinforcer. Making a task more attractive, and consistently dynamically stimulating, as is done in computer gaming, would make children with ADHD better able to persist in their performance over time (e.g., see Shaw, Grayson, & Lewis, 2005), while the relatively static presence of a monetary reinforcer may only improve the mean performance of children with ADHD, but have no effect on their performance over time (Solanto, Wender, & Bartell,

1997). In chapter 2 we made a direct comparison of these two types of reinforcement by examining their effects on mean performance and performance over time in children with ADHD (combined subtype; aged 9-12) on a visuospatial working memory task.

1.4 Components of Working Memory

According to Baddeley (2007; 2010) working memory is a multicomponent system consisting of two storage subsystems and a central executive. The storage subsystems – phonological and visuospatial short-term memory – are dedicated to the short-term storage of modality (phonological or visuospatial) specific information. The central executive is a mental control system with limited attentional resources that is responsible for supervising, controlling and manipulating information in the short-term memory systems. When the context (e.g., in daily life or during task performance) asks for changes in attentional demands, the central executive intervenes; e.g., by dividing, focusing or switching attention to relevant information or by reorganizing/updating information.

Given the relevance of working memory for the understanding of ADHD, interest in identifying which of the specific working memory components (short-term memory and/or the central executive) are impaired in children with ADHD, has increased in recent years. In their meta-analysis of working memory impairments in children with ADHD, Martinussen et al. (2005) found that children with ADHD were both impaired on tasks that measure short-term memory (the highest pooled effect size of difference between ADHD and normal controls, Cohen's d = .85, was found for visuospatial short-term memory) and tasks that measure working memory (the highest pooled effect size of difference between ADHD and normal controls, Cohen's d = 1.06, was found for visuospatial working memory). However, because working memory performance is inherently composed of both short-term memory and central executive performance, deficits in either or both the short-term memory and central executive of children with ADHD may account for their impairments on working memory measures (Nigg, 2006). To address this issue, Rapport, Alderson, Kofler, Sarver, Bolden, and Sims (2008) assessed the performance of children with and without ADHD on a phonological working memory task and a visuospatial working memory task, and used a latent variable approach to partial out task performance related to visuospatial short-term memory, phonological short-term memory and the central executive. This approach was based on the assumption derived from Baddeley's model (2003) that shared variance between the phonological and visuospatial working memory measures reflects the domain-general central executive. Using this approach, Rapport et al. found a deficit in all three working

memory components, including the central executive, in children with ADHD. This was also found in a more recent study by Alderson, Rapport, Hudec, Sarver, and Kofler (2010), which used a similar approach.

However, Rapport et al. (2008), Alderson et al. (2010), and earlier working memory studies (see Martinussen et al., 2005), did not control for the aforementioned motivational deficit in children with ADHD. The regular testing conditions which they used (i.e., without high levels of reinforcement), may therefore have resulted in sub-optimal working memory performance in children with ADHD, and in larger working memory performance differences between children with ADHD and typically developing children. Moreover, the impact of these motivational deficits on the different components of working memory (short-term memory and the central executive) in children with ADHD is unclear.

Nonetheless, there is some evidence that these components may be differentially influenced by the motivational deficits of these children. For example, Shiels et al. (2008) found that additional incentives could improve the visuospatial working memory performance of children with ADHD, but had no effect on their visuospatial short-term memory performance. This suggests that the motivational deficits of children with ADHD may specifically affect performance related to the central executive, without affecting visuospatial short-term memory performance. However, due to the lack of a typically developing control group, it could not be determined if this differential effect of incentives is specific for children with ADHD. If indeed the short-term memory and the central executive are differentially affected by the motivational deficits of children with ADHD, the methodology of partialling out these working memory components from general working memory measures by means of a latent variable approach (i.e., without using specific short-term memory or central executive measures), as used by e.g. Rapport et al. (2008) and Alderson et al. (2010), may not be sufficient to assess the different components of working memory in children with ADHD. In chapter 3 we examine the interplay between motivational deficits and the components of working memory in children with ADHD (combined subtype), by assessing effects of additional incentives on a visuospatial working memory task and a visuospatial short-term memory task in children with and without ADHD (aged 8-12).

1.5 Subtype Differences

The two most prevalent and valid diagnostic subtypes of ADHD are the combined subtype (ADHD-C; characterized by symptoms of hyperactivity, impulsivity, and inattentiveness) and the predominantly inattentive subtype (ADHD-I; characterized predominantly by symptoms

of inattentiveness; Gomez, Harvey, Quick, Scharer, & Harris, 1999; Willcutt et al., 2012; Wolraich, Hannah, Baumgaertel, & Feurer, 1998). The previous sections of this introduction focused mainly on children with ADHD-C. However, ADHD-I appears at least as prevalent as ADHD-C (Neuman et al., 2005), and although ADHD-C and ADHD-I are characterized by distinct patterns of symptomatic behavior, associated features and demographics (e.g. see Milich, Balentine, & Lynam, 2001), it is unclear whether these two subtypes have different underlying deficits with regard to motivation and the components of visuospatial working memory (Diamond, 2005; Willcutt et al., 2012). Nonetheless, a theoretical appraisal by Diamond (2005) suggests that children with ADHD-I may also have motivational deficits, which may interact with their cognitive functioning, and that they have a deficient central executive, but are not impaired in short-term memory related skills such as encoding or retrieving items from memory. Therefore, in chapter 4 we look beyond combined subtype ADHD by investigating the interplay between motivational processes and the components of visuospatial working memory in children with ADHD-I, ADHD-C (aged 9-12), and typically developing children.

1.6 Prevalence and Diagnostic Validity of Motivational- and Working Memory Impairments

Although impaired visuospatial working memory appears characteristic of children with ADHD on a group-level, recent findings suggest that ADHD is a neuropsychologically heterogeneous disorder that probably is not characterized by any single core dysfunction (Fair, Bathula, Nikolas, & Nigg, 2012; Nigg, Willcutt, Doyle, & Sonuga-Barke, 2005; Pineda, Puerta, Aguirre, Gracía-Barrera, & Kamphaus, 2007; Sonuga-Barke, Bitsakou, & Thompson, 2010). Given that not all children with ADHD meet criteria for an executive function deficit (e.g., Biederman et al., 2004; Fair et al., 2012; Lambek, Tannock, Dalsgaard, Trillingsgaard, Damm, & Thomsen, 2010; Nigg et al., 2005; Sonuga-Barke et al., 2010), it is likely that the visuospatial working memory deficits on group-level are carried by only a subset of children with ADHD (Fair et al., 2012). However, despite its obvious significance for assessment and treatment, only two studies (Holmes, Gathercole, Place, Alloway, Elliot, & Hilton, 2010; Lambek, Tannock, Dalsgaard, Trillingsgaard, Damm, & Thompson, 2011) have attempted to demarcate this working memory impaired subset within the ADHD population. These studies found visuospatial working memory impairments in 29-47% of the children with ADHD

(Lambek et al., 2011)[1], and an overall diagnostic hit rate (overall correct classification of children with and without ADHD) based on visuospatial working memory measures of about 75% (correctly identifying 84.3% of the children with ADHD and 58% of typically-developing children; Holmes et al., 2010). In addition, even less is known about the individual differences within the ADHD population on the components of visuospatial working memory: Only Holmes et al. investigated the diagnostic validity of a visuospatial short-term memory measure. They found this measure to be less accurate in discriminating between children with and without ADHD (correctly identifying 81.9% of the children with ADHD, but only 12% of TD children) than their measure of visuospatial working memory.

Moreover, the results of these prevalence- and diagnostic validity studies (Holmes et al, 2010; Lambek et al., 2011) may be confounded by the motivational deficits of children with ADHD. Both Holmes et al. and Lambek et al. used only regular reinforcement, which may have resulted in an overestimation of the prevalence and diagnostic validity of working memory and short-term memory impairments in their ADHD samples. Furthermore, the studies of Holmes et al. and Lambek et al. included both children with ADHD-C and ADHD-I, but did not differentiate between these subtypes. Therefore, their findings may be neither representative of children with ADHD-C, nor of children with ADHD-I.

Finally, the prevalence and diagnostic validity of abnormal reinforcement sensitivity in children with ADHD is largely unknown. No studies investigated the diagnostic validity of these motivational deficits in children with ADHD, and only one study (de Zeeuw, Weusten, van Dijk, van Belle, & Durston, 2012) investigated its prevalence. This study found that less than 8% of these children could be classified as having an abnormal sensitivity to reinforcement. However, de Zeeuw et al. used a small ADHD sample (n=26) which included all ADHD subtypes (obviously, subtype comparisons were not possible), and concluded that the low prevalence rate (e.g., prevalence in TD controls was 10%) was probably related to the high frequency of positive feedback that was applied during their motivation task (80% of the trials were rewarded), which may have attenuated the impact of the motivational deficits in their ADHD sample (de Zeeuw et al., 2012).

[1] Loo et al. (2007; in adolescents), Sjöwall, Roth, Lindqvist, and Thorell (2013), and Wåhlstedt, Thorell, and Bohlin (2009) generally find a somewhat lower prevalence of working memory deficits in ADHD than Lambek et al. (2011). However, this might be explained by the fact that these three studies only use a composite score of both visuospatial and phonological working memory measures (i.e., children with ADHD show more impairment on visuospatial working memory than on phonological working memory; Martinussen et al., 2005).

In chapter 5 we investigate the differences between ADHD subtypes in the prevalence and diagnostic validity of motivational deficits and impairments of visuospatial working memory and short-term memory.

1.7 Training EFs

Research suggests that EF-capacity and its associated levels of brain activity are not static, but may be altered by task-repetition or training (e.g., Klingberg, 2010). Therefore, in the past few years, EF training interventions aimed at ADHD symptom reduction have received considerable interest.

Nonetheless, these EF interventions have yielded mixed results, especially on ADHD behavior (for an overview see Chacko, Feirsen, Bedard, Marks, Uderman, & Chimiklis, 2013; Evans, Owens, & Bunford, 2013; Rapport, Orban, Kofler, & Friedman, 2013; Rutledge, van den Bos, McClure, & Schweitzer, 2012; Shipstead, Redick, & Engle, 2012; Toplak, Connors, Shuster, Knezevic, & Parks, 2008; in addition see Chacko et al., 2014; Egeland, Aarlien, & Saunes, 2013; Kray, Karbach, Haenig, & Freitag, 2012; although it falls outside the scope of the current thesis, for a study in younger children see van Dongen-Boomsma, Vollebregt, Buitelaar, & Slaats-Willemse, 2014). Generally, these interventions focus on training a single domain of cognitive functioning in children with ADHD, such as working memory (WM), inhibition, or cognitive flexibility. However, evidence suggests that most children with ADHD show deficits on multiple EFs (Fair et al., 2012), and that these EFs are largely related to different brain regions (e.g., McNab, Leroux, Strand, Thorell, Bergman, & Klingberg, 2008; Schecklmann et al., 2012; Smith, Taylor, Brammer, Toone, & Rubia, 2006). Therefore, training of multiple EFs might be a potentially more effective strategy to reduce EF related ADHD symptoms.

To date, evidence for multiple EF training interventions is limited. Few studies have investigated the effects of these interventions in children with ADHD (Halperin et al., 2012; Johnstone, Roodenrys, Phillips, Watt, & Mantz, 2010; Johnstone et al., 2012; van der Oord, Ponsioen, Geurts, Ten Brink, & Prins, 2012; Hoekzema et al., 2010; 2011), and although these studies generally show promising results (e.g., improvement of ADHD behavior as rated by parents and/or a significant other [e.g., the teacher]; an increase of neural activity and gray matter volume in ADHD affected brain areas), none of these studies are placebo-controlled, and most are underpowered (mean n = 16).

Furthermore, the elevated need for reinforcement in children with ADHD (e.g., Haenlein & Caul, 1987; Sergeant et al., 1999) may result in motivational problems during EF

training: the child has to repeat the same responses over and over again for many trials, making most EF training programs tedious and boring for children with ADHD (Prins et al., 2013). These motivational problems may have a negative impact on the treatment effects of EF training in children with ADHD (e.g., due to lower treatment compliance, decreased attention during training, or less active training-time). However, there is some evidence that gamification of a cognitive task (e.g., using game mechanics and visuals) can optimize both the motivation (e.g., time on task) and performance of children with ADHD (e.g., Lawrence, Houghton, Tannock, Douglas, Durkin, & Whiting, 2002; Ota & DuPaul, 2002; Shaw et al., 2005; Shaw & Lewis, 2005). Gaming increases the release of striatal dopamine (Koepp et al., 1998; Kühn et al., 2011), promoting long-term potentiation of neural connections within the striatum (Reynolds, Hyland, & Wickens, 2001), which is suggested to improve motivation to continue performing and one's ability to learn (Gray, 2010). This may suggest that gamification of an EF training can improve the motivation and performance of children with ADHD during training, and may enhance the trainings' efficacy (i.e. one's ability to learn from the training).

Therefore, in chapter 6 the effects of adding game elements to a standard computerized working memory training are investigated. We examine whether gamification enhances motivation and training performance in children with ADHD (aged 7-12; no specific ADHD subtype was selected), and if it improves training efficacy. Subsequently, in chapter 7, we present a double-blind, placebo-controlled study, which investigates the near- and far transfer effects (e.g., on ADHD behavior) of a gamified training intervention (Braingame Brian; Prins et al., 2013) that targets multiple EFs in children with ADHD (combined-subtype; aged 8-12). A previous waitlist-controlled study of Braingame Brian showed promising results on reduction of symptoms of ADHD and improvement of EF (see van der Oord et al., 2012). Braingame Brian targets multiple EFs that are commonly impaired in children with ADHD: visuospatial working memory, response inhibition, and cognitive flexibility (e.g., Willcutt et al., 2012).

1.8 Outline

The main aim of this doctoral thesis is to gain insight into the effects of reinforcement on the assessment and training of executive functioning in children with ADHD. This is investigated in six empirical chapters.

In **chapter 2** we examine whether the divergent visuospatial working memory performance of children with ADHD-C is the result of deficits in their sensitivity to

reinforcement. To this end, a visuospatial working memory task is administered to children with ADHD-C and typically developing children (aged 9-12), in four reinforcement conditions: feedback-only, feedback + 1 euro, feedback + 10 euros, and a computer-game version of the task.

In **chapter 3** we investigate the interplay between motivational processes and the components of visuospatial working memory in children with ADHD-C. This is done by examining the effects of a standard (feedback-only) and a high level of reinforcement (feedback + 10 euros) on a visuospatial working memory task and a visuospatial short-term memory task in children with ADHD-C and typically developing children (aged 8-12). In **chapter 4** we look beyond combined subtype ADHD, by investigating this interplay between motivational processes and components of visuospatial working memory in children with ADHD-I, ADHD-C, and typically developing children (aged 9-12), using the same study design as in chapter 3.

Although chapter 4 primarily focusses on differences *between* ADHD subtypes, there is also evidence for heterogeneity *within* these subtypes (e.g., Fair et al., 2012; Sonuga-Barke et al., 2010). Therefore, **in chapter 5** we specify the subgroups within these ADHD subtypes based on their cognitive (i.e., visuospatial working memory and short-term memory) and motivational impairments. We investigate the prevalence and diagnostic validity of impairments in visuospatial working memory, visuospatial short-term memory, and reinforcement sensitivity in children with ADHD-C and ADHD-I. Typically developing controls are used as reference group (i.e., children with ADHD were characterized as impaired if they scored below the 10% worst scoring controls). For this study we use the dataset from the studies described in chapters 3 and 4.

In **chapter 6** the effects of adding game elements to a standard computerized working memory training are investigated. We examine whether gamification enhances motivation and training performance in children with ADHD (aged 7-12; no specific ADHD subtype was selected), and if it improves training efficacy. Subsequently, in **chapter 7**, we present a double-blind, placebo-controlled study, which investigates the near- and far transfer effects (e.g., on ADHD behavior) of a gamified training intervention (Braingame Brian; Prins et al., 2013) that targets multiple EFs (visuospatial working memory, response inhibition, and cognitive flexibility) in children with ADHD-C (aged 8-12).

Finally, **chapter 8** provides a summary of the six empirical chapters, followed by a general discussion and the clinical implications of our findings. We conclude with directions for future research.

Chapter 2

Can motivation normalize working memory and task persistence in children with Attention Deficit/Hyperactivity Disorder?

The effects of money and computer gaming

This chapter is based on:

Dovis, S., Van der Oord, S., Wiers, R.W., & Prins, P.J.M. (2012). Can motivation normalize working memory and task persistence in children with Attention Deficit/Hyperactivity Disorder? The effects of money and computer gaming. *Journal of Abnormal Child Psychology, 40* (5), 669-681.

Abstract

Visual-spatial *Working Memory* (WM) is the most impaired executive function in children with Attention-Deficit/Hyperactivity Disorder (ADHD). Some suggest that deficits in executive functioning are caused by motivational deficits. However, there are no studies that investigate the effects of motivation on the visual-spatial WM of children with- and without ADHD. Studies examining this in executive functions other than WM, show inconsistent results. These inconsistencies may be related to differences in the reinforcement used. **Methods:** The effects of different reinforcers on WM performance were investigated in 30 children with ADHD and 31 non-ADHD controls. A visual-spatial WM task was administered in four reinforcement conditions: Feedback-only, 1 euro, 10 euros, and a computer-game version of the task. **Results:** In the Feedback-only condition, children with ADHD performed worse on the WM measure than controls. Although incentives significantly improved the WM performance of children with ADHD, even the strongest incentives (10 euros and Gaming) were unable to normalize their performance. Feedback-only provided sufficient reinforcement for controls to reach optimal performance, while children with ADHD required extra reinforcement. Only children with ADHD showed a decrease in performance over time. Importantly, the strongest incentives (10 euros and Gaming) normalized persistence of performance in these children, whereas 1 euro had no such effect. **Conclusions:** Both executive and motivational deficits give rise to visual-spatial WM deficits in ADHD. Problems with task-persistence in ADHD result from motivational deficits. In ADHD-reinforcement studies and clinical practice (e.g., assessment), reinforcement intensity can be a confounding factor and should be taken into account. Gaming can be a cost-effective way to maximize performance in ADHD.

2.1 Introduction

Many of the problems children with ADHD experience in daily life are thought to be the result of deficits in executive functioning (e.g., Nigg, 2006). Executive functions allow individuals to regulate their behavior, thoughts and emotions, and thereby enable self-control. Meta-analyses (e.g., Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005) demonstrate that children with ADHD show relatively strong impairments in two executive functions: behavioral inhibition and Working Memory (WM). Visual-spatial WM is considered most impaired in these children, and is described as the ability to maintain and manipulate/reorganize visual-spatial information (e.g., Martinussen et al., 2005). Due to an impaired WM a child has trouble remembering what (s)he was doing or what (s)he has to do to reach his or her current goal.

Alternative theories suggest that motivational deficits are a core problem in ADHD (e.g., Haenlein & Caul, 1987; Sergeant, Oosterlaan, & Van der Meere, 1999). These theories state that children with ADHD are less stimulated by reinforcement than typically developing children (possibly due to a dopaminergic deficit) and therefore, under normal conditions, are not motivated enough to function on a normal level. Deficits in executive functioning are thought to be the result of this abnormal reinforcement sensitivity. In typical - mostly low stimulating - test conditions, children with ADHD would be unable to muster the required motivation to perform optimally on executive tasks, resulting in underperformance (Sergeant et al., 1999). This is supported by the fact that not all studies find an executive dysfunction in children with ADHD (suggesting state dependency; e.g., see Luman, Oosterlaan, & Sergeant, 2005), and that executive deficits only have moderate sensitivity and specificity (Nigg, Willcutt, Doyle, & Sonuga-Barke, 2005). Moreover, a study by Slusarek, Velling, Bunk, and Eggers (2001) demonstrated that the abnormal performance of children with ADHD on a measure of behavioral inhibition – an executive function considered to constitute a core problem in ADHD (Barkley, 2006), normalized when these children were motivated with extra incentives. The finding that not an inhibitory deficit, but aberrant motivation was responsible for poor inhibition in these children, suggests that inhibition may not be a core deficit in ADHD and raises the question to what extent this is the case for the executive function that is considered most impaired in these children: visual-spatial WM.

Only one study has looked at the impact of reinforcement on the visual-spatial WM performance of children with ADHD (Shiels et al., 2008). This study showed that the performance of children with ADHD on a visual-spatial WM task without feedback, improved when feedback and incentives were added. However, due to the lack of a typically

developing control group, it could not be determined whether this reaction to reinforcement is specific for children with ADHD, nor whether their WM performance could be normalized by reinforcement.

When investigating the impact of reinforcement on WM in children with ADHD, it may be important to control for the intensity and form of the reinforcement, since reinforcement studies that investigated the impact of reinforcement on cognitive functions other than WM, have yielded inconsistent results: Only half of these studies reported an abnormal response to reinforcement in children with ADHD (see Carlson & Tamm, 2000; Crone, Jennings, & Van der Molen, 2003; Douglas & Parry, 1994; Geurts, Luman, & van Meel, 2008; Kohls, Herpertz-Dahlmann, & Konrad, 2009; Konrad, Gauggel, Manz, & Scholl, 2000; McInerny & Kerns, 2003; Rapport, Tucker, DuPaul, Merlo, & Stoner, 1986; Shaw, Grayson & Lewis, 2005; Slusarek et al., 2001; Tripp & Alsop, 1999, 2001), whereas the rest of these studies found that children with ADHD responded similarly to reinforcement as typically developing children (see Barber, Milich, & Welsch, 1996; Carlson, Mann, & Alexander, 2000; Demurie, Roeyers, Baeyens, & Sonuga-Barke, 2011; Iaboni, Douglas, & Baker, 1995; Iaboni, Douglas, & Ditto, 1997; Luman, Oosterlaan, & Sergeant, 2008; Luman, Van Meel, Oosterlaan, Sergeant, & Geurts, 2009; Michel, Kerns & Mateer, 2005; Oosterlaan & Sergeant, 1998; Scheres, Oosterlaan, & Sergeant, 2001; Shanahan, Pennington, & Willcutt, 2008; Solanto, 1990; Van der Meere, Hughes, Börger, & Sallee, 1995; for a review see Luman et al., 2005). These inconsistencies may be related to the heterogeneity in intensity and form of the reinforcers used (Luman et al., 2005). Reinforcement studies differ in the form (e.g., money, presents, points, computer gaming) and intensity of reinforcement (e.g., 5ct, 25ct, 1 point, 100 points) they used. These differences may have produced inconsistent results because of the assumed *elevated reward threshold* in children with ADHD: According to Haenlein and Caul (1987) children with ADHD could reach optimal or even normal performance, but require much higher levels of reinforcement to reach this than typically developing children. Haenlein & Caul therefore suggest that the response to reinforcement of children with ADHD may only be distinguishable (abnormal) from that of typically developing children when certain (e.g., high) levels of reinforcement are compared (e.g., when at least one of the levels of reinforcement that are compared is above the reward threshold of typically developing children), but not when other (e.g., low to moderate) levels are compared (*see* Haenlein & Caul, 1987; Slusarek et al., 2001).

Few studies have investigated the impact of the intensity and form of reinforcement on the performance of children with ADHD (Demurie et al., 2011; Kohls et al., 2009; Luman et

al., 2008, 2009; Slusareck et al., 2001). Only Slusareck et al. (2001) examined the impact of different intensities of reinforcement on executive performance, but only regarding inhibition, not WM. Furthermore, apart from the studies that have compared feedback-only with an incentive condition, only Kohls et al. (2009) compared the impact of different forms of reinforcement on executive performance between children with- and without ADHD. They found that children with ADHD showed an abnormal response to reinforcement on executive performance during a social reward condition, but not during a monetary reward condition. However, Kohls et al. did not account for the variation in reinforcement intensity. It is therefore possible that the reinforcement intensity of the monetary reward condition was not high enough (i.e. below the reward threshold of typically developing children) to detect an abnormal response in children with ADHD (*see* also Demurie et al., 2011). Furthermore, Kohls et al. examined inhibition, not WM.

There are indications that a qualitatively different type of reinforcer, like *computer gaming* may influence the performance of children with ADHD differently than a monetary reinforcer. Making a task more attractive, and consistently dynamically stimulating, as is done in computer gaming, would make children with ADHD better able to persist in their performance over time (e.g., see Shaw et al., 2005), while the relatively static presence of a monetary reinforcer may only improve the mean performance of children with ADHD, but have no effect on their performance over time (Solanto, Wender, & Bartell, 1997). However, a direct comparison of these reinforcers and their effects on the performance over time of children with ADHD has never been made.

In this study we investigated the effects of different intensities and forms of reinforcement on the visual-spatial WM performance of children with- and without ADHD. We investigated whether (1) divergent WM performance of children with ADHD is the result of an abnormal sensitivity to reinforcement, (2) finding an abnormal sensitivity to reinforcement is dependent on the intensity or the form of the reinforcement, (3) improvement of the persistence of performance over time in children with ADHD is related to a specific intensity or form of reinforcement.

We compared the performance of children with- and without ADHD on a visual-spatial WM task in four reinforcement conditions: Feedback-only, feedback and a small monetary incentive (1 euro), feedback and a large monetary incentive (10 euros), and a computer game version of the task. We expected that, in the Feedback-only condition, children with ADHD would perform worse on the WM task compared to children without ADHD (Martinussen et al., 2005), that the difference in performance between children with-

and without ADHD would be smaller in the incentive conditions (1 euro, 10 euros, and game) than in the Feedback-only condition (Sergeant et al., 1999), and that this difference would disappear in the high incentive condition (10 euros; Heanlein & Caul, 1987; Slusarek et al., 2001). Finally, we expected that although the mean WM performance of children with ADHD would improve in all incentive conditions, only gaming would improve the persistence of performance over time in these children (Shaw et al., 2005; Solanto et al., 1997).

2.2 Method

Participants

Sixty-one children aged 9 to 12 years participated: 30 children with a diagnosis of ADHD combined-type, and 31 control children. Children with ADHD were recruited from outpatient mental-healthcare centers, controls through elementary schools.

Children met the following criteria:

For both groups. (a) an IQ score ≥80 established by the short version of the Dutch Wechsler Intelligence Scale for Children (WISC-III; Kort et al., 2002). Two subtests, Vocabulary and Block Design were administered to estimate Full Scale IQ (FSIQ). This composite score has satisfactory reliability (r =0.91) and correlates highly with FSIQ (r = 0.86; Sattler, 2001), (b) absence of any neurological disorder, sensory (color blindness and vision) or motor impairment as stated by the parents, (c) not taking any medication other than methylphenidate.

For the ADHD group. (a) a prior DSM-IV-TR (American Psychiatric Association, 2000) diagnosis of ADHD combined-type by a child psychologist or psychiatrist, (b) a score within the clinical range (95^{th} to 100^{th} percentile) on the ADHD scales of both the parent and teacher version of the Disruptive Behavior Disorder Rating Scale (DBDRS; Pelham, Gnagy, Greenslade, & Milich, 1992; Dutch translation Oosterlaan, Scheres, Antrop, Roeyers, & Sergeant, 2000). The DBDRS contains four scales composed of the DSM-IV items for ADHD Inattentive subtype, ADHD hyperactive/Impulsive subtype, Oppositional Defiant Disorder (ODD), and Conduct Disorder (CD). Adequate psychometric properties have been reported (Oosterlaan et al., 2000), (c) meeting criteria for ADHD combined-type on the ADHD section of the Diagnostic Interview Schedule for Children, parent version (PDISC-IV; Shaffer, Fisher, Lucas, Dulcan, & Schwab-Stone, 2000). The PDISC-IV is a structured diagnostic interview based on the DSM-IV, with adequate psychometric properties, (d) absence of CD based on the CD sections of the PDISC-IV and (e) absence of a prior DSM-IV-TR diagnosis of any autism spectrum disorder (ASD) according to a child psychologist or psychiatrist.

For the control group. (a) a score within the normal range (<80th percentile) on the ADHD, ODD and CD scales of both the parent and teacher version of the DBDRS, (b) absence of a prior DSM-IV-TR diagnosis of ASD or any other psychiatric disorder as stated by the parents.

Groups did not differ with respect to gender, age, IQ, amount of money to spend per week, computergame experience, and Dyslexia (*see* Table 1). Twenty-four children in the ADHD group were on Methylphenidate, but discontinued medication at least 24 hours before each session, allowing a complete wash-out (Greenhill, 1998).

Table 1

Means and standard deviations of group demographics and characteristics

Measure	Group					
	ADHD		Controls			
	(n=30)		(n=31)			
	M	SD	M	SD	F / χ^2	*p*
Gender (M : F)	23 : 7	-	18 : 13	-	2.39	.12
Age (years)	11.0	1.2	11.0	1.1	.00	1.0
FSIQ	103	19.4	111	19.7	2.90	.09
DBDRS parent						
Inattention	19.5	3.4	2.9	2.7	444.3	<.001
Hyperactivity/Impulsivity	16.8	3.8	2.4	2.5	309.5	<.001
ODD	11.5	3.6	2.0	2.0	165.7	<.001
CD	2.0	2.1	.2	.5	22.1	<.001
DBDRS teacher						
Inattention	15.0	5.9	1.4	2.3	119.2	<.001
Hyperactivity/Impulsivity	12.1	7.7	1.3	1.9	48.1	<.001
ODD	7.0	3.4	.6	.9	84.2	<.001
CD	1.13	1.6	.1	.3	11.7	.001
Weekly spendable income (in euros)	2.0	1.1	2.4	1.8	1.16	.29
Computergame experience (hours per week)	4.9	3.9	4.4	2.9	.34	.56
Dyslexia (Yes : No)	6 : 24	-	2 : 28	-	2.46	.12

Note. ADHD = attention-deficit/hyperactivity disorder; CD = conduct disorder; DBDRS = Disruptive Behavior Disorder Rating Scale; FSIQ = full scale IQ; M:F = Male:Female; ODD = oppositional defiant disorder.

Procedure

The study was approved by the IRB of the University and consisted of an intake session and two consecutive test sessions. After obtaining written informed consent, the parents and teacher of the child were asked to complete the DBDRS. For the ADHD sample: if a child met the inclusion criteria of the DBDRS, child and parents were invited to the intake session. For the control sample: If the child met the DBDRS inclusion criteria, the child was invited to the intake session. During this session the WISC-III subtests and three additional tests that were part of another study were administered, and the parents of the ADHD sample were interviewed with the PDISC-IV. If the child met the inclusion criteria (s)he was invited to take part in the two test sessions. These 60 minute sessions were spaced one week apart and were scheduled on the same (part of the) day.

During each test session, two of the four reinforcement conditions (Feedback-only, 1 euro, 10 euros and gaming) of the WM task (*see* below) were administered, intermitted by a 5 minute break. To control for order effects, the sequence in which the four reinforcement conditions were presented was counterbalanced across participants (using every possible combination of orders). To control for expectancy effects (e.g., the expectation to receive money while performing the FO condition) parents and children received no information about the reinforcement conditions before testing. Children with ADHD were tested at their mental-healthcare center, controls at their school. Testing took place between 9 a.m. and 5 p.m. Test rooms were quiet and views from windows were blocked. Specific reinforcement instructions (e.g., '*If you perform well enough on this task you will get these 10 euros*') were given to the child at the start of each reinforcement condition. During testing one experimenter was present, sitting behind the child pretending to read a book.

The WM Task

The Chessboard Task[2] is a newly developed WM performance measure based on two WM tasks; the Corsi Block Tapping Task (Corsi, 1972) and the subtest Letter-Number Sequencing from the Wechsler Adult Intelligence Scale (WAIS; Wechsler, 1958). The task, described in Figure 1, assesses the ability to both maintain and manipulate/reorganize visual-spatial information that is relevant for the task at hand. To make it easier to remember the instructions during the task a brief instruction ('first press green, then press blue, both in the same order as they were presented') was continuously visible in the corner of the screen. To

[2] For further information on the task contact the first author

ensure that every presented sequence had to be reorganized (engaging the central executive), the order of stimuli was random with the restriction that in every sequence at least one blue stimulus was presented before the last green stimulus. To ensure optimal attention of the participant during each trial, the task was self-paced (the participant had to click to start a trial). Every square that lit up was presented with the same brief tone. To prevent the use of strategies (e.g., positioning the mouse-cursor on one of the squares in the sequence to unburden WM) the mouse-cursor was not visible during sequence presentation. The difficulty level of the task was adaptive; the first sequence consisted of two stimuli and after two consecutive correct reproductions, the sequence was increased by one stimulus. After two consecutive incorrect reproductions, the sequence was shortened by one stimulus. The minimum sequence length consisted of two stimuli and there was no maximum sequence length. Because the difficulty level adapted to individual performance, the amount of positive and negative feedback received, was approximately the same (55% reward, 45% response-cost) for every child and in every condition.

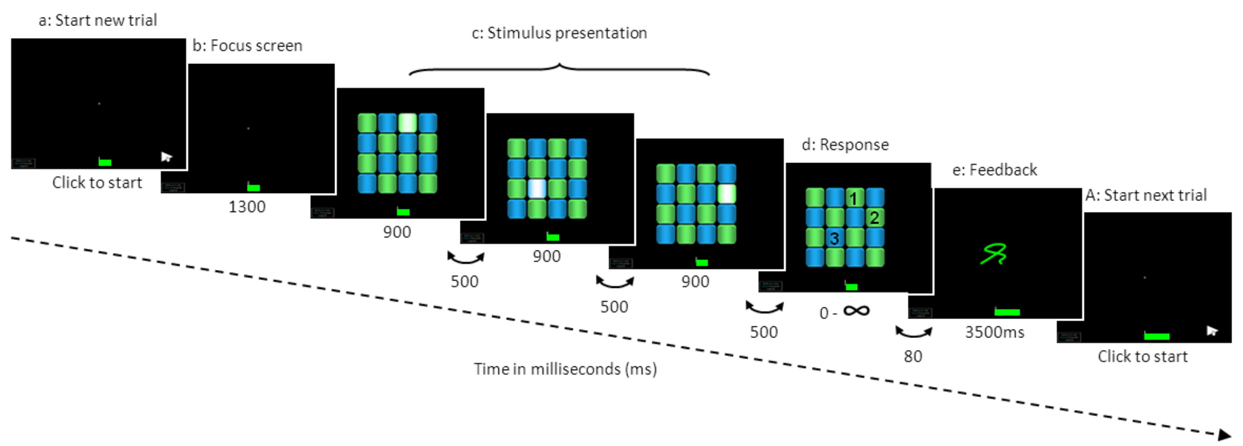

Fig. 1 A trial on the Chessboardtask. (a) To start a trial the arrowhead-button in the bottom-right corner of the screen has to be clicked. (b) Then the focus screen (a black screen with a little white cross) is presented. (c) Subsequently, a sequence of stimuli (squares that light up) is presented one by one on a 4x4 grid with green and blue squares ordered in a chessboard formation. Each stimulus lights up for 900ms and is followed by an inter-stimulus interval of 500ms. (d) After the stimulus-sequence is presented the participant responds by mouse-clicking on the squares. To respond correctly the presented stimuli have to be reproduced in a reorganized way: The green stimuli have to be reproduced before the blue stimuli; both in the same order as presented (the numbers in picture d show an example of a correct reorganization). (e) After a response feedback is presented. (A) After feedback-presentation, the participant can start the next trial by clicking on the arrowhead button

In every reinforcement condition, the task started with a practice block (of 5 trials) followed by one experimental block of 60 trials (which took about 20 minutes to complete). The parameters of the task (described above and in Figure 1) were the same in every reinforcement condition. In the feedback-only (FO) condition, children were instructed to do their best and respond as accurately as possible. They were told that when the task was finished, a purple screen would appear. In the 1 euro and 10 euros condition children were told that they could earn 1 or 10 euros (depending on condition) if they performed well enough on the task. Then, the euro coin(s) they could earn were shown and placed in sight above the laptop keyboard (and remained there during the entire task). The child was told that the euro(s) could only be gained when (s)he made enough correct responses and not too many incorrect responses. The child was told that the computer randomly decided the required amount of correct and incorrect responses. The child was told that when enough correct responses were made, the task would immediately end with a green screen indicating that the euro(s) were won, but that when too many incorrect responses were made, the task would immediately end with a red screen indicating that the euro(s) were lost (for verbatim instructions see Appendix). Although participants were made to believe that their immediate performance directly influenced their chance of winning the euro(s) and that every incorrect or correct response could immediately end the task with a red or a green screen, in reality the task always ended after 60 trials and with the green screen and thus participants always received the money. In both the FO condition and the monetary conditions, participants could monitor their overall and immediate performance by means of a 'performance bar' and visual feedback. The performance bar was always visible at the bottom of the screen (*see* Figure 1). In the FO and the monetary conditions, feedback consisted of the same sounds (a positive guitar sound for correct trials and a negative buzzer sound for incorrect trials), the same distance of adaptation of the performance bar, and of comparable pictures (*see* Figure 2A).

In the game condition the WM-task was presented in the context of a computer-game. Game elements were added, such as varied and stimulating animation, gameplay, storylines, upgrades and competition. In this game the child had to save the world by using his or her Megabot (a big battle-robot) to conquer the various robot-enemy occupied levels. Levels could be conquered by destroying all occupying enemy-robots, without taking too much damage. To destroy an enemy-robot, complete an objective (rewards), or protect his or her Megabot from being damaged (response-cost) the child had to correctly reorganize the WM-task sequence that was presented (sequence presentation and type of feedback [e.g., immediate and consistent] was the same as in the other conditions; *see* Figure 2B). With each

level completion the child got higher in rank, and received upgrades (e.g., stronger armor). After 60 trials a screen was presented that indicated that the enemies surrendered, the player had won the game, and the game was over.

Dependent Measures

Because the first 12 trials on the WM-task were needed to reach the child's optimal difficulty level, these trials were excluded from analysis. [3] WM performance in every reinforcement condition was measured by the mean sequence length of the last 48 trials. To study task performance over time, we divided the trials into three parts: early performance (mean sequence length on trials 13-20), middle performance (mean sequence length on trials 21-40) and later performance (mean sequence length on trials 41-60). [4]

[3] The task started at a very easy level (a sequence of two stimuli), and because the tasks difficulty level adapts gradually (see above), children typically needed the first 12 trials to reach their optimal difficulty level (a sequence length higher than 5 or 6 stimuli). Since the mean of these first 12 trials gave no relevant information on individual performance, and inclusion of these trials resulted in a more inaccurate representation of participant's wm capacity, these first trials were excluded from analysis (results did not change when the first 12 trials were included).

[4] To prevent losing too much power it was necessary to divide the 60 trials into a maximum of 4 blocks. Inspection of a detailed graph of performance over time (with 12 blocks of 5 trials), showed that dividing the task into 3 blocks of 20 trials gave the most accurate depiction of performance over time. The first 12 trials were again excluded from analysis because: (1) footnote 3, (2) to make the mean sequence length of the first trial block comparable with the mean sequence length of the other two trial blocks (results did not change when the 12 trials were included).

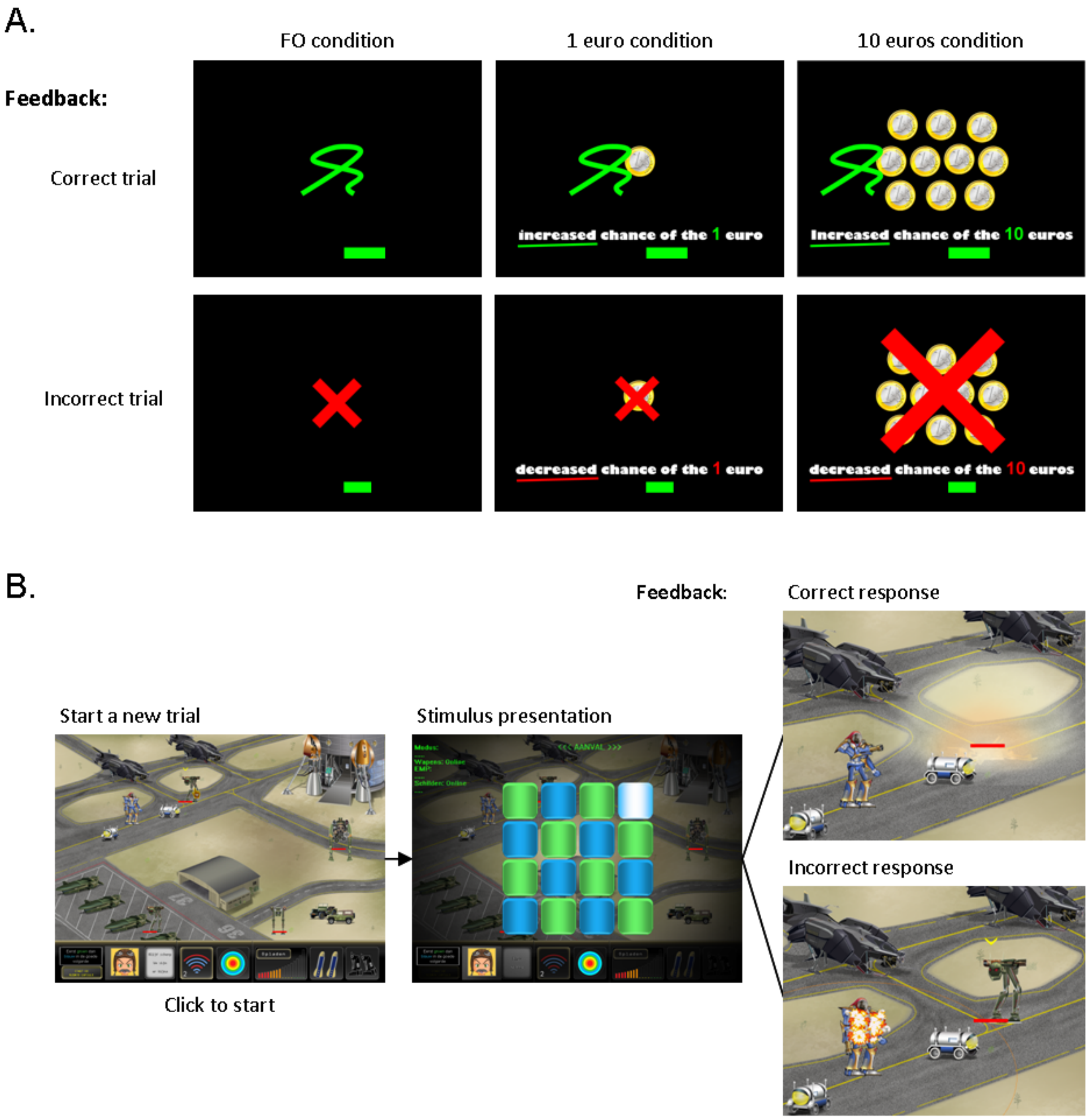

Fig. 2 A: Visual feedback in the Feedback-Only (FO) and monetary conditions **B:** A trial in the game condition. The Megabot stands on the left, the enemies to the right

Data Analysis

The dependent measures were subjected to separate repeated-measures ANOVAs with group (ADHD/control) as between-subject factor and reinforcement condition (FO, 1 euro, 10 euros and gaming) and time on task (early, middle and later performance) as within-subject factors. Partial Eta squared effect sizes are reported (η_p^2).

2.3 Results

Counterbalancing

Order effects were controlled for by counterbalancing the sequence in which the reinforcement conditions were presented. There were no significant differences between the two groups in the number of times the reinforcement conditions (FO, 1 euro, 10 euros and game) were administered first ($\chi^2(3) = .05$, $p = .997$), second ($\chi^2(3) = .05$, $p = .997$), third ($\chi^2(3) = .18$, $p = .981$) or last ($\chi^2(3) = .05$, $p = .997$).

Mean WM Performance

A 2x4 (group x reinforcement conditions) repeated-measures ANOVA with mean sequence length as dependent variable, showed a main effect of reinforcement condition, F (3,177) = 7.74, $p < .001$, $\eta_p^2 = .12$, a main group-effect, F (1,59) = 13.87, $p < .001$, $\eta_p^2 = .19$, and a significant interaction between reinforcement condition and group, F (3,177) = 3.69, $p = .01$, $\eta_p^2 = .06$ (*see* Figure 3). To interpret this interaction, we used simple contrasts for the reinforcement effect. Compared to the FO condition, the difference in performance between the ADHD and control children was smaller when incentives were used; 1 euro, F (1,59) = 4.70, $p = .034$, $\eta_p^2 = .07$, 10 euros, F (1,59) = 9.85, $p = .003$, $\eta_p^2 = .14$, and gaming, F (1,59) = 4.34, $p = .040$, $\eta_p^2 = .07$. Other pair-wise differences in group effects were non-significant.

Differences between reinforcement conditions within each group were tested with paired t-tests. Compared to FO, incentives significantly improved the mean performance of children with ADHD (FO < 1 euro, t (29) = -2.86, $p = .008$; FO < 10 euros, t (29) = -3.98, $p < .001$; FO < game, t (29) = -3.45, $p = .002$), but not of controls (FO = 1 euro, t (30) = -.41, $p = .682$; FO = 10 euros, t (30) = -.37, $p = .711$; FO = game, t (30) = -1.92, $p = .070$). Differences between the incentive conditions were non-significant in both children with ADHD and controls.

Performance differences between the ADHD and control children in each reinforcement condition were tested in a multivariate analysis. Children with ADHD showed lower mean performance in the FO (F (1,59) = 19.57, $p < .001$, $\eta_p^2 = .25$), 1 euro (F (1,59) = 11.55, $p = .001$, $\eta_p^2 = .16$), 10 euros (F (1,59) = 6.11, $p = .016$, $\eta_p^2 = .09$) and game condition (F (1,59) = 9.35, $p = .003$, $\eta_p^2 = .14$), compared to controls. Even the mean performance of children with ADHD in the highest incentive conditions (10 euros and game) was significantly lower than the mean performance of controls in the FO condition (10 euros ADHD vs. FO Controls, F (1,59) = 5.99, $p = .017$, $\eta_p^2 = .09$; Game ADHD vs. FO Controls, F (1,59) = 5.93, $p = .018$, $\eta_p^2 = .09$) (*see* Figure 3).

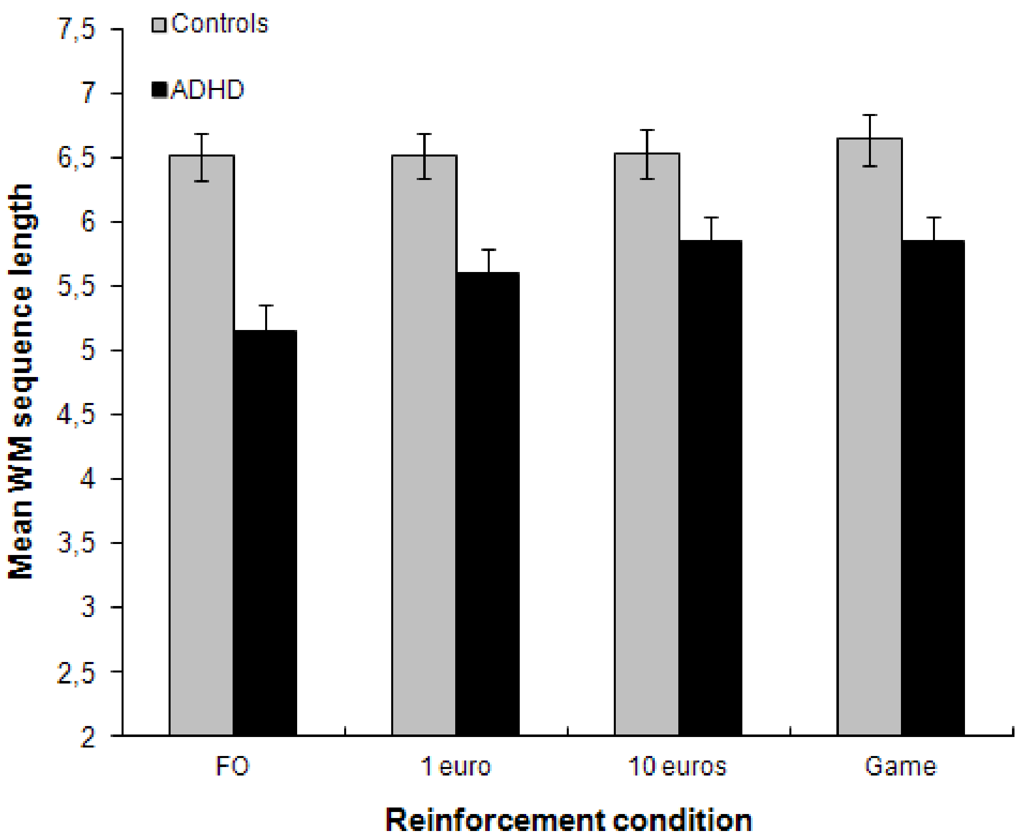

Fig. 3 Mean performance of children with ADHD and control children on the visual-spatial working memory (WM) task in the Feedback-only (FO), 1 euro, 10 euros, and Game condition

Time on Task

For the ADHD group, a 3x4 (time on task x reinforcement conditions) repeated-measures ANOVA showed a main effect of reinforcement condition, F (3,87) = 6.14, p = .001, η_p^2 = .18, a main effect of time on task, where performance decreased with time, F (2,58) = 3.47, p = .038, η_p^2 = .11, and a significant interaction between reinforcement and time on task, F (6,174) = 2.72, p = .015, η_p^2 = .09 (Figure 4, left hand panel). In order to interpret this interaction, we used linear contrasts for the time on task effect and simple contrasts for the reinforcement effect. In this way we examined whether the linear decrease in performance due to time on task differed between the reinforcement conditions. As compared to the FO condition, the linear decrease in performance was significantly less in the game condition, F (1,29) = 8.80, p = .006, η_p^2 = .23, and in the 10 euros condition, F (1,29) = 7.49, p = .010, η_p^2 = .21, but not in the 1 euro condition, F (1,29) = .44, p = .511, η_p^2 = .02. Other pair-wise condition differences in time on task effects were non-significant, except that the linear decrease in performance was less pronounced in the 10 euros condition as compared to the 1

euro condition, F (1,29) = 4.31, p = .047, η_p^2 = .13. These results indicate that only strong incentives (10 euros and gaming) can reduce time on task effects in the ADHD sample.

This effect of reinforcement intensity on time on task was not observed in control children. In this group, a 3x4 (time on task x reinforcement conditions) repeated-measures ANOVA showed no main effect of reinforcement condition, F (3,90) = 1.16, p = .330, η_p^2 = .04, no main effect of time on task, F (2,60) = 1.17, p = .317, η_p^2 = .04, and no significant interaction between reinforcement and time on task, F (6,180) = .15, p = .989, η_p^2 = .005 (Figure 4, right hand panel).

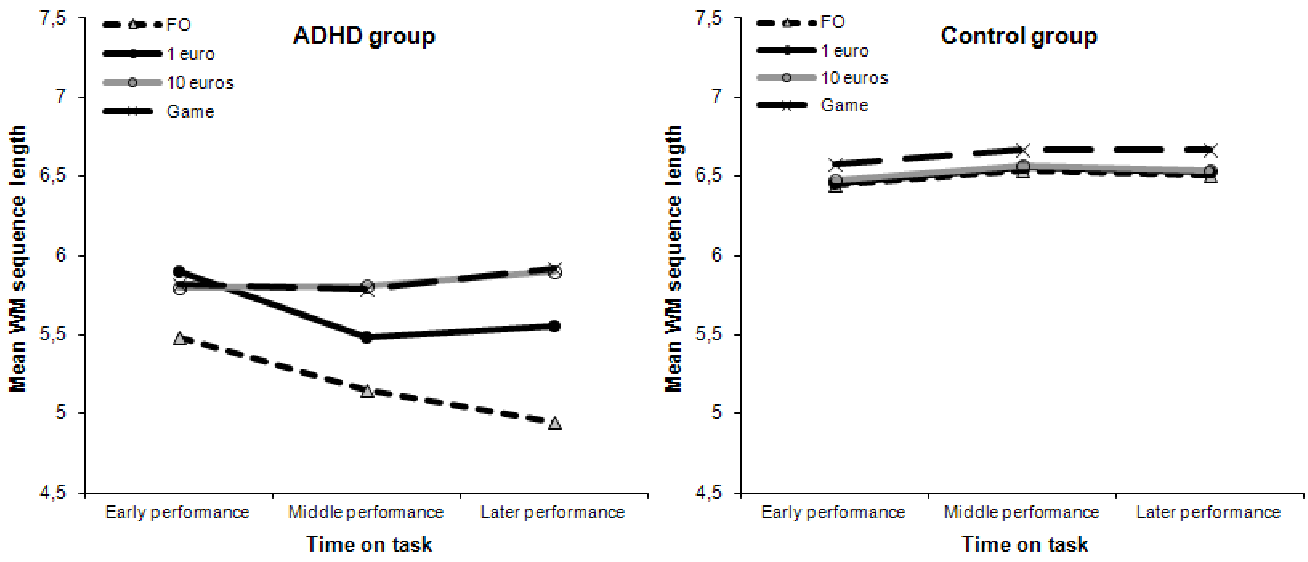

Fig. 4 Mean performance over time of children with ADHD, and control children on the visual-spatial working memory (WM) task in the Feedback-only (FO), 1 euro, 10 euros, and Game condition

These results thus indicate that in the ADHD group there is a pronounced time on task effect which can only be diminished by providing strong incentives (1 euro was insufficient), whereas in the control group, this time on task effect was absent. This conclusion was further supported in a 2x3x4 (group x time on task x reinforcement conditions) repeated-measures ANOVA. Linear contrasts for the time on task effect and simple contrasts for the reinforcement effect indicated that the reduction of time on task effects in the 10 euro condition, as compared to the FO condition, and as compared to the 1 euro condition, was more pronounced in children with ADHD than in controls (10 euros vs FO: F (1,59) = 3.206, p = .041, η_p^2 = .07; 10 euros vs 1 euro: F (1,59) = 3.846, p < .05, η_p^2 = .06). Finally, four

additional 3x2 (time on task x group) repeated-measures ANOVAs (one for each reinforcement condition) indicated that children with ADHD only showed a stronger decrease in performance over time than control children in the FO condition (F (2,118) = 3.31, p = .040, η_p^2 = .05) and in the 1 euro condition (F (2,118) = 3.97, p = .021, η_p^2 = .06), but not in the 10 euros condition (p = .671) or in the game condition (p = .643).

2.4 Discussion

This study examined the impact of different intensities and forms of reinforcement on the performance of children with combined-type ADHD and typically developing control children on a visual-spatial WM task. The present findings showed that children with ADHD performed worse on the WM task compared to control children, and although incentives improved the WM performance of children with ADHD, even the strongest incentives (10 euros and gaming) were unable to normalize their performance completely. Furthermore, unlike control children, children with ADHD showed a decrease in performance over time. However, the strongest incentives (10 euros and gaming) were able to normalize their persistence of performance, whereas small incentives (1 euro) had no effect. This suggests that, although motivational deficits might explain problems with persistence of performance in children with ADHD, it cannot completely explain the aberrant visual-spatial WM performance of these children.

Compared to feedback-only, incentives improved performance in children with ADHD, but not in control children. This suggests that for typically developing children, providing feedback-only constituted sufficient reinforcement to reach optimal performance, while this was clearly not the case for children with ADHD. This is in line with the idea that children with ADHD have an abnormal sensitivity to reinforcement (e.g., Sergeant et al., 1999), and, more specifically, is consistent with the theory of Haenlein and Caul (1987) which suggests that children with ADHD require higher amounts of reward in order to perform optimally due to an elevated reward threshold. No support was found, however, for Haenlein and Caul’s hypothesis that a large amount of reward would normalize performance in children with ADHD. That is, although the persistence of performance over time was normalized by high reinforcement, executive performance was still lower in children with ADHD. Our findings therefore support models that state that multiple deficits, both executive and motivational, give rise to ADHD (e.g., the dual pathway model, Sonuga-Barke, 2002), and models that emphasize the intertwined nature of executive control and motivation to

control (Castellanos, Sonuga-Barke, Milham, & Tannock, 2006; Gladwin, Figner, Crone, & Wiers, 2011; Sonuga-Barke, Sergeant, Nigg, & Willcutt; 2008).

For performance on an inhibition task, Slusarek et al. (2001) also reported differential effects of reinforcement in children with ADHD. However, in contrast to our findings, they found that high reinforcement normalized mean performance on this task. This implies that the effects of reinforcement may differ per executive function (*see* Luman et al., 2005); while inhibition may be normalized by strong reinforcement, performance on a visual-spatial WM task improves, but does not normalize. Since motivational factors could not fully explain the WM deficit in the ADHD group, and because we controlled for other situational factors (e.g., test rooms were quiet and views from windows were blocked) and cognitive factors (e.g., the task was self-paced for optimal attention/vigilance) which could provoke errors on the task, our findings support the notion that visual-spatial WM is a core neurocognitive deficit in ADHD (Rapport, Chung, Shore, & Isaacs, 2001).

No differential effects of intensity and form of the incentives were found on the mean WM performance; e.g., for children with ADHD all reinforcement conditions were associated with better mean WM performance than the feedback-only condition. For the *performance over time*, however, we found that in children with ADHD, persistence of performance over time depended on the intensity of the incentive, which was not found in controls. For children with ADHD, both money and gaming (form) improved persistence of performance over time, but the amount of money (intensity) determined whether this improvement was found; while reinforcement with 10 euros improved persistence of performance over time, reinforcement with 1 euro did not. Solanto et al. (1997) also reported differential results for mean performance and performance over time for an incentive comparable to 1 euro. They reported that although methylphenidate and a monetary reinforcer (max. 1 dollar) were both able to improve mean performance of children with ADHD on a sustained attention task, only methylphenidate improved their persistence of performance over time. Our findings suggest that children with ADHD only achieve improvement in persistence of performance over time when stronger reinforcements (> 1 euro) are used. Future studies of ADHD should therefore take intensity of reinforcement into account and examine performance over time next to mean performance. Especially for longer tasks (≥ 10 minutes), the intensity of incentives can be a confounding factor between reinforcement studies. Also in clinical practice, when interpreting task-performance of a child with ADHD, it seems crucial to take into account the amount of reinforcement that is used. It is important to be aware that what is stimulating or motivating enough for typically developing children, probably is insufficient for children with ADHD,

resulting in their underperformance. Therefore, performance of children with ADHD measured under normal conditions is probably in part the result of their elevated threshold for reinforcement, and powerful reinforcers are necessary to assess their full abilities.

Our finding that gaming can optimize the performance of children with ADHD as much as 10 euros can, is important because in real-life situations it is often impossible to give a child 10 euros every time (s)he has to perform optimally. However it may be possible to present tasks in a more game-like format. This implies that, especially for children with ADHD, the use of game-like motivational strategies at home, or using computer gaming in schoolwork, computerized testing and computerized interventions (e.g., Klingberg et al., 2005) could be a cost-effective way to optimize performance (*see* also Prins, Dovis, Ponsioen, Ten Brink, & Van der Oord et al., 2011; Lawrence, Houghton, Tannock, Douglas, Durkin, & Whiting, 2002). However, from our study it is not clear which of the various elements of the game format (e.g., stimulating animation, variation, gameplay, upgrades, competition) specifically contributed to the improved performance. Future studies should systematically vary and rate these game elements and their influence on performance.

Because our focus in the present study was primarily on the direct comparison of the different reward conditions, we did not vary ADHD-subtype (we only looked at children with combined-type ADHD). In future research it may be important to look at the different ADHD subtypes, since there is evidence that different subtypes of ADHD share similar neuropsychological weaknesses in cognitive control, but differ in their responses to success and failure (Huang-Pollock, Mikami, Pfiffner, & McBurnett, 2007; *see* also Scheres, Lee, & Sumiya, 2008). In future research it would also be interesting to specify and map ADHD subgroups based on their cognitive and/or motivational impairments (Sonuga-Barke, Bitsakou, & Thompson, 2010), and to include and investigate effects of comorbid- and/or related disorders (e.g., CD, ASD or learning disorders; e.g. *see* Demurie et al., 2011; Van der Meere et al., 1995). Finally, possible effects of developmental factors on the performance and sensitivity to reward of children with ADHD should also be investigated; for example, there are reasons to expect a different (larger) response to reward in adolescence than in adulthood (Steinberg, Albert, Cauffman, Banich, Graham, & Woolard, 2008; but *see* also Scheres, Milham, Knutson, & Castellanos, 2007; Ströhle et al., 2008).

In conclusion, our results demonstrated that children with ADHD, in contrast to typically developing children, require powerful motivational incentives to reach optimal performance on a visual-spatial WM task. While persistence of performance in children with ADHD can be normalized by these powerful incentives, their optimal WM performance is

still worse than the standard level of performance in controls. Therefore, professionals, parents and teachers should be aware of both the potentials and limitations of motivational incentives. We suggest that on the one hand they should motivate children with ADHD as strongly as possible (e.g., using game-like strategies/formats) to enable utilization and assessment of their full cognitive abilities, but also be aware that incentives will only partially resolve their WM related problems in daily life (e.g., forgetfulness, lack of planning). This is consistent with the clinical efficacy of evidence-based interventions such as behavioral parent- and teacher training. These interventions (Pelham & Fabiano, 2008) aim at improving behavioral control in children with ADHD by teaching parents and teachers to use token (reward) systems/programs and techniques to unburden the WM of these children (e.g., providing reminders and a structured environment). Finally, our findings underline the potential additive value of explicitly training executive functions such as working memory to optimally reduce the daily problems of children with ADHD.

Acknowledgments

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Appendix Chapter 2

Task instruction in the Feedback-Only condition (translated from Dutch):

On this task, do your best and try to perform as accurately as possible.

If you reproduce a sequence of squares correctly, a green curl will appear on the screen.
If you reproduce a sequence of squares incorrectly, a red cross will appear on the screen.

You can also monitor how you are doing by looking at the bar at the bottom of the screen.
If you reproduce a sequence correctly the bar gets longer, and if you reproduce a sequence incorrectly the bar gets shorter.
When the task is finished, a purple screen will appear.

Task instruction in the monetary conditions (instructions in the 1 euro and 10 euro condition were the same):

With this task, you can earn this 1 euro
(instructor shows euro and places it in sight above the laptop keyboard).

If you have earned this 1 euro, you can take it home and do with it what you want:
The 1 euro is yours.
You can earn this 1 euro by performing well enough on this task

If you reproduce a sequence of squares correctly, a green curl will appear on the screen with a picture of the 1 euro next to it. This indicates that you have an increased chance to get this 1 euro.

If you reproduce a sequence of squares incorrectly, a red cross will appear on the screen with a picture of the 1 euro behind it. This indicates that you have a decreased chance to get this 1 euro.

Only when you have made enough correct reproductions a green screen will appear: You are then finished with the task, and you can take the 1 euro home and keep it.

But beware. If you make too many incorrect reproductions, a red screen will immediately appear: Then you will also be finished with the task, but you will not get the 1 euro (then I'll take back the 1 euro).
I don't know how many correct reproductions are required to get a green screen or how many incorrect reproductions are required to get a red screen; the computer decides this randomly.

You can also monitor how you are doing by looking at the bar at the bottom of the screen.
If you reproduce a sequence correctly the bar gets longer, and if you reproduce a sequence incorrectly the bar gets shorter.

Chapter 3

What part of working memory is not working in ADHD?

Short-term memory, the central executive and effects of reinforcement

This chapter is based on:

Dovis, S., Van der Oord, S., Wiers, R.W. & Prins, P.J.M. (2013). What part of working memory is not working in ADHD? Short-term memory, the central executive and effects of reinforcement. *Journal of Abnormal Child Psychology, 41* (6), 901-917.

Abstract

Deficits in Working Memory (WM) are related to symptoms of Attention-Deficit/Hyperactivity Disorder (ADHD). In children with ADHD visuospatial WM is most impaired. WM is composed of Short-Term Memory (STM) and a Central Executive (CE). Therefore, deficits in either or both STM and the CE may account for WM impairments in children with ADHD. WM-component studies investigating this find deficits in both STM and the CE. However, recent studies show that not only cognitive deficits, but also motivational deficits give rise to the aberrant WM performance of children with ADHD. To date, the influence of these motivational deficits on the components of WM has not been investigated. This study examined the effects of a standard (feedback-only) and a high level of reinforcement (feedback+10euros) on the visuospatial WM-, visuospatial STM-, and the CE performance of 86 children with ADHD and 62 typically-developing controls. With standard reinforcement the STM, CE, and WM performance of children with ADHD was worse than that of controls. High reinforcement improved STM and WM performance more in children with ADHD than in controls, but was unable to normalize their performance. High reinforcement did not appear to improve the CE-related performance of children with ADHD and controls. Motivational deficits have a detrimental effect on both the visuospatial WM performance and the STM performance of children with ADHD. Aside from motivational deficits, both the visuospatial STM and the CE of children with ADHD are impaired, and give rise to their deficits in visuospatial WM.

3.1 Introduction

Deficits in executive functioning are proposed to play a pivotal role in explaining the problems children with ADHD encounter in daily life (e.g., Barkley, 2006; Nigg, 2006). Executive functions allow individuals to regulate their behavior, thoughts and emotions, and thereby enable self-control. Meta-analyses investigating executive functioning (Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005) demonstrate that compared to typically developing children, children with ADHD are most impaired on tasks that measure working memory. Working memory is described as the ability to maintain, control and manipulate goal-relevant information. Working memory enables skills like reasoning, planning, problem solving, and goal-directed behavior (e.g., see Baddeley, 2007; Conway, Jarrold, Kane, Miyake, & Towse, 2007; Martinussen et al., 2005). Impairments in working memory make it difficult for a person to remember what (s)he was doing, thinking or saying, or to keep in mind what (s)he has to do to reach his or her current goal. There is evidence suggesting that the working memory impairments of children with ADHD account for their deficits in attention (Burgess et al., 2010; Kofler, Rapport, Bolden, Sarver, & Raiker, 2010; Tilmann, Eninger, Forssman, & Bohlin, 2011), hyperactivity (Rapport et al., 2009), and impulsivity (Raiker, Rapport, Kofler, & Sarver, 2012). Finally, there is evidence suggesting that improvement of working memory in children with ADHD is associated with a reduction of ADHD symptoms (Beck, Hanson, Puffenberger, Benninger, & Benninger, 2010; Klingberg et al., 2005; Van der Oord, Ponsioen, Geurts, Ten Brink, & Prins, 2012).

According to Baddeley (2007; 2010) working memory is a multicomponent system consisting of two storage subsystems and a central executive. The storage subsystems – phonological and visuospatial short-term memory – are dedicated to the short-term storage of modality (phonological or visuospatial) specific information. The central executive is a mental control system with limited attentional resources that is responsible for supervising, controlling and manipulating information in the short-term memory systems. When the context (e.g., in daily life or during task performance) asks for changes in attentional demands, the central executive intervenes; e.g., by dividing, focusing or switching attention to relevant information or by reorganizing/updating information.

Given the relevance of working memory for the understanding and treatment of ADHD, interest in identifying which of the specific working memory components (short-term memory and/ or the central executive) are impaired in children with ADHD, has increased in the last few years. In their meta-analysis of working memory impairments in children with

ADHD, Martinussen et al. (2005) found that children with ADHD were both impaired on tasks that measure short-term memory (the highest pooled effect size of difference between ADHD and normal controls, Cohen's *d* = .85, was found for visuospatial short-term memory) and tasks that measure working memory (the highest pooled effect size of difference between ADHD and normal controls, Cohen's *d* = 1.06, was found for visuospatial working memory). However, because working memory performance is inherently composed of both short-term memory and central executive performance, deficits in either or both the short-term memory and central executive of children with ADHD may account for the impairments found on the working memory measures (Nigg, 2006). To address this issue, Rapport et al. (2008) assessed the performance of children with and without ADHD on a phonological working memory task and a visuospatial working memory task, and used a latent variable approach to partial out task performance related to visuospatial short-term memory, phonological short-term memory and the central executive. This approach was based on the assumption derived from Baddeley's model (2003) that shared variance between the phonological and visuospatial working memory measures reflects the domain-general central executive. Using this approach, Rapport et al. found a deficit in all three working memory components, including the central executive, in children with ADHD. This was also found in a more recent study by Alderson, Rapport, Hudec, Sarver, and Kofler (2010).

However, another factor that may play a role when assessing working memory deficits was not accounted for in these studies. Dovis, Van der Oord, Wiers and Prins (2012) showed that not only executive deficits, but also motivational deficits give rise to the poor working memory performance of children with ADHD. In contrast to typically developing children, children with ADHD showed strong underperformance on a visuospatial working memory task under regular reinforcement conditions (feedback-only), and required high incentives (e.g., 10 euros) to perform to their full working memory abilities. These findings were supported by Strand et al. (2012), who also reported that additional incentives improved working memory performance more in children with ADHD than in typically developing children. These findings are in line with motivational theories such as Haenlein and Caul's theory (1987) which suggests that children with ADHD require higher amounts of reward in order to perform optimally due to an elevated reward threshold. However, Rapport et al. (2008), Alderson et al. (2010), and earlier working memory studies (see Martinussen et al., 2005), did not control for this motivational deficit in children with ADHD. The regular testing conditions which they used (i.e., without high levels of reinforcement), may therefore have resulted in the sub-optimal working memory performance of children with ADHD and in

larger working memory performance differences between children with ADHD and typically developing children.

Also, the impact of these motivational deficits of children with ADHD on the different components of working memory (short-term memory and the central executive) has not been studied, while there is some evidence to suggest that these components may be differentially influenced by the motivational deficits of children with ADHD. For example, Shiels et al. (2008) found that incentives could improve the visuospatial working memory performance of children with ADHD, but had no effect on their visuospatial short-term memory performance. This suggests that the motivational deficits of children with ADHD may specifically affect performance related to the central executive part of working memory, but not to the visuospatial short-term storage component. However, due to the lack of a typically developing control group, it could not be determined whether this discriminative effect of incentives is specific for children with ADHD. Strand et al. (2012) investigated the effect of incentives on tasks that required different working memory loads (low to high loads) in both children with ADHD and typically developing children. They found that the abnormal effect of incentives on the performance of children with ADHD was not dependent on the working memory load of the task. However, Strand et al. used a general working memory task which did not differentiate between short-term memory and central executive performance. If indeed the short-term memory and the central executive are differentially affected by the motivational deficits of children with ADHD, the methodology of partialling out these working memory components from general working memory measures by means of a latent variable approach (i.e., without using specific short-term memory or central executive measures), as used by e.g. Rapport et al. (2008) and Alderson et al. (2010), may not be sufficient to assess the different components of working memory in ADHD.

In this study, we investigated (1) whether poor visuospatial short-term memory performance and working memory performance in children with ADHD are differentially influenced by motivational deficits, and (2) while using high levels of reinforcement to optimize performance, whether the divergent visuospatial working memory performance of children with ADHD is the result of a deficit in their central executive, a deficit in their visuospatial short-term memory, or both. We investigated this by comparing the effects of a standard (feedback-only) and a high amount of reinforcement (10 euros) on the visuospatial short-term memory and visuospatial working memory (short-term memory + central executive) task performance of children with and without ADHD, using a mixed factorial design.

We compared the mean performance of children with and without ADHD on two versions of the Chessboard working memory task (see Dovis et al., 2012): (1) A visuospatial short-term memory version of the task and (2) a visuospatial working memory version of the task. We presented these task versions in two reinforcement conditions: a feedback-only (FO) condition and a condition with feedback and a large monetary incentive (10 euros). This 10 euros condition was found in previous research to optimize task performance in children with ADHD (Dovis et al., 2012). To investigate the central executive performance, we examined the individual difference between mean visuospatial short-term memory performance and mean visuospatial working memory performance.[5]

We expected: (1) That, in the feedback-only condition, the mean working memory performance and mean short-term memory performance of children with ADHD would be lower than that of typically developing children (Martinussen et al., 2005), (2) that, in the feedback-only condition, the difference between the short-term memory performance and working memory performance (i.e. the effect of the increased taxation of the central executive) would be larger in children with ADHD than in typically developing children (Martinussen et al., 2005), (3) that the difference in working memory performance between children with and without ADHD would be smaller in the 10 euros condition than in the FO condition; suggesting a motivational deficit in ADHD (Dovis et al., 2012; Strand et al., 2012), (4) that, even in the 10 euros condition, the mean working memory performance of children with ADHD would be lower than that of typically developing children (Dovis et al., 2012; Strand et al., 2012), and finally, (5) that the difference in short-term memory performance between children with and without ADHD would not be smaller in the 10 euros condition than in the FO condition; suggesting no sub-optimal short-term memory performance in children with ADHD in the feedback-only condition (Shiels et al., 2008).

3.2 Method

Participants

One hundred forty eight children aged 8-12 years participated: 86 children with a diagnosis of ADHD combined-type, and 62 typically developing (TD) children. Children with ADHD

[5] Operationalizing central executive performance by using the difference between working memory performance and short-term memory performance is based upon the theorem of Engle, Tuholski, Laughlin, and Conway (1999) – which is consistent with other influential working memory models like those of Cowan (1995) and Baddeley and Hitch (1974) - that the working memory system consists of the contents of short-term memory plus the central executive. According to Engle et al. “working memory capacity = short-term memory capacity + central executive + the error of measurement” (p. 313).

were recruited from outpatient mental-healthcare centers, TD children through elementary schools.

Children met the following criteria:

For both groups. (a) an IQ score ≥80 established by the short version of the Dutch Wechsler Intelligence Scale for Children (WISC-III; Kort et al., 2002). Two subtests, Vocabulary and Block Design were administered to estimate Full Scale IQ (FSIQ). This composite score has satisfactory reliability (r =0.91) and correlates highly with FSIQ (r = 0.86; Sattler, 2001), (b) absence of any neurological disorder, sensory (color blindness and vision) or motor impairment as stated by the parents, (c) not taking any medication other than methylphenidate.

For the ADHD group. (a) a prior DSM-IV-TR (American Psychiatric Association, 2000) diagnosis of ADHD combined-type by a child psychologist or psychiatrist, (b) a score within the clinical range (95^{th} to 100^{th} percentile) on the ADHD scales of both the parent and teacher version of the Disruptive Behavior Disorder Rating Scale (DBDRS; Pelham, Gnagy, Greenslade, & Milich, 1992; Dutch translation: Oosterlaan, Scheres, Antrop, Roeyers, & Sergeant, 2000). The DBDRS contains four scales composed of the DSM-IV items for ADHD Inattentive subtype, ADHD hyperactive/Impulsive subtype, Oppositional Defiant Disorder (ODD), and Conduct Disorder (CD). Adequate psychometric properties have been reported (Oosterlaan et al., 2000), (c) meeting criteria for ADHD combined-type on the ADHD section of the Diagnostic Interview Schedule for Children, parent version (PDISC-IV; Shaffer, Fisher, Lucas, Dulcan, & Schwab-Stone, 2000). The PDISC-IV is a structured diagnostic interview based on the DSM-IV, with adequate psychometric properties, (d) absence of CD based on the CD sections of the PDISC-IV and (e) absence of a prior DSM-IV-TR diagnosis of any autism spectrum disorder (ASD) according to a child psychologist or psychiatrist.

For the control group. (a) a score within the normal range ($<80^{th}$ percentile) on the ADHD, ODD and CD scales of both the parent and teacher version of the DBDRS, (b) absence of a prior DSM-IV-TR diagnosis of ASD or any other psychiatric disorder as stated by the parents.

Groups did not differ with respect to age, dyscalculia, and dyslexia. Groups did differ with respect to gender, IQ, and amount of money to spend per week (see Table 1). 61 children in the ADHD group (71%) were taking Methylphenidate, but discontinued medication at least 24 hours before each session, allowing a complete wash-out (Greenhill, 1998).

Table 1

Means and standard deviations of group demographics and characteristics

Measure	Group					
	ADHD (n=86)		Controls (n=62)			
	M	SD	M	SD	F / χ^2	*p*
Gender (M : F)	70 : 16	-	27 : 35	-	22.9	<.001
Age (years)	10.4	1.3	10.1	1.2	2.9	.092
FSIQ	101	11.2	110	12.6	22.0	<.001
DBDRS parent						
Inattention	21.7	4.0	2.5	2.4	1139.7	<.001
Hyperactivity/Impulsivity	20.7	4.6	2.2	2.3	854.0	<.001
ODD	13.9	5.0	1.9	2.2	309.6	<.001
CD	2.6	2.3	.1	.3	79.5	<.001
DBDRS teacher						
Inattention	17.2	5.0	1.6	1.8	558.6	<.001
Hyperactivity/Impulsivity	15.6	5.7	1.0	1.5	378.8	<.001
ODD	9.9	5.8	.7	.9	153.1	<.001
CD	1.6	2.2	.1	.2	32.5	<.001
Weekly spendable income (in euros)	2.5	2.7	1.7	1.1	5.7	.019
Dyscalculia (Yes : No)	0 : 86	-	0 : 62	-	-	-
Dyslexia (Yes : No)	6 : 80	-	2 : 60	-	1.0	.319

Note. ADHD = attention-deficit/hyperactivity disorder; CD = conduct disorder; DBDRS = Disruptive Behavior Disorder Rating Scale; FSIQ = full scale IQ; M:F = Male:Female; ODD = oppositional defiant disorder.

Procedure

The study consisted of one test session and was approved by the IRB of the University. After obtaining written informed parental consent, the parents and teacher of the child were asked to complete the DBDRS. For the ADHD sample: if a child met the inclusion criteria of the DBDRS, child and parents were invited to a 100-minute test session. For the TD sample: if the child met the DBDRS inclusion criteria, the child was invited to a 100-minute test session. During the first 60 minutes of the test session the two reinforcement conditions (FO and 10 euros) of the short-term memory and the working memory task versions were administered, intermitted by a 5-minute break. After this first part of the test session there was a 10-minute

break, followed by the administration of the WISC-III subtests. During the test session with the child, the parents of the children with ADHD were interviewed with the PDISC-IV. If the child met the inclusion criteria (s)he was included in the data set.

To control for order effects, the order of administration of the reinforcement conditions (FO and 10 euros) and the task versions (short-term memory and working memory) were counterbalanced separately within groups (resulting in 2x2x2 = 8 orders of presentation)[6]. To control for expectancy effects (e.g., the expectation to receive money while performing the FO condition) parents and children received no information about the reinforcement conditions before the test session. Children with ADHD were tested at their mental-healthcare center, TD children at their school. Testing took place between 9 a.m. and 5 p.m. Test rooms were quiet and views from windows were blocked. Specific reinforcement instructions (e.g., *'If you perform well enough on this task you will get these 10 euros'*) were given to the child at the start of each reinforcement condition (for complete instructions see description of the reinforcement conditions). During testing an experimenter was present, sitting behind the child pretending to read a book.

The Working Memory Version of the Chessboard Working Memory task

The working memory version of the Chessboard working memory task is a visuospatial working memory performance measure developed by Dovis et al. (2012) and is based on two working memory tasks: the Corsi Block Tapping Task (CBTT; Corsi, 1972) and the subtest Letter-Number Sequencing from the Wechsler Adult Intelligence Scale (WAIS; Wechsler, 1958). The working memory task version taps the ability to both maintain and manipulate/reorganize visuospatial information that is relevant for the task at hand. The working memory version of the Chessboard task is described in Figure 1. To ensure that every presented sequence of stimuli (see Figure 1) has to be reorganized (and the central executive is tapped), the order of stimuli presentation is random with the restriction that in every sequence at least one blue stimulus is presented before the last green stimulus.

[6] Orders of presentation used in counterbalancing :

1.	FO: STM > WG	>	10 euros: STM > WG
2.	10 euros: STM > WG	>	FO: STM > WG
3.	FO: WG > STM	>	10 euros: WG > STM
4.	10 euros: WG > STM	>	FO: WG > STM
5.	FO: STM > WG	>	10 euros: WG > STM
6.	10 euros: STM > WG	>	FO: WG > STM
7.	FO: WG > STM	>	10 euros: STM > WG
8.	10 euros: WG > STM	>	FO: STM > WG

Note: STM = short-term memory, WM = working memory, FO = Feedback-only

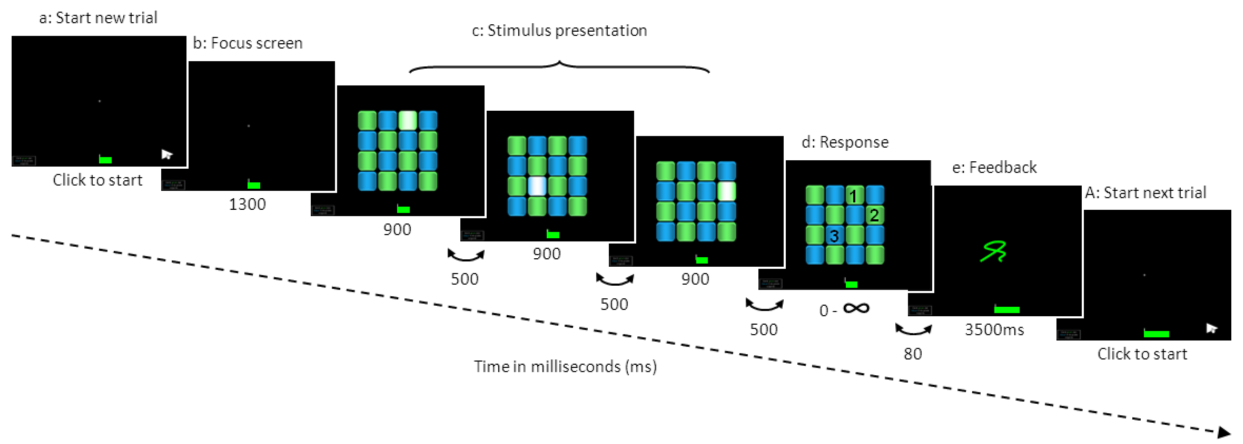

Fig. 1 A trial on the working memory version of the Chessboard task (a) To start a trial the arrowhead-button in the bottom-right corner of the screen has to be clicked. (b) Then the focus screen (a black screen with a little white cross) is presented. (c) Subsequently, a sequence of stimuli (squares that light up) is presented one by one on a 4x4 grid with green and blue squares ordered in a chessboard formation. Each stimulus lights up for 900ms and is followed by an inter-stimulus interval of 500ms. (d) After the stimulus-sequence is presented the participant responds by mouse-clicking on the squares. To respond correctly the presented stimuli have to be reproduced in a reorganized way: The green stimuli have to be reproduced before the blue stimuli; both in the same order as presented (the numbers in picture d show an example of a correct reorganization). (e) After a response feedback is presented. (A) After feedback-presentation, the participant can start the next trial by clicking on the arrowhead button

The Short-Term Memory Version of the Chessboard Working Memory Task

The short-term memory version of the Chessboard working memory task is a visuospatial short-term memory performance measure tapping the ability to maintain visuospatial information relevant for the task at hand. The short-term memory version is developed as a short-term memory analogue of the working memory version of the chessboard task. On the short-term memory task version the stimuli have to be reproduced in the same way as on the working memory task version: green stimuli have to be reproduced before the blue stimuli. However, in contrast to the working memory task version, on each trial of the short-term memory version all the green stimuli are presented before the blue stimuli. Therefore, none of the presented sequences on the short-term memory task version have to be reorganized (and only the storage component is tapped). The short-term memory version of the Chessboard task is described in Figure 2.

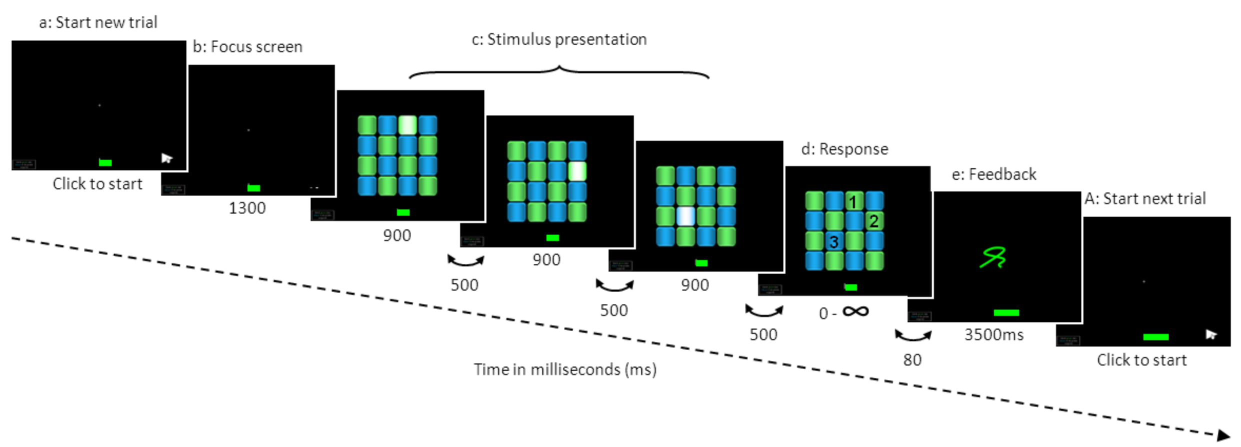

Fig. 2 A trial on the short-term memory version of the Chessboard task (a) To start a trial the arrowhead-button in the bottom-right corner of the screen has to be clicked. (b) Then the focus screen (a black screen with a little white cross) is presented. (c) Subsequently, a sequence of stimuli (squares that light up) is presented one by one on a 4x4 grid with green and blue squares ordered in a chessboard formation. Each stimulus lights up for 900ms and is followed by an inter-stimulus interval of 500ms. (d) After the stimulus-sequence is presented the participant responds by mouse-clicking on the squares. To respond correctly the presented stimuli have to be reproduced in the following way: The green stimuli have to be reproduced before the blue stimuli; both in the same order as presented. On every trial the order of stimuli presentation is random with the restriction that in every sequence the green stimuli are presented before the blue stimuli (the numbers in picture d show an example of a correct reproduction). (e) After a response feedback is presented. (A) After feedback-presentation, the participant can start the next trial by clicking on the arrowhead button

Parameters that are the Same for Both Versions of the Chessboard Task

To facilitate remembering the instructions during the task a brief instruction (‘first press green, then press blue, both in the same order as they were presented’) is continuously shown in the corner of the screen. To ensure optimal attention/vigilance of the participant during each trial, the task is self-paced (the participant has to click to start a trial). Every square that lights up is presented with the same short tone. To prevent the use of strategies (e.g., positioning the mouse-cursor on one of the squares in the sequence to unburden WM) the mouse-cursor is not visible during sequence presentation. The difficulty level of the task is adaptive; the first sequence consists of two stimuli and after two consecutive correct reproductions, the sequence is increased by one stimulus. After two consecutive incorrect reproductions, the sequence is shortened by one stimulus. The minimal sequence length consists of two stimuli and there is no maximum sequence length. Because the difficulty level adapts to individual performance, the amount of positive and negative feedback is approximately the same (55% reward, 45% response-cost) for each child and in both task versions and both reinforcement conditions.

Reinforcement Conditions

There are two reinforcement conditions (FO and 10 euros) that both contain the short-term memory version and the working memory version of the Chessboard task. Both reinforcement conditions and the task versions within these conditions are presented in counterbalanced order (see footnote 6). For both reinforcement conditions the procedure is as follows: After a brief introduction the task version (short-term memory or working memory) that will be presented first in the reinforcement condition starts with a practice block (of about 5 trials). Next, the first instruction of the reinforcement condition is presented (see Appendix 3.1 & 3.3). After this instruction, 30 trials of the first task version are presented. After the first task version is completed (every task version takes about 10 minutes to complete), the second task version in the reinforcement condition is introduced and practiced. Next, the second instruction of the reinforcement condition is presented (see Appendix 3.2 & 3.4). After this second instruction 30 trials of the second task version are presented. When the second task version of the first presented reinforcement condition is completed (and after a 5 minute break), the remaining reinforcement condition (also containing the two task versions) is administered using the same procedure.

In the feedback-only (FO) condition, children are instructed to do their best and respond as accurately as possible. In the second instruction they are also told that when the task is finished, a purple screen will appear (see Appendix 3.1 & 3.2).

In the 10 euros condition, children are told that they can earn 10 euros if they perform well enough on the task. Then, the euro coins which can be earned are shown and placed in sight above the laptop keyboard (the coins remain there during both task versions). The child is told that the euros can only be gained if (s)he makes enough correct responses and not too many incorrect responses. The child is told that the computer randomly decides the required amount of correct and incorrect responses. Further, the child is told that if enough correct responses are made, the task will immediately end with a green screen indicating that the euros are won, but that if too many incorrect responses are made, the task will immediately end with a red screen indicating that the euros are lost (for verbatim instructions see Appendix 3.3 & 3.4). Although participants are made to believe that their immediate performance directly influences their chance of winning the euros and that every incorrect or correct response can immediately end the task with a red or a green screen, in reality the

reinforcement condition always ends with the green screen and after both task versions are completed[7]; thus, participants always received the money.

In both the FO condition and the 10 euros condition, participants received immediate visual and auditory feedback and could monitor their overall performance by means of a ‘performance bar’. The performance bar was always visible at the bottom of the screen (see Figure 1 & 2). In the FO and the 10 euros condition, feedback consisted of the same sounds (a positive guitar sound for correct trials and a negative buzzer sound for incorrect trials), the same distance of adaptation of the performance bar, and of comparable pictures (see Figure 3).

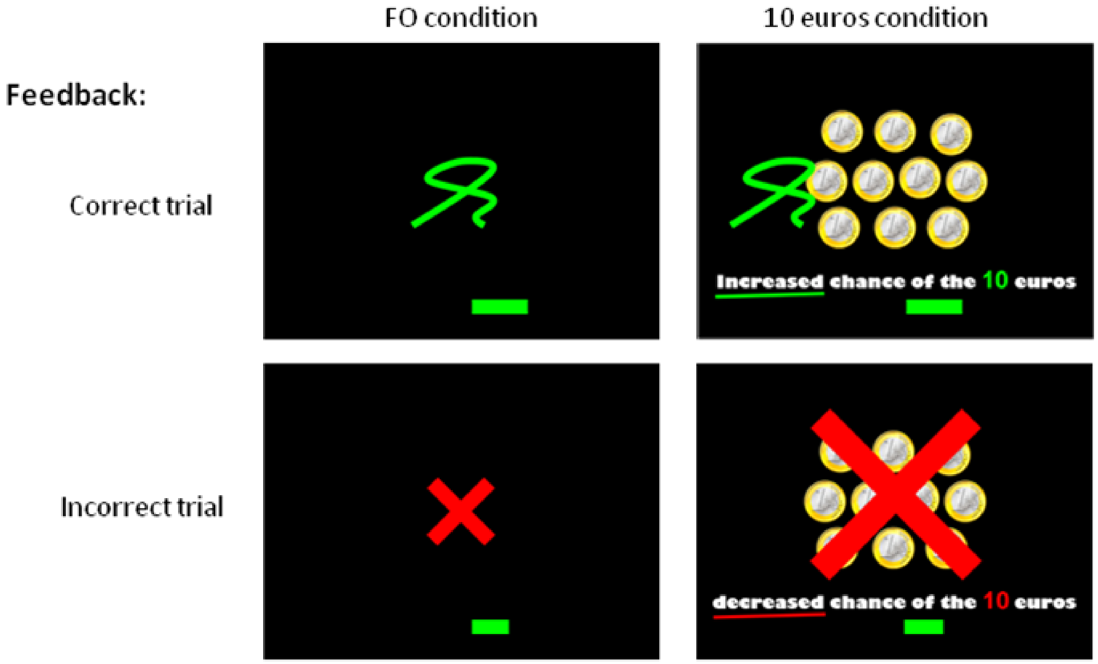

Fig. 3 Visual feedback in the Feedback-Only (FO) and 10 euros condition

Dependent measures

Because the first 12 trials on the short-term memory task version and on the working memory task version were needed to reach the child’s optimal level of difficulty, these trials were

[7] If the 10 euros were given contingent upon performance (for instance after 20 correct trials) then the number of performed trials (i.e. the work load) in the 10 euros condition could differ between participants and groups (e.g., with some children needing 24 trials to reach 20 correct trials and other children needing 34 trials). This difference in work load between participants and groups in the 10 euro condition could then result in differences in task performance in the subsequent reinforcement condition (e.g. due to more fatigue in one group than in the other).

excluded from analysis (this procedure and rationale[8] are identical with that of Dovis et al., 2012). Therefore, short-term memory performance and working memory performance in both reinforcement conditions were measured by the mean sequence length of the last 18 trials of the two task versions.

Data Analysis

Because there were significant group differences on IQ, gender, and weekly spendable income (see Table 1) we used these variables as covariates in all analysis. As there is debate as to whether IQ should be covaried (e.g., see Dennis et al., 2009), all analyses were also conducted without IQ as a covariate. If these results differed, we describe both analyses (with and without IQ as a covariate) in the text, whereas if the pattern of results was the same, we describe only the findings of the most conservative model including all covariates (IQ, gender and weekly spendable income).

The dependent measures were subjected to a repeated-measures ANCOVA with group (ADHD/control) as between-subject factor and reinforcement condition (FO and 10 euros) and task version (short-term memory task version vs. working memory task version) as within-subject factors. Because a repeated-measures ANCOVA was used, IQ, gender, and weekly spendable income were entered as covariates after mean centering the WISC scores, the gender scores, and the weekly spendable income scores (see Delaney & Maxwell, 1981). For the repeated-measures ANCOVA the central executive performance was investigated by means of the between-subject factor 'Task version' (i.e. the difference in performance between the short-term memory version and the working memory version of the task). For the additional within-group analysis (e.g., paired t-tests) the central executive performance was calculated by extracting the mean working memory performance from the mean short-term memory performance for each participant. Partial Eta squared effect sizes (η_p^2) are reported for all analyses: η_p^2 =.01 is regarded a small effect size, .06 a medium effect size, and .14 a large effect size (Kittler, Menard, & Phillips, 2007).

[8] The task started at a very easy level (a sequence of two stimuli), and because the difficulty level of the task adapts gradually (*see* above), children typically needed the first 12 trials to reach their optimal difficulty level (a sequence length higher than 5 or 6 stimuli). Since the mean of these first 12 trials gave no relevant information on individual performance, and inclusion of these trials resulted in a more inaccurate representation of participant's short-term memory and working memory capacity, these first trials were excluded from analysis (results did not change when the first 12 trials were included; *see* also Dovis et al., 2012).

3.3 Results

Counterbalancing

Order effects were controlled for by counterbalancing the order in which the reinforcement conditions (FO and 10 euros), and the task versions (short-term memory and working memory) within these reinforcement conditions were presented (see footnote 6). There were no significant differences between the two groups in the relative number of times each of the orders that were used for counterbalancing were presented, $\chi^2(7) = 1.11$, $p = .993$. Also, including counterbalancing-order as a covariate in the analyses did not change the results.

Mean Short-Term Memory, Central Executive and Working Memory Performance

A 2x2x2 (Group x Reinforcement condition x Task version [short-term memory vs. working memory]) repeated-measures ANCOVA with mean sequence length as dependent variable and IQ, gender, and weekly spendable income as covariates[9], showed a main effect of Reinforcement condition, where mean performance in the 10 euros condition was higher than in the FO condition, F (1,143) = 29.94, $p < .001$, $\eta_p^2 = .17$ (see figure 4), a main effect of Task version, where mean performance on the short-term memory version of the task was higher than on the working memory version of the task, F (1,143) = 4.78, $p = .030$, $\eta_p^2 = .03$, and a main Group-effect, were mean performance was lower in the ADHD group than in the control group, F (1,143) = 28.01, $p < .001$, $\eta_p^2 = .16$. There was a significant interaction between Reinforcement condition and Group, where the difference in performance between the ADHD group and the control group was smaller in the 10 euros condition than in the FO condition, F (1,143) = 6.27, $p = .013$, $\eta_p^2 = .05$. Further, a significant interaction between Task version and Group was found, where the difference in performance between the short-term memory version and the working memory version of the task (i.e. the effect of increased taxation of the central executive on performance) was more pronounced in children with ADHD than in the control children, F (1,143) = 5.73, $p = .018$, $\eta_p^2 = .04$ (see Figure 4). This interaction suggests less central executive capacity in children with ADHD than in control children. We found no significant interaction between Reinforcement condition and Task version, F (1,143) = 1.00, $p = .319$, $\eta_p^2 = .007$, and no significant interaction between Reinforcement condition, Task version, and Group, suggesting that the effect of reinforcement on the difference in performance between the short-term memory version and the working memory version of the

[9] Without covarying for IQ, gender, and weekly spendable income the pattern of the results was the same. Further, IQ, gender, and weekly spendable income did not significantly interact with Reinforcement condition or Task version.

task (i.e. the central executive) was not more pronounced in children with ADHD than in control children, F (1,143) = 0.03, p = .866, $\eta_p^2 < .001$.

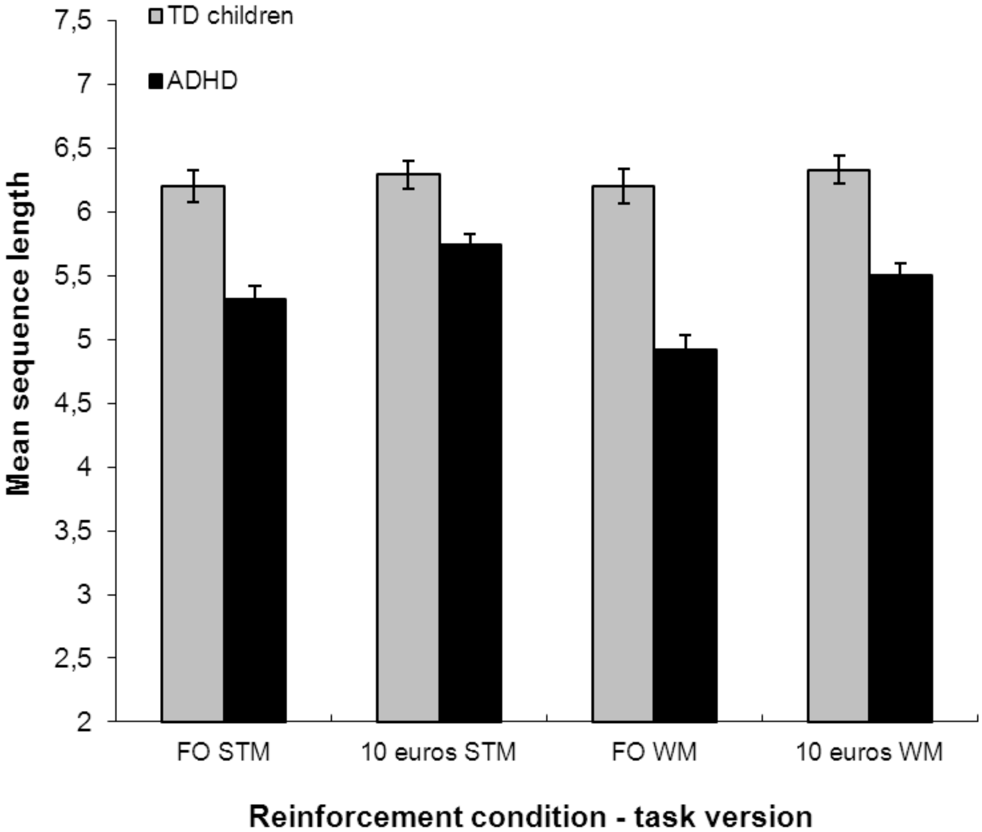

Fig. 4 Mean performance of children with ADHD and control children on the visual-spatial short-term memory (STM) task version and the working memory (WM) task version in the Feedback-only (FO) and 10 euros condition

In order to obtain more insight into the two way interactions, we performed follow-up t-tests. For both task versions (short-term memory and working memory) and for the difference in performance between the task versions (i.e. the central executive), differences between the reinforcement conditions within each group were tested with paired t-tests (*p*-values were not corrected for multiple comparisons). For the working memory version of the task: Compared to FO, 10 euros significantly improved the mean performance of children with ADHD, t (85) = -5.08, $p < .001$, but not of controls, t (61) = -1.73, p = .098. For the short-term memory version of the task: Compared to FO, 10 euros significantly improved the mean performance of children with ADHD, t (85) = -4.76, $p < .001$, but not of controls, t (61) = -1.49, p = .143. For the central executive: Compared to FO, 10 euros did not significantly

reduce the difference in mean performance between the two task versions of children with ADHD, t (85) = .78, p = .440, nor that of controls, t (61) = .72, p = .472.

To investigate whether the effect of reinforcement that was found for the short-term memory and working memory task version could normalize the performance of the children with ADHD to the level of typically developing children, the performance differences between the ADHD and control children on these task versions were tested for both reinforcement conditions using a MANCOVA (covaried for IQ, gender, and weekly spendable income). For the working memory version of the task: Children with ADHD showed lower mean performance in the FO condition (F (1,143) = 29.72, p < .001, η_p^2 = .17) and in the 10 euros condition (F (1,143) = 21.03, p < .001, η_p^2 = .13), compared to controls. Even the mean working memory performance of children with ADHD in the 10 euros condition was significantly lower than the mean working memory performance of controls in the FO condition (10 euros ADHD vs. FO Controls, F (1,143) = 11.86, p = .001, η_p^2 = .08). For the short-term memory version of the task: Children with ADHD showed lower mean performance in the FO condition (F (1,143) = 17.50, p < .001, η_p^2 = .11) and in the 10 euros condition (F (1,143) = 8.76, p = .004, η_p^2 = .06), compared to controls. Even the mean short-term memory performance of children with ADHD in the 10 euros condition was significantly lower than the mean short-term memory performance of controls in the FO condition (10 euros ADHD vs. FO Controls, F (1,143) = 5.83, p = .017, η_p^2 = .04; see Figure 4).

3.4 Discussion

This study examined the impact of a standard (feedback-only) and a high level of reinforcement (10 euros) on the visuospatial working memory, visuospatial short-term memory and the central executive performance of children with combined-type ADHD and typically developing control children. The present findings showed that with a standard level of reinforcement the short-term memory, central executive and working memory performance of children with ADHD was worse than that of control children. The high level of reinforcement improved both the short-term memory and working memory performance of children with ADHD, but not of control children. The difference in performance between the short-term memory task and the working memory task (i.e. the effect of increased taxation of the central executive) of both children with ADHD and control children was not reduced by the high level of reinforcement. Although the high level of reinforcement improved both short-term memory and working memory performance more in children with ADHD than in control children, it was unable to normalize their performance on these measures. These

findings suggest that motivational deficits have a detrimental effect on both working memory performance and short-term memory performance of children with ADHD (see Dovis et al., 2012; Strand et al., 2012). Furthermore, these findings suggest that, even when motivational deficits are controlled for, both the short-term memory and the central executive performance of children with ADHD are impaired and give rise to the working memory deficits in these children.

Compared to feedback-only, the high level of reinforcement improved the short-term memory and working memory performance of children with ADHD, but not of control children. This suggests that for typically developing children, providing feedback-only constituted sufficient reinforcement to reach optimal performance, while this was clearly not the case for children with ADHD. This is in line with previous studies (Dovis et al., 2012; Strand et al., 2012) showing that not only impairments in cognitive control, but also motivational deficits give rise to the aberrant working memory performance of children with ADHD, and is in accordance with theories that suggest that children with ADHD have an abnormal sensitivity to reinforcement (e.g., Haenlein & Caul, 1987; Sergeant, Oosterlaan, & Van der Meere, 1999). However, again (as in Dovis et al., 2012) no support was found for the hypothesis that is proposed in these motivational theories (e.g., see Haenlein & Caul, 1987) that a large amount of reward will normalize performance in children with ADHD. That is, when we controlled for motivational deficits (by using high levels of reinforcement), we still found that the short term memory, the central executive, and the working memory performance of children with ADHD was impaired compared to that of typically developing control children. Our findings therefore support models that state that multiple deficits, both cognitive and motivational, give rise to ADHD (e.g., the dual pathway model, Sonuga-Barke, 2002), and models that emphasize the intertwined nature of cognitive control and motivation to control (Castellanos, Sonuga-Barke, Milham, & Tannock, 2006; Gladwin, Figner, Crone, & Wiers, 2011; Sonuga-Barke, Sergeant, Nigg, & Willcutt; 2008). Moreover, since motivational factors could not fully explain the short-term memory, central executive, and working memory deficits in the ADHD group, and because we controlled for other situational factors (e.g., test rooms were quiet and views from windows were blocked) and cognitive factors (e.g., the task versions were self-paced for optimal attention/vigilance) which could provoke errors on the task, we consider our results to be consistent with the previously debated conclusions of Rapport et al. (2008) and Alderson et al. (2010), in that both components of visuospatial working memory; the short-term memory and the central executive, are impaired in children with ADHD, and give rise to working memory deficits in these children.

Our finding that both the short-term memory and working memory performance of children with ADHD can be improved by high incentives is only partially in line with the study of Shiels et al. (2008). Shiels et al. reported that only the working memory performance, but not the short-term memory performance of children with ADHD was improved by additional incentives. However, in contrast to our study, the order in which both tasks (short-term memory and working memory) were presented in the study of Shiels et al. was not counterbalanced across participants, but was always the same: the working memory task always came after the short-term memory task. Furthermore, the enhancement of working memory performance by incentives was found to be primarily driven by the order in which the incentives were presented: the incentive effect on the working memory task was only found in participants who experienced the incentive condition first and the no-incentive condition last. Therefore, it is plausible that because of the confounding order effects, it may not have been the specific effect of incentives on short-term memory and working memory performance, but only the general effect of incentives on the decrement of performance over time that might have been responsible for the differential incentive effect that was found by Shiels et al (2008). This would be consistent with our previous study (Dovis et al., 2012), where we found that strong incentives normalized persistence of performance over time on a working memory task in children with ADHD.

In the present study it was found that children with ADHD perform sub-optimally (i.e. below their optimal level of performance) in test conditions that are sufficiently motivating for typically developing children to show optimal performance (see also Dovis et al., 2012). However, despite the fact that high levels of reinforcement improved both the short-term memory and working memory performance of children with ADHD, high reinforcement did not reduce the difference between their short-term memory and working memory performance (i.e. the effect of increased taxation of the central executive). This might suggest that the sub-optimal state of the visuospatial storage system in children with ADHD can be ameliorated by incentives, whereas the state of their central executive cannot. This differential effect of incentives may be explained by the specific influence that incentives have on the stimulation of dopamine D1- and D2-class receptors in frontostriatal brain regions. Evidence suggests that motivation improves frontostriatal processing (including working memory) through its inducing effect on dopamine (for an overview see Aarts, van Holstein, & Cools, 2011). However, some researchers (e.g., Durstewitz & Seamans, 2002; 2008) propose that the dopamine related brain networks, like the frontostriatal brain regions, can be either in a D1-dominated state – which is characterized by a high-energy barrier favoring robust stabilization

of information (e.g., the maintenance of information) – or in a D2-dominated state – which is characterized by a low-energy barrier favoring fast flexible updating of information (e.g., updating or switching between relevant information; Cools & D'Esposito, 2011). Our finding that incentives may only have a facilitating effect on short-term storage of information, but not on updating of information (the central executive), might therefore suggest that high incentives particularly induce a more D1-dominated state (by activating mostly dopamine D1-class receptors). Future research should investigate this suggestion (e.g., Nakamura and Hikosaka [2006] found some evidence for this in primates; see also Frank, Moustafa, Haughey, Curran, & Hutchison, 2007) and its specificity for children with ADHD (for a review on dopamine and ADHD see Tripp & Wickens, 2008). However, it must be noted that because the central executive performance in this study is reflected by the difference in performance between the short-term memory task and the working memory task, and not by a task itself, it is difficult to argue how exactly the central executive is influenced by incentives. Therefore, future studies should use a task that measures central executive performance by itself: for example, by using a task that keeps the short-term memory load constant while the taxation of the central executive is varied.

In contrast to children with ADHD, control children showed no performance differences between the short-term memory task and working memory task. Thus, in typically developing children a task that needs additional central executive involvement does not seem to require the additional processing space that is needed to obtain an observable impact on their task-performance. The finding that the additional central executive load of the working memory task was only high enough to impact the task-performance of children with ADHD but not of control children, does not affect our conclusion that children with ADHD have less central executive capacity compared to typically developing children. However, it does suggest that the difference in central executive capacity between children with ADHD and typically developing children might be even larger than was found in the present study. Therefore, in future research it would be interesting to use a working memory task with a higher central executive load to assess the precise extent of the central executive deficit in children with ADHD.

As in our previous study (Dovis et al., 2012), we found no significant effect of incentives on the performance of typically developing children. This suggests that even a modest level of reinforcement (e.g., feedback-only) can maximize the performance of typically developing children. Although the absence of an incentive effect in typically developing children does not affect our conclusion that children with ADHD have an

abnormal sensitivity to reinforcement, it does make it impossible to assess the precise extent of their motivational abnormalities. To obtain an incentive effect in typically developing children, the baseline condition should probably not contain any immediate reinforcement. This is supported by Strand et al. (2012), who found an incentive effect in both children with and without ADHD (the incentive effect was more pronounced in the ADHD group) when they compared a no-feedback condition to a monetary incentive condition. Therefore, in future working memory component studies it would be interesting to include a no-feedback condition to be able to make a more precise assessment of the motivational abnormalities in children with ADHD.

In this study participants were provided with immediate, overall, and reward-specific feedback (i.e., the presented immediate and overall feedback in the 10 euros condition was related to the chance of winning the 10 euros). However, this does not exclude the possibility that an even more powerful reinforcer, such as a condition in which the participant immediately receives or loses a reward (e.g., 50 cent coins for each correct trial, instead of feedback about the chance of winning 10 euros)[10] or a condition in which the participant could win 100 euros, would have been necessary in order for the performance of children with ADHD to normalize. Although 10 euros are probably a more powerful reinforcer than any reinforcer that is used in daily life, for theoretical purposes it would be interesting to investigate the effect on performance of an even more powerful reinforcer.

Another possible limitation of our study could have been the difference in gender-ratio between the ADHD group and control group (see table 1). However, since gender did not significantly interact with our within-subject factors (Reinforcement condition and Task version) and because including gender as a covariate in the analyses did not change the results, we assume that the outcome of this study was not confounded by the difference in gender-ratio.

Although all children were screened for externalizing disorders and control children were only included in the study if their parents stated they had no prior or current DSM-IV-

[10]However, note that such a strategy may cause a procedural confound when the impact of reward on performance is compared between groups: If the total amount of reward that can be earned is contingent upon cognitive performance (i.e. when better performance results in a higher reward), then a participant's cognitive ability is likely to influence the maximum amount of reward this participant can earn. This means that a group characterized by cognitive impairments (e.g., ADHD) is likely to receive less rewards than a typically developing group. However, to properly compare the impact of reward on performance between two such groups, it is required that the amount of reward in both groups is the same. Otherwise, it cannot be determined whether a difference in the impact of reward on performance between these two groups is the result of the difference in symptomatology between these groups or of the difference in the presented amount of reward.

TR diagnosis, participants were not specifically screened for internalizing disorders. However, evidence suggests that anxiety and depressive disorders can affect working memory performance in typically developing groups (e.g., Hadwin, Brogan, & Stevenson, 2005; Rose & Ebmeier, 2006; Walsh et al., 2007), and there is some (although conflicting) evidence regarding the effect of comorbid anxiety or depression on the working memory performance of children with ADHD (e.g., see Mayes, Calhoun, Chase, Mink, & Stagg, 2009; Sarkis, Sarkis, Marshall, & Archer, 2005; Schatz & Rostain, 2006). Therefore, in future research it may be useful and interesting to assess symptoms of anxiety and depression and to examine their influence on the working memory performance within these two groups.

Further, because our focus in the present study was primarily on the comparison of the components of working memory, we did not vary ADHD-subtype (we only looked at children with combined-type ADHD). In future research it may be important to look at the different ADHD subtypes, since there is evidence that different subtypes of ADHD share similar neuropsychological weaknesses in cognitive control (Willcutt et al., 2012; but also see Diamond, 2005), but differ in their responses to success and failure (Huang-Pollock, Mikami, Pfiffner, & McBurnett, 2007; see also Scheres, Lee, & Sumiya, 2008). In future research it would also be interesting to specify and map ADHD subgroups based on their cognitive (i.e., working memory, short-term memory and central executive) and/or motivational impairments (Sonuga-Barke, Bitsakou, & Thompson, 2010), and to include and investigate effects of comorbid and/or related disorders (e.g., CD, ASD or learning disorders; e.g., see Demurie, Roeyers, Baeyens, & Sonuga-Barke, 2011; Van der Meere, Hughes, Börger, & Sallee, 1995). Finally, possible effects of developmental factors on the cognitive performance and sensitivity to reward of children with ADHD should also be investigated; for example, there are reasons to expect a different (larger) response to reward in adolescence than in adulthood (Steinberg et al., 2008; but see also Scheres, Milham, Knutson, & Castellanos, 2007; Ströhle et al., 2008).

In conclusion, our results demonstrated that children with ADHD, in contrast to typically developing children, require additional motivational incentives to reach their optimal short-term memory and working memory performance. Moreover, even when we controlled for these motivational deficits in children with ADHD, it was found that these children function worse compared to typically developing children on both components of working memory: the short-term memory and the central executive. We therefore conclude that, aside from motivational deficits, both the visuospatial short-term memory and the central executive

of children with ADHD are impaired, and give rise to their deficits in visuospatial working memory.

Therefore, professionals, parents and teachers should be aware that in situations that are motivating enough for typically developing children to perform optimally (e.g., the average daily context), children with ADHD are likely to perform sub-optimally (i.e. below their optimal level of performance) on short-term memory and working memory related tasks and functioning (e.g., reasoning, keeping information in mind, remembering, problem solving, goal-directed behavior, planning, etc.). To prevent sub-optimal performance and enable utilization and assessment of their full cognitive abilities, we suggest that they should motivate children with ADHD as strongly as possible. However, they should also be aware that even when children with ADHD are optimally motivated, they will still show impairments (although to a lesser extent) on short-term memory and working memory related functioning. Also, problems of children with ADHD that are associated with central executive functioning, but not with short-term memory functioning (like dual-tasking) will probably persist even when children are highly motivated. These considerations are consistent with the clinical efficacy of evidence-based interventions such as behavioral parent and teacher training. These interventions (Pelham & Fabiano, 2008) aim at improving behavioral control in children with ADHD by teaching parents and teachers to use token (reward) systems/programs and techniques to unburden the short-term memory and central-executive of these children (e.g., providing reminders and a structured environment). Finally, our findings underline the potential additive value of explicitly training executive functions such as working memory to optimally reduce the daily problems of children with ADHD and help us understand why current working memory training programs, that predominately seem to train short-term memory (see e.g. Klingberg et al., 2005), achieve improvements in the cognitive and behavioral functioning of children with ADHD.

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Appendix Chapter 3

3.1. The reinforcement instruction for the first presented task version in the Feedback-Only condition (translated from Dutch):

On this task, do your best and try to perform as accurately as possible.

If you reproduce a sequence of squares correctly, a green curl will appear on the screen.

If you reproduce a sequence of squares incorrectly, a red cross will appear on the screen.

You can also monitor how you are doing by looking at the bar at the bottom of the screen.

If you reproduce a sequence correctly the bar gets longer, and if you reproduce a sequence incorrectly the bar gets shorter.

3.2. The reinforcement instruction for the second presented task version in the Feedback-Only condition (translated from Dutch):

On this task, do your best and try to perform as accurately as possible.

If you reproduce a sequence of squares correctly, a green curl will appear on the screen.

If you reproduce a sequence of squares incorrectly, a red cross will appear on the screen.

You can also monitor how you are doing by looking at the bar at the bottom of the screen.

If you reproduce a sequence correctly the bar gets longer, and if you reproduce a sequence incorrectly the bar gets shorter.

When the task is finished, a purple screen will appear.

3.3. The reinforcement instruction for the first presented task version in the 10 euros condition (translated from Dutch):

With this task, you can earn these 10 euros

(instructor shows euros and places them in sight above the laptop keyboard).

If you have earned these 10 euros, you can take them home and do with them what you want:

These 10 euros are then yours.

You can earn these 10 euros by performing well enough on this task

If you reproduce a sequence of squares correctly, a green curl will appear on the screen with a picture of the 10 euros next to it. This indicates that you have an increased chance to get these 10 euros.

If you reproduce a sequence of squares incorrectly, a red cross will appear on the screen with a picture of the 10 euros behind it. This indicates that you have a decreased chance to get these 10 euros.

Only when you have made enough correct reproductions a green screen will appear: You are then finished with the task, and you can take the 10 euros home and keep them.

But beware. If you make too many incorrect reproductions, a red screen will immediately appear: Then you will also be finished with the task, but you will not get the 10 euros (then I'll take back the 10 euros).

I don't know how many correct reproductions are required to get a green screen or how many incorrect reproductions are required to get a red screen; the computer decides this randomly.

You can also monitor how you are doing by looking at the bar at the bottom of the screen.

If you reproduce a sequence correctly the bar gets longer, and if you reproduce a sequence incorrectly the bar gets shorter.

3.4. The reinforcement instruction for the second presented task version in the 10 euros condition (translated from Dutch):

Only by performing well enough on this last part of the task you can earn these 10 euros.

<u>You will now go on to the last part of the task and the following still applies:</u>

If you have earned these 10 euros, you can take them home and do with them what you want:

These 10 euros are then yours.

You can earn these 10 euros by performing well enough on this task

If you reproduce a sequence of squares correctly, a green curl will appear on the screen with a picture of the 10 euros next to it. This indicates that you have an increased chance to get these 10 euros.

If you reproduce a sequence of squares incorrectly, a red cross will appear on the screen with a picture of the 10 euros behind it. This indicates that you have a decreased chance to get these 10 euros.

Only when you have made enough correct reproductions a green screen will appear: You are then finished with the task, and you can take the 10 euros home and keep them.

But beware. If you make too many incorrect reproductions, a red screen will immediately appear: Then you will also be finished with the task, but you will not get the 10 euros (then I'll take back the 10 euros).

I don't know how many correct reproductions are required to get a green screen or how many incorrect reproductions are required to get a red screen; the computer decides this randomly.

You can also monitor how you are doing by looking at the bar at the bottom of the screen.

If you reproduce a sequence correctly the bar gets longer, and if you reproduce a sequence incorrectly the bar gets shorter.

Chapter 4

ADHD subtype differences in reinforcement sensitivity and visuospatial working memory

This chapter is based on:

Dovis, S., Van der Oord, S., Wiers, R.W. & Prins, P.J.M. (2014). ADHD subtype differences in reinforcement sensitivity and visuospatial working memory. *Journal of Clinical Child & Adolescent Psychology*, in press (available online ahead of print).

Abstract

Both cognitive and motivational deficits are thought to give rise to the problems in the combined (ADHD-C) and inattentive subtype (ADHD-I) of ADHD. In both subtypes one of the most prominent cognitive weaknesses appears to be in visuospatial working memory (WM), which is composed of short-term memory (STM) and a central executive (CE). In children with ADHD-C, both STM and the CE seem impaired, and together with motivational impairments, give rise to their deficits in visuospatial WM. In children with ADHD-I, no studies investigated these WM components and their interplay with motivational impairments. **Methods:** Effects of a standard (feedback-only) and a high level of reinforcement (feedback+10euros) on visuospatial WM-, STM-, and CE performance were examined in 27 children with ADHD-I (restrictive-subtype), 70 children with ADHD-C, and 40 typically-developing controls (aged 9-12). **Results:** In both ADHD-subtypes CE and WM performance was worse than in controls. STM performance of children with ADHD-I was, in contrast to that of children with ADHD-C, not different from controls. STM and WM performance was worse in ADHD-C than in ADHD-I, whilst CE-related performance did not differ. High reinforcement improved STM and WM performance in both subtypes, but not in controls. This improvement was equally pronounced in both subtypes. High reinforcement did not improve CE-related performance. **Conclusions:** Both subtypes have equally pronounced motivational deficits, which have detrimental effects on their visuospatial STM and WM performance. In contrast to children with ADHD-C, children with ADHD-I seem unimpaired on visuospatial STM; only an impaired CE and motivational impairments give rise to their deficits in visuospatial WM.

4.1 Introduction

The two most prevalent and valid diagnostic subtypes of Attention-deficit hyperactivity disorder (ADHD) are the predominantly inattentive subtype (ADHD-I) and the combined subtype (ADHD-C; Gomez, Harvey, Quick, Scharer, & Harris, 1999; Willcutt et al., 2012; Wolraich, Hannah, Baumgaertel, & Feurer, 1998). Although ADHD-C and ADHD-I are characterized by distinct patterns of symptomatic behavior, associated features and demographics (e.g. see Milich, Balentine, & Lynam, 2001), it is unclear whether these two subtypes have different underlying deficits.

Theories of ADHD state that both cognitive and motivational deficits give rise to the problems children with ADHD-C and ADHD-I experience in daily life (e.g., Barkley, 2006; Diamond, 2005; Sonuga-Barke, 2003; 2011). Motivational deficits in ADHD are thought to be characterized by an abnormal sensitivity to reinforcement (e.g., Haenlein & Caul, 1987; Sergeant et al., 1999) and by a disposition to be more easily under-aroused compared to typically-developing children (Diamond, 2005). Meta-analyses investigating cognitive deficits in ADHD (e.g., Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005; Willcutt et al., 2012) demonstrate that, compared to typically-developing children, both children with ADHD-C and children with ADHD-I are strongly impaired on tasks measuring *working memory* (especially *visuospatial* working memory).

Working memory is described as the ability to maintain, control and manipulate goal-relevant information. Working memory enables skills like reasoning, planning, problem solving, and goal-directed behavior (Baddeley, 2007; Conway, Jarrold, Kane, Miyake, & Towse, 2007; Martinussen et al., 2005). According to Baddeley (2007; 2010) working memory is a multicomponent system consisting of two storage subsystems and a *central executive*. The storage subsystems – phonological and visuospatial *short-term memory* – are dedicated to the short-term storage of modality (phonological or visuospatial) specific information. The central executive is a mental control system with limited attentional resources that is responsible for supervising, controlling and manipulating information in these short-term memory systems. When the context (e.g. in daily life or during task performance) asks for changes in attentional demands, the central executive intervenes; e.g. by dividing, focusing or switching attention to relevant information or by reorganizing/updating information.

Studies investigating working memory components in children with ADHD-C find that both their short-term memory and central executive are impaired (e.g., Alderson,

Rapport, Hudec, Sarver, & Kofler, 2010; Dovis, Van der Oord, Wiers, & Prins, 2013; Rapport et al., 2008; Rhodes, Park, Seth, & Coghill, 2012; but also see Karatekin, 2004). However, less is known about the level of impairment of these working memory components in children with ADHD-I. A recent meta-analysis by Willcutt et al. (2012) concluded that children with ADHD-I are impaired on tasks assessing short-term memory and on tasks assessing working memory. However, because working memory performance is inherently composed of both short-term memory and central executive performance, deficits in either or both these components may account for the impairments found on the working memory measures in children with ADHD-I (Nigg et al., 2006). Furthermore, close inspection of the studies examining short-term memory in Willcutt et al. showed that only a minority (30%) of these studies found a significant difference between the short-term memory performance of children with ADHD-I and typically-developing children. Outcomes of the working memory studies were more consistent; about 70% found a significant difference between children with ADHD-I and typically-developing children (e.g., Willcutt et al., 2012; see also Alloway et al., 2010; Cockcroft et al., 2011; Marusiak et al., 2005). [11] These findings seem in line with a theoretical appraisal by Diamond (2005) who proposed that children with ADHD-I have a deficient central executive, but are not impaired in short-term memory related skills such as encoding or retrieving items from memory. Moreover, Diamond suggested that children with ADHD-I have motivational deficits, which may interact with their cognitive functioning: children with ADHD-I would be more easily under-aroused than typically-developing children and therefore, under average (mostly low-stimulating) test conditions, have difficulty maintaining sufficient motivation during task performance. Under average test conditions this motivational deficit could then result in unstable cognitive performances in children with ADHD-I and might thereby explain the inconsistencies found in the short-term memory and working memory studies investigated by Willcutt et al. (2012).

Although no studies directly investigate this proposed interaction between motivational processes and working memory, short-term memory, and central executive performance in children with ADHD-I, evidence suggests motivational deficits in children with ADHD-C (for reviews see; Luman, Oosterlaan, & Sergeant, 2005; Luman, Tripp, & Scheres, 2010), and an interaction of these motivational deficits with their short-term memory and working memory performance: Dovis et al. (2013) demonstrated that not only cognitive

[11] For comparison: 50% of the studies that were examined in Willcutt et al. (2012) found a difference between ADHD-C and controls on short-term memory, and 80% found a difference on working memory.

deficits, but also motivational deficits give rise to the poor visuospatial short-term memory and working memory performance of children with ADHD-C (see also Dovis, Van der Oord, Wiers, & Prins, 2012; Strand et al., 2012). There is even evidence suggesting that the components of working memory may be differentially influenced by motivational deficits. For example, Dovis et al. (2013) found that additional incentives (10 euros) only improved the short-term memory performance, but not the central executive-related performance of children with ADHD-C.

To date, few studies have investigated motivational processes and their interaction with cognitive functioning in children with ADHD-I at all (see Carlson, Booth, Shin, & Canu, 2002; Huang-Pollock, Mikami, Pfiffner, & Burnett, 2007; Derefinko et al., 2008). Although the results of these studies are not entirely consistent, they appear broadly in line with Diamond’s (2005) notion that children with ADHD-I have motivational deficits that may interact with their cognitive functioning. For instance, Carlson, Booth, Shin and Canu (2002) used parent, teacher, and self-report ratings to investigate motivational styles in children with ADHD-I, ADHD-C and typically developing children, and found motivational impairments that are likely to interact with cognitive functioning (e.g., a stronger preference for easy work, less persistence) in both ADHD subtypes. Furthermore, Huang-Pollock, Mikami, Pfiffner and Burnett (2007) found that children with ADHD-I showed a stronger decline in performance on an inhibition task when incentives decreased over time than typically-developing children or children with ADHD-C. In contrast, Derefinko et al. (2008) found no effect of incentives on the slow and variable inhibitory functioning of children with ADHD-I. However, Derefinko et al. concluded that the incentives (trial-based monetary incentives, adding up to a total of about 1 dollar) may not have been sufficient to arouse the children with ADHD-I to improve their performance. Although we are not aware of studies that compare the effects of different amounts of incentives on cognitive performance in children with ADHD-I (but see Scheres, Tontsch, Thoeny, & Kaczkurkin, 2010), this conclusion of Derefinko et al. seems in line with a recent study by Dovis et al. (2012) which found that, compared to feedback-only, only relatively high incentives (e.g., feedback + 10 euros), but not incentives of a lower value (feedback + 1 euro), could improve and stabilize the persistence of performance over time in children with ADHD-C.

In sum, although it is suggested that children with ADHD-I have no impairment in short-term memory (in contrast to children with ADHD-C), but have a deficient central executive and motivational deficits that interact with cognitive functioning (Diamond, 2005), to date no studies have investigated this interplay between motivational processes and the

short-term memory, central executive or working memory performance in children with ADHD-I.

Finally, in the benchmark review of Milich et al. (2001), it is suggested that using the standard DSM-IV (American Psychiatric Association, 2000) cut-off of six hyperactivity/ impulsivity symptoms to distinguish between ADHD-I and ADHD-C, compromises the discriminant validity of these subtypes (since individuals with subthreshold ADHD-C may also be classified as having ADHD-I). Therefore, Milich et al. proposed that only ADHD-I with few (e.g. three or less) hyperactivity/ impulsivity symptoms may be qualitatively distinct from ADHD-C. Several studies have investigated this and, in contrast to studies including the broader subtype of ADHD-I, reported potential success differentiating this restrictive inattentive subgroup from ADHD-C on several neuropsychological measures (see Willcutt et al., 2012). However, no studies have investigated this for working memory and its interplay with motivational processes.

In this study, we investigated (1) whether the visuospatial[12] working memory, short-term memory and central executive performance of children with ADHD-I (restrictive-subtype) is different from that of typically-developing children and children with ADHD-C, and (2) whether these differences result from motivational deficits. We investigated this by comparing the effects of a standard and a relatively high amount of reinforcement on the visuospatial short-term memory and visuospatial working memory (short-term memory + central executive) performance of children with ADHD-I, ADHD-C and typically-developing children (controls), using a mixed factorial design.

We compared the mean performance of these groups of children on the working memory version and short-term memory version of the Chessboard task (Dovis et al., 2013). We presented these visuospatial task versions in two reinforcement conditions: a feedback-only (FO) condition and a condition with feedback and a large monetary incentive (10 euros). This 10 euros condition was previously found to optimize task performance in children with ADHD-C (Dovis et al., 2012). Performance related to the central executive was examined by the individual difference between mean short-term memory performance and mean working memory performance.[13]

[12] Meta-analytic findings suggest that children with ADHD show much more impairment on tasks that measure *visuospatial* working memory or short-term memory than on tasks measuring *phonological* working memory or short-term memory (Martinussen et al., 2005; Nigg, 2006; Willcutt et al., 2005). Therefore, in this study we focus on visuospatial working memory and its components.

[13] Operationalizing central executive performance by using the difference between working memory performance and short-term memory performance is based upon the theorem of Engle, Tuholski,

We expected that: (1) with feedback-only, the short-term memory, central executive, and working memory performance of children with ADHD-I and ADHD-C would be worse than that of controls (Diamond, 2005; Dovis et al., 2013; Willcutt et al., 2012), (2) the performance differences between children with ADHD (of both subtypes) and controls, on both the short-term memory and working memory task, would be smaller in the 10 euros condition than in the FO condition; suggesting an abnormal sensitivity to reinforcement in both ADHD subtypes (e.g., Sonuga-Barke, 2003; Carlson et al., 2002), (3) in the 10 euros condition, only the short-term memory performance of children with ADHD-C, but not of children with ADHD-I, would be worse than that of controls, suggesting no short-term memory deficit in ADHD-I (Diamond, 2005), and (4) that in the 10 euros condition, the working memory and central executive performance of both children with ADHD-I and ADHD-C would be worse than that of controls (e.g., Diamond, 2005; Dovis et al., 2013).

4.2 Method

Participants

137 children aged 9-12 years participated: 27 children with ADHD-I, 70 children with ADHD-C, and 40 typically-developing (TD) children. Children with ADHD were recruited from outpatient mental-healthcare centers, TD children through elementary schools. This study was conducted in the Netherlands, within a predominantly urban type of community. The ADHD-C and TD samples are subsamples from the ADHD-C and TD samples previously examined by Dovis et al. (2013) matched on age with the ADHD-I sample (i.e. because the ADHD-I sample in the present study was aged 9-12 years, only 9-12 year old children were included in this study, whereas Dovis et al. included 8-12 year olds).

Inclusion criteria:

For all groups. (a) an IQ score ≥80 established by the short version of the Dutch Wechsler Intelligence Scale for Children (WISC-III; Kort et al., 2002). Two subtests, Vocabulary and Block Design, were administered to estimate Full Scale IQ (FSIQ). This composite score has satisfactory reliability and correlates highly with FSIQ (Sattler, 2001), (b) absence of any neurological disorder, sensory (color blindness, vision) or motor

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Laughlin, and Conway (1999) – which is consistent with other influential working memory models like those of Cowan (1995) and Baddeley and Hitch (1974) - that the working memory system consists of the contents of short-term memory plus the central executive. According to Engle et al. “working memory capacity = short-term memory capacity + central executive + the error of measurement” (p. 313).

impairment as stated by the parents, (c) not taking any medication other than methylphenidate.

For the ADHD-C group. (a) a prior DSM-IV-TR (American Psychiatric Association, 2000) diagnosis of ADHD combined-type and absence of any autism spectrum disorder (ASD) according to a child psychologist or psychiatrist, (b) a score within the clinical range (95^{th} to 100^{th} percentile) on the ADHD scales of both the parent and teacher version of the Disruptive Behavior Disorder Rating Scale (DBDRS; Pelham, Gnagy, Greenslade, & Milich, 1992; Dutch translation: Oosterlaan, Scheres, Antrop, Roeyers, & Sergeant, 2000). The DBDRS contains four DSM-IV scales; Inattention, Hyperactivity/ Impulsivity, Oppositional Defiant Disorder (ODD), and Conduct Disorder (CD). Adequate psychometric properties are reported (Oosterlaan et al., 2000), (c) meeting criteria for ADHD combined-type on the ADHD section of the Diagnostic Interview Schedule for Children, parent version (PDISC-IV; Shaffer, Fisher, Lucas, Dulcan, & Schwab-Stone, 2000). The PDISC-IV is a structured diagnostic interview based on the DSM-IV, with adequate psychometric properties, (d) absence of CD based on the CD sections of the PDISC-IV.[14]

For the ADHD-I group. (a) a prior DSM-IV-TR diagnosis of ADHD inattentive-type and absence of any ASD according to a child psychologist or psychiatrist, (b) a score within the clinical range on the Inattention scale and a score below the clinical range on the Hyperactivity/ Impulsivity scale of both the parent and teacher version of the DBDRS, (c) To ensure that the ADHD-I group did not include any children with subthreshold ADHD-C, we followed recommendations made in the benchmark review of Milich et al. (2001; also see Barkley, 2006; Diamond, 2005): children in the ADHD-I group not only had to meet criteria for ADHD inattentive-type on the ADHD section of the PDISC-IV, but also had to have less than four hyperactivity/ impulsivity symptoms, (d) no CD based on the CD sections of the PDISC-IV.

For the control group. (a) a score within the normal range ($<80^{th}$ percentile) on all scales of both the parent and teacher version of the DBDRS, (b) absence of a prior DSM-IV-TR diagnosis of ASD or any other psychiatric disorder as stated by the parents.

Group differences in demographics and characteristics are listed in Table 1. Eight children in the ADHD-I group (30%) and 47 children in the ADHD-C group (67%) were

[14] CD was excluded because it seems independently associated with motivational impairment (possibly caused by different underlying processes than in ADHD; Rubia et al., 2009).

taking Methylphenidate[15], but discontinued medication at least 24 hours before the test-session, allowing a complete wash-out (Greenhill, 1998).

Table 1

Group demographics

Measure	Group							
	ADHD-I		ADHD-C		TD children			
	(n=27)		(n=70)		(n=40)			
	M	SD	M	SD	M	SD	F / χ^2	*Group Comparison*[a]
Gender (M : F)	18 : 9	-	56 : 14	-	20 : 20	-	10.7	I = C, TD; C ≠ TD
Age (years)	11.1	1.1	10.8	1.1	10.7	0.8	1.4	ns (p = .251)
FSIQ	106	10.5	100	11.6	109	13.3	7.7	I = C, TD; C < TD
DBDRS parent								
Inattention	19.0	4.5	21.5	3.9	2.5	2.6	349.4	TD < I < C
Hyp/Imp	7.0	3.4	20.8	4.4	2.4	2.5	356.8	TD < I < C
ODD	5.5	4.4	12.1	5.4	1.8	2.1	71.6	TD < I < C
CD	0.9	1.4	2.7	2.4	0.1	0.3	27.9	TD = I; C > TD, I
DBDRS teacher								
Inattention	15.4	5.0	17.2	4.9	1.7	1.8	170.7	TD < I, C; I = C
Hyp/Imp	2.9	2.4	15.3	5.5	1.0	1.5	174.7	TD = I; C > TD, I
ODD	2.0	2.8	8.10	5.9	0.6	1.0	37.4	TD = I; C > TD, I
CD	0.3	0.8	1.7	2.1	0.1	0.2	17.2	TD = I; C > TD, I
Weekly spendable income (in euros)	2.3	1.6	2.8	2.8	2.0	1.2	1.8	ns (p = .177)
Dyscalculia (Yes : No)	0 : 27	-	0 : 70	-	0 : 40	-	-	-
Dyslexia (Yes : No)	0 : 27	-	5 : 65	-	2 : 38	-	2.1	ns (p = .358)

Note. I = ADHD-I; C = ADHD-C; TD = typically-developing children; CD = conduct disorder; DBDRS = Disruptive Behavior Disorder Rating Scale; FSIQ = full scale IQ; Hyp/Imp = Hyperactivity/Impulsivity; M : F = Male : Female; ODD = oppositional defiant disorder; [a] MANOVAs were performed. If the group-effect was significant (p < .05), post-hoc Tukey tests were performed to clarify the differences (for all significant differences p-values were < .02). Nominal data were investigated using chi-square tests.

[15] This relative difference between the ADHD groups in medication-use was significant, $\chi^2(1)$ = 11.168, p = .001. However, including medication-use as a covariate in analyses where the ADHD groups were compared did not change the results.

Procedure

The study was approved by the faculty's IRB. After informed parental consent, parents and teacher completed the DBDRS. If DBDRS inclusion criteria were met, participants were invited to one 100-minute test-session. During this session's first hour the two reinforcement conditions (feedback-only and 10 euros), each containing the working memory and short-term memory version of the chessboard task, were administered, intermitted by a 5-minute break. Thereafter, the WISC-III subtests were administered. In parallel, parents of children with ADHD were interviewed with the PDISC-IV. If the child met the inclusion criteria (s)he was included in the data set.

To control for order effects, the order of administration of the reinforcement conditions and the task versions (short-term memory and working memory) were counterbalanced separately within groups (resulting in 2x2x2 = 8 orders of presentation)[16]. No information about the reinforcement conditions was provided before the test-session (e.g., to avoid expectations of receiving money). Children and their families were not compensated for participating in this study over and above the 10 euros from the high reinforcement condition. Children with ADHD were tested at their mental-healthcare center (both ADHD samples were recruited and tested in the same outpatient mental-healthcare centers, using the same testing procedures and experimenters), TD children at their school. Testing took place between 9 a.m. and 5 p.m. Test rooms were quiet and views from windows were blocked. Specific reinforcement instructions (e.g. *'If you perform well enough on this task you will get these 10 euros'*) were given to the child at the start of each reinforcement condition (for complete instructions *see* description of the reinforcement conditions). During testing an experimenter was present, sitting behind the child pretending to read a book.

The Chessboard Task: Working Memory and Short-Term Memory

The *working memory version* of the Chessboard task (Dovis et al., 2012; 2013) is a visuospatial working memory performance measure that is based on two working memory

[16] Orders of presentation used in counterbalancing :

1.	FO: STM > WM	>	10 euros: STM > WM
2.	10 euros: STM > WM	>	FO: STM > WM
3.	FO: WM > STM	>	10 euros: WM > STM
4.	10 euros: WM > STM	>	FO: WM > STM
5.	FO: STM > WM	>	10 euros: WM > STM
6.	10 euros: STM > WM	>	FO: WM > STM
7.	FO: WM > STM	>	10 euros: STM > WM
8.	10 euros: WM > STM	>	FO: STM > WM

Note: STM = short-term memory, WM = working memory, FO = Feedback-only

tasks: the Corsi Block Tapping Task (CBTT; Corsi, 1972) and the subtest Letter-Number Sequencing from the Wechsler Adult Intelligence Scale (WAIS-III; Wechsler, 1997). The working memory task taps the ability to both maintain and reorganize visuospatial information that is relevant for the task at hand (see Figure 1). To ensure that every presented sequence of stimuli (see Figure 1) has to be reorganized (and the central executive is tapped), the order of stimuli presentation is random with the restriction that in every sequence at least one blue stimulus is presented before the last green stimulus.

The *short-term memory version* of the Chessboard task (Dovis et al., 2013) is a visuospatial short-term memory performance measure tapping the ability to maintain visuospatial information relevant for the task at hand. The short-term memory version is a short-term memory analogue of the working memory task: the stimuli have to be reproduced in the same way as on the working memory task; green stimuli have to be reproduced before the blue stimuli (see Figure 1). However, in contrast to the working memory task, on each trial of the short-term memory task all the green stimuli are presented before the blue stimuli. Therefore, none of the presented sequences on the short-term memory task have to be reorganized (and only the storage component is tapped; for a more detailed description see Dovis et al., 2013).

The difficulty level of both tasks is adaptive; after two consecutive correct or incorrect reproductions, the sequence is increased or shortened by one stimulus. Minimal sequence length is two stimuli and there is no maximum sequence length. Because the difficulty level adapts to individual performance, the amount of positive and negative feedback is approximately the same (55% reward, 45% response-cost) for each child and in both task versions and both reinforcement conditions. To ensure optimal attention/vigilance of the participant during each trial, the tasks are self-paced (the participant has to click to start a trial), and each stimulus is presented with the same short tone. To prevent the use of strategies (e.g., positioning the mouse-cursor on one of the squares in the sequence to unburden WM) the mouse-cursor is not visible during sequence presentation. Each task consists of approximately 5 practice trials followed by 30 experimental trials, and takes about 10 minutes to complete (for more details see Dovis et al., 2013).

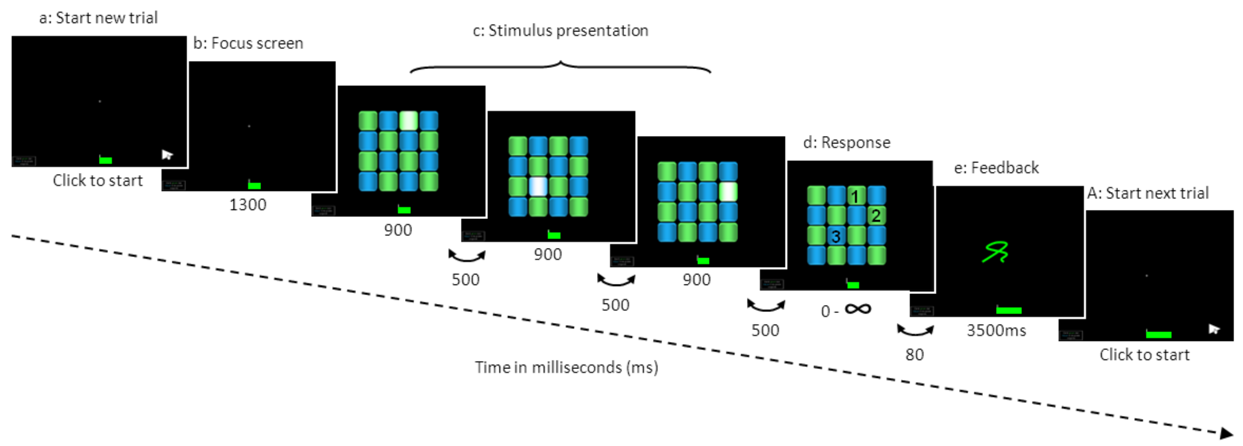

Fig. 1 A trial on the working memory version of the Chessboard task (a) To start a trial the arrowhead-button in the bottom-right corner of the screen has to be clicked. (b) Then the focus screen (a black screen with a little white cross) is presented. (c) Subsequently, a sequence of stimuli (squares that light up) is presented one by one on a 4x4 grid with green and blue squares ordered in a chessboard formation. Each stimulus lights up for 900ms and is followed by an inter-stimulus interval of 500ms. (d) After the stimulus-sequence is presented the participant responds by mouse-clicking on the squares. To respond correctly, the presented stimuli have to be reproduced in a reorganized way: The green stimuli have to be reproduced before the blue stimuli; both in the same order as presented (the numbers in picture d show an example of a correct reorganization). (e) After a response feedback is presented. (A) After feedback-presentation, the participant can start the next trial by clicking on the arrowhead button (from Dovis et al., 2013)

Reinforcement Conditions

Each participant completed both reinforcement conditions, and each reinforcement condition contained both the short-term memory and working memory task. In *the feedback-only condition*, children were instructed to do their best and respond as accurately as possible. In *the 10 euros condition*, children were told that they could earn 10 euros if they performed well enough on the task. In both reinforcement conditions, participants received immediate visual and auditory feedback and could monitor their overall performance by means of a 'performance bar' (for a detailed description see Dovis et al., 2013 or Appendix 4.1).

Dependent measures. On both task versions, the first 12 trials are required to reach the child's optimal difficulty level and were therefore excluded from analysis (Dovis et al., 2012; 2013). Thus, performance on each task version was measured by the mean sequence length of the last 18 trials.

Data Analysis

The ADHD-C and TD group differed significantly on IQ and gender (see Table 1), therefore these variables were used as covariates when these groups were compared. As there is debate whether IQ should be covaried when comparing ADHD and TD children (Dennis et al., 2009), all analyses were also conducted without covarying for IQ. If these results differed, we describe both analyses (with and without covarying for IQ), otherwise we describe only the most conservative findings (including IQ and gender as covariates).

Because the ADHD groups differed significantly on parent-rated Inattention on the DBDRS (Table 1) and showed a trend toward a significant difference on IQ (p=.062), we included these variables as covariates when these two groups were compared. The ADHD groups also differed on ODD and CD on the DBDRS. However, children with ADHD-I generally show less symptoms of ODD and CD than children with ADHD-C (e.g., Eiraldi, Power, & Nezu, 1997; Willcutt, Pennington, Chhabildas, Friedman, & Alexander, 1999), and covarying for ODD and CD may therefore take away characteristic subtype differences. Hence, if results with and without covarying for ODD and CD differed, we describe both analyses, otherwise we only describe the findings without these covariates.

Dependent measures were subjected to repeated-measures ANCOVAs with Group (ADHD-I/ADHD-C/control) as between-subject factor and Reinforcement condition (FO vs. 10 euros) and Task version (short-term memory vs. working memory) as within-subject factors. Because repeated-measures were used, covariates were entered after mean centering (see Delaney & Maxwell, 1981). In AN(C)OVAs *the central executive performance* was investigated using the factor 'Task version' (i.e. the difference in performance between the short-term memory- and the working memory task). In additional within-group analysis (e.g. paired t-tests) central executive performance was calculated for each reinforcement condition by extracting the working memory performance from the short-term memory performance for each participant.[17] Partial Eta squared effect sizes (η_p^2) are reported for all analyses: η_p^2 =.01 is regarded a small effect size, .06 a medium effect size, and .14 a large effect size (Kittler, Menard, & Phillips, 2007).

[17] CE FO = STM FO – WM FO; CE 10 euros = STM 10 euros – WM 10 euros
CE = central executive performance, WM = mean score on working memory task; STM = mean score on short term memory task; FO = feedback-only condition; 10 euros = 10 euros condition

4.3 Results

Counterbalancing

The three groups did not differ in the relative number of times that each counterbalancing-order was presented, $\chi^2(14) = 2.032$, $p = 1.000$. Also, including counterbalancing-order as a covariate did not change the results.

Mean Performance

A 3x2x2 (Group x Reinforcement condition x Task version) repeated-measures ANCOVA with mean sequence length as dependent variable (covaried for IQ and gender), showed a main effect of: Reinforcement condition, where performance was better with 10 euros than with feedback-only, F (2,132) = 25.18, $p < .001$, $\eta_p^2 = .16$ (see Figure 2), Task version, where performance was better on the short-term memory task than on the working memory task, F (2,132) = 5.11, $p = .025$, $\eta_p^2 = .04$, and Group, F (2,132) = 12.35, $p < .001$, $\eta_p^2 = .16$. Both the Reinforcement condition x Group interaction, F (2,132) = 4.29, $p = .016$, $\eta_p^2 = .06$, and Task version x Group interaction, F (2,132) = 4.76, $p = .010$, $\eta_p^2 = .07$, were significant. Other interactions were non-significant. Next, in order to obtain more insight into the two way interactions, follow up repeated measures AN(C)OVAs were performed.

ADHD-I vs. TD Children

A 2x2x2 (Group x Reinforcement condition x Task version) repeated-measures ANOVA with mean sequence length as dependent variable, showed a main effect of Reinforcement condition, where performance was better with 10 euros than with feedback-only, F (1,65) = 10.35, $p = .002$, $\eta_p^2 = .14$ (see Figure 2), no main effect of Task version, F (1,65) = 1.32, $p = .255$, $\eta_p^2 = .02$, and a main Group-effect, where performance was worse in children with ADHD-I than in TD children, F (1,65) = 4.67, $p = .034$, $\eta_p^2 = .07$. The Reinforcement condition x Group interaction was significant: the performance difference between the ADHD-I and TD group was smaller with 10 euros than with feedback-only, F (1,65) = 4.13, $p = .046$, $\eta_p^2 = .06$ (suggesting motivational deficits in children with ADHD-I). The Task version x Group interaction was also significant: the difference in performance between the short-term memory and the working memory task (i.e. the effect of increased taxation of the central executive) was more pronounced in children with ADHD-I than in TD children, F (1,65) = 8.05, $p = .006$, $\eta_p^2 = .11$ (suggesting less central executive capacity in children with ADHD-I). We found no significant Reinforcement condition x Task version interaction, F (1,65) = 0.18, $p = .669$, $\eta_p^2 = .003$, and no significant Reinforcement condition x Task version

x Group interaction, suggesting that the effect of reinforcement on the difference in performance between the short-term memory and the working memory task (i.e. central executive related performance) was not more pronounced in children with ADHD-I than in control children, F (1,65) = 0.04, p = .836, η_p^2 = .001.

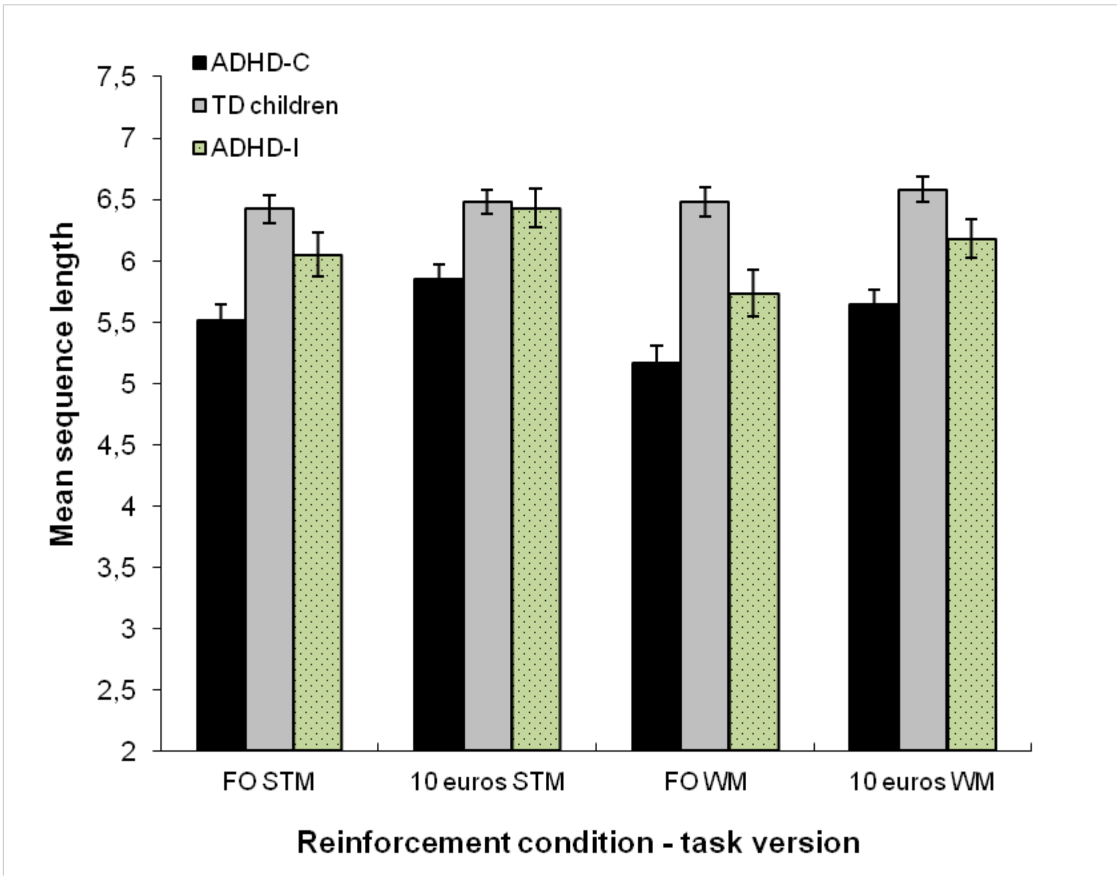

Fig. 2 Mean performance of children with ADHD-I, ADHD-C and typically-developing (TD) children on the visual-spatial short-term memory (STM) and working memory (WM) task in the Feedback-only (FO) and 10 euros condition

ADHD-C vs. TD Children

The effects of a 2x2x2 (Group x Reinforcement condition x Task version) repeated-measures ANCOVA with mean sequence length as dependent variable (covaried for IQ and gender) were comparable to the effects found in the ADHD-I vs. TD analyses (see above): There was a main effect of Reinforcement condition, F (1,106) = 14.63, p < .001, η_p^2 = .12, no main effect of Task version, F (1,106) = 1.35, p = .248, η_p^2 = .01, and a main Group-effect, F (1,106) = 22.94, p < .001, η_p^2 = .18 (see Figure 2). The Reinforcement condition x Group interaction, F (1,106) = 8.48, p = .004, η_p^2 = .07, and Task version x Group interaction, F

(1,106) = 7.14, p = .009, η_p^2 = .06, were significant. The Reinforcement condition x Task version interaction, F (1,106) = 0.48, p = .488, η_p^2 = .005, and Reinforcement condition x Task version x Group interaction, F (1,106) = 1.18, p = .280, η_p^2 = .01, were non-significant.

ADHD-I vs. ADHD-C

A 2x2x2 (Group x Reinforcement condition x Task version) repeated-measures ANCOVA with mean sequence length as dependent variable (covaried for IQ and parent-rated Inattention),[18] showed a main effect of: Reinforcement condition, where performance was better with 10 euros than with feedback-only, F (1,93) = 29.71, p < .001, η_p^2 = .24, Task version, where performance was better on the short-term memory task than on the working memory task, F (1,93) = 9.83, p = .002, η_p^2 = .10, and Group, were performance was better in children with ADHD-I than in children with ADHD-C, F (1,93) = 5.93, p = .017, η_p^2 = .06 (see Figure 2). The Reinforcement condition x Group interaction was non-significant, F (1,93) = 0.21, p = .886, η_p^2 < .001, suggesting that the ADHD groups have comparable reactions to reinforcement. The Task version x Group interaction was also non-significant, F (1,93) = 0.45, p = .503, η_p^2 = .005, suggesting that the ADHD groups have comparable central executive capacity. Other interactions were also non-significant.

Within-group Analyses per Task Version

For each task version (short-term memory and working memory) and for the difference in performance between the task versions (i.e. the central executive), differences between the reinforcement conditions within each group were tested with additional paired t-tests (p-values were not corrected for multiple comparisons).

Working memory task version: Compared to feedback-only, 10 euros significantly improved performance of children with ADHD-I, t (26) = -2.98, p = .006, and ADHD-C, t (69) = -4.84, p < .001, but not of controls, t (39) = -0.80, p = .429 (see Figure 2).

Short-term memory task version: Compared to FO, 10 euros significantly improved performance of children with ADHD-I, t (26) = -2.47, p = .020, and ADHD-C, t (69) = -3.77, p < .001, but not of controls, t (39) = -0.82, p = .415.

[18] With covarying for ODD and CD, the pattern of the results was the same. Further, these covariables did not significantly interact with Task version, and only parent-rated CD interacted significantly with Reinforcement condition, F (1,91) = 5.23, p = .025, η_p^2 = .05. Covarying for IQ or Inattention also did not change the pattern of the results.

Central executive performance: Compared to FO, 10 euros did not significantly improve performance of children with ADHD-I, t (26) = 0.45, p = .655, ADHD-C, t (69) = 1.22, p = .228, nor that of controls, t (39) = 0.17, p = .870.

Between-group Comparison per Task Version

To investigate whether the reinforcement effect that was found for the short-term memory and working memory task version could 'normalize' the performance of children with ADHD to the level of typically-developing children, and to compare differences in task performance between the subtypes, the performance differences between the groups on these task versions were tested for both reinforcement conditions using MAN(C)OVAs (covaried for IQ and gender when ADHD-C was compared to controls; covaried for IQ and parent-rated inattention when the ADHD groups were compared).[19]

Working memory task version: Children with ADHD-I performed worse than controls in both the FO condition (F (1,65) = 10.12, p = .002, η_p^2 = .14) and the 10 euros condition (F (1,65) = 4.05, p = .048, η_p^2 = .06). Children with ADHD-C performed worse than controls in both the FO condition (F (1,106) = 31.53, p < .001, η_p^2 = .23) and the 10 euros condition (F (1,106) = 15.40, p < .001, η_p^2 = .13). Children with ADHD-I performed better than children with ADHD-C in both the FO condition (F (1,93) = 5.06, p = .027, η_p^2 = .05) and the 10 euros condition (F (1,93) = 4.85, p = .030, η_p^2 = .05).

Short-term memory task version: Children with ADHD-I did not perform different from controls in the FO condition (F (1,65) = 2.663, p = .108, η_p^2 = .04) and the 10 euros condition (F (1,65) = 0.10, p = .757, η_p^2 = .001; see Figure 2). Children with ADHD-C performed worse than controls in both the FO condition (F (1,106) = 11.30, p = .001, η_p^2 = .10) and the 10 euros condition (F (1,106) = 5.05, p = .027, η_p^2 = .05). Children with ADHD-I did not perform different from children with ADHD-C in the FO condition (F (1,93) = 2.04, p = .157, η_p^2 = .02), but performed better in the 10 euros condition (F (1,93) = 5.71, p = .019, η_p^2 = .06).

4.4 Discussion

This study examined the impact of a standard (feedback-only) and a high level (feedback + 10 euros) of reinforcement on the visuospatial working memory, visuospatial short-term memory and the central executive performance of children with ADHD-I, ADHD-C and typically-

[19] Covarying did not change the pattern of the results.

developing children. In the feedback-only condition, the working memory and the central executive performance of children with ADHD-I and ADHD-C was worse than that of typically-developing children. However, the short-term memory performance of children with ADHD-I was, in contrast to that of children with ADHD-C, not significantly different from typically-developing children. High reinforcement improved the short-term memory and the working memory performance in both ADHD groups, but not in typically-developing children. Nonetheless, high reinforcement did not 'normalize' the short-term memory and working memory performance of children with ADHD-C, nor the working memory performance of children with ADHD-I. High reinforcement appeared not to improve central executive-related performance. In both reinforcement conditions, children with ADHD-I showed better working memory performance than children with ADHD-C (although effect sizes were small). Short-term memory performance was also better in children with ADHD-I than in children with ADHD-C, but only in the high reinforcement condition (where the effect size was medium). There was no difference between the ADHD groups in central executive-related performance. Reinforcement effects were also equally pronounced in both ADHD subtypes.

These findings suggest that both children with ADHD-I and ADHD-C have motivational deficits that have a detrimental effect on their visuospatial short-term memory and working memory performance. These motivational deficits seem to be equally pronounced in both ADHD subtypes. Furthermore, in contrast to children with ADHD-C, children with ADHD-I seem not impaired on visuospatial short-term memory; only an impaired central executive and motivational deficits seem to give rise to the visuospatial working memory deficits in children with this subtype. The central executive seems equally impaired in both subtypes.

The high level of reinforcement improved performance in both ADHD subtypes, but not in controls. This may suggest that for typically-developing children, providing feedback-only constituted sufficient reinforcement to reach optimal performance, while this was clearly not the case for children with ADHD-I and ADHD-C.[20] This is in line with theories

[20] Here we assume that the typically-developing group was highly motivated in both reinforcement conditions, whereas the ADHD groups were only highly motivated in the 10 euros condition. This assumption is substantiated by participants' reports: After both reinforcement conditions were administered, children were asked what they thought of the task with FO and of the task with 10 euros. In line with our assumption, children in both ADHD groups were less positive about the task in the FO condition (40% reported that the FO task was fun) than about the task in 10 euros condition (80% reported that the 10 euros task was fun), whereas typically-developing children were positive about the

suggesting that children with ADHD are characterized by an abnormal sensitivity to reinforcement (ADHD-C; e.g., Haenlein & Caul, 1987; Sergeant et al., 1999) and by a disposition to be more easily under-aroused compared to typically-developing children (ADHD-I; Diamond, 2005), and contradicts theories stating that motivational abnormalities characterize the combined subtype only (e.g., Sagvolden, Johansen, Aase, & Russell, 2005).

Further, our findings support the notion that motivational deficits interact with cognitive functioning in children with ADHD-I (Diamond, 2005; Carlson et al., 2002; Huang-Pollock et al., 2007), and ADHD-C (e.g., Dovis et al., 2012; 2013; Sonuga-Barke, 2011; Strand et al., 2012). However, although high reinforcement improved cognitive performance more in the ADHD groups than in the typically-developing group, the central executive and working memory performance of children with ADHD-I, and the short-term memory, central executive, and working memory performance of children with ADHD-C was still impaired compared to that of typically-developing children (i.e. high reinforcement did not 'normalize' performance). These findings suggest that motivational factors can only partially explain the working memory-related impairments in these subtypes. This, and the fact that we found no significant short-term memory deficit in children with ADHD-I, supports Diamond's suggestion that children with ADHD-I have deficient working memory, which is mainly characterized by central executive impairments, not by impairments in short-term memory (Diamond, 2005). In addition, our findings are consistent with previous studies showing that children with ADHD-C are impaired on both components of working memory (e.g., Alderson et al., 2010; Dovis et al., 2013*;* Rapport et al., 2008; Rhodes et al., 2012).

Our study shows equally pronounced motivational deficits in both ADHD subtypes. However, since two reinforcement conditions were compared that differ widely in intensity (feedback-only vs. high reward), subtle differences between the motivational deficits may not have been detected. For example, Huang-Pollock et al. (2007) compared the effects of two reward conditions (2 vs. 10 points) and found that children with ADHD-I only showed a stronger decline of performance than children with ADHD-C when rewards decreased over time. In future studies it would be interesting to compare the effects of more diverse reinforcement intensities between the ADHD subtypes.

Visuospatial short-term memory performance only differentiated between the ADHD subtypes in the high reinforcement condition (medium effect size), not in the standard reinforcement condition. This is consistent with previous studies that were unable to find

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tasks in both reinforcement conditions (72.5% reported that the FO task was fun and 80% reported that the 10 euros task was fun; for more details see appendix 4.2).

subtype differences in visuospatial short-term memory performance when standard reinforcement was used (for an overview see Willcutt et al., 2012; but also see Geurts, Verté, Oosterlaan, Roeyers, & Sergeant, 2005), and promotes the use of additional incentives in such studies to optimize cognitive differentiation between ADHD-I and ADHD-C.

A strength of our study is the stringently selected ADHD-I group. Following recommendations made in the benchmark review of Milich et al. (2001), children in the ADHD-I group were required to have less than four symptoms of hyperactivity/ impulsivity. According to Milich et al. the standard cut-off of six hyperactivity/ impulsivity symptoms compromises the discriminant validity of ADHD-I and ADHD-C (since individuals with subthreshold ADHD-C may also be included in the ADHD-I group). The significance of this suggestion may be underlined by the difference between our findings and the findings of studies using the standard cut-off: in contrast to our findings, the latter did not find significant differences between ADHD-I and ADHD-C on visuospatial working memory performance (see Willcutt et al., 2012; but note that the effect size for the difference in our study was small).

In contrast to children with ADHD-I and ADHD-C, control children showed no performance differences between the short-term memory task and the working memory task. Thus, in typically-developing children a task that needs additional central executive involvement does not seem to require the additional processing space that is needed to obtain an observable impact on their task-performance. The finding that the additional central executive load of the working memory task was only high enough to impact the task-performance of children in the ADHD groups, but not of control children, does not affect our conclusion that both children with ADHD-I and ADHD-C seem to have less central executive capacity compared to typically-developing children. However, it does suggest that the difference in central executive capacity between children with ADHD and typically-developing children might be even larger than was found in the present study. In future research it would be interesting to include an additional working memory task with a higher central executive load to assess the precise extent of the central executive deficits in the subtypes of ADHD. Further, the fact that central executive performance in this study was represented by the difference in performance between the short-term memory task and the working memory task, and not by a task itself, may have impacted the reliability of our central-executive-related results. Therefore, future studies should preferably use a task that measures central executive performance by itself: for example, by using a task that keeps the short-term memory load constant while the taxation of the central executive is varied.

As in previous studies (Dovis et al., 2012; 2013), we found no significant effect of incentives on the performance of typically-developing children. Although this does not affect our conclusion that both children with ADHD-I and ADHD-C have an abnormal sensitivity to reinforcement, it does make it impossible to assess the precise extent of their motivational abnormalities. To obtain an incentive effect in typically-developing children, the baseline condition should probably not contain any immediate reinforcement. This is supported by Strand et al. (2012), who found an incentive effect in both children with ADHD-C and typically-developing children (although the incentive effect was still more pronounced in children with ADHD-C) when they compared a no-feedback condition to a monetary incentive condition. Therefore, in future studies it would be interesting to include a no-feedback condition to be able to make a more precise assessment of the motivational abnormalities in the ADHD subtypes.

Another possible limitation of our study may have been the difference between the ADHD groups on parent-rated inattention on the DBDRS (see Table 1). However, in ADHD group-comparisons, this inattention score did not significantly interact with our within-subject factors (Reinforcement condition and Task version), and covarying for this inattention score did not change the results. This suggests that our outcomes were not confounded by this difference in inattention. In addition, the ADHD groups did not differ on teacher-rated inattention on the DBDRS.

The sample size of the ADHD-I group was relatively small (n=27), which suggests that the null finding between children with ADHD-I and TD children on the short-term memory task should be interpreted with some caution (due to the possibility of type II error). Nonetheless, at least in the high reinforcement condition (which is most important since findings are less confounded by motivational deficits than in the FO condition) the p-value was high ($p = .757$) and the effect size was very low ($\eta_p^2 = .001$) suggesting that a replication study using a larger sample is not likely to find a different result.

Although all children discontinued their ADHD medication at least 24 hours before testing (allowing a complete wash-out), there was a difference between the ADHD groups in prior medication use: medication use was more common among children with ADHD-C. However, since evidence suggests that performance on working memory measures is not influenced by the chronic use of ADHD medication (Coghill, Rhodes, & Matthews, 2007; Rhodes, Coghill, & Matthews, 2004), and because including medication use as a covariate did not change our results, we assume that the outcome of this study was not confounded by the difference in medication use.

Although our findings suggest that both children with ADHD-I and ADHD-C require extra reinforcement to optimize performance, we did not specifically investigate what causes this aberrant reaction to standard levels of reinforcement. For instance, additional reinforcement might compensate for deficits in arousal (i.e. the phasic physiological responses to input; Pribram & McGuinness, 1975) in children with ADHD (Diamond, 2005), but effects are indirect via the effort pool (Sergeant et al., 1999) and may therefore also compensate deficits in activation (the tonic physiological readiness to respond; Pribram & McGuinness, 1975). Future research should investigate this further (for inspiration see Loo et al., 2009).

This study primarily focused on differences *between* ADHD subtypes. However, there is also evidence for heterogeneity *within* these subtypes (e.g., Fair, Bathula, Nikolas, & Nigg, 2012; Sonuga-Barke, Bitsakou, & Thompson, 2010). Therefore, future research should (also) look beyond traditional ADHD subtypes, and specify the subgroups within these subtypes based on their cognitive (i.e. working memory, short-term memory and central executive) and/or motivational impairments.

Clinical implications

Professionals, parents and teachers should be aware that in situations that are motivating enough for typically-developing children, both children with ADHD-I and ADHD-C are likely to perform sub-optimally on short-term memory and working memory related tasks and functioning (e.g., keeping information in mind, reasoning, problem solving). To prevent sub-optimal performance and to enable utilization and assessment of their full cognitive abilities, children of both ADHD subtypes should be motivated as strongly as possible. Moreover, to further reduce working memory related problems in children with ADHD-I, it is especially important to minimize demands on their central executive: Due to a lack of attentional resources in their central executive, normal increases in attentional demands (i.e. ‘working’ with stored information) will presumably strongly impair utilization of the information that is stored in their probably intact short-term memory. These considerations support the use of token/reward systems and techniques to unburden working memory in evidence-based ADHD interventions such as behavioral parent and teacher training (Pelham & Fabiano, 2008). Finally, our results imply that interventions such as working memory training, of which there is debate as to whether mainly short-term memory is trained (e.g., Shipstead, Redick, & Engle, 2012), should focus more on training the central executive, especially in children with ADHD-I.

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Appendix Chapter 4

4.1. Detailed description of the reinforcement conditions (from Dovis et al., 2013).

Reinforcement conditions

There are two reinforcement conditions (Feedback-only and 10 euros) that both contain the short-term memory version and the working memory version of the Chessboard task. Both reinforcement conditions and the task versions within these conditions are presented in counterbalanced order. For both reinforcement conditions the procedure is as follows: after a brief introduction the task version (short-term memory or working memory) that will be presented first in the reinforcement condition starts with a practice block (of about 5 trials). Next, the first instruction of the reinforcement condition is presented (*see* Appendix A & C). After this instruction, 30 trials of the first task version are presented. After the first task version is completed, the second task version in the reinforcement condition is introduced and practiced. Next, the second instruction of the reinforcement condition is presented (*see* Appendix B & D). After this second instruction 30 trials of the second task version are presented. When the second task version of the first presented reinforcement condition is completed (and after a 5 minute break), the remaining reinforcement condition (also containing the two task versions) is administered using the same procedure.

In *the feedback-only (FO) condition*, children are instructed to do their best and respond as accurately as possible. In the second instruction they are also told that when the task is finished, a purple screen will appear (*see* Appendix A & B).

In *the 10 euros condition*, children are told that they can earn 10 euros if they perform well enough on the task. Then, the euro coins which can be earned are shown and placed in sight above the laptop keyboard (the coins remain there during both task versions). The child is told that the euros can only be gained if (s)he makes enough correct responses and not too many incorrect responses. The child is told that the computer randomly decides the required amount of correct and incorrect responses. Further, the child is told that if enough correct responses are made, the task will immediately end with a green screen indicating that the euros are won, but that if too many incorrect responses are made, the task will immediately end with a red screen indicating that the euros are lost (for verbatim instructions see Appendix C & D). Although participants are made to believe that their immediate performance directly influences their chance of winning the euros and that every incorrect or correct response can immediately end the task with a red or a green screen, in reality the reinforcement condition

always ends with the green screen and after both task versions are completed; thus, participants always received the money.

In both the FO condition and the 10 euros condition, participants received immediate visual and auditory feedback and could monitor their overall performance by means of a 'performance bar'. The performance bar was always visible at the bottom of the screen. In the FO and the 10 euros condition, feedback consisted of the same sounds (a positive guitar sound for correct trials and a negative buzzer sound for incorrect trials), the same distance of adaptation of the performance bar, and of comparable pictures (*see* Figure A).

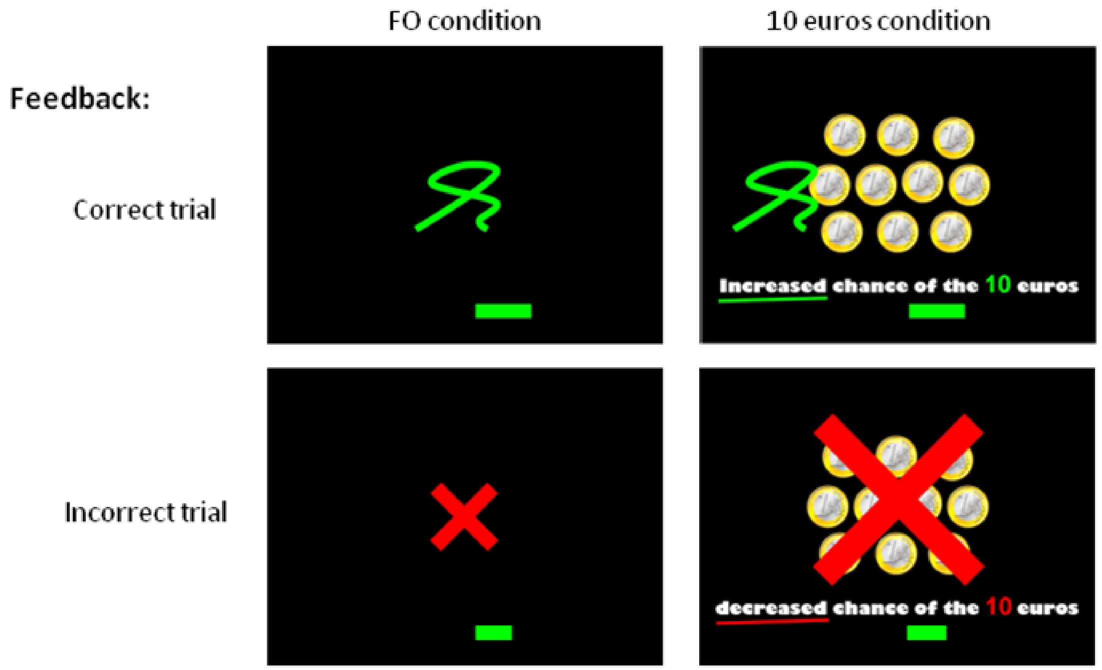

Fig. A Visual feedback in the Feedback-Only (FO) and 10 euros condition (from Dovis et al., 2013)

4.2. Details of reinforcement condition evaluation by participants

Procedure

After both reinforcement conditions were administered, the child was asked two questions (translated from Dutch): "What did you think of the task with the curl and the cross?"(i.e. FO task), and "What did you think of the task with the 10 euros?". Possible answers were: (1) fun, (2) not fun/not tedious, (3) tedious.

Results

In both ADHD groups children were less positive about the task in the FO condition than about the task in the 10 euros condition (see figure B), whereas typically-developing children were positive about both reinforcement conditions.

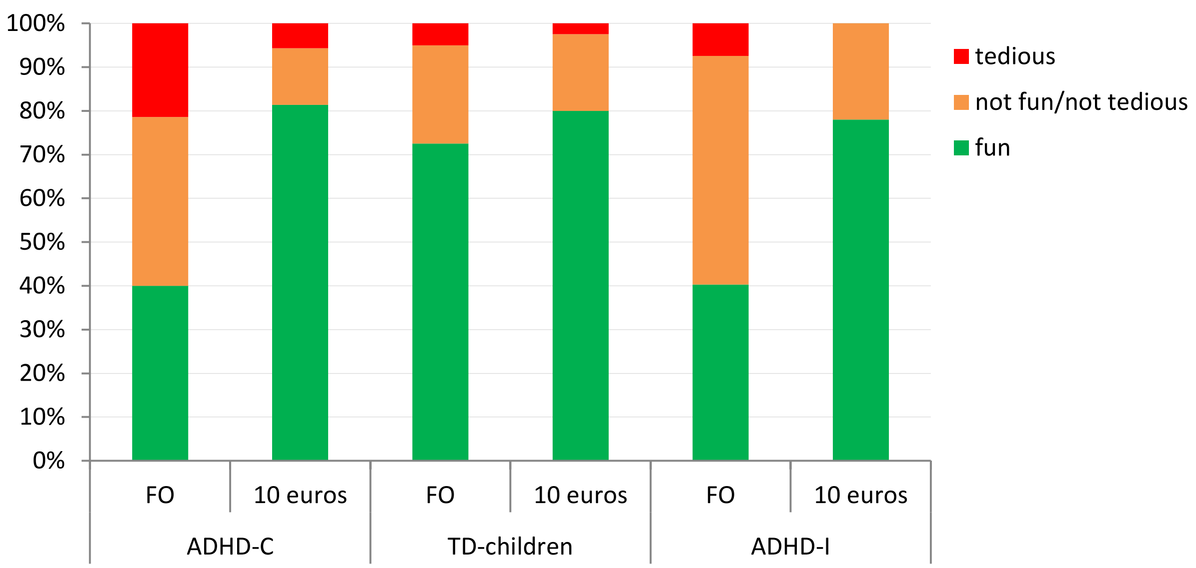

Fig. B Proportion of answers of children with ADHD-I (n=27), ADHD-C (n=70) and typically-developing (TD; n=40) children on the questions: "What did you think of the task with the curl and the cross?"(FO) and "what did you think of the task with the 10 euros?" (10 euros). Possible answers were: fun, not fun/not tedious, tedious.

A. The reinforcement instruction for the first presented task version in the Feedback-Only condition (translated from Dutch; from Dovis et al., 2013):

On this task, do your best and try to perform as accurately as possible.

If you reproduce a sequence of squares correctly, a green curl will appear on the screen.

If you reproduce a sequence of squares incorrectly, a red cross will appear on the screen.

You can also monitor how you are doing by looking at the bar at the bottom of the screen.

If you reproduce a sequence correctly the bar gets longer, and if you reproduce a sequence incorrectly the bar gets shorter.

B. The reinforcement instruction for the second presented task version in the Feedback-Only condition (translated from Dutch; from Dovis et al., 2013):

On this task, do your best and try to perform as accurately as possible.

If you reproduce a sequence of squares correctly, a green curl will appear on the screen.

If you reproduce a sequence of squares incorrectly, a red cross will appear on the screen.

You can also monitor how you are doing by looking at the bar at the bottom of the screen.

If you reproduce a sequence correctly the bar gets longer, and if you reproduce a sequence incorrectly the bar gets shorter.

When the task is finished, a purple screen will appear.

C. The reinforcement instruction for the first presented task version in the 10 euros condition (translated from Dutch; from Dovis et al., 2013):

With this task, you can earn these 10 euros

(instructor shows euros and places them in sight above the laptop keyboard).

If you have earned these 10 euros, you can take them home and do with them what you want:

These 10 euros are then yours.

You can earn these 10 euros by performing well enough on this task

If you reproduce a sequence of squares correctly, a green curl will appear on the screen with a picture of the 10 euros next to it. This indicates that you have an increased chance to get these 10 euros.

If you reproduce a sequence of squares incorrectly, a red cross will appear on the screen with a picture of the 10 euros behind it. This indicates that you have a decreased chance to get these 10 euros.

Only when you have made enough correct reproductions a green screen will appear: You are then finished with the task, and you can take the 10 euros home and keep them.

But beware. If you make too many incorrect reproductions, a red screen will immediately appear: Then you will also be finished with the task, but you will not get the 10 euros (then I'll take back the 10 euros).

I don't know how many correct reproductions are required to get a green screen or how many incorrect reproductions are required to get a red screen; the computer decides this randomly.

You can also monitor how you are doing by looking at the bar at the bottom of the screen.

If you reproduce a sequence correctly the bar gets longer, and if you reproduce a sequence incorrectly the bar gets shorter.

D. The reinforcement instruction for the second presented task version in the 10 euros condition (translated from Dutch; from Dovis et al., 2013):

Only by performing well enough on this last part of the task you can earn these 10 euros.

<u>You will now go on to the last part of the task and the following still applies:</u>

If you have earned these 10 euros, you can take them home and do with them what you want:

These 10 euros are then yours.

You can earn these 10 euros by performing well enough on this task

If you reproduce a sequence of squares correctly, a green curl will appear on the screen with a picture of the 10 euros next to it. This indicates that you have an increased chance to get these 10 euros.

If you reproduce a sequence of squares incorrectly, a red cross will appear on the screen with a picture of the 10 euros behind it. This indicates that you have a decreased chance to get these 10 euros.

Only when you have made enough correct reproductions a green screen will appear: You are then finished with the task, and you can take the 10 euros home and keep them.

But beware. If you make too many incorrect reproductions, a red screen will immediately appear: Then you will also be finished with the task, but you will not get the 10 euros (then I'll take back the 10 euros).

I don't know how many correct reproductions are required to get a green screen or how many incorrect reproductions are required to get a red screen; the computer decides this randomly.

You can also monitor how you are doing by looking at the bar at the bottom of the screen.

If you reproduce a sequence correctly the bar gets longer, and if you reproduce a sequence incorrectly the bar gets shorter.

Chapter 5

Prevalence and diagnostic validity of motivational impairments and deficits in visuospatial short-term memory and working memory in ADHD subtypes

This chapter is based on:

Dovis, S., Van der Oord, S., Huizenga, H.M., Wiers, R.W. & Prins, P.J.M. (2014). Prevalence and diagnostic validity of motivational impairments and deficits in visuospatial short-term memory and working memory in ADHD subtypes. *European Child & Adolescent Psychiatry*, in press (available online ahead of print).

Abstract

Deficits in working memory (WM) and reinforcement sensitivity are thought to give rise to symptoms in the combined (ADHD-C) and inattentive subtype (ADHD-I) of ADHD. Children with ADHD are especially impaired on *visuospatial* WM, which is composed of short-term memory (STM) and a central executive. Although deficits in visuospatial WM and reinforcement sensitivity appear characteristic of children with ADHD on a group-level, the prevalence and diagnostic validity of these impairments is still largely unknown. Moreover, studies investigating this did not control for the interaction between motivational impairments and cognitive performance in children with ADHD, and did not differentiate between ADHD-subtypes. **Methods:** Visuospatial WM and STM tasks were administered in a standard (feedback-only) and a high reinforcement (feedback+10euros) condition, to 86 children with ADHD-C, 27 children with ADHD-I (restrictive-subtype), and 62 typically-developing controls (aged 8-12). Reinforcement sensitivity was indexed as the difference in performance between the reinforcement conditions. **Results:** WM and STM impairments were most prevalent in ADHD-C. In ADHD-I, only WM impairments, not STM impairments, were more prevalent than in controls. Motivational impairments were not common (22% impaired) and equally prevalent in both subtypes. Memory and motivation were found to represent independent neuropsychological domains. Impairment on WM, STM, and/or motivation was associated with more inattention-symptoms, medication-use, and lower IQ-scores. Similar results were found for analyses of diagnostic-validity. **Conclusions:** The majority of children with ADHD-C is impaired on visuospatial WM. In ADHD-I, STM impairments are not more common than in controls. Within both ADHD-subtypes only a minority has an abnormal sensitivity to reinforcement.

5.1 Introduction

Deficits in executive functioning are proposed to play a pivotal role in explaining the problems individuals with ADHD encounter in daily life (Barkley, 2006; Nigg, 2006). Executive functions allow individuals to regulate their behavior, thoughts and emotions, and thereby enable self-control. *Working memory* (WM) is considered a core causal executive process in ADHD (Rapport, Chung, Shore, & Isaacs, 2001), and is described as the ability to maintain, control and manipulate goal-relevant information (Baddeley, 2007; Conway, Jarrold, Kane, Miyake, & Towse, 2007). Research indeed suggests that WM is one of the most impaired executive function in ADHD (Kasper, Alderson, & Hudec, 2012; Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005; Willcutt et al., 2012), and that WM impairments in children with ADHD may account for their deficits in attention (Burgess, Depue, Ruzic, Willcutt, Du, & Banich, 2010; Kofler, Rapport, Bolden, Sarver, & Raiker, 2010), hyperactivity (Rapport, Bolden, Kofler, Sarver, Raiker, & Alderson, 2009), and impulsivity (Raiker, Rapport, Kofler, & Sarver, 2012).

According to Baddeley (2007), WM is a multicomponent system consisting of two storage subsystems and a central executive. The storage subsystems – phonological and visuospatial *short-term memory (STM)* – are dedicated to the short-term storage of modality (phonological or visuospatial) specific information. The *central executive* is a mental control system with limited attentional resources that is responsible for supervising, controlling and manipulating information in the STM systems. Studies investigating WM components in children with ADHD indicate that, on a group-level, both their STM and central executive are impaired (e.g., Alderson, Rapport, Hudec, Sarver, & Kofler, 2010; Dovis, van der Oord, Wiers, & Prins, 2013; Rapport, Alderson, Kofler, Saver, Bolden, & Sims, 2008; Rhodes, Park, Seth, & Coghill, 2012). Furthermore, meta-analytic findings suggest that children with ADHD show more impairment on tasks measuring *visuospatial* WM than on tasks measuring *phonological* WM (e.g., Martinussen et al., 2005; Nigg, 2006).

Although impaired *visuospatial WM* appears characteristic of children with ADHD on a group-level, recent findings suggest that ADHD is a neuropsychologically heterogeneous disorder that probably is not characterized by any single core dysfunction (Fair, Bathula, Nikolas, & Nigg, 2012; Nigg, Willcutt, Doyle, & Sonuga-Barke, 2005; Pineda, Puerta, Aguirre, García-Barrera, & Kamphaus, 2007; Sonuga-Barke, Bitsakou, & Thompson, 2010). Given that only a subset of children with ADHD meets criteria for an executive function deficit (Biederman et al., 2004; Fair et al., 2012; Lambek, Tannock, Dalsgaard, Trillingsgaard, Damm, & Thomsen, 2010; Nigg et al., 2005; Pineda et al., 2007; Sjöwall,

Roth, Lindqvist, & Thorell, 2013; Sonuga-Barke et al., 2010; de Zeeuw, Weusten, van Dijk, van Belle, & Durston, 2012), visuospatial WM deficits on group-level are probably carried by only a subset of children with ADHD (Fair et al., 2012). However, despite its obvious significance for assessment and treatment, only two studies (Holmes, Gathercole, Place, Alloway, Elliot, & Hilton, 2010; Lambek, Tannock, Dalsgaard, Trillingsgaard, Damm, & Thompson, 2011) have attempted to demarcate this WM impaired subset within the ADHD population. These studies found visuospatial WM impairments in 29-47% of the children with ADHD (Lambek et al., 2011)[21], and an overall diagnostic hit rate (overall correct classification of children with and without ADHD) based on visuospatial WM measures of about 75% (correctly identifying 84.3% of the children with ADHD and 58% of typically-developing [TD] children; Holmes et al., 2010). In addition, even less is known about the individual differences within the ADHD population on the components of visuospatial WM: Only Holmes et al. investigated the diagnostic validity of a visuospatial STM measure. They found this measure to be less accurate in discriminating between children with and without ADHD (correctly identifying 81.9% of the children with ADHD, but only 12% of TD children) than their measure of visuospatial WM.

Moreover, the results of these prevalence- and diagnostic validity studies (Holmes et al., 2010; Lambek et al., 2011) may be confounded by motivational deficits. Motivational models propose that children with ADHD are less stimulated by reinforcement (i.e. reward) than typically developing children (probably due to a dopaminergic deficit) and therefore require higher amounts of reward in order to perform optimally (Diamond, 2005; Haenlein & Caul, 1987; Sergeant, Oosterlaan, & van der Meere, 1999; Sagvolden, Johansen, Aase, & Russell, 2005; Sonuga-Barke, 2011). Research indeed shows that children with ADHD, in contrast to their TD peers, show suboptimal performance on visuospatial WM- and visuospatial STM tasks under regular reinforcement conditions (e.g. feedback-only), and require relatively high incentives (e.g. feedback + 10 euros) to perform to their full abilities (Dovis, van der Oord, Wiers, & Prins, 2012; 2013; Strand, Hawk, Bubnik, Shiels, Pelham, & Waxmonsky, 2012). Holmes et al. and Lambek et al. did not control for these motivational deficits in children with ADHD (both studies used only regular reinforcement conditions),

[21] Loo et al. (2007; in adolescents), Sjöwall et al. (2013) and Wåhlstedt, Thorell, and Bohlin (2009) generally find a somewhat lower prevalence of working memory deficits in the ADHD population than Lambek et al. (2011). However, this lower prevalence might be explained by the fact that these three studies only use a composite score of both visuospatial and phonological working memory measures.

which may have resulted in an overestimation of the prevalence and diagnostic validity of WM and STM impairments in their ADHD samples.

Furthermore, ADHD can be divided into multiple subtypes (American Psychiatric Association, 2000). The two most prevalent and valid diagnostic subtypes of ADHD are the combined subtype (ADHD-C) and the predominantly inattentive subtype (ADHD-I; Gomez, Harvey, Quick, Scharer, & Harris, 1999; Willcutt et al., 2012; Wolraich, Hannah, Baumgaertel, & Feurer, 1998). ADHD-C and ADHD-I are characterized by distinct patterns of symptomatic behavior, associated features and demographics (e.g. see Milich, Balentine, & Lynam, 2001). Nevertheless, the studies of Holmes et al. (2010) and Lambek et al. (2011) included both children with ADHD-C and ADHD-I, but did not differentiate between these subtypes. Moreover, although (on a group level) both subtypes appear to have equally pronounced motivational deficits (i.e. abnormal reinforcement sensitivity), evidence suggests that children with ADHD-I seem less impaired on visuospatial WM than children with ADHD-C and, in contrast to children with ADHD-C, seem unimpaired on visuospatial STM (at least when motivational deficits are taken into account; Diamond, 2005; Dovis, Van der Oord, Wiers, & Prins, 2014; Martinussen & Tannock, 2006; Pasini, Paloscia, Alessandrelli, Porfirio, & Curatolo, 2007; also see Ferrin & Vance, 2014; Geurts, Verté, Oosterlaan, Roeyers, & Sergeant, 2005; Willcutt et al., 2012). Therefore, the findings of Holmes et al. and Lambek et al. may be neither representative of children with ADHD-C, nor of children with ADHD-I.

Finally, although an abnormal sensitivity to reinforcement (as defined by Haenlein & Caul, 1987) might be characteristic for children with ADHD on a group-level (for reviews see Luman, Oosterlaan, & Sergeant, 2005; Luman, Tripp, & Scheres, 2010; see also Dovis et al., 2012; 2013; Strand et al., 2012), the prevalence and diagnostic validity of this motivational deficit within the ADHD population is largely unknown. Only one recent study (de Zeeuw et al., 2012) investigated its prevalence in children with ADHD, and found that less than 8% of these children could be classified as having an abnormal sensitivity to reinforcement. However, de Zeeuw et al. used a small ADHD sample (n=26) which included all ADHD subtypes (obviously, subtype comparisons were not possible), and concluded that the low prevalence rate (e.g., prevalence in TD controls was 10%) was probably related to the high frequency of positive feedback that was applied during their motivation task (80% of the trials were rewarded), which may have attenuated the impact of the motivational deficits in their ADHD sample (de Zeeuw et al.). To our knowledge no studies investigated the diagnostic validity of abnormal reinforcement sensitivity in ADHD.

The current study therefore investigated (1) the prevalence and diagnostic validity of visuospatial WM impairments and visuospatial STM impairments in children with ADHD, taking their motivational deficits into account, (2) the prevalence and diagnostic validity of these motivational deficits in children with ADHD, and (3) whether the prevalence and diagnostic validity of these impairments differ between ADHD subtypes. Exploratively, we examined the differences between the neuropsychologically/motivationally impaired and unimpaired children with ADHD-C and ADHD-I on behavioral symptoms and other demographic variables (e.g., medication use, gender, IQ, etc.).

We investigated these questions by using the task scores of children with ADHD-C, ADHD-I and TD children on the visuospatial WM- and STM version of the Chessboard task (Dovis et al., 2012; 2013). To account for, and investigate, the motivational deficits in the ADHD samples we presented these tasks in two reinforcement conditions: a feedback-only condition and a condition with feedback and a large monetary incentive (10 euros). This 10 euros condition was previously found to optimize task performance in children with ADHD-C (Dovis et al., 2012). The change in performance between the feedback-only and 10 euros condition was considered the measure of sensitivity to reinforcement (the *reinforcement sensitivity index*; see Footnote 23).

We predicted that: (1) visuospatial WM and reinforcement sensitivity would significantly discriminate children with ADHD (of both subtypes) from TD children, and that related impairments would be more prevalent in children with ADHD-C and ADHD-I than in TD children (Diamond, 2005; Dovis, 2012; Holmes et al., 2010; Lambek et al., 2010), (2) visuospatial STM would only discriminate children with ADHD-C, but not children with ADHD-I, from TD children (Diamond, 2005), and (3) children with ADHD-C and ADHD-I who were classified as impaired on WM, STM and/or reinforcement sensitivity would have more behavioral problems and less favorable demographic characteristics than their unimpaired ADHD-C or ADHD-I peers (Willcutt et al., 2012).

5.2 Method

Participants

175 children participated: 86 children with ADHD-C (aged 8-12 years), 27 children with ADHD-I (aged 9-12 years), and 62 TD children (aged 8-12 years). Children with ADHD were recruited from outpatient mental-healthcare centers, TD children through elementary schools. Portions of the data were presented elsewhere (Dovis et al., 2013; 2014).

Inclusion criteria:

For all groups. (a) an IQ score ≥80 established by the short version of the Dutch Wechsler Intelligence Scale for Children (WISC-III; Kort et al., 2002). Two subtests, Vocabulary and Block Design, were administered to estimate Full Scale IQ (FSIQ). This composite score has satisfactory reliability and correlates highly with FSIQ (Sattler, 2001), (b) absence of any neurological disorder, sensory (color blindness, vision) or motor impairment as stated by the parents, (c) not taking any medication other than methylphenidate.

For the ADHD-C group. (a) a prior DSM-IV-TR (American Psychiatric Association, 2000) diagnosis of ADHD combined-type and absence of any autism spectrum disorder (ASD) according to a child psychologist or psychiatrist, (b) a score within the clinical range (95^{th} to 100^{th} percentile) on the ADHD scales of both the parent and teacher version of the Disruptive Behavior Disorder Rating Scale (DBDRS; Pelham, Gnagy, Greenslade, & Milich, 1992; Dutch translation: Oosterlaan, Scheres, Antrop, Roeyers, & Sergeant, 2000). The DBDRS contains four DSM-IV scales; Inattention, Hyperactivity/Impulsivity, Oppositional Defiant Disorder (ODD), and Conduct Disorder (CD). Adequate psychometric properties are reported (Oosterlaan et al., 2000), (c) meeting criteria for ADHD combined-type on the ADHD section of the Diagnostic Interview Schedule for Children, parent version (PDISC-IV; Shaffer, Fisher, Lucas, Dulcan, & Schwab-Stone, 2000). The PDISC-IV is a structured diagnostic interview based on the DSM-IV, with adequate psychometric properties, (d) absence of CD based on the CD sections of the PDISC-IV.

For the ADHD-I group. (a) a prior DSM-IV-TR diagnosis of ADHD inattentive-type and absence of any ASD according to a child psychologist or psychiatrist, (b) a score within the clinical range on the Inattention scale and a score below the clinical range on the Hyperactivity/Impulsivity scale of both the parent and teacher version of the DBDRS, (c) To ensure that the ADHD-I group did not include any children with subthreshold ADHD-C, we followed recommendations made in the benchmark review of Milich, Balentine, and Lynam (2001; see also Barkley, 2006; Diamond, 2005): Children in the ADHD-I group not only had to meet criteria for ADHD inattentive-type on the ADHD section of the PDISC-IV, but also had to have less than four hyperactivity/impulsivity symptoms, (d) no CD based on the CD sections of the PDISC-IV.

For the control group. (a) a score within the normal range ($<80^{th}$ percentile) on all scales of both the parent and teacher version of the DBDRS, (b) absence of a prior DSM-IV-

TR diagnosis of ASD or any other psychiatric disorder (apart from a mathematics disorder or reading disorder) as stated by the parents.

Group differences in demographics and characteristics are listed in Table 1 (including the presence of a DMS-IV-TR diagnosis of a mathematics disorder or reading disorder as stated by the parents). Eight children in the ADHD-I group (30%) and 61 children in the ADHD-C group (71%) were taking Methylphenidate,[22] but discontinued medication at least 24 hours before the test-session, allowing a complete wash-out (Greenhill, 1998).

The Chessboard Task: WM and STM

The *WM version* of the Chessboard task (Dovis et al., 2012; 2013) is a visuospatial WM performance measure based on two WM tasks: the Corsi Block Tapping Task (CBTT; Corsi, 1972) and the subtest Letter-Number Sequencing from the Wechsler Adult Intelligence Scale (WAIS-III; Wechsler, 1997). The WM task taps the ability to both maintain and reorganize visuospatial information that is relevant for the task at hand (see Figure 1). To ensure that every presented sequence of stimuli has to be reorganized (and the central executive is tapped), the order of stimuli presentation is random with the restriction that in every sequence at least one blue stimulus is presented before the last green stimulus.

The *STM version* of the Chessboard task (Dovis et al., 2013) is a visuospatial STM performance measure tapping the ability to maintain visuospatial information relevant for the task at hand. The STM version is a STM analogue of the WM task: the stimuli have to be reproduced in the same way as on the WM task; green stimuli have to be reproduced before the blue stimuli (see Figure 1). However, in contrast to the WM task, on each trial of the STM task all the green stimuli are presented before the blue stimuli. Therefore, none of the presented sequences on the STM task have to be reorganized (and only the storage component is tapped; for more details see Dovis et al.).

The difficulty level of both tasks is adaptive; after two consecutive correct or incorrect reproductions, the sequence is increased or shortened by one stimulus. Minimal sequence length is two stimuli and there is no maximum sequence length. Because the difficulty level adapts to individual performance, the amount of positive and negative feedback is approximately the same (55% reward, 45% response-cost) for each child and in both task versions and both reinforcement conditions. Each task consists of approximately 5 practice

[22] This relative difference between the ADHD groups in medication-use was significant, $\chi^2(1) = 13.814$, $p < .001$. However, including medication-use as a covariate in analyses where the ADHD groups were compared (and covariation was possible) did not change the pattern of the results.

trials followed by 30 experimental trials, and takes about 10 minutes to complete (for more details see Dovis et al., 2013).

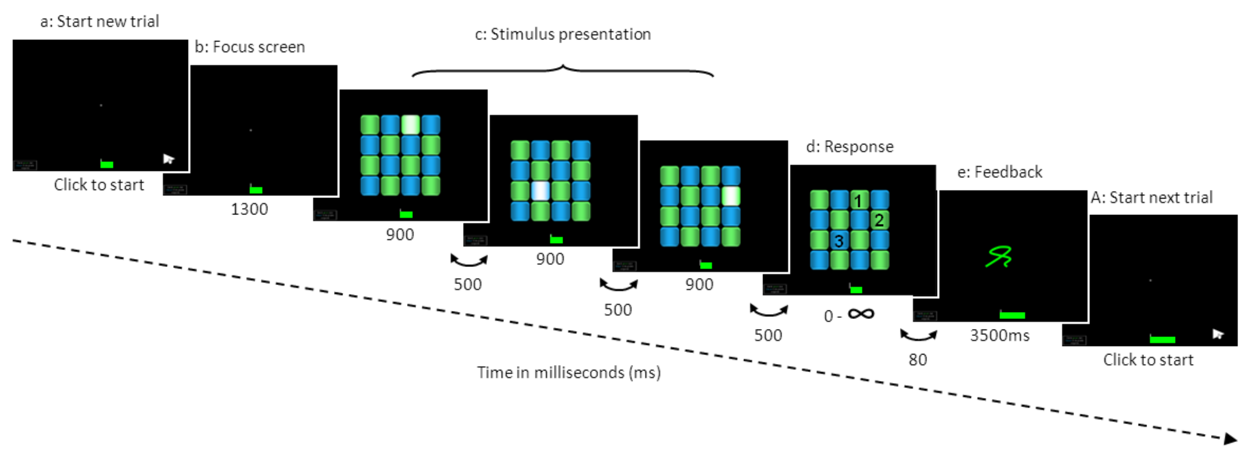

Fig. 1 A trial on the working memory version of the Chessboard task (a) To start a trial the arrowhead-button in the bottom-right corner of the screen has to be clicked. (b) Then the focus screen (a black screen with a little white cross) is presented. (c) Subsequently, a sequence of stimuli (squares that light up) is presented one by one on a 4x4 grid with green and blue squares ordered in a chessboard formation. Each stimulus lights up for 900ms and is followed by an inter-stimulus interval of 500ms. (d) After the stimulus-sequence is presented the participant responds by mouse-clicking on the squares. To respond correctly the presented stimuli have to be reproduced in a reorganized way: The green stimuli have to be reproduced before the blue stimuli; both in the same order as presented (the numbers in picture d show an example of a correct reorganization). (e) After a response feedback is presented. (A) After feedback-presentation, the participant can start the next trial by clicking on the arrowhead button (Dovis et al., 2013). Dimensions of the task (height x width): 4x4 grid (14 x 13.9 cm), individual stimuli (3.4 x 3.2 cm); distances between adjacent stimuli: 0.3 cm between horizontally adjacent stimuli and 0.2 cm between vertically adjacent stimuli (differences between the height and the width were the result of a small 3D-effect in the stimuli).

Reinforcement Conditions

Each participant completed both reinforcement conditions, and each reinforcement condition contained both the STM and WM task (see Footnote 24). In *the feedback-only condition*, children were instructed to do their best and respond as accurately as possible. In *the 10 euros condition*, children were told that they could earn 10 euros if they performed well enough on the task. In both reinforcement conditions, participants received immediate visual and auditory feedback and could monitor their overall performance by means of a ‘performance bar’ (for a detailed description see Dovis et al., 2013 or Appendix 5.1).

Dependent measures. On both task versions, the first 12 trials are required to reach the child's optimal difficulty level and were therefore excluded from analysis (Dovis et al., 2013; 2014 and see Appendix 5.2). Thus, performance on each task was measured by the mean sequence length of the last 18 trials. The reinforcement sensitivity index was defined as the relative difference in mean (STM and WM) performance between the 10 euros condition and the feedback-only condition (i.e. the percentage difference in mean performance as a result of extra reinforcement).[23]

Procedure

The study was approved by the faculty's IRB. The participating mental-healthcare centers sent recruitment letters to the parents of all children aged 8-12 years with a DSM-IV-TR diagnosis of ADHD (all subtypes). The participating elementary schools sent recruitment letters to the parents of all children aged 8-12 years (no matching procedure was applied). If parents were interested to participate they could contact the researchers for more information and to sign up for the study After obtaining informed consent from the parents (on behalf of the participating children), parents and teachers completed the DBDRS. If DBDRS inclusion criteria were met, participants were invited to one 100-minute test-session. During this session's first hour the two reinforcement conditions (feedback-only and 10 euros), each containing the WM and STM version of the chessboard task, were administered, intermitted by a 5-minute break. Thereafter, the WISC-III subtests were administered. In parallel, parents of children with ADHD were interviewed with the PDISC-IV. If the child met the inclusion criteria (s)he was included in the data set. To control for order effects, the order of administration of the reinforcement conditions and the task versions (STM and WM) were counterbalanced separately within groups (resulting in 8 orders of presentation)[24]. No information about the reinforcement conditions was provided before the test-session (e.g., to

[23] Reinforcement sensitivity index = ([WM + STM 10 euros] – [WM + STM FO]) x (100 / [WM + STM 10 euros]). WM = age corrected mean score on WM task; STM = age corrected mean score on STM task; FO = feedback-only condition

[24] Orders of presentation used in counterbalancing :

1.	FO: STM > WM	>	10 euros: STM > WM
2.	10 euros: STM > WM	>	FO: STM > WM
3.	FO: WM > STM	>	10 euros: WM > STM
4.	10 euros: WM > STM	>	FO: WM > STM
5.	FO: STM > WM	>	10 euros: WM > STM
6.	10 euros: STM > WM	>	FO: WM > STM
7.	FO: WM > STM	>	10 euros: STM > WM
8.	10 euros: WM > STM	>	FO: STM > WM

Note: STM = short-term memory, WM = working memory, FO = Feedback-only

avoid expectations of receiving money). Children and their families were not compensated for participating in this study over and above the 10 euros from the high reinforcement condition. Children with ADHD were tested at their mental-healthcare center, TD children at their school. Testing took place between 9 a.m. and 5 p.m. Test rooms were quiet and views from windows were blocked. Specific reinforcement instructions (e.g. *'If you perform well enough on this task you will get these 10 euros'*) were given to the child at the start of each reinforcement condition (for complete instructions *see* description of the reinforcement conditions). During testing an experimenter was present, sitting behind the child pretending to read a book.

Data Analysis

Given the difference in age range between the ADHD-I group (aged 9-12 years) and the ADHD-C and TD groups (aged 8-12 years), task scores were, after checking for normality and outliers[25], adjusted for age using a regression procedure. That is, in the entire sample we regressed task scores on age, and the discrepancy between observed and predicted data was taken as the age-adjusted task score. These age adjusted task scores were used in all analyses.

Prevalence. On the STM- and WM task children with ADHD were characterized as impaired if their age corrected task score fell below the lowest 10th percentile of scores in the TD group. Children with ADHD were characterized as impaired on the reinforcement sensitivity index if their score fell above the 90th percentile of the TD group (this 10% cut-off was also used in Nigg et al., 2005; Sonuga-Barke et al., 2010; Lambek et al., 2011).[26] Group differences were examined using 2-sided Chi-square analyses.

Diagnostic validity. Discriminant analyses were conducted to evaluate the extent to which age adjusted scores on STM and WM tasks in the feedback-only- (FO) and 10 euros conditions, and on the reinforcement sensitivity index accurately discriminated between ADHD-C and controls, between ADHD-I and controls, and between both ADHD groups. Differences were examined using 2-sided Chi-square analyses.

Finally, analyses were conducted comparing clinical and demographic variables between children with ADHD who were classified as either impaired or non-impaired on WM, STM and/or reinforcement sensitivity (based on the 10% cut-off), using MANOVAs or

[25] Participants were excluded from analyses when both of the following criteria were met: (1) a standardized residual on any of the dependent measures with an absolute value greater than 2, and (2) a Cook's distance ≥ 1 (Field, 2005). Based on this criterion none of the participants had to be excluded.

[26] For the sake of completeness prevalence using a 5% cut-off is reported in Appendix 5.3.

Chi-square as appropriate. Partial Eta squared effect sizes (η_p^2) are reported for the MANOVAs: η_p^2 =.01 is regarded a small effect size, .06 a medium effect size, and .14 a large effect size (Kittler, Menard, & Phillips, 2007). For Chi-square analyses phi (Φ) or Cramér's (V) effect sizes are reported (depending on the number of categories): Φ / V = .10 indicates a small effect size, .30 a medium effect size, and .50 a large effect size (Cohen, 1992). Unless otherwise stated, analyses had adequate statistical power (power ≥ .80) to detect at least medium effects.

5.3 Results

Counterbalancing and Mean Scores

The three groups did not differ in the relative number of times that each counterbalancing-order was presented, $\chi^2(14) = 1.83$, $p = .999$, Cramér's V = .07, power to detect a medium effect was .72. Also, including counterbalancing-order as a covariate did not change the results.

Group demographics and age adjusted mean scores for each of the five performance indices (STM performance in both reinforcement conditions, WM performance in both reinforcement conditions, and the reinforcement sensitivity index) are listed in Table 1. For a detailed discussion of comparable mean results see Dovis et al. (2013; 2014).

Table 1

Group demographics, parent and teacher ratings and mean performance differences

Measure	Group								
	ADHD-C		ADHD-I		TD children				
	(n=86)		(n=27)		(n=62)				
	M	SD	M	SD	M	SD	F / χ^2	η_p^2	*Group Comparison* [a, b]
Gender (M : F)	70 : 16	-	18 : 9	-	27 : 35	-	22.9		C = I; TD ≠ C, I
Age (years)	10.4	1.3	11.1	1.1	10.1	1.2	6.9		I > C, TD; C = TD
FSIQ	101	11.2	106	10.5	110	12.6	11.6		I = C, TD; C < TD
DBDRS parent									
Inattention	21.6	4.0	19.0	4.5	2.5	2.4	538.3		TD < I < C
Hyp/Imp	20.7	4.6	7.0	3.4	2.2	2.3	476.4		TD < I < C
ODD	12.4	5.3	5.5	4.4	1.9	2.2	158.1		TD < I < C
CD	2.6	2.3	0.9	1.4	0.1	0.3	41.2		TD = I; C > TD, I
DBDRS teacher									
Inattention	17.2	5.0	15.7	4.9	1.6	1.8	307.5		TD < I, C; I = C
Hyp/Imp	15.6	5.7	2.9	2.5	1.0	1.5	261.0		TD = I; C > TD, I
ODD	9.9	5.8	3.9	2.8	0.7	0.9	93.0		TD < I < C
CD	1.6	2.2	0.3	0.8	0.1	0.2	20.4		TD = I; C > TD, I
Weekly spendable income (in euros)	2.5	2.7	2.3	1.6	1.7	1.1	3.1		I = C, TD; C > TD
Mathematics Disorder (Yes : No)	0 : 86	-	0 : 27	-	0 : 62	-	-		-
Reading Disorder (Yes : No)	6 : 80	-	0 : 27	-	2 : 60	-	2.7		ns (p = .260)
Medication-use (Yes : No)	61 : 25	-	8 : 19	-	-	-	13.8		I ≠ C
WM (age adjusted)									
Feedback-only	5	1.0	5.5	1.0	6.3	0.8	22.4	0.21	C < I < TD
10 euros	5.5	0.8	6	0.8	6.5	0.7	17.4	0.17	C < I < TD
STM (age adjusted)									
Feedback-only	5.3	1.0	5.8	0.9	6.3	0.8	13.0	0.13	TD > C, I; C = I;
10 euros	5.7	0.8	6.2	0.8	6.4	0.6	8.6	0.09	C < TD, I; TD = I
Reinf. sens. index	7.4%	11.1%	6.7%	11.7%	2.2%	9.5%	3.9	0.05	TD < C, I; C = I

Note. I = ADHD-I; C = ADHD-C; TD = typically-developing children; CD = Conduct Disorder; DBDRS = Disruptive Behavior Disorder Rating Scale; FSIQ = full scale IQ; Hyp/Imp = Hyperactivity/Impulsivity; M : F = Male : Female; ODD = Oppositional Defiant Disorder; Reinf. sens. Index = Reinforcement Sensitivity index; STM = Short-term Memory; WM = Working Memory; [a] MAN(C)OVAs were performed. If the overall group-effect was significant (p < .05), additional post-hoc Tukey tests or additional MANCOVAs were performed to clarify the group-differences (for all significant differences p-values were < .01). Nominal data were analyzed with chi-square tests. [b] If an independent measure (i.e. gender, age, FSIQ, parent and teacher ratings, weekly spendable income, or medication use) differed between certain groups (e.g., ADHD-C vs. TD group) it was subsequently used as covariate in the matching group comparison of the performance indices (i.e. the working memory, short-term memory, and reinforcement sensitivity index). Therefore, in analyses of the performance indices, IQ, weekly spendable income and gender were used as covariates when all groups were compared and when ADHD-C was compared to controls; gender was used as covariate when ADHD-I was compared to controls ; and parent-rated inattention, ODD, CD and medication-use were used as covariates when the ADHD groups were compared. Covarying for these independent measures did not change the pattern of the results.

Prevalence of Impairment

To account for the effect of motivational deficits on performance, only WM- and STM performance in the 10 euros condition were used to estimate prevalence of WM and STM impairment (unless otherwise stated). Figure 2 presents the proportion of children with ADHD-C and ADHD-I who met the 10% threshold for an impairment on the WM-, the STM-, and/or the reinforcement sensitivity index. 75.6% of the ADHD-C group, 55.6% of the ADHD-I group, and 27.4% of the TD group had an impairment on any one of these dependent measures, these group differences were significant (ADHD-C vs. TD, $\chi^2(1) = 33.82$, $p < .001$, $\Phi = .48$; ADHD-I vs. TD, $\chi^2(1) = 6.47$, $p < .05$, $\Phi = .27$; ADHD-C vs. ADHD-I, $\chi^2(1) = 3.99$, $p < .05$, $\Phi = .19$).

Next, prevalence of impairment was examined per performance index (see Figure 2):

Working memory: 58.1% of the ADHD-C group, 33.3% of the ADHD-I group, and 9.7% of the TD group was impaired on WM. These group differences were significant (ADHD-C vs. TD, $\chi^2(1) = 35.97$, $p < .001$, $\Phi = .49$; ADHD-I vs. TD, $\chi^2(1) = 7.51$, $p = .012$, $\Phi = .29$; ADHD-C vs. ADHD-I, $\chi^2(1) = 5.07$, $p = .024$, $\Phi = .21$).

Short-term memory: 40.7% of the ADHD-C group, 18.5% of the ADHD-I group, and 9.7% of the TD group was impaired on STM. Except for the difference between the ADHD-I and the TD group, these group differences were significant (ADHD-C vs. TD, $\chi^2(1) = 17.31$, $p < .001$, $\Phi = .34$; ADHD-I vs. TD, $\chi^2(1) = 1.36$, $p = .298$, $\Phi = .12$; ADHD-C vs. ADHD-I, $\chi^2(1) = 4.42$, $p = .036$, $\Phi = .20$).

Reinforcement sensitivity: 22.1% of the ADHD-C group, 22.2% of the ADHD-I group, and 9.7% of the TD group was classified as having an abnormal reinforcement sensitivity (motivational impairment). Only the difference between the ADHD-C and the TD group was significant, but the effect size was comparable to the effect size of the difference between the ADHD-I and TD group (ADHD-C vs. TD, $\chi^2(1) = 3.96$, $p < .05$, $\Phi = .16$; ADHD-I vs. TD, $\chi^2(1) = 2.54$, $p = .174$, $\Phi = .17$; ADHD-C vs. ADHD-I, $\chi^2(1) = .00$, $p = .989$, $\Phi = .001$).

In the ADHD-C group, WM impairments were more prevalent than STM impairments ($\chi^2(1) = 5.23$, $p = .022$, $\Phi = .17$), and both were more prevalent than motivational impairments (WM vs. Motivation, $\chi^2(1) = 23.26$, $p < .001$, $\Phi = .37$; STM vs. Motivation, $\chi^2(1) = 6.91$, $p = .009$, $\Phi = .20$). In the ADHD-I group these differences were non-significant (WM vs. STM, $p = .214$, $\Phi = .17$; WM vs. Motivation, $p = .362$, $\Phi = .12$; STM vs. Motivation, $p = .735$, $\Phi = .05$, power to detect medium effects was .60).

Overlap of impairments: In both ADHD groups there was significant overlap between WM and STM deficits (ADHD-C: $\chi^2(1) = 6.32$, $p = .01$, $\Phi = .27$; ADHD-I: $\chi^2(1) = 6.01$, $p = .03$, $\Phi = .47$; 30.3% of children with ADHD-C and 14.8% of children with ADHD-I were impaired on both indices; see Figure 2). However, overlap between the reinforcement sensitivity index and the memory indices was non-significant (WM and motivation: ADHD-C, $\chi^2(1) = .304$, $p = .581$, $\Phi = .06$; ADHD-I, $\chi^2(1) = .964$, $p = .628$, $\Phi = .19$; STM and motivation: ADHD-C, $\chi^2(1) = .450$, $p = .502$, $\Phi = .07$; ADHD-I, $\chi^2(1) = 1.75$, $p = .555$, $\Phi = .16$), suggesting that these impairments are not associated. However, the power for the analyses of the ADHD-I group was low (power to detect a medium effect was .34).

Prevalence differences between reinforcement conditions: In both ADHD groups prevalence rates of WM- and STM impairments were not significantly influenced by type of reinforcement condition (ADHD-C: WM 10 euros [58.1% prevalence] vs. WM FO [50%], $\chi^2(1) = 1.15$, $p = .284$, $\Phi = .08$; STM 10 euros [40.7%] vs. STM FO [54.7%], $\chi^2(1) = 3.36$, $p = .067$, $\Phi = .14$; ADHD-I: WM 10 euros [33.3%] vs. WM FO [37%], $\chi^2(1) = .081$, $p = .776$, $\Phi = .04$; STM 10 euros [18.5%] vs. STM FO [25.9%], $\chi^2(1) = .429$, $p = .513$, $\Phi = .09$, the power to detect a medium effect for the ADHD-I group was .60), but note the trend for the effect of reinforcement on the prevalence of STM impairments in the ADHD-C group.

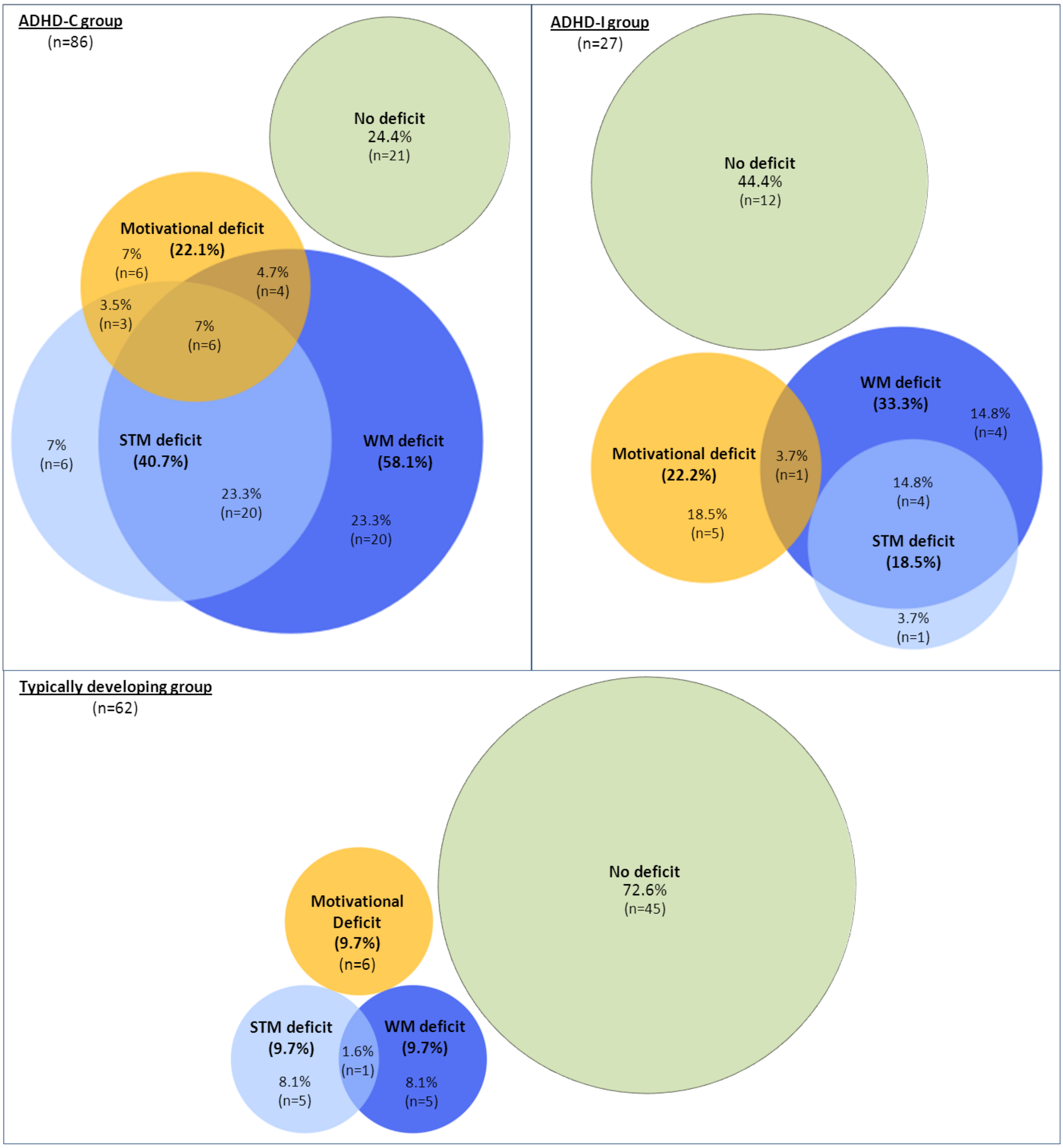

Fig. 2 Proportion of the ADHD-C, ADHD-I and TD children with visuospatial working memory- (WM), visuospatial short-term memory- (STM) (based on performance in the high reinforcement condition), and motivational deficits (i.e. abnormal reinforcement sensitivity), and their degree of co-occurrence.[27]

[27] Totals may not equal 100% because of rounding

Discriminant Analyses

Multiple discriminant analyses were conducted to evaluate the extent to which the five age corrected performance indices could accurately discriminate between the groups (see Table 2).

Table 2

Classification rates based on the age corrected performance measures

Measures included in discriminant analyses	Group comparison								
	ADHD-C vs. TD children (n=148)			ADHD-I vs. TD children (n=89)			ADHD-C vs. ADHD-I (n=113)		
	Correct ADHD-C classif.	Correct TD child classif.	Correct overall classif.	Correct ADHD-I classif.	Correct TD child classif.	Correct overall classif.	Correct ADHD-C classif.	Correct ADHD-I classif.	Correct overall classif.
All measures	76.7%	83.9%	79.7%*	66.7%	72.6%	70.8%*	65.1%	59.3%	63.7%
Working memory									
Feedback-only	73.3%	85.5%	78.4%*	63%	74.2%	70.8%*	52.3%	63%	54.9%*
10 euros	74.4%	75.8%	75.0%*	55.6%	66.1%	62.9%*	62.8%	63%	62.8%*
Short-term memory									
Feedback-only	66.3%	75.8%	70.3%*	70.4%	62.9%	65.2%*	61.6%	63%	61.9%*
10 euros	70.9%	72.6%	71.6%*	59.3%	64.5%	62.9%	62.8%	59.3%	61.9%*
Reinf. sens. index	53.5%	62.9%	57.4%*	55.6%	61.3%	59.6%†	40.7%	55.6%	44.2%

Note. TD = typically-developing children; Correct ADHD classif. = correctly classified children with ADHD; Correct TD child classif. = correctly classified TD children; Correct overall classif. = Overall correct classification of group membership; All measures = using the five indices; both short-term memory and working memory tasks in both reinforcement conditions and the motivational index; Reinf. sens. index = Reinforcement sensitivity index; * Wilks's Lambda was significant ($p < .05$); † $p = .06$.

ADHD-C vs. TD children. First, the five indices were entered in the analysis together (see Table 2). The overall Wilks's Lambda was significant ($\Lambda = .61$, $\chi^2(5, N = 148) = 72.23$, $p < .001$). Canonical variate correlation coefficients for the five indices were: WM FO (.88), WM 10 euro (.81), STM FO (.66), STM 10 euro (.60), reinforcement sensitivity index (-.30). The higher the absolute value of the coefficient, the more the dependent measure contributes

to group separation; positive and negative coefficients contribute to group separation in opposite ways.

Next, separate discriminant analyses were run to investigate how useful each single measure was at discriminating between the ADHD-C and TD group. Wilks's Lambda was significant for each measure[28], suggesting that each of these measures significantly discriminates between the ADHD-C and TD group. Classification rates for these measures are shown in Table 2. The overall correct classification rates based on WM performance (WM FO = 78.4%; WM 10 euros = 75%) or STM performance (STM FO = 70.3%; STM 10 euros = 71.6%) were not significantly influenced by the amount of reinforcement (WM FO vs. WM 10 euros, $\chi^2(1) = .47$, $p = .492$, $\Phi = .04$; STM FO vs. STM 10 euros, $\chi^2(1) = .066$, $p = .798$, $\Phi = .02$), suggesting that the diagnostic validity of WM performance and STM performance does not change when motivation is taken into account.

The reinforcement sensitivity index provided a significantly worse overall classification rate (57.4%) than all other indices (Motivation vs. WM FO, $\chi^2(1) = 14.90$, $p < .001$, $\Phi = .22$; Motivation vs. WM 10 euros, $\chi^2(1) = 10.21$, $p = .001$, $\Phi = .19$; Motivation vs. STM FO, $\chi^2(1) = 5.28$, $p = .022$, $\Phi = .13$; Motivation vs. STM 10 euros, $\chi^2(1) = 6.51$, $p = .011$, $\Phi = .15$).

ADHD-I vs. TD children. When the five indices were entered in the analysis together, Wilks's Lambda was significant ($\Lambda = .82$, χ^2 (5, $N = 89$) = 16.88, $p = .005$, power for this analysis to detect a medium effect was .56). Canonical variate correlation coefficients were: WM FO (.91), WM 10 euro (.74), STM FO (.58), STM 10 euro (.36), reinforcement sensitivity index (-.43).

Next, separate discriminant analyses were run for each single measure. Wilks's Lambda was not significant for STM performance in the 10 euros condition ($p = .121$), nor for the reinforcement sensitivity index (although there was a trend; $p = .06$), suggesting that these measures do not significantly discriminate between the ADHD-I group and the TD group. For all other measures Wilks's Lambda was significant.[29] Classification rates are shown in Table 2. The overall correct classification rates based on WM performance (WM FO = 70.8%; WM 10 euros = 62.9%) or STM performance (STM FO = 65.2%; STM 10 euros = 62.9%) were

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[28] WM FO, $\Lambda = .67$, χ^2 (1, $N = 148$) = 59.12, $p < .001$; WM 10 euros, $\Lambda = .70$, χ^2 (1, $N = 148$) = 52.25, $p < .001$; STM FO, $\Lambda = .78$, χ^2 (1, $N = 148$) = 36.25, $p < .001$; STM 10 euros, $\Lambda = .81$, χ^2 (1, $N = 148$) = 30.73, $p < .001$; reinforcement sensitivity index, $\Lambda = .94$, χ^2 (1, $N = 148$) = 8.42, $p = .004$.

[29] WM FO, $\Lambda = .85$, χ^2 (1, $N = 89$) = 14.57, $p < .001$; WM 10 euros, $\Lambda = .89$, χ^2 (1, $N = 89$) = 9.80, $p = .002$; STM FO, $\Lambda = .93$, χ^2 (1, $N = 89$) = 6.26, $p = .012$

not significantly influenced by the amount of reinforcement (WM FO vs. WM 10 euros, $\chi^2(1) = 1.24$, $p = .265$, $\Phi = .08$; STM FO vs. STM 10 euros, $\chi^2(1) = .098$, $p = .755$, $\Phi = .02$), suggesting that the diagnostic validity of WM performance and STM performance does not change when motivation is taken into account.

The overall correct classification rate of the reinforcement sensitivity index (59.6%) was not significantly different from other indices (Motivation vs. WM FO, $\chi^2(1) = 2.48$, $p = .116$, $\Phi = .12$; Motivation vs. WM 10 euros, $\chi^2(1) = .21$, $p = .644$, $\Phi = .04$; Motivation vs. STM FO, $\chi^2(1) = .60$, $p = .439$, $\Phi = .06$; Motivation vs. STM 10 euros, $\chi^2(1) = .21$, $p = .644$, $\Phi = .04$).

ADHD-C vs. ADHD-I. When the five indices were entered in the analysis together, Wilks's Lambda was not significant, $\Lambda = .92$, χ^2 (5, $N = 113$) = 9.38, $p = .095$; but note that the power to detect a medium effect was .69. Canonical variate correlation coefficients for the five indices were: WM FO (-.70), WM 10 euro (-.85), STM FO (-.72), STM 10 euro (-.84), reinforcement sensitivity index (.09).

Next, separate discriminant analyses were run for each single measure. Wilks's Lambda was not significant for the reinforcement sensitivity index ($p = .771$), suggesting that this measure did not significantly discriminate between the ADHD groups. For all other measures Wilks's Lambda was significant.[30] Classification rates are shown in Table 2. The overall correct classification rates based on WM performance (WM FO = 54.9%; WM 10 euros = 62.8%) or STM performance (STM FO = 61.9%; STM 10 euros = 61.9%) were not significantly influenced by the amount of reinforcement (WM FO vs. WM 10 euros; $\chi^2(1) = 1.48$, $p = .224$, $\Phi = .08$; STM FO vs. STM 10 euros; $\chi^2(1) = .00$, $p = 1.00$, $\Phi = .00$).

Comparing Impaired vs. Non-Impaired Children with ADHD

Of all independent variables (see Table 1), only teacher-rated inattention on the DBDRS, medication-use, and IQ differed significantly between impaired[31] and non-impaired children with ADHD-C (power to detect medium effects was .59). Teacher-rated inattention and medication-use were higher in impaired children (DBDRS-score = 18.2 vs. 15.8, $p = .026$, $\eta_p^2 = .07$; medication-use = 75.4% vs. 38.1%, $p = .002$), and IQ was lower in impaired children

[30] WM FO, $\Lambda = .96$, χ^2 (1, $N = 113$) = 4.71, $p = .030$; WM 10 euros, $\Lambda = .94$, χ^2 (1, $N = 113$) = 6.96, $p = .008$; STM FO, $\Lambda = .96$, χ^2 (1, $N = 113$) = 5.09, $p = .024$; STM 10 euros, $\Lambda = .94$, χ^2 (1, $N = 113$) = 6.88, $p = .009$

[31] Impaired on WM (10 euros), and/or STM (10 euros), and/or reinforcement sensitivity; using the 10% cut-off

(99 vs. 107 points; p = .002, η_p^2 = .11). Subdividing the impaired ADHD-C sample into a memory impaired (only impaired on WM and/or STM) and a motivationally impaired group did not reveal specific memory- or motivation-related effects (but power to detect medium effects was .60). No differences were found between impaired and non-impaired children with ADHD-I, but sample sizes were too small (power to detect medium effects was only .13). For correlations between ADHD symptoms and performance on the indices see Appendix 5.4.

5.4 Discussion

This study investigated (1) the prevalence and diagnostic validity of visuospatial WM and STM impairments in children with ADHD when motivational deficits are taken into account, (2) the prevalence and diagnostic validity of reinforcement sensitivity deficits in children with ADHD, and (3) whether the prevalence and diagnostic validity of these impairments differ between ADHD subtypes. Exploratively, differences between the impaired (see Footnote 31) and unimpaired children with ADHD-C and ADHD-I were examined.

The present findings showed that when motivational deficits of children with ADHD were taken into account, both WM and STM impairments were more prevalent in the ADHD-C group than in the ADHD-I and TD group. In the ADHD-I group, only WM impairments, not STM impairments, were more prevalent than in the TD group. In the discriminant analyses the same pattern of results was found. In general, correct classification- and prevalence rates were not significantly affected by the type of reinforcement condition, except that STM performance only discriminated between ADHD-I and TD children in the feedback-only condition. In both ADHD groups there was a significant association between WM and STM impairments, but these memory impairments were not associated with deficits in reinforcement sensitivity (although power for the analysis in the ADHD-I group was low). Reinforcement sensitivity deficits were equally prevalent in both ADHD groups, but only in the ADHD-C group this deficit was significantly more prevalent than in the TD group. In children with ADHD-C, this motivational deficit was less prevalent than impairments of WM and STM. The reinforcement sensitivity index only discriminated significantly between ADHD-C and TD children (although there was a trend for ADHD-I and TD children), and its predictive power was significantly lower than that of either WM or STM performance. Children with ADHD-C who were classified as impaired (see Footnote 31) had more teacher-rated inattention symptoms, were more likely to use ADHD medication, and had lower IQ scores.

Memory

With motivation taken into account, 58.1% of the children with ADHD-C were found to be impaired on visuospatial WM. This prevalence rate is somewhat higher than that of the only other study that examined the prevalence of visuospatial WM in ADHD (Lambek et al., 2011; where 29-47% of the ADHD sample was found impaired). Our findings suggest that this difference might be related to the fact that Lambek et al., did not differentiate between ADHD subtypes; since the prevalence of WM impairments was significantly higher in ADHD-C than in ADHD-I (58.1% vs. 33.3%). Further, our finding suggests that visuospatial WM impairments are at least as prevalent in children with ADHD-C as other 'key' neuropsychological dysfunctions (prevalence of inhibition, 45-51%; reaction time variability, 44-48%; delay aversion, 14-56%; e.g., Nigg et al., 2005; Sjöwall et al., 2013; Solanto et al., 2001; Sonuga-Barke et al., 2010), and are more prevalent than phonological WM impairments (27-35% impaired; Lambek et al., 2011). These findings further suggest that impaired visuospatial WM may indeed be a core causal executive process for a majority of children with ADHD-C (Rapport et al., 2001). However, at the same time, these results support models and previous findings which suggest that ADHD is a neuropsychologically heterogeneous disorder that cannot be characterized by a single core dysfunction (Biederman et al., 2004; Fair et al., 2012; Lambek et al., 2010; 2011; Nigg et al., 2005; Pineda et al., 2007; Sjöwall et al., 2013; Sonuga-Barke et al., 2010). Furthermore, although WM impairments in ADHD-I were less prevalent than in ADHD-C, they were more prevalent than in the TD group, and WM performance significantly discriminated between ADHD-I and TD children, suggesting that visuospatial WM deficits may also cause problems in a substantial part (33.3%) of the ADHD-I population.

This is the first study to investigate the prevalence of visuospatial STM impairments in children with ADHD. In children with ADHD-C, STM impairments were less common than WM impairments (40.7% vs. 58.1% impaired). Furthermore, we found that about half of the WM-impaired children with ADHD-C could not be classified as STM-impaired. Since WM capacity is regarded as the sum of both STM- and central executive capacity (Engle, Tuholski, Laughlin, & Conway, 1999), this finding suggests that about half of the cases with visuospatial WM impairments in the ADHD-C population are not the result of visuospatial STM impairments, but are solely caused by impairments in their central executive. In the other half of the cases WM impairments may be the result of STM impairments only, or of a combination of STM and central executive impairments. To examine this, future prevalence

studies should include an additional task: one that only measures central executive performance.[32]

Although less prevalent than WM impairments, more than 40% of the ADHD-C group was impaired on STM, and STM performance correctly discriminated between ADHD-C and TD children in 71.6% of the cases. This suggests that STM impairments may give rise to ADHD-related problems in a substantial part of the ADHD-C population. In contrast, STM impairments were not more prevalent in the ADHD-I group than in the TD group, nor did STM performance significantly discriminate between these samples (at least not when the confounding effect of motivation was taken into account). These results are in line with the theoretical appraisal by Diamond (2005) and with recent studies which suggest that children with ADHD-I, in contrast to children with ADHD-C, are especially impaired on the central executive component, but not on the STM component of WM (Diamond, 2005; Dovis et al., 2014; Martinussen & Tannock, 2006). Furthermore, STM performance only discriminated between ADHD-I and TD children in the feedback-only condition, not in the high reinforcement condition. This suggests that impaired STM performance in children with ADHD-I results from insufficient motivation to perform (also see Dovis et al., 2014), and promotes the use of additional incentives in studies that investigate STM in children with ADHD-I.

Motivation

Although both theory (e.g., Haenlein & Caul, 1987; Sergeant et al., 1999) and research (Luman et al., 2005; 2010; also see Dovis et al., 2012; 2013; Strand et al., 2012) suggest that an abnormal sensitivity to reinforcement is characteristic of children with ADHD on a group level, our findings show that this motivational impairment, apart from being a valid and distinct impairment, is actually not so common among these children (only 22% were classified as impaired). De Zeeuw et al. (2012) found an even lower prevalence rate (less than 8% impaired), but this difference in results probably is related to a difference in reward frequency schedules: It has been suggested that high reward frequency schedules attenuate reinforcement sensitivity problems in children with ADHD (Sagvolden et al., 2005; de Zeeuw et al., 2012) and reward frequency was much higher in the study of de Zeeuw et al. (80% of the trials were rewarded, compared to 55% of the trials in our study). Although further expansion of our research design was not possible in our current study (e.g., increasing testing

[32] Future studies should be aware that impaired inhibitory performance can also have a small impact on the central executive performance of children with ADHD (see Alderson et al., 2010).

time would potentially have impacted the sustained attention, motivation and performance of our participants), it would be interesting for future studies to explore the effects of different reward frequencies on the prevalence of reinforcement sensitivity problems in children with ADHD (e.g., by adding a condition where only a minority of the trials is rewarded, or a condition without reinforcement).

Reinforcement sensitivity deficits were equally prevalent in both ADHD subtypes, but only in the ADHD-C group this impairment was significantly more prevalent than in the TD group, and the reinforcement sensitivity index did not discriminate significantly between ADHD-I and TD children. These findings are consistent with theories stating that motivational abnormalities characterize the combined subtype only (Sagvolden et al., 2005), and contradict theories stating they apply to the inattentive subtype in particular (Diamond, 2005). However, we found a trend towards significance ($p = .06$) for the reinforcement sensitivity index to discriminate between ADHD-I and TD children, which suggests that this difference would have been significant in a study with higher statistical power. Future studies should test this hypothesis using a more substantial ADHD-I sample. Based on our current results, we can conclude that reinforcement/reward sensitivity deficits are not so common in children with ADHD (e.g., less common than memory impairments in ADHD-C), and seem equally prevalent in both ADHD subtypes.

Memory and Motivation

To our knowledge our data provide the first evidence that impairments in visuospatial WM and STM in ADHD are dissociable from impairments in reinforcement sensitivity. This absence of associations across motivational and memory domains highlights the neuropsychological heterogeneity in ADHD and supports recent evidence suggesting separable neuropsychological subtypes in ADHD (e.g., Fair et al., 2012; Sonuga-Barke et al., 2010; de Zeeuw et al., 2012). In this context our findings are especially strong since they are based on neuropsychological measures that were probably not confounded by motivational deficits. Furthermore, the absence of overlap between memory and reinforcement sensitivity suggests that the combined assessment of these domains may contribute to improved neuropsychological differentiation of ADHD. Nonetheless, it must be noted that this absence of associations between deficits in motivation and memory was also found in controls. This suggests that the neuropsychological heterogeneity in ADHD may be a derivative of normal variation (see also Fair et al., 2012).

Correlates of Impairments on WM, STM and/or Reinforcement Sensitivity

Children with ADHD-C who were classified as impaired on WM, STM, and/or reinforcement sensitivity had more teacher-rated inattention symptoms, were more likely to use ADHD medication (methylphenidate), and had lower IQ scores than their unimpaired ADHD-C peers (for the ADHD-I group power was inadequate to interpret this analysis).

This seems consistent with models that suggest that inattentiveness results from WM dysfunctions (Barkley, 2006; Rapport et al., 2001) and with previous studies demonstrating that inattention, not hyperactivity/ impulsivity, is associated with neuropsychological impairment in children with ADHD (Bauermeister, Barkley, Bauermeister, Martínez, & McBurnett, 2012; Biederman et al., 2004; Tillman, Eninger, Forssman, & Bohlin, 2011; Wåhlstedt et al., 2009; Willcutt et al. 2012). However, because this was a cross-sectional study it is difficult to make causal inferences. Further, it is unclear why impairment was only associated with teacher-rated inattention, not with parent-rated inattention.

Impaired children with ADHD-C (on WM, STM and/or reinforcement sensitivity) were more likely to be treated with methylphenidate (75.4% vs. 38.1% medication-use). This is in line with evidence (in normal adults) suggesting that the effectiveness of dopaminergic medication can be predicted by WM performance in an un-drugged state (Cools & D'Esposito, 2011), and might be explained by the finding that WM capacity predicts baseline levels of dopamine synthesis in the striatum (Cools, Gibbs, Miyakawa, Jagust, & D'Esposito, 2008). Future studies should investigate this in ADHD, using larger samples (particularly for ADHD-I) to better differentiate between memory and motivational impairments (especially since there also is a strong relationship between dopamine synthesis and motivation; see Cools et al., 2008).

Our finding that WM, STM and/or reinforcement sensitivity impairments in ADHD-C are associated with lower IQ scores is in line with previous ADHD prevalence studies (Lambek et al., 2010; de Zeeuw et al., 2012), and with findings in TD children (e.g., Swanson, 2008). Further, it supports the assumption that WM is crucial for the mental activities basic to children's intelligence (Swanson, 2008), and is consistent with the idea that neuropsychological impairments (e.g., in WM) are responsible for the lower level of intellectual performance typically found in children with ADHD (Barkley, 2006). [33]

[33] In ADHD-C only the mean IQ score of the impaired subsample was sign. lower than that of the TD group.

Limitations

The sample size of the ADHD-I group was relatively small (n=27) and as a result some of the analyses (especially the within-group analyses) were underpowered (i.e., power was inadequate to detect medium effects). Therefore the underpowered null findings in the ADHD-I group should be interpreted with caution (due to the possibility of type II error). Although it must be noted that effect sizes of the underpowered null findings were small, future studies should use a larger sample size to replicate the findings in the ADHD-I group.

Another potential limitation may have been the difference in IQ and weekly spendable income between the ADHD-C and the TD group, and the difference between the TD group and the ADHD groups on gender. However, in ADHD-TD group comparisons, covarying for these independent variables did not change the pattern of the mean results (see Table 1). Further, the ADHD groups differed on parent-rated inattention on the DBDRS. However, in ADHD group-comparisons, covarying for this inattention score did not change the mean results (see Table 1).This suggests that our outcomes were not confounded by this difference in inattention. In addition, the ADHD groups did not differ on teacher-rated inattention.

Although all children discontinued their ADHD medication at least 24 hours before testing (allowing a complete wash-out), there was a difference between the ADHD groups in prior medication use: medication use was more common in ADHD-C. However, since evidence suggests that performance on WM measures is not influenced by the chronic use of ADHD medication (Coghill, Rhodes, & Matthews, 2007), and because including medication use as a covariate did not change the pattern of our mean results, we assume that the outcome of this study was not confounded by this difference in prior medication use.

Although all children were screened for externalizing disorders, ASD, learning disorders (i.e., reading disorder and mathematics disorder) and intellectual disabilities (i.e., an IQ score ≥ 80), and control children were only included in the study if their parents stated they had no prior or current DSM-IV-TR diagnosis (other than a reading disorder or a mathematics disorder), participants were not specifically screened for internalizing disorders such as anxiety or depressive disorders. However, evidence suggests that anxiety and depressive disorders can affect WM performance in typically developing groups (e.g., Ferrin & Vance, 2014; Hadwin, Brogan, & Stevenson, 2005; Rose & Ebmeier, 2006; Vance, Ferrin, Winther, & Gomez, 2013; Walsh et al., 2007), and there is some (although conflicting) evidence regarding the effect of comorbid anxiety or depression on the working memory performance of children with ADHD (e.g., see Ferrin & Vance, 2014; Mayes, Calhoun, Chase, Mink, & Stagg, 2009; Sarkis, Sarkis, Marshall, & Archer, 2005; Schatz & Rostain,

2006; Vance et al., 2013). There is also recent evidence suggesting that high levels of anxiety and depression can differentially modify WM performance according to ADHD subtype (Ferrin & Vance, 2014). Interestingly, it is suggested that emotional states (e.g., anxiety) interact with cognitive functioning through motivation (Pessoa, 2009). However, little is known about this interaction in children with ADHD [but see Ferrin & Vance, 2014]. Therefore, future prevalence studies investigating ADHD subtype differences in WM, STM and/or motivational deficits should also assess and examine effects of symptoms of anxiety and depression.

A strong point of the current study is that we investigated the prevalence and diagnostic validity of WM and STM impairments in children with ADHD by using measures that were probably not confounded by motivational deficits (i.e., as strong incentives were used to optimize performance[34]). Nonetheless, the prevalence and diagnostic validity of many other important ADHD-associated neuropsychological dysfunctions are still not examined in this way. For example, we are unaware of studies that investigate the prevalence and diagnostic validity of impairments in inhibition or sustained attention in children with ADHD by using measures that are not likely to be confounded by motivational deficits. Future prevalence and diagnostic validity studies should therefore adapt their neuropsychological assessment tools to account for these motivational deficits in children with ADHD.

We did not specifically investigate the extent to which problems with sustained attention impacted the WM and STM performance of children with ADHD. However, we did control for situational factors (e.g., test rooms were quiet and views from windows were blocked) and cognitive factors (e.g., the task versions were self-paced for optimal attention/vigilance) that could provoke lapses of attention. Moreover, in a previous study (Dovis et al., 2012), where we used the same WM task, we found that a 10 euros reinforcement condition (the same as in the current study) normalized the sustained attention of children with ADHD (i.e., if children with ADHD were motivated with 10 euros, their mean WM performance was as stable over time as the WM performance of controls). Because the WM and STM-related results in the current study were mainly based on performance in the 10 euros condition, we assume that these results were not confounded by problems with sustained attention in children with ADHD. This assumption is also substantiated by the slopes of the figures in Appendix 5.2.

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[34] The 10 euros condition was previously found to optimize task performance in children with ADHD-C (Dovis et al., 2013).

In the current study we only investigated the effects of immediate reinforcement. However, as the prevalence of delay aversion in children with ADHD might be at least as high as the prevalence of immediate reinforcement deficits (e.g., see Sonuga-Barke et al., 2010; Sjöwall et al., 2013), it would be interesting to also investigate the impact of delayed reinforcement on the prevalence and diagnostic validity of WM and STM impairments in children with ADHD-I and ADHD-C (especially as there might be some conceptual overlap between delay aversion and memory; e.g., see Sjöwall et al., 2013; but also see Sonuga-Barke, Dalen, & Remington, 2003).

Clinical Implications

First of all, it should be noted that 24.4% of the children with ADHD-C and no less than 44.4% of the children with ADHD-I showed no impairment on any of the investigated indices (WM, STM, or reinforcement sensitivity). Furthermore, clinicians should be aware that although all these indices discriminated significantly between children with ADHD-C and TD children, only the WM and STM measures showed clinically acceptable diagnostic validity, with both sensitivity and specificity being ≥70% (as was recommended by Glascoe & Squires, 2007). In addition, based on these guidelines, none of the indices showed acceptable diagnostic validity to distinguish children with ADHD-I from TD children, or to distinguish between the ADHD subtypes. Moreover, when it comes to distinguishing children with ADHD-C from TD children, the diagnostic validity of ADHD rating scales is, at this point, still much better (with correct overall classification rates of 90-95%, Conners, 1999) than that of any neuropsychological task (including visuospatial WM or STM measures). As such, measures of visuospatial WM, visuospatial STM or reinforcement sensitivity are not the best choice for making DSM-oriented ADHD diagnoses in children (especially not for diagnosing ADHD-I). That said, a majority of children with ADHD-C is characterized by a visuospatial memory and/or motivational impairment, and assessment of these impairments may (independently) provide information about possible causal mechanisms of the ADHD behavior of an individual child (e.g., the association between his/her low WM and his/her classroom inattention problems), and can help clinicians choose the best approach for treatment. For example, it may help clinicians choose the best treatment approach within behavioral parent- and teacher training[35] (e.g., using reward systems versus techniques to

[35] These evidence-based interventions (Pelham & Fabiano, 2008; Evans, Owens, & Bunford, 2014) aim at improving behavioral control in children with ADHD by teaching parents and teachers to use token (reward) systems and techniques to unburden the WM of these children (e.g., providing

unburden WM; only a minority of children with ADHD-C may require an intensive reward system, whereas a majority of these children require strategies to unburden WM and have less need for an additional intensive reward system), or may help determine the relevance of a neuropsychological training program (like STM or WM training) for an individual child with ADHD. In line with this, our results imply that interventions such as Cogmed working memory training, of which there is debate as to whether mainly short-term memory is trained (e.g., Shipstead, Hicks, & Engle, 2012), should focus more on training the central executive, especially in children with ADHD-I.

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reminders and a structured environment).

Appendix Chapter 5

Appendix 5.1

Detailed description of the reinforcement conditions (from Dovis et al., 2013).

Reinforcement conditions

There are two reinforcement conditions (Feedback-only and 10 euros) that both contain the short-term memory version and the working memory version of the Chessboard task. Both reinforcement conditions and the task versions within these conditions are presented in counterbalanced order. For both reinforcement conditions the procedure is as follows: after a brief introduction the task version (short-term memory or working memory) that will be presented first in the reinforcement condition starts with a practice block (of about 5 trials). Next, the first instruction of the reinforcement condition is presented (*see* Appendix A & C). After this instruction, 30 trials of the first task version are presented. After the first task version is completed, the second task version in the reinforcement condition is introduced and practiced. Next, the second instruction of the reinforcement condition is presented (*see* Appendix B & D). After this second instruction 30 trials of the second task version are presented. When the second task version of the first presented reinforcement condition is completed (and after a 5 minute break), the remaining reinforcement condition (also containing the two task versions) is administered using the same procedure.

In *the feedback-only (FO) condition*, children are instructed to do their best and respond as accurately as possible. In the second instruction they are also told that when the task is finished, a purple screen will appear (*see* Appendix A & B).

In *the 10 euros condition*, children are told that they can earn 10 euros if they perform well enough on the task. Then, the euro coins which can be earned are shown and placed in sight above the laptop keyboard (the coins remain there during both task versions). The child is told that the euros can only be gained if (s)he makes enough correct responses and not too many incorrect responses. The child is told that the computer randomly decides the required amount of correct and incorrect responses. Further, the child is told that if enough correct responses are made, the task will immediately end with a green screen indicating that the euros are won, but that if too many incorrect responses are made, the task will immediately end with a red screen indicating that the euros are lost (for verbatim instructions see Appendix C & D). Although participants are made to believe that their immediate performance directly influences their chance of winning the euros and that every incorrect or correct response can

immediately end the task with a red or a green screen, in reality the reinforcement condition always ends with the green screen and after both task versions are completed; thus, participants always received the money.

In both the FO condition and the 10 euros condition, participants received immediate visual and auditory feedback and could monitor their overall performance by means of a 'performance bar'. The performance bar was always visible at the bottom of the screen. In the FO and the 10 euros condition, feedback consisted of the same sounds (a positive guitar sound for correct trials and a negative buzzer sound for incorrect trials), the same distance of adaptation of the performance bar, and of comparable pictures (*see* Figure A).

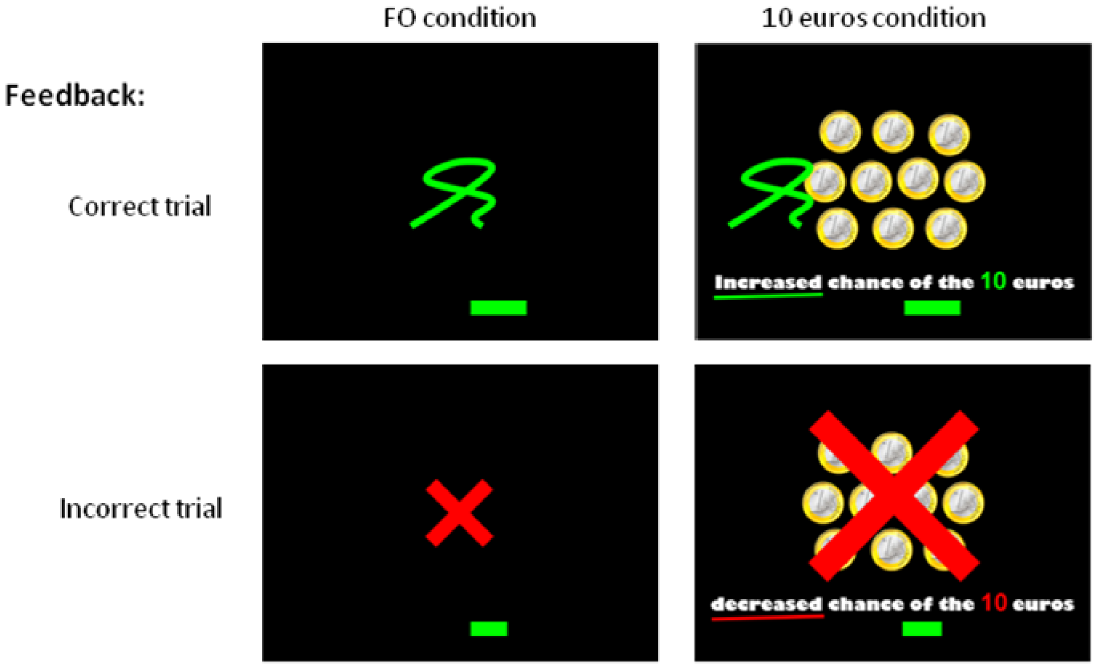


Fig. A Visual feedback in the Feedback-Only (FO) and 10 euros condition (from Dovis et al., 2013)

A. The reinforcement instruction for the first presented task version in the Feedback-Only condition (translated from Dutch; from Dovis et al., 2013):

> **On this task, do your best and try to perform as accurately as possible.**
>
> **If you reproduce a sequence of squares correctly, a green curl will appear on the screen.**
>
> **If you reproduce a sequence of squares incorrectly, a red cross will appear on the screen.**
>
> You can also monitor how you are doing by looking at the bar at the bottom of the screen.
>
> If you reproduce a sequence correctly the bar gets longer, and if you reproduce a sequence incorrectly the bar gets shorter.

B. The reinforcement instruction for the second presented task version in the Feedback-Only condition (translated from Dutch; from Dovis et al., 2013):

> **On this task, do your best and try to perform as accurately as possible.**
>
> **If you reproduce a sequence of squares correctly, a green curl will appear on the screen.**
>
> **If you reproduce a sequence of squares incorrectly, a red cross will appear on the screen.**
>
> You can also monitor how you are doing by looking at the bar at the bottom of the screen.
>
> If you reproduce a sequence correctly the bar gets longer, and if you reproduce a sequence incorrectly the bar gets shorter.
>
> **When the task is finished, a purple screen will appear.**

C. The reinforcement instruction for the first presented task version in the 10 euros condition (translated from Dutch; from Dovis et al., 2013):

With this task, you can earn these 10 euros

(instructor shows euros and places them in sight above the laptop keyboard).

If you have earned these 10 euros, you can take them home and do with them what you want:

These 10 euros are then yours.

You can earn these 10 euros by performing well enough on this task

If you reproduce a sequence of squares correctly, a green curl will appear on the screen with a picture of the 10 euros next to it. This indicates that you have an increased chance to get these 10 euros.

If you reproduce a sequence of squares incorrectly, a red cross will appear on the screen with a picture of the 10 euros behind it. This indicates that you have a decreased chance to get these 10 euros.

Only when you have made enough correct reproductions a green screen will appear: You are then finished with the task, and you can take the 10 euros home and keep them.

But beware. If you make too many incorrect reproductions, a red screen will immediately appear: Then you will also be finished with the task, but you will not get the 10 euros (then I'll take back the 10 euros).

I don't know how many correct reproductions are required to get a green screen or how many incorrect reproductions are required to get a red screen; the computer decides this randomly.

You can also monitor how you are doing by looking at the bar at the bottom of the screen.

If you reproduce a sequence correctly the bar gets longer, and if you reproduce a sequence incorrectly the bar gets shorter.

D. The reinforcement instruction for the second presented task version in the 10 euros condition (translated from Dutch; from Dovis et al., 2013):

Only by performing well enough on this last part of the task you can earn these 10 euros.

<u>You will now go on to the last part of the task and the following still applies:</u>

If you have earned these 10 euros, you can take them home and do with them what you want:

These 10 euros are then yours.

You can earn these 10 euros by performing well enough on this task

If you reproduce a sequence of squares correctly, a green curl will appear on the screen with a picture of the 10 euros next to it. This indicates that you have an increased chance to get these 10 euros.

If you reproduce a sequence of squares incorrectly, a red cross will appear on the screen with a picture of the 10 euros behind it. This indicates that you have a decreased chance to get these 10 euros.

Only when you have made enough correct reproductions a green screen will appear: You are then finished with the task, and you can take the 10 euros home and keep them.

But beware. If you make too many incorrect reproductions, a red screen will immediately appear: Then you will also be finished with the task, but you will not get the 10 euros (then I'll take back the 10 euros).

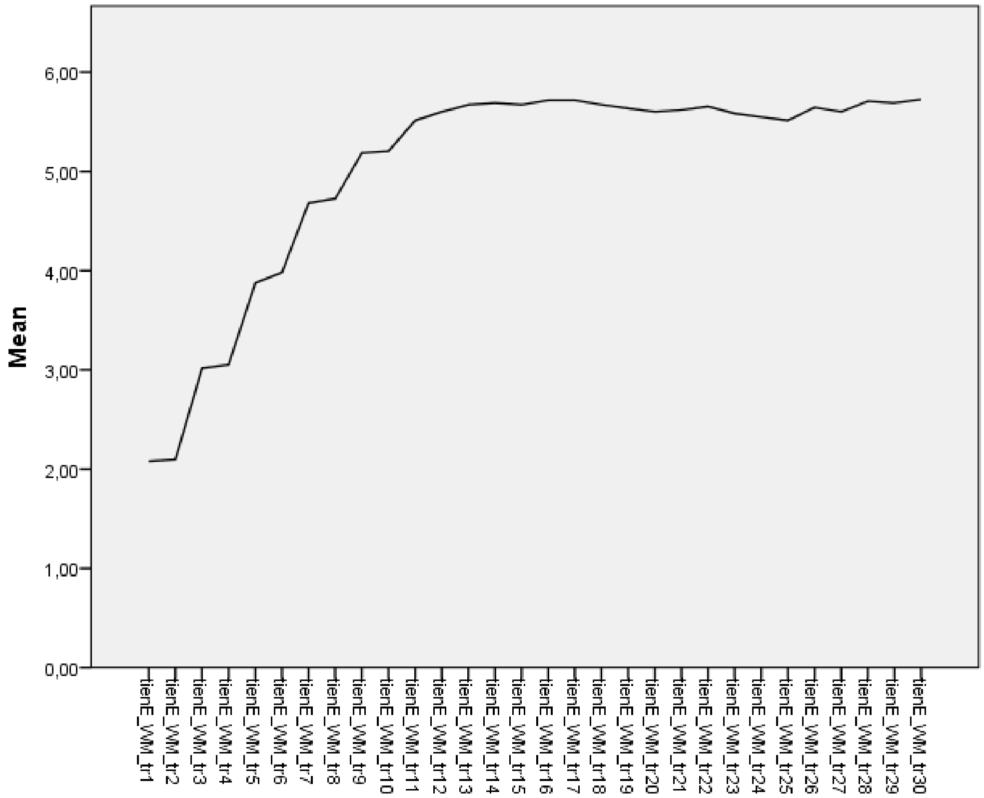
I don't know how many correct reproductions are required to get a green screen or how many incorrect reproductions are required to get a red screen; the computer decides this randomly.

You can also monitor how you are doing by looking at the bar at the bottom of the screen.

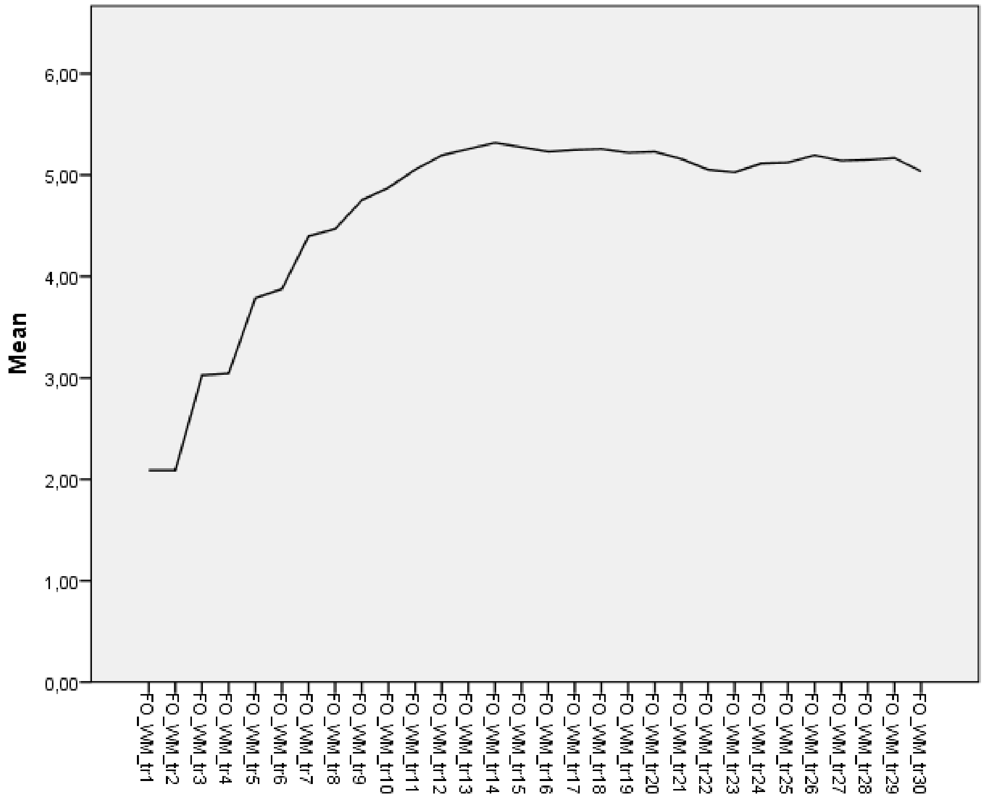
If you reproduce a sequence correctly the bar gets longer, and if you reproduce a sequence incorrectly the bar gets shorter.

Appendix 5.2

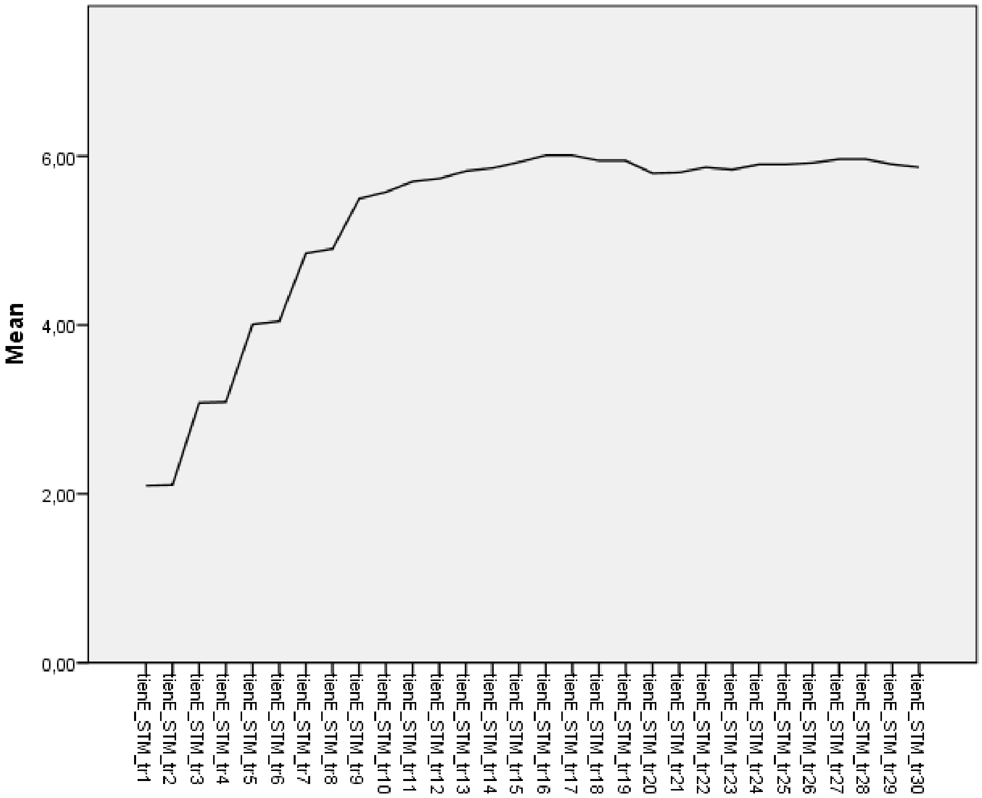
Performance (mean sequence length) over trials (_tr1 t/m _tr30) in the ADHD groups* (WM performance in the 10 euros condition; scores are not corrected for age)



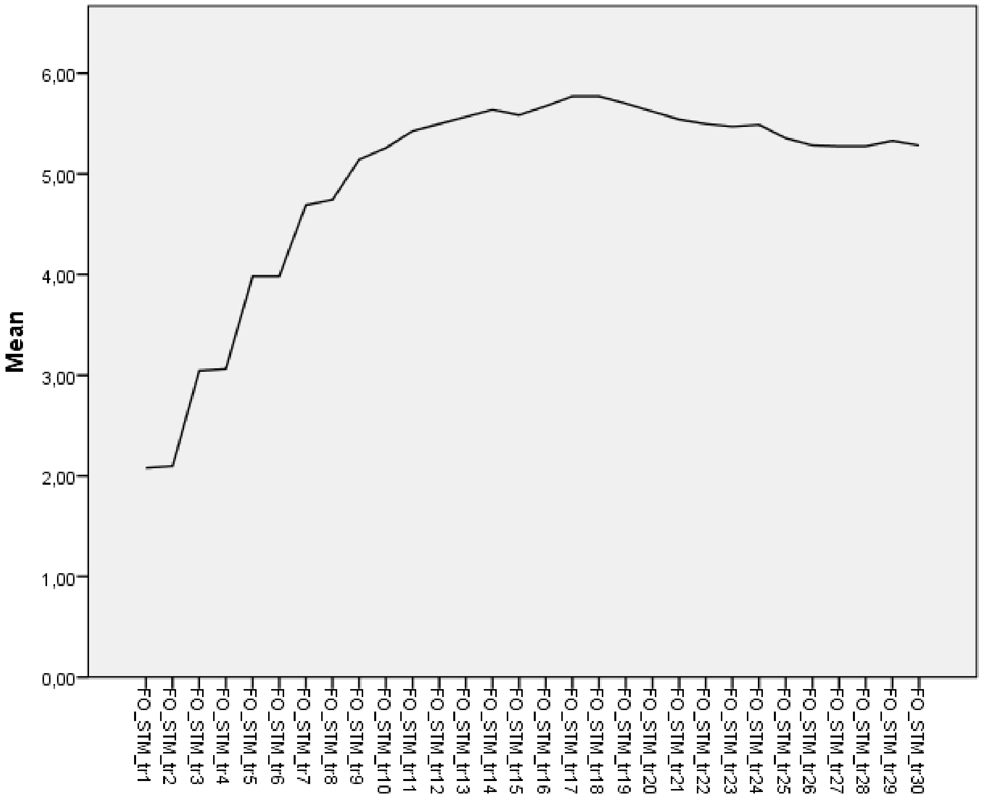
Performance (mean sequence length) over trials (_tr1 t/m _tr30) in the ADHD groups* (WM performance in the feedback-only condition; scores are not corrected for age)



Performance (mean sequence length) over trials (_tr1 t/m _tr30) in the ADHD groups* (STM performance in the 10 euros condition; scores are not corrected for age)



Performance (mean sequence length) over trials (_tr1 t/m _tr30) in the ADHD groups* (STM performance in the feedback-only condition; scores are not corrected for age)



* We found no differences in the slope of performance over trials between ADHD-C and ADHD-I. Therefore, in these figures the ADHD groups were combined.

Appendix 5.3

Proportion of children impaired on the age corrected dependent measures

Measure	Group				
	ADHD-C	ADHD-I	TD children		
	(n=86)	(n=27)	(n=62)	χ^2	*Group Comparison*[a]
Working memory (10 euros)					
% children below:					
10th percentile of TD children	58.1%	33.3%	9.7%	36.4	C > I > TD
5th percentile of TD children	45.3%	25.9%	4.8%	39.4	C = I [b]; TD < C, I
Short-term memory (10 euros)					
% children below:					
10th percentile of TD children	40.7%	18.5%	9.7%	18.9	C > I, TD; I = TD
5th percentile of TD children	34.9%	14.8%	4.8%	20.3	C > I, TD; I = TD
Reinforcement sensitivity index					
% children above:					
90th percentile of TD children	22.1%	22.2%	9.7%	4.3	C > TD; I = C, TD
95th percentile of TD children	10.5%	7.4%	4.8%	1.6	C = I = TD

Note. TD = typically-developing children. [a] Chi-square tests were performed to compare the group-differences (for all significant differences *p*-values were < .05). [b] $p = .057$. When the assumption of the chi-square test was violated (e.g, when 1 cell had an expected count of less than 5), Fisher's exact test was performed (for all significant differences *p*-values were < .05).

Appendix 5.4

Pearson correlations between ADHD symptoms (measured with the DBDRS) and the age-corrected performance indices

	All groups (n=175)					ADHD-C + ADHD-I (n=113)				
	WM FO	WM 10	STM FO	STM 10	Reinf.	WM FO	WM 10	STM FO	STM 10	Reinf.
P-Inattention	-.501**	-.461**	-.429**	-.365**	.231**	-.044	-.076	-.160	-.101	.048
P-Hyp/Imp	-.462**	-.437**	-.418**	-.411**	.182*	-.149	-.154	-.215*	-.278**	.021
T-Inattention	-.479**	-.489**	-.409**	-.350**	.217**	-.033	-.166	-.108	-.006	.009
T-Hyp/Imp	-.425**	-.410**	-.390**	-.328**	.211**	-.131	-.105	-.167	-.127	.094

Note: ADHD-C = ADHD-combined subtype; ADHD-I = ADHD-inattentive subtype; All groups = ADHD-C + ADHD-I + Controls; DBDRS = Disruptive Behavior Disorder Rating Scale; FO = Feedback-only; Hyp/Imp = Hyperactivity/Impulsivity; P- = Parent; Reinf. = Reinforcement sensitivity index; STM = Short-term memory; T- = Teacher; WM = Working memory; 10 = 10 euros; * p < .05 (2-tailed); ** p < .01 (2-tailed).

Chapter 6

Does computerized working memory training with game elements enhance motivation and training efficacy in children with ADHD?

This chapter is based on:

Prins, P.J.M., Dovis, S., Ponsioen, A., ten Brink, E., & Van der Oord, S. (2011). Does computerized working memory training with game elements enhance motivation and training efficacy in children with ADHD? *Cyberpsychology, Behavior and Social Networking*, *14*(3), 115–22.

Abstract

This study examined the benefits of adding game elements to standard computerized working memory (WM) training. Specifically, it examined whether game elements would enhance motivation and training performance of children with ADHD, and whether it would improve training efficacy. A total of 51 children with ADHD (aged 7 to 12) were randomly assigned to WM training in a gaming format or to regular WM training that was not in a gaming format. Both groups completed three weekly sessions of WM training. Children using the game version of the WM training showed greater motivation (i.e., more voluntary training time), better training performance (i.e., more sequences reproduced and fewer errors), and better WM at post-training (i.e., higher scores on a WM task) than children using the regular WM training. Results are discussed in terms of executive functions and reinforcement models of ADHD. It is concluded that adding game elements to a WM training can significantly improve motivation and training performance in children with ADHD, and can enhance the trainings' efficacy. The findings of this study are encouraging and may have wide-reaching practical implications in terms of the role of game elements in the design and implementation of new intervention efforts for children with ADHD.

6.1 Introduction

Current research on childhood ADHD is based on two theoretical approaches: one focusing primarily on executive functioning (Barkley, 1997) and the second on motivational variables (e.g., Sagvolden & Sergeant, 1998). In his comprehensive theory, Barkley (1997) assumes that self-regulation deficits are at the core of the ADHD syndrome, and are related to executive functions (EFs) such as working memory (WM), response inhibition, and temporal processing. EFs play an important role in everyday life, such as paying attention in class, waiting one's turn to say or do something, and keeping track of homework. Children with ADHD exhibit significant impairments in WM and response inhibition (Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005). WM has been defined as the ability to retain information during a delay and then to make a response based on that internal representation (Baddeley, 1986). Visuospatial WM is considered the most important neuropsychological deficit in children with ADHD (Nigg, 2006).

A second approach to ADHD assumes an abnormal sensitivity to reinforcement (e.g., Douglas, 1999; Sagvolden, Johansen, Aase, & Russell, 2005). Research has indicated that reinforcement contingencies, including reward, punishment/response cost, and (accuracy) feedback, as well as combinations of feedback and reward or response cost, have a positive impact on the task performance and motivation in both children with ADHD and controls. In a meta-analysis, Luman, Oosterlaan, and Sergeant (2005) concluded that this effect is somewhat more prominent in children with ADHD: the high intensity of reinforcement appeared highly effective in ADHD, and children with ADHD prefer immediate over delayed reward. When reinforcers are powerful and frequent, the differences in behavior between children with ADHD and controls are expected to be minimal. Since reinforcement is highly associated with motivation, research suggests that an unusually low level of effort or intrinsic motivation accounts for the performance deficits in children with ADHD. When tasks are extremely boring, or without supervision, the attention span of children with ADHD will be very limited (Luman et al., 2005). Adding external incentives to a potentially boring task may help children with ADHD optimize their motivational state and normalize their performance (Shanahan, Pennington, & Willcutt, 2008).

Relatedly, Sergeant, Oosterlaan, & van der Meere (1999) hypothesized that children with ADHD suffer from a non-optimal energetic state explained in terms of the cognitive-energetic model (CEM), which is based on the assumption that information processing is influenced by both computational (process) factors and state factors such as effort, arousal, and activation. Effort, which is related to motivation, is conceived as the energy necessary to

meet the demands of the task. Reinforcement contingencies are presumed to have their influence on effort. If children with ADHD suffer from a deficit in effort, performance may be poor due to a non-optimal energetic state. Since reinforcement is expected to activate effort, reinforcement will induce the necessary energy to meet the task demands. As a result, performance on cognitive tasks improves (Luman et al., 2005). If state factors are manipulated by contextual changes, then, given the correct degree of incentive, increased activation and effort result in cortical stimulation and thus improvements in performance (Shaw & Lewis, 2005).

As well as adding external incentives, a feature that has shown to increase an ADHD child's interest and motivation is the computerization of tasks (Pfiffner, Barkley, & DuPaul, 2006). Computer assisted instruction (CAI) programs typically include clear goals and objectives, highlighting of important material, and immediate feedback regarding response accuracy. Many - perhaps the more effective CAI programs- also have a game-like format (Pfiffner et al.). Parents, teachers, and clinicians have reported that children with ADHD, when playing a computer game, can sustain attention, concentrate for longer periods of time, and behave less impulsively (Barkley, 2006).

A gaming format uses multiple sensory modalities (color, sounds, movement) and provides frequent, immediate feedback about quality/accuracy of performance (via graphics, sounds, and scoring). It further includes animated characters, narratives, colorful interactive environments, and player advancement through levels (Shaw & Lewis, 2005). Gameplay is a complex, multi-requirement cognitive domain, and is known to be very motivating for children, including those with ADHD (Emes, 1997; Tannock, 1997). Tasks with a game format should promote optimal cognitive performance (relative to repetitive and boring experimental tests) in children with ADHD by providing external motivating contingencies just prior to and at the moment of responding. They should also heighten the activation/arousal state, which may further promote optimal performance (Koepp et al., 1998; Lawrence et al., 2002).

Ota and DuPaul (2002) investigated the effects of CAI software with a game format on attending behavior and math performance of children with ADHD, relative to a written seatwork condition. The game format included games (activities), difficulty levels that adjusted to the child's ability, and rewards (points) earned throughout the game and provided following each correct response. Computer software with a game format strongly improved the attending behavior, time on-task, and task performance of the children, “presumably because of the stimulating nature of the stimuli and the immediate performance feedback.” In

another study, Lawrence, Houghton, Tannock, Douglas, Durkin, and Whiting (2002) found that boys with ADHD compared to controls were equally capable of inhibiting responses when playing a computer game. These studies suggest that computer gaming facilitates attention and impulse control.

Shaw, Grayson, and Lewis (2005) studied the influence of computer-game elements on the performance of children with ADHD. In the first part of the study, children with ADHD and controls played two commercial computer games. In the second part, the children performed a computerized version of the Continuous Performance Test (CPT) and a Pokémon task. This task was similar to the CPT, but the target letters were in the form of Pokémon characters. Each child was instructed to catch as many Pokémon as they could. Results showed that the behavior of children with ADHD when using the commercial computer game (number of impulsive errors and the amount of attention) was similar to the behavior of controls. This result further supports the facilitating role of computer games on children's impulse control and attention. The findings of the second part of the study showed that children with ADHD made fewer impulsive errors and were more attentive on the Pokémon version of the CPT. In the control group, no difference was found between the two versions of the CPT.

Introducing game elements per se does not enhance performance; it may distract children from the main aim of the task. In a study by Shaw and Lewis (2005), adding animation did not enhance the attractiveness of a computer task; children with ADHD performed less well on a computerized task with game features. They reported that they were distracted by the animations. Perhaps they experienced problems in remembering the main aim of the task in the presence of more interesting stimuli. Or perhaps processing resources were allocated to more interesting surface features or distractions and not to task content (see Shaw & Lewis, 2005).

In summary, these findings suggest that to increase the chances of a child with ADHD maintaining concentration and attention and withholding impulsive behaviors and inappropriate behaviors, the child needs to be specifically motivated and stimulated. This is where the use of computerization and gaming seems to be critical (e.g., Shaw & Lewis, 2005).

Recently, attempts have been made to train specific EF deficits with computerized training. Klingberg et al. (2005) successfully trained the WM of children with ADHD. Fifty-three children with ADHD were randomly assigned to either computerized treatment or a comparison program. The treatment consisted of performing WM tasks implemented using a computer program (RoboMemo®), which included visuospatial WM tasks (remembering the

position of objects in a 4 × 4 grid), as well as verbal tasks (remembering phonemes, letters, or digits). The children were trained for 5 weeks, with 90 trials on each training day. The level of difficulty was automatically adjusted on a trial-by-trial basis to match the WM span of the child on each task. After training, the children in the treatment condition not only performed better on a task measuring visuospatial WM (span-board task), but also on tasks assessing verbal WM (digit-span task), and complex reasoning (Raven task). Finally, a significant reduction in the number of parent-rated ADHD behaviors was found. The WM training of Klingberg et al. was computerized, including some animation and feedback, but without elaborate gaming elements. Based on previous research and clinical observations, it was expected that adding more game elements to computerized WM training would enhance its effects.

The present study examined the value of adding game elements to standard computerized WM training without game elements on motivation, training performance, and WM. It was expected that children in the WM game training condition would spend more time on training (motivation), reproduce more training sequences, make fewer errors (performance), and show greater effects on a WM task (training efficacy) compared with children in the standard computerized WM training condition.

6.2 Methods

Participants

Participants were 62 children from a suburban area, who had been referred to three outpatient mental-health clinics, and were on a waiting list for ADHD treatment. Inclusion criteria were: (a) meeting DSM-IV (American Psychiatric Association, 2000) diagnostic criteria for ADHD; (b) aged between 7 and 12 years; (c) a clinical score on the Attention Deficit and/or Hyperactivity/Impulsivity subscales of the Disruptive Behavior Disorder Rating Scale, parent and/or teacher version (see below); and (d) no use of medication on days of training. A total of 52 children (42 boys, 10 girls) met the inclusion criteria, with an average age of 9.47 years (SD = 1.08). Participants with ADHD on stimulant medication discontinued treatment for a minimum of 24 hours prior to the test sessions. Only participants on short-acting stimulants were included.

Controls were matched to participants with ADHD for age, gender, IQ, comorbid behavior disorders, dyslexia, and experience with computer gaming. Participants were then randomly assigned to either standard WM training (n = 25) or a game version of the training

(n = 27). One child (control condition) dropped out before training, leaving a final sample of 51 children. Demographic information and baseline characteristics are shown in Table 1.

Table 1

Demographics and baseline characteristics of participants in the computerized WM-game training and control training (SDs in Parentheses)

Variables	Game n = 27	Control n = 24
Mean age (years)	9.59 (1.12)	9.33 (1.05)
Male, no (%)	21 (78%)	21 (88%)
DBDRS (parent version)		
- Attention Deficit	15.30 (5.23)	15.08 (4.68)
- Hyperactivity/Impulsivity	14.67 (5.45)	15.04 (4.96)
- ODD	7.74 (4.75)	8.38 (4.99)
- CD	1.85 (3.42)	1.88 (2.27)
DBDRS (teacher version)		
- Attention Deficit	12.24 (7.24)	11.96 (5.97)
- Hyp/Imp	11.38 (7.96)	11.21 (5.60)
- ODD	7.69 (4.84)	8.38 (4.99)
- CD	1.31 (3.28)	1.42 (1.64)
WISC III		
- Substitution	9.00 (3.20)	9.00 (2.50)
- Block design	10.74 (3.79)	9.83 (2.96)
- Vocabulary	11.85 (3.39)	10.83 (2.93)
Dyslexia	2 (7%)	2 (8%)
Computer game experience	27 (yes)	24 (yes)
Hours p/w gaming	9.73 (4.91)	7.58 (5.02)
Memory Span (CBTT)	4.96 (.76)	4.96 (.75)

Note: DBDRS= Disruptive Behavior Disorder Rating Scale; ODD = Oppositional Defiant Disorder; CD = Conduct Disorder; WISC-III= Wechsler Intelligent Scale for Children, 3d Ed; CBTT= Corsi Block Tapping Task.

Screening and Selection Measures

Intake questionnaire. A questionnaire was developed especially for this study to assess demographic and school information, and the child's treatment history, medication use, and experience with computers.

Disruptive Behavior Disorders Rating Scale (DBDRS). The DBDRS (Pelham, Gnagy, Greenslade, & Milich, 1992; Dutch translation: Oosterlaan, Scheres, Antrop, Roeyers, & Sergeant, 2000) assesses DSM-IV disruptive behavior disorder symptoms in children between 6 and 12 years. It consists of 42 items and four subscales: inattention (nine items), hyperactivity/impulsivity (nine items), oppositional defiant (eight items), and conduct disorder (16 items). Items are scored by parents and teachers on a 4-point Likert scale, ranging from 0 = “not at all” to 3 = “very much”. The maximum score on the ADHD subscales is 27. Higher scores indicate more severe symptoms. The Dutch translation has adequate reliability (α range = 0.88–0.94); validity and Dutch norms are available (Oosterlaan et al., 2000).

Wechsler Intelligence Scale for Children III (WISC-III) short version. The WISC-III short version (Kort et al., 2002; Wechsler, 1991) designed for children between the ages of 6 and 16 years, consists of five subtests: information, vocabulary, incomplete drawings, block design, and substitution. Scores of children with ADHD on this short version correlate highly (r = 0.94) with scores of children with ADHD on the complete version (Furgueson, McGuffin, Greenstein, & Soffer, 1998). To reduce testing time, the full-scale IQ was estimated with three subtests: vocabulary, block design, and substitution.

Outcome Measures

Corsi Block-Tapping Test. The Corsi Block-Tapping Test (CBTT, Corsi, 1972) assesses the capacity of visuospatial short-term memory and WM (Kessels, van Zandvoort, Postma, Kappelle, & de Haan, 2000). In the present study, the same test format (size of board and blocks, distances between blocks) was used as in Kessels et al. and the same scoring procedure was used as in Geurts, Verté, Oosterlaan, Roeyers, and Sergeant (2004). The task consists of nine cubes (blocks of 30 × 30 × 30 mm) that are positioned on a square board (225 × 225 mm). The blocks, numbered one through nine, are visible for the test leader only. The test leader taps a sequence of blocks, starting with a sequence of three blocks, which the child must repeat three times in the correct order (e.g., 1-2-3 > 1-2-3). If the child reproduces at least one of three sequences of a particular number of blocks correctly, the sequence is extended with one block to a maximum of eight blocks. After three successive errors within

the same sequence length, the test is stopped. The last sequence length in which the child has reproduced at least two sequences correctly is considered his/her memory span. The minimum score on the CBTT is two and the maximum score is eight. The CBTT takes approximately 10 minutes, and was the main outcome measure in our study (see below).

Motivation level. This was assessed in both an objective and subjective manner: objectively by assessing the amount of time the child used the training (see absence time) and the number of sequences performed during training, and subjectively by asking children questions about the computerized WM task and the WM game (see exit questionnaire).

Absence time. The average time (in seconds) that the children spent not using the training was recorded automatically by the computer. If the child did not interact with the mouse within 60 seconds, the time was recorded by the computer until the child interacted again. This resulting time interval is considered the amount of time that the child was not using the training.

Exit questionnaire. At the end of the third training session, an exit questionnaire was administered to the children consisting of four questions concerning the computer task: (a) How did you like the computer task? (very nice/nice/neutral/boring/very boring); (b) What did you think of the computer task? (very difficult/difficult/neither difficult nor easy/easy/very easy); (c) Would you like to have it at home? (yes/no); (4) How often would you use it at home? (never/almost never/sometimes/often/very often).

Training Conditions

Control training. In the computerized WM training without gaming elements, adapted from Klingberg et al. (2005), children were presented with a 4 × 4 grid consisting of 16 blue squares in rows of four against a black background. The squares lit up in random order, one after the other, and, as such, formed a sequence. The child had to reproduce this sequence by clicking with the computer mouse on the squares that lit up. The first sequence consisted of three squares that lit up. After two consecutive correct reproductions, the sequence increased by one square. After two consecutive incorrect reproductions, the sequence was shortened by one square. This upward and downward adjustment was the only form of “feedback” in this condition. No external visual or auditory feedback was given. This training format without explicit feedback and without gaming elements is similar to most neuropsychological assessment tasks. The minimal length of a sequence was two squares. Each square in a sequence lit up for 900 milliseconds and it took 500 milliseconds for the next square to light up. The next sequence automatically started 5 seconds after the child tried to

reproduce the sequence. These trial and inter-trial times are similar to the Klingberg et al. study. During this control version of the WM training, in each training session of 30 minutes, the child could maximally reproduce 110 sequences. If the child did not interact with the mouse within 60 seconds, the time was recorded by the computer until the child interacted again. This was considered the absence time. Each participant was allowed to try out the training for a maximum of 5 minutes before the training began properly.

The control training used in the present study differed, to our knowledge, from the computerized treatment of Klingberg et al. in that: we used only visuospatial tasks instead of additional verbal WM tasks; we used blue squares instead of red circles; and we used three training sessions instead of five weeks of training. The Klingberg et al. training included several gaming elements such as animations and various forms of feedback (www.cogmed.com). These were not included in the control training condition.

Game training. The game training was also a simple visuospatial WM training in which participants had to reproduce sequences of randomly lit-up squares in a 4×4 grid. However, game elements were added, such as animation, a story line, a goal, rewards and response cost (shots) earned or lost throughout the game, control (child chose moment to do a sequence), competition, and identification (with a game character). The story was that the child had to save the world from an evil group of robots, named Mechas, which had taken control and invaded villages. The child had to identify with a “good” robot, the Supermecha, and had to fight the evil robots. The game training consisted of three levels, one level played each week. In each level, several villages could be “re-conquered.” Once a village had been entered by the Supermecha, the evil robots could be shot. Whether the shot was successful in destroying the evil robot depended on the child's performance in a WM task. This was the actual visuospatial WM training, where sequences of blocks that lit up one at a time—in a 4×4 grid—had to be reproduced. These sequences were called the coordinates of the bullets, which were to be remembered correctly in order to be able to attack the evils robots successfully. The Supermecha could also be attacked by the evil robots; the child had to protect himself by correctly reproducing the sequence of the evil robots. If the child correctly reproduced the sequence, he received a protection bonus, and if he reproduced incorrectly, he lost a bonus. If the child collected five bonuses, he won an extra shot. Similar to the control condition, in each training session of 30 minutes, the child could reproduce a maximum of 110 sequences. In both training conditions, the computer kept a record of the length of each sequence, the number of correct and incorrect sequences, and the total training time.

Materials

Computer. A laptop was used (Dell Latitude D600 Refurbished Notebook PC Intel Pentium M 1.4GHz, 802.11b/g Wireless, 512MB DDR, 40GB HDD, CD-RW/DVD Combo, 14.1″ XGA, Windows XP Professional) with an optical mouse.

Reading materials. Each training session lasted about 35 minutes (see Procedure below). After 15 minutes of training, participants could choose during the second half of each session to continue using the training or to stop and read magazines at any time. The interior of the testing room in each of the three locations was such that participants could only play the game training or read "neutral" magazines, that is, magazines that children will leaf through if they have nothing else to do but which they would not choose to read if an attractive alternative was available.

Procedure

The study consisted of an intake session and three successive training sessions, spaced one week apart. The study was approved by the Research Ethics Committee of the University of Amsterdam. After a description of the study, written informed consent was obtained from the parents, and each child gave verbal consent. Parents were then invited for an intake session. The DBDRS was mailed to the parents to give to the child's teacher to complete. During the intake session, the parents and child were interviewed with the intake questionnaire. Parents were then asked to complete the DBDRS, while the child was administered the WISCIII and the CBTT subtests. This session lasted 50 minutes. If the child met the inclusion criteria, he/she was randomly assigned—after matching—to one of the two conditions, and three training appointments were scheduled.

Training sessions were held once a week for three consecutive weeks. Appointments were scheduled as much as possible on the same (part of the) day. No toys were allowed in the training room, and views from the windows were blocked. Standard instructions for the training were read to the child, after which a test session of 5 minutes was run. The child then started training, while the experimenter was seated behind the child. After 15 minutes of training, the experimenter gave the following instructions:

"The training is over and you did very well. I have to look at the results and you'll have to wait here for a short while. It'll take me about 15 minutes and then I'll come back. In the meantime you can do something for yourself. You may read the magazines or continue playing on the computer. It's up to you. I'll be in the hallway to look at the results."

Following this, the experimenter left the training room. After 15 minutes, he returned to the test room and stopped the computer. The first two training sessions lasted 35 minutes (5 min pre-training + 2 × 15 min training). At the third training session, after the second 15-minute training session, the experimenter administered the exit questionnaire and finally the CBTT. This session lasted 50 minutes. Each participant received a medallion with a picture of the Supermecha as a reward for participation.

Data Analysis

First, pre-training group differences were tested using analysis of variance (ANOVA), and Chi-square tests were used for categorical variables. Second, training effects were examined with 2 × 3 (training: standard or game version × time: training sessions 1, 2, and 3) repeated measures ANOVAs. Bonferroni post-hoc analyses were conducted. Effect sizes for all analyses (partial η^2 and Cohen's d; Cohen, 1988) are reported. As the value of η^2 depends on the number and magnitude of other effects in the model, the partial η^2 is considered a practical alternative (Tabachnick & Fiddell, 2001). All analyses were conducted with SPSS statistical software (V14.0; SPSS, Inc., Chicago, IL).

6.3 Results

Pre-Training Comparisons and Comparability of Control and Game Training

At pre-training the two training conditions were not significantly different on demographic variables and baseline characteristics (Table 1). In the control condition, the length of sequences (= level of difficulty) was automatically adjusted to the child's performance, while in the game condition the sequence-length, which ranged between 3 and 6 squares, was presented in random order. A one-way ANOVA showed no significant difference between the average length of sequences in the two training conditions (M-control = 4.12; M-game = 4.02), (F (1, 44) = 0.28, p = .60). Participant responses relating to gaming familiarity were subjected to chi-square analysis. No group differences were revealed for level of game familiarity, X^2 = 0.788, df =1, p = 038.

Motivation

Motivation was measured by 'absence time', number of sequences performed during training, and by asking children if they would do the training at home, as reported on the Exit questionnaire.

Absence time. The average time (in seconds) that children were not using the mouse was recorded automatically. Four scores were calculated: absence time for each training session, and total absence time over all three sessions (see Table 2). Maximum total absence time per training session was 1800 seconds. A 2 (conditions) x 3 (training sessions) ANOVA with repeated measures showed a significant main effect for condition (F (1, 44) = 81.41, $p < .001$). More time of absence was found in the control condition than in the game condition. Further, a significant main effect for training sessions was found, (F (2, 88) = 6.45, $p < .01$). There were no significant interactions. Bonferroni post hoc analyses showed that the average absence time in the first session (M = 397.22, SD = 37.38) was significantly shorter than in the third session (M = 521.44, SD = 39.22), $p < .05$. Over all three sessions, children in the control condition were not using the training for 42% of the time, compared to 9% in the game condition.

Table 2

Total absence time (seconds) and absence time for each of the three training sessions in the Game condition and Control condition

	Condition	Mean	SD	*n*	F	η_p^2
Absence time, first session	Game	107.68	192.91	25	55.92*	.560
	Control	666.76	309.34	21		
Absence time, second session	Game	189.04	278.84	25	43.16*	.495
	Control	758.57	308.90	21		
Absence time, third session	Game	177.16	279.10	25	77.04*	.636
	Control	865.71	247.07	21		
Absence time, total	Game	473.88	615.70	25	81.41*	.649
	Control	2291.05	750.68	21		

* $p < .001$

Number of sequences. The average number per training session and the total number of performed sequences are presented in Table 3. The maximum possible number of sequences to be reproduced in both conditions was 110 (based on the minimum amount of time needed to reproduce 10 sequences). A 2 (conditions) x 3 (training sessions) ANOVA with repeated measures showed a significant main effect for condition (F (1, 44) = 27.45, $p < .001$). Significantly more sequences were performed in the game condition than in the control condition. Further, a significant main effect for sessions was found (F(2, 88) = 4.50, $p < .01$). No significant interaction effect was found (F(2, 88) = 0.60, $p = .55$). Post hoc analyses

(Bonferroni) showed that the average number of sequences in session 3 (M=51.56, SD=2.52) was significantly smaller than in session 2 (M=58.58, SD=2.85), p <.05.

Exit questionnaire. Children in the game condition significantly endorsed more often that they: liked the task (X^2 = 17.752, df = 2, p < .01), would like to have the task at home (X^2 = 21.359, df = 1, p < .01), would like to do the task at home (X^2 = 16.461, df = 1, p < .01), and would often use the task at home (X^2 = 14.206, df = 1, p < .01).

Table 3

Total number of performed sequences and number of sequences during each of the three training sessions in the Game condition and Control condition

	Condition	Mean	SD	*n*	F	η_p^2
Performed sequences, first session	Game	66.48	14.42	25	21.47*	.328
	Control	47.14	13.70	21		
Performed sequences, second session	Game	70.88	22.07	25	18.60*	.297
	Control	46.29	15.22	21		
Performed sequences, third session	Game	62.12	20.65	25	17.53*	.285
	Control	41.00	11.28	21		
Performed sequences, total	Game	199.48	47.46	25	27.45*	.384
	Control	134.43	34.18	21		

* p <.001

Training Performance

Training performance was evaluated using the percentage of incorrect sequences per session and the percentage of incorrect sequences over all three sessions. Only sequences of three to six squares were included in this analysis, because in the game training the sequences varied between three and six squares. A 2 (condition) x 3 (sessions) ANOVA with repeated measures showed a significant main effect for condition. Significantly less incorrect sequences over all three sessions together were reproduced in the gaming condition (31% in the game and 49% in the control condition), (F (1, 44) = 21. 89, p < .001). No significant main effect for sessions, nor an interaction effect was found.

Training Efficacy

Working memory. A 2 (conditions) x 2 (pre- vs. posttest) ANOVA with repeated measures showed a significant interaction effect for condition and time (F (1, 49) = 8.30, p < .01), d = .80. Post hoc analysis showed that memory span in the game training condition

significantly increased from pre- to posttest (t = 3.075, df = 26, *p* < .01), while no significant increase was found in the control training condition (t = -1.072, df = 23, *p*= .29, two-tailed; see Table 4). The number of sequences performed significantly differed between the two conditions (see above) and was taken into consideration as a covariate. With the number of performed sequences covaried out (ANCOVA), group differences remained significant: the game condition remained superior to the control condition, F(1,48)= 5.887, *p* = .02. d = 0.66.

Table 4

Scores on the Corsi Block Tapping Test (CBTT) in the Game condition and Control condition

	Pre test Mean (SD) [*n*]	Post - test Mean (SD) [*n*]
CBTT (visuospatial WM)		
Game condition	4.96 (0.76) [27]	5.41 (0.90) [27]
Control condition	4.96 (0.75) [24]	4.79 (1.02) [24]

Note: WM = working memory

6.4 Discussion

This study examined the impact of game elements on the motivation and performance of children with ADHD on a WM task. The game condition, compared to a control condition without game elements, yielded more impact on WM as measured by CBTT. The introduction of an elaborate game environment to a WM training task has not been investigated before. Children who trained on the game version of a visuospatial WM task were more strongly motivated to do the training (reduced absence time during the training and a greater number of trials completed), did better during training (fewer incorrect trials), and significantly improved after training on an untrained WM task (i.e., the CBTT), while no such improvement was observed for the control group.

Training in a game setting may affect WM outcome in two ways: (a) it may directly enhance the effect of training, or (b) it may enhance training (e.g., more training), and the enhanced training then improves the effect on the WM outcome. This second possibility may have been the case, as the gaming group performed significantly more sequences (32%). However, the covariate effect of number of sequences was not significant and did not appear to contribute significantly to the superior efficacy of the game condition. This supports the

first possibility that training in a game environment may directly enhance the effect of WM training..

It is not clear from our study which of the various elements of the game format contributed to superior training efficacy. Different forms of feedback, animation, control over when to perform a trial (training at one's own pace), use of levels, and a long-term goal are all elements of the game format (Gee, 2005). To determine the impact of these elements, future research should systematically vary these elements.

Interestingly, positive results in the game condition were found after only three sessions of 30 minutes, while other WM training programs are much longer. Klingberg et al. (2005) for example, used 25 sessions. By using a gaming format, fewer training sessions may be necessary for WM training to be effective.

The majority of participants in the present study were boys, with only a small number of girls ($n = 9$). At intake, all children, girls included, reported that they had a computer at home on which they could play games (PC, Playstation, Nintendo, or XBOX). In fact, boys reported that they played games for an average of 8.7 hours per week, while girls reported playing games for an average of 8.2 hours, indicating that the amount of time boys and girls with ADHD reported playing games at home did not differ greatly. Some authors have suggested that in the general population boys play games more frequently than girls (Pleysier & Wydooghe, 2007). Despite the fact that the number of girls in the present study was very small, it is remarkable that boys and girls with ADHD did not differ in the amount of self-reported game playing. Moreover, at the end of the training, we asked the boys and girls in the game condition questions such as: “Would you like to play this computer game at home?”, “How did you like the game?”, and “If you would have this game at home, how often would you play it?” Girls who had performed the game-training did not differ from the boys in their answers to these exit questions. Although the number of girls in the game condition was small (6 out of 27), this finding suggest that girls with ADHD did not evaluate the game as less attractive than boys with ADHD, even though the game training was typically boyish (e.g., warlike with shooting and explosions). Given the small number of girls in our sample, no definite conclusions on the gender variable can be drawn. Future studies may examine whether, indeed, girls with ADHD are more inclined to play games than girls without ADHD.

An interesting question relates to the real-life implications of the present findings. Would, for example, participating in game-like training have a “spill-over” or generalization effect on children's learning in non-preferred areas? Or, is the implication that non-preferred areas must be modified for children with ADHD to learn? Klingberg et al. (2005) found that

the positive effects of their WM training generalized to non-trained executive functions and even to ADHD-related behaviors as rated by parents in real life, suggesting a "spill-over" effect. Similarly, Holmes, Gathercole, and Dunning (2009) found that the effects of their WM training in a computerized game environment generalized to non-trained mathematical ability, which improved 6 months following WM training. In the present study, we did not evaluate generalization effects. However, some evidence for generalization of the effects of our brief game-like WM training was found in another study we recently conducted in our lab (van Es, 2007). Boys with ADHD who were trained in the same brief, game-like WM training again showed substantial improvement in WM, but also improved on a non-trained EF (i.e., inhibition). Moreover, ADHD-related behaviors as rated by the parents on a standardized behavior questionnaire also significantly decreased after training. Clearly, the generalization issue is an important one in the area of the remediation of EF, and future studies should investigate which cognitive functions can be trained and to what extent the effects of cognitive training generalize to real-world learning situations.

The findings of the present study should be considered in light of several limitations. First, a number of the elements in the new game task were not controlled for in the control condition, such as not adjusting the difficulty level of the task on a trial-by-trial basis in the game condition. Instead, trials of varying difficulty were presented in random order in the game condition. In designing the present study, in our opinion, adjusting the difficulty level on a trial-by-trial basis, as was done in the Klingberg et al. study (2005), did not fit with a game-like format and would eventually result in frustration and possibly a decrease in motivation. We chose therefore to present the difficulty level in a way that was more similar to computer games: the child would have to adjust himself to the level of the game. Generally, the level is challenging but not too difficult, as the aim was to keep the child interested and motivated to do the sequences. Thus not adjusting the difficulty level of the task on a trial-by-trial basis was one of the game elements added to our WM training. Whether this element is a critical one in terms of the impact of a game version on WM training should be examined in future research. Despite this difference between the game and the control condition, it should be noted that this element did not differentially affect the level of difficulty of the two training conditions, as the length of sequences to be reproduced in the two conditions did not differ significantly. Second, no information on the stability of the effects is available as no follow-up assessments were conducted.

These limitations notwithstanding, our study is the first to evaluate the significance of motivational factors through gaming and their relevance to the efficacy of cognitive training.

By drastically reducing the intensity of the standard WM training program yet achieving sizable training effects, our study raises the issue of the required duration and intensity of such training and consequently highlights the need for more research into the long-term maintenance of the so-far reported training effects. Even though the game training used in the present study needs further development, the results are promising with regard to the use of computer games in the treatment of ADHD. Overall, our study may have wider implications on the future development of new, innovative, and feasible interventions for children with ADHD.

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Chapter 7

Improving Executive Functioning in Children with ADHD:

Training Multiple Executive Functions within the Context of a Computer Game. A randomized double-blind placebo controlled trial

This chapter is based on:

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Abstract

Executive functions (EFs) training interventions aimed at ADHD-symptom reduction have yielded mixed results. Generally, these interventions focus on training a single cognitive domain (e.g., working memory [WM], inhibition, or cognitive-flexibility). However, evidence suggests that most children with ADHD show deficits on multiple EFs, and that these EFs are largely related to different brain regions. Therefore, training multiple EFs might be a potentially more effective strategy to reduce EF-related ADHD symptoms. **Methods:** Eighty-nine children with a clinical diagnosis of ADHD (aged 8-12) were randomized to either a *full-active-condition* where visuospatial WM, inhibition and cognitive-flexibility were trained, a *partially-active-condition* where inhibition and cognitive-flexibility were trained and the WM-training task was presented in placebo-mode, or to a full *placebo-condition*. Short-term and long-term (3-months) effects of this *gamified*, 25-session, home-based computer-training were evaluated on multiple outcome domains. **Results:** During training compliance was high (only 3% failed to meet compliance criteria). After training, visuospatial short-term-memory (STM) and WM performance improved more in the full-active condition than in the partially-active- or placebo-condition. Compared to the placebo-condition, inhibitory performance improved more in the full-active- and partially-active condition, and interference control improved more in the full-active condition. No Treatment-condition x Time interactions were found for cognitive-flexibility, verbal WM, complex-reasoning, nor for any parent-, teacher-, or child-rated ADHD behaviors, EF-behaviors, motivational behaviors, or general problem behaviors. Nonetheless, almost all measures showed main Time-effects, including the teacher-ratings. **Conclusions:** Improvements on inhibition and visuospatial STM and WM were specifically related to the type of treatment received. However, transfer to untrained EFs and behaviors was mostly nonspecific (i.e., only interference control improved more than in the placebo condition). As such, in this multiple EF-training, mainly nonspecific treatment factors – as opposed to the specific effects of training EFs - seem related to far-transfer effects found on EF and behavior.

7.1 Introduction

Theories of ADHD suggest that deficits in executive functioning are at the core of the ADHD-syndrome, and play a pivotal role in explaining the problems children with ADHD encounter in daily life (e.g., Barkley, 2006; Nigg, 2006; Rapport, Chung, Shore, & Isaacs, 2001; Sonuga-Barke, 2003). Via dorsal frontostriatal brain circuits, executive functions (EF) allow individuals to regulate their behavior, thoughts and emotions, and thereby enable self-control (Durston, van Belle, & de Zeeuw, 2011). Evidence indeed suggests that impairments in EF are related to deficits in attention, hyperactivity and impulsivity (e.g., Burgess, Depue, Ruzic, Willcutt, Du, & Banich, 2010; Crosbie et al., 2013; Kofler, Rapport, Bolden, Sarver, & Raiker, 2010; Raiker, Rapport, Kofler, & Sarver, 2012; Rapport, Bolden, Kofler, Sarver, Raiker, & Alderson, 2009; Tillman, Eninger, Forssman, & Bohlin, 2011), and with associated problems such as deficient academic functioning (Biederman et al., 2004; Titz & Karbach, 2014). Moreover, research suggests that EF-capacity and its associated levels of brain activity are not static, but may be altered by task-repetition or training (e.g., Klingberg, 2010). Therefore, in the past few years, EF training interventions aimed at ADHD symptom reduction have received considerable interest.

Nonetheless, these EF interventions have yielded mixed results, especially on ADHD behavior (for an overview see Chacko, Feirsen, Bedard, Marks, Uderman, & Chimiklis, 2013; Evans, Owens, & Bunford, 2013; Rapport, Orban, Kofler, & Friedman, 2013; Rutledge, van den Bos, McClure, & Schweitzer, 2012; Shipstead, Redick, & Engle, 2012; Toplak, Connors, Shuster, Knezevic, & Parks, 2008; in addition see Chacko et al., 2014; Egeland, Aarlien, & Saunes, 2013; Kray, Karbach, Haenig, & Freitag, 2012). Generally, these interventions focus on training a single domain of cognitive functioning in children with ADHD, such as working memory (WM), inhibition, or cognitive flexibility. However, evidence suggests that most children with ADHD show deficits on multiple EFs (Fair, Bathula, Nikolas, & Nigg, 2012), and that these EFs are largely related to different brain regions (e.g., McNab, Leroux, Strand, Thorell, Bergman, & Klingberg, 2008; Schecklmann et al., 2012; Smith, Taylor, Brammer, Toone, & Rubia, 2006). Therefore, training of multiple EFs might be a potentially more effective strategy to reduce EF related ADHD symptoms.

To date, evidence for multiple EF training interventions is limited. Few studies have investigated the effects of these interventions in children with ADHD (Halperin et al., 2012; Johnstone, Roodenrys, Phillips, Watt, & Mantz, 2010; Johnstone et al., 2012; van der Oord, Ponsioen, Geurts, Ten Brink, & Prins, 2012; Hoekzema et al., 2010; 2011), and although these studies generally show promising results (e.g., improvement of ADHD behavior as rated

by parents and/or a significant other [e.g., the teacher]; an increase of neural activity and gray matter volume in ADHD affected brain areas), none of these studies are placebo-controlled, and most are underpowered (mean n = 16).

Besides EF deficits, children with ADHD have problems with motivation. Motivational models (Haenlein & Caul, 1987; Sergeant, Oosterlaan, & van der Meere, 1999; Sagvolden, Johansen, Aase, & Russel, 2005; Sonuga-Barke, 2011) and subsequent research (Luman, Oosterlaan, & Sergeant, 2005; Luman, Tripp, & Scheres, 2010; also see Dovis, Van der Oord, Wiers, & Prins, 2012; 2013; 2014; Strand, Hawk, Bubnik, Shiels, Pelham, & Waxmonsky, 2012) suggest that children with ADHD are less stimulated by reinforcement (i.e. reward) than typically developing children (probably due to a dopaminergic deficit), and therefore require higher amounts and frequencies of reward in order to perform optimally. This elevated need for reinforcement in children with ADHD may result in motivational problems during EF training: the child has to repeat the same responses over and over again for many trials, making most EF training programs tedious and boring for children with ADHD (Prins et al., 2013). Research suggests that motivational problems can decrease the effects of EF training in children with ADHD (Prins, Dovis, Ponsioen, Ten Brink, & Van der Oord et al., 2011). However, gamification of an EF training or task (e.g., by using game mechanics and visuals) has been found to optimize both motivation and training-effects in children with ADHD (e.g., Dovis et al., 2012; Prins et al., 2011; Shaw, Grayson, & Lewis, 2005). Gaming increases the release of striatal dopamine (Koepp et al., 1998; Kühn et al., 2011), promoting long-term potentiation of neural connections within the striatum (Reynolds, Hyland, & Wickens, 2001), which is suggested to improve motivation and one's ability to learn (Gray, 2010; e.g., during EF training).

In the current double-blind, placebo-controlled study, we investigated the efficacy of a gamified, 5-week, home-based, multiple EF training intervention titled Braingame Brian (BGB; Prins et al., 2013) in children with ADHD (combined-subtype). A previous waitlist-controlled study of BGB showed promising results on reduction of symptoms of ADHD and improvement of EF (see Van der Oord et al., 2012). BGB targets multiple EFs that are commonly impaired in children with ADHD: visuospatial WM, response inhibition, and cognitive flexibility (e.g., Willcutt et al., 2012). To date, most EF-training studies focus on the effects of WM training (e.g., see Chacko et al., 2013), whereas very few studies investigate the unique effects (i.e. without WM training) of response inhibition- and/or cognitive flexibility training in children with ADHD. Only Kray et al. (2012) investigated effects of a cognitive flexibility training in children with ADHD; they found placebo-controlled effects on

untrained EF performance (i.e., interference control), but they did not investigate effects on behavior. Moreover, we are not aware of any studies investigating the unique effects of inhibition training in children with ADHD (for studies of combined WM and inhibition training see Halperin et al., 2012; Johnstone et al., 2010; 2012). Therefore, participants in the current study were randomized to one of three treatment conditions: (1) a full-active-condition where visuospatial WM, response inhibition and cognitive flexibility were trained, (2) a partially-active-condition where only inhibition and cognitive flexibility were trained and the visuospatial WM training-task was presented in placebo-mode, or (3) to a full placebo-condition. Short-term and long-term (3-months) effects were evaluated across various outcome measures (including performance measures of WM, inhibition, cognitive-flexibility, interference control, and complex reasoning, and rating scales assessing parent- and teacher-rated ADHD behavior, parent-rated EF- and motivational behavior, and parent-, teacher- and child-rated general problem behavior).

We expected that: (1) improvement on outcome measures of WM, inhibition, and cognitive flexibility (i.e., performance measures and EF rating-scales) would be specifically related to the type of treatment received (e.g., greatest improvement on WM if WM was trained), (2) the (far-) transfer of treatment effects to other, untrained, domains of EF (such as interference control or parent-rated planning, organization of materials or self-monitoring) would be limited[36], (3) children in the full-active condition would improve significantly more on ADHD behavior than children in either the partially-active condition or placebo condition, and (4) children in the partially-active condition would improve significantly more on ADHD behavior than children in the placebo condition. Finally, we also investigated other domains of impairment that are associated with ADHD (such as sensitivity to reward and punishment, oppositional defiant behavior, quality of life, and problems in daily situations). However, given the current knowledge-base in the field (e.g., there are no placebo-controlled EF training studies that investigate effects on sensitivity to reward and punishment, quality of life or problems in daily situations, and placebo-controlled studies investigating effects on oppositional defiant behavior show mixed results (Chacko et al., 2014; Green et al., 2012; Klingberg et al., 2005; Klingberg, Forssberg, & Westerberg, 2002; Kray et al., 2012), we refrained from presenting hypotheses regarding these domains of impairment.

[36] We expected that spill-over effects to untrained domains of EF (far transfer) would be limited because different EFs are largely related to different brain regions (McNab et al., 2008; Schecklmann et al., 2013; Smith et al., 2006), and because most placebo-controlled EF training studies that investigate children with ADHD do not find such far transfer effects (e.g., see Shipstead et al., 2012).

7.2 Methods

Trial Design

This was a multicenter (14 sites), double-blind, placebo-controlled, multi-arm parallel-group study conducted in the Netherlands (trial register: http://www.trialregister.nl/trialreg/admin/rctview.asp?TC=2728). No important changes to methods were made after trial commencement.

Participants

Study settings. Children were recruited from 14 outpatient mental-healthcare centers. This study was conducted in the Netherlands, within a predominantly urban type of community.

Eligibility criteria. Eligible participants were all children aged 8 to 12 years with (a) a prior DSM-IV-TR (American Psychiatric Association, 2000) diagnosis of ADHD combined-type and absence of any autism spectrum disorder according to a child psychologist or psychiatrist, (b) a score within the clinical range (95th to 100th percentile) on the ADHD scales of both the parent and teacher version of the Disruptive Behavior Disorder Rating Scale (DBDRS; Pelham, Gnagy, Greenslade, & Milich, 1992; Dutch translation: Oosterlaan, Scheres, Antrop, Roeyers, & Sergeant, 2000), (c) meeting criteria for ADHD combined-type on the ADHD section of the Diagnostic Interview Schedule for Children, parent version (PDISC-IV; Shaffer, Fisher, Lucas, Dulcan, & Schwab-Stone, 2000). The PDISC-IV is a structured diagnostic interview based on the DSM-IV, with adequate psychometric properties, (d) absence of conduct disorder (CD) based on the CD sections of the PDISC-IV, (e) an IQ score ≥80 established by the short version of the Dutch Wechsler Intelligence Scale for Children (WISC-III; Kort et al., 2002). Two subtests, Vocabulary and Block Design, were administered to estimate Full Scale IQ (FSIQ). This composite score has satisfactory reliability and correlates highly with FSIQ (Sattler, 2001), (f) absence of any neurological disorder, sensory (color blindness, vision) or motor impairment as stated by the parents, (g) not taking any medication other than Methylphenidate or Dextroamphetamine. Participants discontinued their Methylphenidate at least 24 hours before each test-session, allowing a complete wash-out (Greenhill, 1998). Participants taking Dextroamphetamine discontinued medication 48 hours before each test-session (Wong & Stevens, 2012), finally, (h) parents had to agree to keep the dose of ADHD medication stable between the intake and the 3-months follow-up session, and had to consent not to initiate or participate in other psychosocial

treatments. Group differences in baseline demographics and clinical characteristics are listed in Table 1.

Table 1

Baseline Demographics and Clinical Characteristics by Treatment Group

Measure	Treatment Group							
	Full-Active (n=31)		Partially-Active (n=28)		Placebo (n=30)			
	M	SD	M	SD	M	SD	F / χ^2	*Group Comparison*[a]
Gender (M : F)	25 : 6	-	22 : 6	-	24 : 6	-	.04	ns (*p* = .980)
Age (years)	10.6	1.4	10.3	1.3	10.5	1.3	.58	ns (*p* = .564)
FSIQ	101	11.5	101	11.4	101	11.6	.05	ns (*p* = .956)
DBDRS parent								
Inattention	22.0	3.6	21.3	4.1	21.9	4.6	.23	ns (*p* = .793)
Hyp/Imp	21.3	3.8	20.0	4.6	20.5	5.1	.69	ns (*p* = .504)
ODD	11.6	5.8	12.8	4.6	11.7	5.9	.40	ns (*p* = .674)
CD	2.9	3.1	2.7	2.9	3.2	2.9	.20	ns (*p* = .820)
DBDRS teacher								
Inattention	16.1	5.6	15.9	5.0	18.0	4.8	1.54	ns (*p* = .220)
Hyp/Imp	13.8	6.2	14.3	5.8	16.6	6.0	1.84	ns (*p* = .166)
ODD	7.4	6.0	7.1	5.0	8.6	6.6	.49	ns (*p* = .614)
CD	1.1	1.7	2.1	3.0	1.9	2.5	1.22	ns (*p* = .300)
PDISC-IV								
ODD diagnosis, *N* (%)	17 (55%)	-	18 (64%)	-	15 (50%)	-	1.24	ns (*p* = .539)
Taking ADHD medication[b], *N* (%)	20 (65%)	-	19 (68%)	-	22 (73%)	-	.56	ns (*p* = .756)
Game experience (hours per week)	8.6	5.0	9.8	9.1	11.6	8.4	1.17	ns (*p* = .314)
Dyscalculia, *N* (%)	0 (0%)	-	0 (0%)	-	0 (0%)	-	-	-
Dyslexia, *N* (%)	2 (7%)	-	5 (18%)	-	5 (17%)	-	2.03	ns (*p* = .362)

Note. CD = conduct disorder; DBDRS = Disruptive Behavior Disorder Rating Scale; FSIQ = full scale IQ; Hyp/Imp = Hyperactivity/Impulsivity; M : F = Male : Female; ODD = oppositional defiant disorder; PDISC-IV = Diagnostic Interview Schedule for Children, parent version; [a] Continuous data were investigated using a MANOVA. Nominal data were investigated using Pearson's chi-squared tests; [b] Four children were taking Dextroamphetamine (two in the full-active condition, one in the partially-active condition, and one in the placebo condition).

Treatment Conditions

General characteristics of the intervention. "Braingame Brian" (BGB; Prins et al., 2013) is a computerized, home-based EF training, embedded in a game world and is named after its main character "Brian". Brian is a young inventor who, throughout the game, helps and befriends the game-worlds inhabitants by creating increasingly elaborate inventions (e.g., a delivery-rocket for the grocery-store owner). BGB consists of 25 training sessions. Within each session, the player can create inventions by completing two *blocks* of three training tasks. Within each block, the first training task is always a WM task (used for drawing a blueprint of the invention), the second and third task, a cognitive flexibility task and an inhibition task, are presented in changing order (and are used for sorting building-materials, and electrically-charging the invention). Each session takes about 35-50 minutes (30 minutes for completing the tasks and an optional amount of time for game-world exploration). An additional standardized external reward system – receiving game-related stickers, reward ribbons and medals for completing sessions (the same for all participants) – is used to even further raise the child's motivation to do the training (for more details see Prins et al., 2013 and Appendix). In the current study BGB was presented in three conditions:

Full-active condition. In this condition WM, inhibition and cognitive-flexibility were all in training-mode. Training-mode entailed that, after each block of training tasks, the difficulty level of the training task was automatically adjusted to the child's level of performance. Furthermore, in training-mode (a) the WM task (Dovis, Ponsioen, Geurts, Ten Brink, Van der Oord, & Prins 2008a) consisted of five training levels: the first level targeted visuospatial short-term memory (STM) only, whereas the other four levels targeted combinations of visuospatial STM, updating and manipulation of information (i.e. these four levels targeted both STM and the central executive). Each level was trained for 5 of the 25 sessions. The difficulty level was increased by increasing the amount of information that had to be remembered, updated and manipulated, (b) the inhibition task (Dovis, Geurts, Ponsioen, Ten Brink, Van der Oord, & Prins, 2008b) was designed to decrease the time needed to inhibit a prepotent response (comparable with the

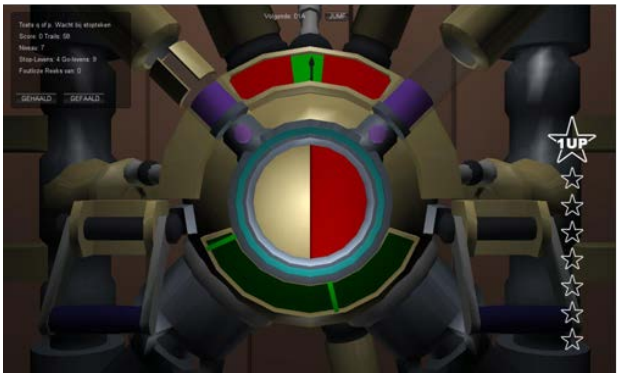


Fig. 1 The inhibition training task with the green colored time-frame (response window) in the upper middle of the screen.

stop signal reaction time measured by the STOP task; Logan, 1997). On most trials the child had to respond to a go-stimulus by pressing left or right within a specific time-frame (a green colored response window between 550-850 ms; see Figure 1). This created a prepotent response tendency. However, on 25% of the trials, somewhere after the go-stimulus and before the middle of the response window, a stop-signal was presented (a tone and a visual cue) and the child had to inhibit the prepotent response (stop-trials). The difficulty level was increased by shortening the time allowed to inhibit this response, (c) the cognitive-flexibility task (Dovis et al., 2008b) was designed to decrease the time a child needs to adapt his/her behavior when task-rules change (i.e. switch cost). Specifically, the child had to sort objects with different shapes and colors (e.g. blue or red colored plungers and wheels) to either the left or the right according to a rule. The rule was either to sort according to shape or to sort according to color. In 25% of the trials the rule switched (switch-trials). The difficulty level was increased by shortening the time allowed to switch between the two rules (for a more detailed description of the three training tasks see Van der Oord et al., 2012).

Partially-active condition. In this condition the inhibition and cognitive-flexibility tasks were in training-mode, and the WM task was in placebo-mode. Placebo-mode entailed that only the first level of the WM task was presented (for all 25 sessions), and that the difficulty level was not adjusted to the child's level of performance (no more than two items had to be remembered). The amount of trials in placebo-mode was increased to match the training time in training-mode (10 minutes training per session for each EF domain).

Placebo condition. In this condition WM, inhibition and cognitive-flexibility were all in placebo-mode. In placebo-mode the inhibition task and the cognitive-flexibility task were presented the same way as in training-mode except that the stop-trials and switch-trials were replaced by go-trials and non-switch trials (i.e., no stop-trials and switch-trials were presented) and the difficulty level was not adjusted.

Outcome Measures

Process measures.

Compliance. Compliance was defined as completing all of the 25 training sessions within a 5-week period. Using this algorithm, each child was categorized as compliant or noncompliant to treatment.

Blinding. At post-test, parents were asked to report the condition they thought their child was assigned to (full-active, partially-active, or placebo).

Improvement index during training. To validate whether the training actually improved task performance on the designated EFs, the improvement on training performance from beginning to end of training was assessed. It was tested whether children improved during training with paired t-tests. For the inhibition training and the cognitive flexibility training the results of day 2 and 3 of training (the Start Index) were compared with the results of their two best training days (the Max Index). The WM training had five levels and each level covered only 5 of the 25 training days. Therefore, to measure improvement on the WM training, within each level, the results of day 2 of training (the Start Index) were compared with the results of the best training day (the Max Index).

Performance measures.

Stop task. The Stop task was used to measure the time needed to inhibit an ongoing response (Logan, 1997). Two types of trials were presented: go-trials and stop-trials. During go-trials a go-stimulus (an arrow) that was either pointing right or left was presented. Participants were instructed to press a response button that corresponded to the direction of the stimulus as quickly and as accurately as possible. Stop-trials were identical to the go-trials but in addition a stop-signal was presented (a tone and a visual cue), which indicated that the participant had to withhold his/her ongoing response. The delay between the go- and stop-signal was dynamically varied (in steps of 50ms) so that inhibition was successful in 50% of the stop-trials. At this point, the go-process and stop-process are of equal duration, which makes it possible to estimate the latency of the stop-process: the stop signal reaction time (SSRT; Logan, 1997). Aside from two practice blocks, four experimental blocks (of 64 trials each) were administered. The SSRT was used as outcome measure of inhibitory processing. Test retest reliability of the SSRT in children with ADHD is .72 (Soreni, Crosbie, Ickowicz, & Schachar, 2009).

Stroop. The Stroop Color and Word Test (Hammes, 1978) measures interference control and consists of three pages with words and/or colors. On the first page, word naming is measured by naming the words red, green, yellow, and blue, printed in black ink. On the second page, color naming is measured by naming the colors of small rectangles. The first and second page represent the congruent trials. On the third page, colors are then named when shown as nonmatching color words (incongruent trials). The interference score on the Stroop is the time needed for the third page minus the time needed for the second page, and was used as our outcome measure of interference control. The STROOP has adequate reliability (Egberink, Vermeulen, & Frima, 2014).

Corsi Block Tapping Task (CBTT). The CBTT (Corsi, 1972) assesses the capacity of visuospatial STM and WM. The task consists of nine cubes (blocks) that are positioned on a board. In the present study, the same test format (size of board and blocks, distances between blocks) was used as in Kessels, van Zandvoort, Postma, Kappelle, and de Haan (2000) and the same procedure was used as in Geurts, Verté, Oosterlaan, Roeyers, and Sergeant (2004). The experimenter tapped a sequence of blocks that a child then had to reproduce in the same (CBTT-forward) or in reversed order (CBTT-backward). The minimum sequence length was three and the maximum was eight blocks, and each length was presented on three trials. The total amount of sequences that is correctly reproduced is the total score. The total score on the CBTT-forward (max. total score = 18) was used as an outcome measure for visuospatial STM and the total score on the CBTT-backward (max. total score = 18) was used as an outcome measure of visuospatial WM. The CBTT shows good reliability (Schellig, 1997).

Digit span. The scaled score on the Digit-span subtest from the WISC-III testing battery (Kort et al., 2002) was used as a composite measure of verbal STM and WM. Participants were orally given sequences of numbers and were asked to repeat them, either in the same (i.e. STM) or in reversed order (i.e. WM). Digit span has adequate reliability (Kort et al., 2002).

Trail Making Test (TMT). The TMT of the Delis-Kaplan Executive Function System (D-KEFS; Delis, Kaplan, & Kramer, 2007) measures cognitive flexibility and is a timed task that requires the individual to connect a series of letters and numbers in ascending order while alternating between numbers and letters. The scaled contrast score – the contrast between the scaled non-switch trials (number- and letter sequencing) and the scaled switch trials (number-letter switching) – was used as outcome measure of cognitive flexibility (i.e., switch-cost). Test-retest reliabilities range from .20 to .77 (Delis et al.).

Raven coloured progressive matrices. Raven’s coloured progressive matrices (Raven, 1995) measures non-verbal reasoning ability. The test consists of 36 items. The total amount of items correct (total score; max. = 36) was used as outcome measure for non-verbal reasoning. Test-retest reliability ranges from .68 to .90 (Costenbader & Ngari, 2001).

Questionnaires and rating scales.

DBDRS (parent and teacher versions). The DBDRS contains four DSM-IV scales; Inattention, Hyperactivity/ Impulsivity, Oppositional Defiant Disorder (ODD), and CD. Parents and teachers rate the child’s behavior on a 4-point Likert-type scale. Adequate psychometric properties have been reported (Oosterlaan et al., 2000). The scores on the

Inattention and Hyperactivity/Impulsivity scales were used as outcome measure of ADHD behavior. The scores on the ODD and CD scales were used as outcome measures of general problem behavior.

Behavior Rating Inventory of Executive Function questionnaire (BRIEF)(Gioia, Isquith, Guy, & Kenworthy, 2000). The Dutch version of the BRIEF is used to assess parent-rated EF. The BRIEF consists of 75 questions and includes eight EF sub-domains: Inhibit, Shift, Emotional Control, Initiate, WM, Plan/Organize, Organization of Materials, and Monitor. The test has adequate psychometric properties (Smidts & Huizinga, 2009). T-scores on the EF sub-domains were used as outcome measures.

Sensitivity to Punishment and Sensitivity to Reward Questionnaire for children (SPSRQ-C). The SPSRQ-C measures parent-rated sensitivity to punishment and reward (Colder & O'Connor 2004; Dutch translation: Luman, van Meel, Oosterlaan, & Geurts, 2012) and contains 33 items, divided in a Punishment Sensitivity scale, and three Reward Sensitivity scales: Reward Responsivity, Impulsivity/Fun-Seeking, and Drive. Each item is scored on a 5-point Likert scale. Adequate psychometric properties are reported (Colder & O'Connor, 2004). Subscale scores were used as outcome measures.

Pediatric Quality of Life Inventory (PedsQL; parent and child versions) (Varni, Seid, & Kurtin, 2001; Dutch translation: Bastiaansen, Koot, Bongers, Varni, & Verhulst, 2004). The PedsQL consists of 23 items, scored on a five-point Likert-scale, and is divided in four subscales: Physical, Emotional, Social, and School Functioning. The Psychosocial Health Summary score (a composite of the Emotional, Social and School Functioning subscales) was used as outcome measure. Adequate psychometric properties are reported (Bastiaansen et al., 2004).

The Home Situations Questionnaire (HSQ). The HSQ (Barkley & Edelbrock, 1987) is designed to assess the impact of problem behavior at home and in public situations. Parents report whether each of 16 daily situations (e.g. getting dressed and going to bed) was a problem and rate their severity on a 9-point scale. The mean severity score was used as outcome measure. The HSQ has adequate psychometric properties (Cunningham & Boyle, 2002).

Procedure

This study was approved by the faculty's IRB (the Ethics Review Board of the Faculty of Social and Behavioral Sciences of the university of Amsterdam). After obtaining written informed consent from the parents (on behalf of the participating children), parents and

teachers completed the DBDRS. At this first screening the 6-month version of the DBDRS was administered (regarding the child's behavior over the past 6-months), whereas at the pre-test, post-test and follow-up a two-week version of the DBDRS was administered (regarding the child's behavior over the past two-weeks). If DBDRS inclusion criteria were met, children and parents were invited to the intake session. During this session questions regarding demographics were asked (see Table 1), and the PDISC-IV and the short-form of the WISC-III were administered. If inclusion criteria were met, parent and child were invited to the pre-test session and the startup session, and were independently allocated to one of the three treatment conditions using the process of randomization by minimization (Altman & Bland, 2005) on the basis of age, gender, IQ, medication-use (yes/no), and parent- and teacher-rated inattention and hyperactivity/impulsivity symptoms (using the 6-months DBDRS). During the pre-test session the outcome measures were administered, and in the same week the teacher completed the two-week version of the DBDRS. The pre-test occurred approximately 1-2 weeks prior to the startup session (which was the start of the training). During the startup session parent and child were instructed about the training program, the computer, and the external reward system (see Appendix), and a schedule for implementing the intervention and for weekly coaching calls was established. Once a research assistant completed a startup session with a particular family, he/she could not test or have further contact with that family or the teacher (to preserve blinding). During the 5-week, home-based training, a coach (a research assistant blind to the treatment condition) made weekly calls (of about 15 minutes; using a standardized telephone protocol) to the participating families to monitor progress, motivation and compliance, and to solve technical and game-related problems. Parents and children were explicitly instructed not to discuss the content of the training tasks with the coach. If a coach did receive information revealing the treatment condition, he/she was replaced and could no longer have contact with the family or the teacher. 1-2 weeks after the final training session the post-test was scheduled and the teacher completed the DBDRS. 3-months after the final training session the follow-up was scheduled and the teacher completed the DBDRS. At each test-session experimenters were blind to condition.

Statistical Analyses

Sample size was determined by a prospective power analyses for univariate testing (using G*Power) based on the effect sizes of two previous EF-treatment studies (Klingberg et al., 2005; Prins et al., 2011). These studies suggested that the treatment effects on our primary outcome measures (i.e., EF measures, ADHD rating-scales) would be medium in size. Groups

did not differ with respect to any of the baseline demographics or clinical characteristics (see Table 1). Also, including these baseline demographics and clinical characteristics (i.e., Gender, Age, FSIQ, DBDRS parent and teacher ratings, ODD diagnosis, ADHD medication use, Computergame experience, and Dyslexia) as covariates in the main analyses did not change the pattern of our results.[37] Pearson's chi-squared test was used for assessing the effectiveness of blinding. An Intent-To-Treat (ITT) approach, using single imputations (i.e., for each treatment group stochastic regression imputation was used to predict the missing posttest and follow-up values. The missing posttest values were based on the non-missing pretest and posttest scores of each treatment group. The missing follow-up values were based on the non-missing pretest scores, posttest scores, follow-up scores, and pretest-posttest difference scores of each treatment group), was used to compare treatment effects of the three treatment conditions. Dependent measures were subjected to repeated measures MANOVAs (the covariance matrix was assumed to be unstructured), with Treatment condition (full-active, partially-active, placebo) as between-subject factor and Time (pre-test, post-test, follow-up) as within-subject factors. Significant effects were further analyzed with simple contrasts. For additional within-group analyses paired t-tests were used. Partial Eta squared effect sizes (η_p^2) are reported for all analyses: η_p^2 =.01 is regarded a small effect size, .06 a medium effect size, and .14 a large effect size (Kittler, Menard, & Phillips, 2007).

7.3 Results

Process Measures

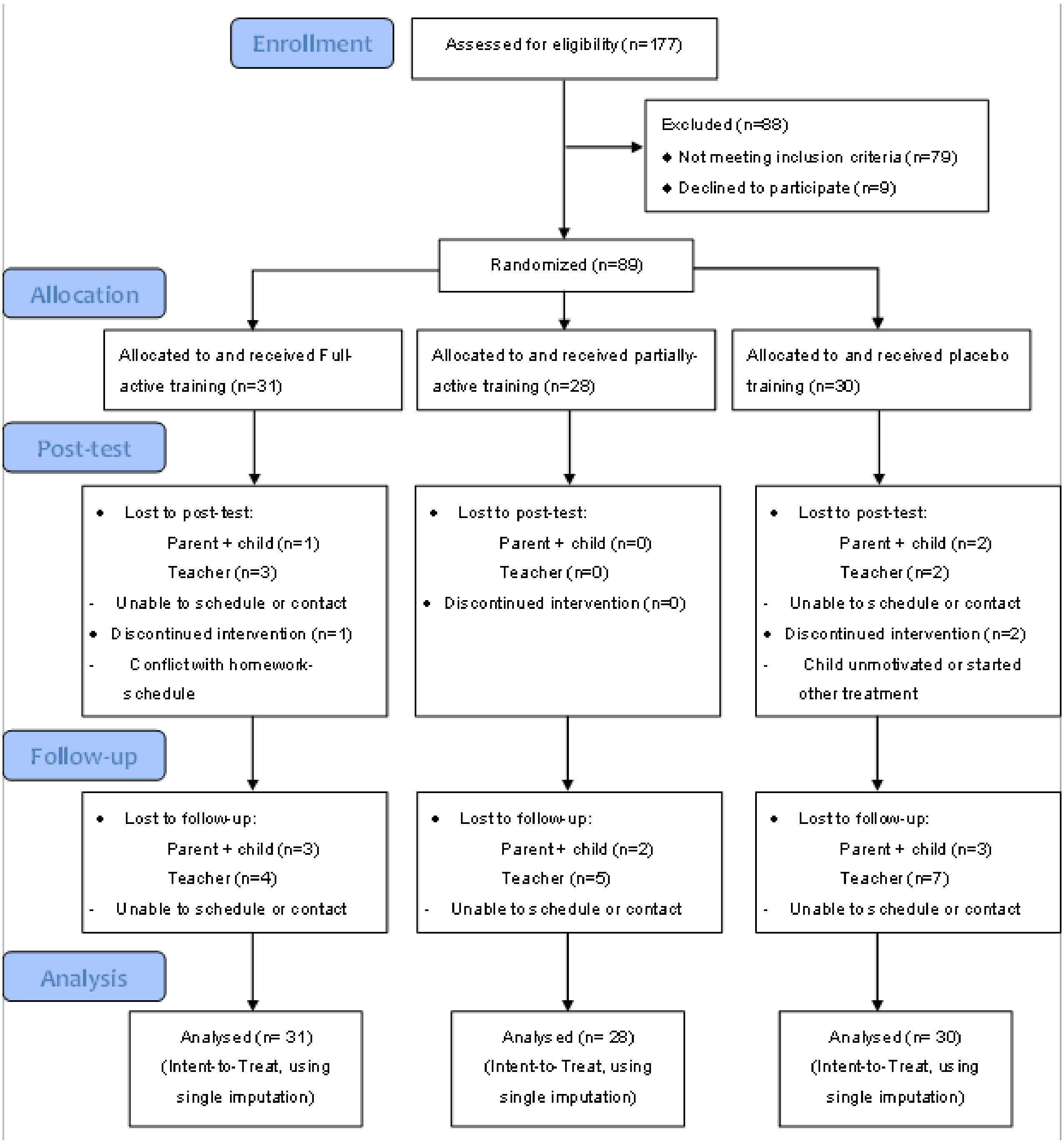
Compliance during training. Of the 31 participants assigned to the full-active condition, 30 (96.7%) met compliance criteria (25 training days within 5 weeks). All of the 28 participants assigned to the partially-active condition met compliance criteria. Of the 30 participants assigned to the placebo condition, 28 (93.3%) met compliance criteria. Overall, compliance to treatment was high, given that this was a home-based intervention that included a substantial portion of participants with ODD (see Figure 2).

Post-training dropout. Eight participants (9%) of our total sample (i.e., 3 children in the full-active condition, 2 children in the partially-active condition, and 3 children in the placebo condition) were lost to post-test and follow-up testing (see Figure 2). There were no significant differences on baseline demographics and clinical characteristics (i.e., gender, age, IQ, DBDRS parent and teacher ratings, ODD-diagnosis, medication use, computergame

[37] Because repeated-measures were used, covariates were entered after mean centering (see Delaney & Maxwell, 1981).

experience, Dyscalculia and Dyslexia) between the children lost to post-test and follow-up testing and the children who participated in these assessments (but note that the sample size of the post-training drop out group was small).[38]

Fig. 2 CONSORT flow diagram



[38] Depending on the level of measurement a MANOVA or Pearson's chi-squared tests were used

Blinding. There was no significant association between the conditions wherein participants were actually included and the conditions whereof parents afterwards reported (guessed) that their child was assigned to, $\chi^2(4) = 1.21$, $p = .875$. This suggests that, based upon their experience with the actual training condition, parents were not able to guess the condition wherein their child was included. Further, no participant (child, parent, teacher, experimenter, or coach) was unblinded at any point during the conduct of the trial.

Improvement index during training. It was tested whether children improved during training with paired t-tests (*p*-values were corrected for multiple comparisons by using a more conservative α-level of .01). Within the full-active condition, paired t-tests showed a significant difference (improvement) between the Start Index and Max Index for the Inhibition training, t (30) = -18.66, $p < .001$, the Cognitive flexibility training, t (30) = -19.14, $p < .001$, and for all the levels of the WM training (level 1, t (30) = -7.25, $p < .001$; level 2, t (30) = -7.90, $p < .001$; level 3, t (30) = -7.19, $p < .001$, level 4, t (30) = -9.21, $p < .001$; level 5, t (30) = -7.72, $p < .001$). Within the partially-active condition (where WM was in placebo-mode), paired t-tests showed significant difference (improvement) between the Start Index and the Max Index for both the Inhibition training, t (27) = -15.86, $p < .001$, and the Cognitive flexibility training, t (27) = -22.89, $p < .001$.

Performance Measures

A 3x3 (Treatment condition x Time [pre-test, post-test, follow-up) repeated measures MANOVA with the main scores of the EF tasks (Stoptask [SSRT], STROOP [interference score], CBTT-fwd [total score], CBTT-bkw [total score], Digit recall [scaled score], TMT [scaled contrast score]) and the Raven (total score) as dependent variables, showed a main effect of Time, F (14,334) = 6.74, $p < .001$, $\eta_p^2 = .22$, no main effect of Treatment condition, F (14,162) = 1.41, $p = .154$, $\eta_p^2 = .11$, and a significant interaction between Treatment condition and Time, F (28,676) = 1.59, $p = .027$, $\eta_p^2 = .06$. To interpret these significant effects for each performance based measure, we used simple contrasts:

For each performance based measure, main Time effects and Treatment condition x Time interactions are presented per pair-wise time difference (i.e. pre- vs. post-test, post- vs. follow-up test; pre- vs. follow-up test) in Table 2.

Between the pre- and post-test there was a significant Treatment condition x Time interaction for the Stoptask, the CBTT-fwd, and the CBTT-bkw (see Table 2). Between the pre-test and follow-up there was a significant Treatment condition x Time interaction for the CBTT-fwd, and a non-significant trend for the STROOP (see Table 2). Other pair-wise time

differences in Treatment condition x Time interaction effects were non-significant.[39] Next, in order to obtain more insight into these two-way interactions, follow up repeated measures MANOVAs were performed for each combination of treatment conditions.

[39] Investigating Digit recall forward and backward separately (using raw scores) did not change the results (no main time effects, nor time x treatment condition effects).

Table 2. Outcomes at baseline, post-test and follow-up

	Full-active Condition						Partially-active Condition						Placebo Condition						Time constrasts. *F* (1. 86)						Treatment*Time constrasts. *F* (2. 86)					
	Pre		Post		FU		Pre		Post		FU		Pre		Post		FU		Pre vs. Post		Post vs. FU		Pre vs. FU		Pre vs. Post		Post vs. FU		Pre vs. FU	
Domain and Measure	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*F*	η_p^2	*F*	η_p^2	*F*	η_p^2	*F*	η_p^2	*F*	η_p^2	*F*	η_p^2
Performance Measures																														
Stoptask (SSRT)	189.6	43.7	151.4	39.7	147.4	40.9	197.0	65.2	158.8	31.6	150.2	48.7	200.1	73.8	197.7	69.0	189.0	68.6	16.50***	.16	1.18	.01	18.41***	.18	3.42*	.07	.06	.001	2.08	.05
STROOP (interfence score)	68.8	33.9	53.2	24.1	46.2	19.9	70.5	33.0	49.4	23.7	53.2	25.3	68.0	30.4	55.9	26.4	62.6	33.0	28.50***	.25	.17	.002	23.27***	.21	.71	.02	2.29	.05	2.69†	.06
CBTT-forward (total score)	9.6	2.4	11.7	2.3	11.0	2.4	9.5	2.2	10.1	2.3	9.7	2.5	9.9	2.9	10.1	1.9	9.6	2.1	18.08***	.17	10.13**	.11	2.72	.10	6.96**	.14	.21	.01	4.59*	.10
CBTT-backward (total score)	8.7	2.3	10.1	2.9	10.0	2.3	9.1	2.5	9.4	2.0	9.3	2.3	9.2	2.5	9.2	2.3	9.4	2.3	5.33*	.06	.004	<.001	4.87*	.05	3.36*	.07	.23	.01	2.53	.06
Digit Recall (scaled score)	9.3	2.9	9.9	3.3	9.9	3.1	9.1	3.2	9.9	3.3	9.6	3.3	9.8	2.6	9.9	2.9	9.5	3.1	3.12	.04	.45	.01	.98	.01	.47	.01	.21	.01	.95	.02
TMT (scaled contrast score)	8.9	3.1	8.6	2.8	8.6	2.8	8.7	3.1	8.9	3.5	9.0	2.3	8.7	2.6	8.6	2.4	8.7	2.1	.02	<.001	.002	<.001	.01	<.001	.16	<.001	.02	<.001	.23	.01
Raven (total score)	33.0	2.7	33.5	2.1	34.2	1.7	32.1	3.5	32.9	3.3	33.6	2.5	33.2	2.2	33.7	2.0	33.7	1.9	6.86*	.07	5.21*	.06	25.81***	.23	.11	.002	1.50	.03	2.04	.05
ADHD Behavior																														
P-DBDRS Inattention	17.5	4.3	11.9	5.7	12.9	4.1	17.7	5.5	12.6	4.5	14.6	5.3	18.2	4.4	13.6	5.2	14.1	4.7	66.21***	.44	5.31*	.06	48.37***	.36	.23	.01	.92	.02	.69	.02
P-DBDRS Hyp/Imp	17.0	5.3	12.2	6.6	12.6	6.4	16.5	4.5	12.0	5.3	13.0	5.1	17.0	4.7	12.9	6.5	12.5	5.7	63.01***	.42	.55	.01	55.70***	.39	.11	.003	.85	.02	.37	.01
T-DBDRS Inattention	14.0	4.5	11.7	5.6	12.2	5.8	14.7	5.0	11.0	5.6	13.3	6.6	13.8	5.4	12.3	5.0	11.3	5.1	19.27***	.18	.89	.01	10.11**	.11	1.20	.03	2.20	.05	.30	.01
T-DBDRS Hyp/Imp	12.7	6.4	11.1	5.5	9.3	4.9	13.1	6.6	10.0	6.2	11.5	7.0	12.4	5.1	11.6	6.0	9.1	4.0	13.29***	.13	2.65	.03	20.94***	.20	1.66	.04	4.77*	.10	.93	.02
EF- & Motiv. Behavior																														
P-BRIEF Inhibit	70.5	11.5	63.8	10.9	63.1	10.9	69.8	7.6	65.6	10.1	65.8	10.4	71.5	9.4	63.8	10.2	62.7	10.4	37.42***	.30	.51	.01	41.24***	.32	1.05	.02	.25	.01	1.85	.04
P-BRIEF Working Memory	68.0	6.8	59.1	9.6	60.9	8.9	67.1	7.7	60.3	9.3	62.4	8.3	67.8	6.8	59.5	6.6	61.1	8.1	94.93***	.53	5.82*	.06	81.63***	.49	.61	.01	.04	.001	1.21	.03
P-BRIEF Shift	58.8	10.5	53.1	8.1	51.8	10.2	58.8	11.1	54.3	11.8	53.1	10.1	64.6	9.6	56.7	8.2	54.8	8.5	40.34***	.32	4.08*	.05	60.10***	.41	1.09	.03	.09	.002	1.55	.04
P-BRIEF Emotional Control	59.4	11.0	53.1	10.5	54.0	11.0	59.2	11.1	56.7	12.9	56.5	12.2	63.4	9.3	57.2	10.6	55.7	11.4	27.45***	.24	.07	.001	25.84***	.23	1.71	.04	.56	.01	1.97	.04
P-BRIEF Initiate	58.9	9.2	53.3	10.1	53.3	10.5	58.3	6.2	53.1	9.8	54.4	8.2	62.4	9.0	54.7	9.3	56.3	10.8	45.23***	.35	1.05	.012	38.56***	.31	.73	.02	.26	.01	.66	.02
P-BRIEF Plan/Organize	61.5	8.7	56.4	9.0	55.9	8.2	61.6	7.7	56.8	9.2	57.8	9.5	63.1	7.3	58.1	7.6	59.4	7.0	32.26***	.27	.54	.01	29.66***	.26	.01	<.001	.44	.01	.56	.01
P-BRIEF Organiz. Materials	54.5	10.0	51.8	12.4	52.0	11.1	58.5	6.2	56.5	8.2	55.1	10.4	55.8	9.5	52.6	9.9	54.5	9.8	9.87**	.10	.08	.001	6.23*	.07	.18	.004	1.19	.02	.42	.01
P-BRIEF Monitor	63.5	5.6	58.2	7.1	60.6	8.3	63.1	7.5	59.4	10.3	59.5	9.3	65.4	5.5	58.5	7.9	60.3	8.2	34.30***	.29	2.83	.03	19.72***	.19	.99	.02	.64	.02	.58	.01
P-SPSRQ Punish. Sens.	2.6	0.6	2.4	0.5	2.4	0.6	2.3	0.5	2.2	0.5	2.4	0.6	2.8	0.6	2.6	0.9	2.6	0.7	5.46*	.06	1.33	.02	2.08	.02	.14	.003	.73	.02	1.52	.03
P-SPSRQ Imp/Fun Seeking	3.2	0.6	3.0	0.5	3.0	0.4	3.3	0.5	3.1	0.5	3.3	0.6	3.4	0.6	3.2	0.6	3.3	0.7	10.95**	.11	3.39†	.04	3.19	.04	.28	.01	1.21	.03	.36	.01
P-SPSRQ Reward Respons.	3.7	0.6	3.6	0.6	3.4	0.6	3.8	0.6	3.6	0.7	3.7	0.6	3.6	0.7	3.6	0.8	3.6	0.7	3.78†	.04	.09	.001	7.65**	.08	.66	.02	2.06	.05	1.01	.02
P-SPSRQ Drive	3.1	0.9	3.2	0.9	3.0	0.8	3.5	0.8	3.5	0.7	3.6	1.0	3.4	0.9	3.1	1.1	3.2	0.8	1.06	.01	.17	.002	1.94	.02	2.45	.06	1.30	.03	1.45	.03
Gen. Problem Behavior																														
P-DBDRS ODD	8.3	4.8	6.0	5.1	7.0	5.3	10.0	5.1	8.3	5.3	8.6	4.6	9.4	4.2	6.9	4.1	6.9	4.7	25.35***	.23	1.93	.02	20.90***	.20	.25	.01	.65	.02	1.02	.02
P-DBDRS CD	1.1	1.6	0.7	1.0	1.0	1.7	1.5	1.5	0.8	1.3	1.3	1.4	1.6	1.9	1.2	1.6	0.8	1.5	13.29***	.13	1.44	.02	5.85*	.06	.45	.01	2.63	.06	1.72	.04
T-DBDRS ODD	6.6	5.0	5.9	4.9	5.3	4.6	6.0	4.7	4.5	4.3	5.8	5.7	6.8	6.0	5.1	5.4	4.3	4.7	10.02**	.10	.01	<.001	7.44**	.08	.66	.02	1.89	.04	1.68	.04
T-DBDRS CD	1.2	1.6	1.1	1.9	1.5	2.4	1.6	2.3	1.5	2.4	1.2	2.1	1.9	2.6	1.1	1.8	1.0	1.6	3.55†	.04	.01	.001	2.73	.03	1.96	.04	.89	.02	2.70	.06
P-PEDsQL Psy.soc. Hlth.	61.8	12.1	73.1	13.9	72.6	9.1	61.0	14.1	69.0	14.3	65.3	12.9	51.3	14.5	63.8	14.9	62.2	15.6	53.48***	.38	1.84	.02	47.39***	.36	.81	.02	.87	.01	2.77†	.06
C-PEDsQL Psy.soc. Hlth.	67.2	17.3	67.8	13.5	66.9	15.1	68.3	14.1	70.0	16.2	70.7	13.5	63.7	11.7	67.2	15.3	66.3	15.4	2.88	.03	.18	.001	2.06	.02	.54	.01	.18	.004	.71	.02
P-HSQ Mean Severity Score	4.3	1.8	3.6	1.8	3.8	1.9	4.2	1.8	3.5	1.6	3.7	2.0	4.7	1.5	3.7	1.5	3.5	1.5	15.71***	.15	.12	.001	12.69**	.13	.28	.01	.55	.02	1.36	.03

Note. BRIEF = Behavior Rating Inventory of Executive Function; C- = Child-rated; CBTT = Corsi Block Tapping Task; CD = conduct disorder; DBDRS = Disruptive Behavior Disorder Rating Scale; FU = Follow-up-test (after 3 months); HSQ = Home Situations Questionnaire; Imp/Fun Seeking = Impulsivity/Fun Seeking; ODD = oppositional defiant disorder; Organiz. Materials = Organization of Materials; P- = Parent-rated; PEDsQL = Pediatric Quality of Life Inventory; Post = Post-test; Pre = Pre-test; Psy.soc. Hlth. = Psychosocial Health Summary Score; Punish. Sens. = Punishment Sensitivity; Reward Respons. = Reward Responsiveness; SPSRQ = Sensitivity to Punishment and Sensitivity to Reward Questionnaire for children; SSRT = Stop Signal Reaction Time; T- = Teacher-rated; TMT = Trail Making Task; * $p < .05$; ** $p < .01$; *** $p < .001$; † $p < .075$

Full-active condition versus placebo condition. A 2x3 (Treatment condition x Time) repeated measures MANOVA with the main scores of the Stoptask, STROOP, CBTT-fwd, and CBTT-bkw as dependent variables, showed a main effect of Time, F (8,232) = 6.22, $p <$ .001, η_p^2 = .18, a main effect of Treatment condition, F (4,56) = 5.06, p = .009, η_p^2 = .21, and a significant interaction between Treatment condition and Time, F (8,232) = 3.90, $p <$ .001, η_p^2 = .12. To further interpret this interaction for each pair-wise time difference and each performance based measure, we used simple contrasts:

These contrasts are presented in Table 3 and indicate that, compared to pre-test performance, post-test- and/or follow-up performance on the Stoptask, the STROOP and the CBTT forward and backward improved significantly more in the full-active condition than in the placebo condition (effect sizes ranged from medium to large; see Table 3 and Figure 3A-D).

Partially-active condition versus placebo condition. A 2x3 (Treatment condition x Time) repeated measures MANOVA with the main scores of the Stoptask, STROOP, CBTT-fwd, and CBTT-bkw as dependent variables, showed a main effect of Time, F (8,220) = 3.49, p = .001, η_p^2 = .11, no main effect of Treatment condition, F (4,53) = 1.44, p = .235, η_p^2 = .10, and no significant interaction between Treatment condition and Time, F (8,220) = 1.07, p = .388, η_p^2 = .04. However, since we had specific expectations regarding the Treatment condition x Time interactions - we only expected this interaction for the Stoptask and the STROOP, not for the CBTT forward and backward (as WM was not trained in either condition) - simple contrasts were used to further explore the non-significant interaction effect:

These contrasts are presented in Table 3 and indicate that, compared to pre-test performance, post-test performance on the Stoptask improved significantly more in the partially-active condition than in the placebo condition (medium effect size; see Table 3 and Figure 3A).

Full-active condition versus partially-active condition. A 2x3 (Treatment condition x Time) repeated measures MANOVA with the main scores of the Stoptask, STROOP, CBTT-fwd, and CBTT-bkw as dependent variables, showed a main effect of Time, F (8,224) = 9.79, $p <$ .001, η_p^2 = .26, no main effect of Treatment condition, F (4,54) = 1.76, p = .151, η_p^2 = .12, and a significant interaction between Treatment condition and Time, F (8,224) = 2.00, p = .048, η_p^2 = .07. To further interpret this interaction, we used simple contrasts:

These contrasts are presented in Table 3 and indicate that, compared to pre-test performance, post-test and/or follow-up performance on the CBTT (forward and backward),

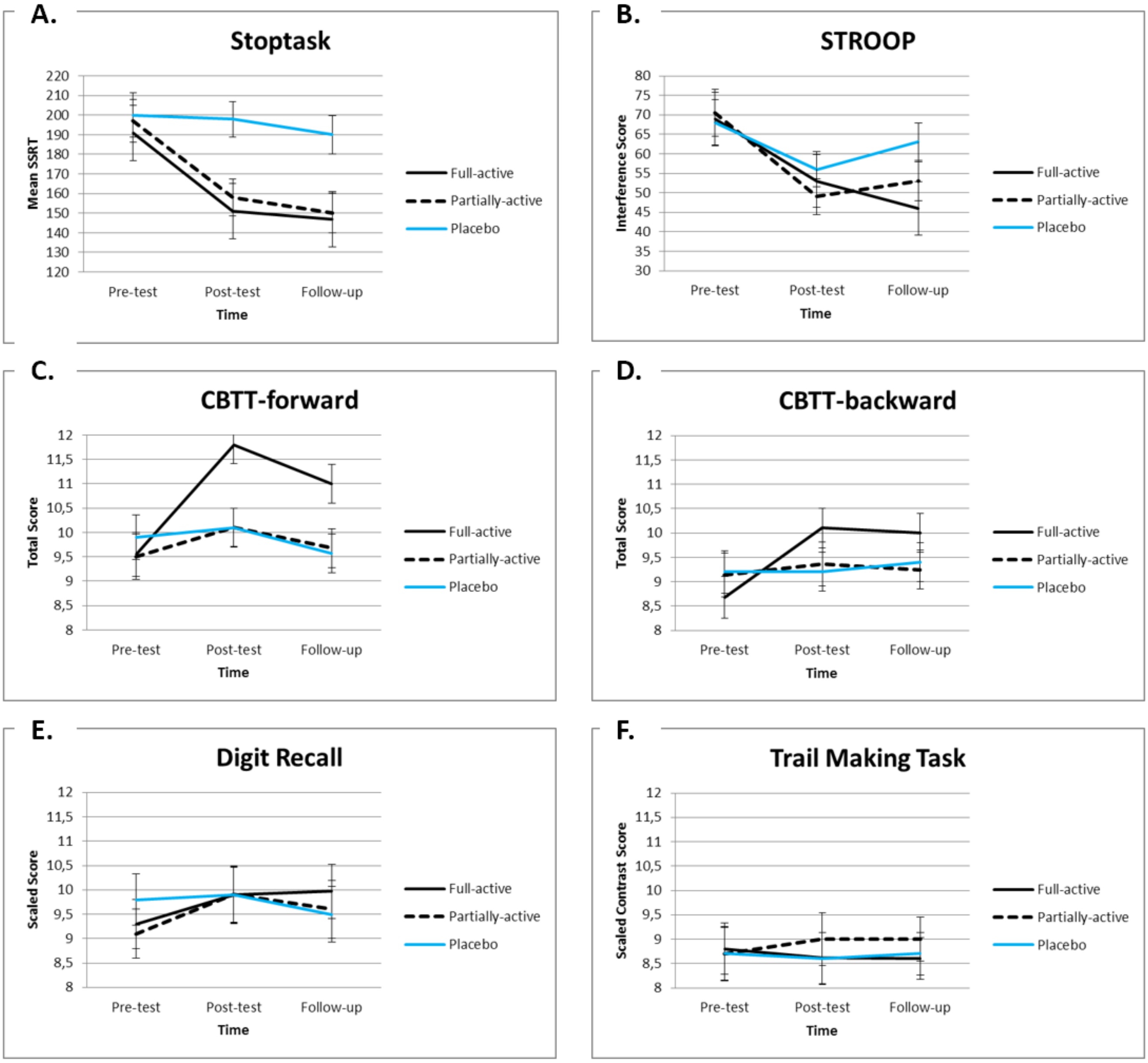
improved more in the full-active condition than in the partially-active condition (effect sizes were medium; see Table 3 and Figure 3 C-D).

Table 3

Outcome of repeated measures MANOVAs contrasts for task performance in each combination of treatment conditions

	Full-active vs. Placebo						**Partially-active vs. Placebo**						**Full-active vs. Partially-active**					
	Treatment*Time constrasts, *F* (1,59)						Treatment*Time constrasts, *F* (1,56)						Treatment*Time constrasts, *F* (1,57)					
	Pre vs. Post		Post vs. FU		Pre vs. FU		Pre vs. Post		Post vs. FU		Pre vs. FU		Pre vs. Post		Post vs. FU		Pre vs. FU	
Measure	F	η_p^2	F	η_p^2	F	η_p^2	F	η_p^2	F	η_p^2	F	η_p^2	F	η_p^2	F	η_p^2	F	η_p^2
Stoptask (SSRT)	5.73*	.09	.08	.001	2.63	.04	4.22*	.07	<.001	<.001	2.68	.05	<.001	<.001	.15	.003	.09	.002
STROOP (interf.)	.25	.004	4.34*	.07	6.53*	.10	1.16	.02	.16	.003	2.26	.04	.60	.01	2.73	.05	.39	.01
CBTT-forward	11.03**	.16	.24	.004	8.35**	.12	.83	.02	.03	<.001	.77	.01	6.92*	.11	.32	.01	4.15*	.07
CBTT-backward	5.98*	.09	.29	.005	2.91	.05	.19	.003	.51	.01	.02	<.001	3.71†	.06	.01	<.001	5.76*	.09

Note. CBTT = Corsi Block Tapping Task; FU = Follow-up-test (after 3 months); Interf. = Interference score; Post = Post-test; Pre = Pre-test; SSRT = Stop Signal Reaction Time; * $p < .05$; ** $p < .01$; *** $p < .001$; † $p < .06$



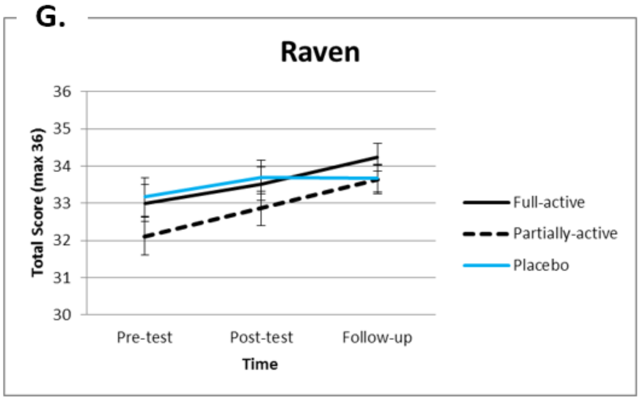


Fig. 3 Mean values and standard errors of the executive functioning tasks (A –F) and the Raven (G) on the pre-test, post-test and (3 month) follow-up of children in the three treatment groups. *Note:* SSRT = Stop Signal Reaction Time; CBTT = Corsi Block Tapping Task.

Within-group analyses. For each EF task where a Treatment condition x Time interaction was significant (Stoptask, STROOP, CBTT-fwd, CBTT-bkw), differences within each treatment group between the pre- and post-test, the post-test and follow-up, and the pre-test and follow-up were tested with additional paired t-tests (*p*-values were corrected for multiple comparisons by using a more conservative α-level of .01).

Results are presented in Table 4 and indicate that in the full-active condition performance on the Stoptask, the STROOP, the CBTT-fwd and the CBTT-bkw significantly improved between pre- and post-test and between pre-test and follow-up. In the partially-active condition performance on the Stoptask significantly improved between pre- and post-test and between pre-test and follow-up, and performance on the STROOP significantly improved between pre- and post-test. In the placebo condition none of the differences were significant (see Table 4).

Table 4

Within-group comparisons of pair-wise time differences in task performance (using paired t-tests)

	Full-active			**Partially-active**			**Placebo**		
	Paired t-tests, t (30)			Paired t-tests, t (27)			Paired t-tests, t (29)		
	Pre vs Post	Post vs FU	Pre vs FU	Pre vs Post	Post vs FU	Pre vs FU	Pre vs Post	Post vs FU	Pre vs FU
Measure	t	t	t	t	t	t	t	t	t
Stoptask (SSRT)	4.29**	.70	4.64**	3.03*	.80	3.53*	.20	.56	.65
STROOP (interf.)	3.91**	1.76	4.47**	3.49*	-.71	2.57†	2.12†	-1.27	1.22
CBTT-forward	- 4.70**	**2.19**†	-3.25*	-1.88	1.32	-.41	-.43	**2.15**†	.83
CBTT-backward	-3.39*	.21	-3.49*	-.59	.40	-.34	<.001	-.67	-.38

Note. CBTT = Corsi Block Tapping Task; FU = Follow-up-test (after 3 months); Interf. = Interference score; Post = Post-test; Pre = Pre-test; SSRT = Stop Signal Reaction Time; To corrected for multiple comparisons, differences were only marked as significant if α-level were < .01; * $p < .01$; ** $p < .001$; † $p < .05$; **Bold number** = a decrease in performance

Questionnaires and Rating Scales

ADHD behavior (parent and teacher DBDRS). A 3x3 (Treatment condition x Time) repeated measures MANOVA with mean scores on the Inattention and Hyperactivity/Impulsivity scales of the parent and the teacher version of the DBDRS as dependent variables, showed a main effect of Time, F (8,340) = 13.32, $p < .001$, $\eta_p^2 = .24$, no main effect of Treatment condition, F (8,166) = .33, $p = .953$, $\eta_p^2 = .02$, and no significant

interaction between Treatment condition and Time, F (16,688) = .77, p = .718, η_p^2 = .02. The significant Time effect was further explored using simple contrasts:

For each ADHD scale, main Time effects are presented per pair-wise time difference in Table 2. Results indicate that, compared to the pre-test, both parents and teachers reported a significant decrease in ADHD symptoms at the post-test and at the follow-up (effect sizes of parent-ratings were large; effect sizes of teacher-ratings ranged from medium to large). However, the non-significant Treatment x Time interaction indicates that this decrease did not differ between the Treatment conditions (in addition see Table 2 & Figure 4).

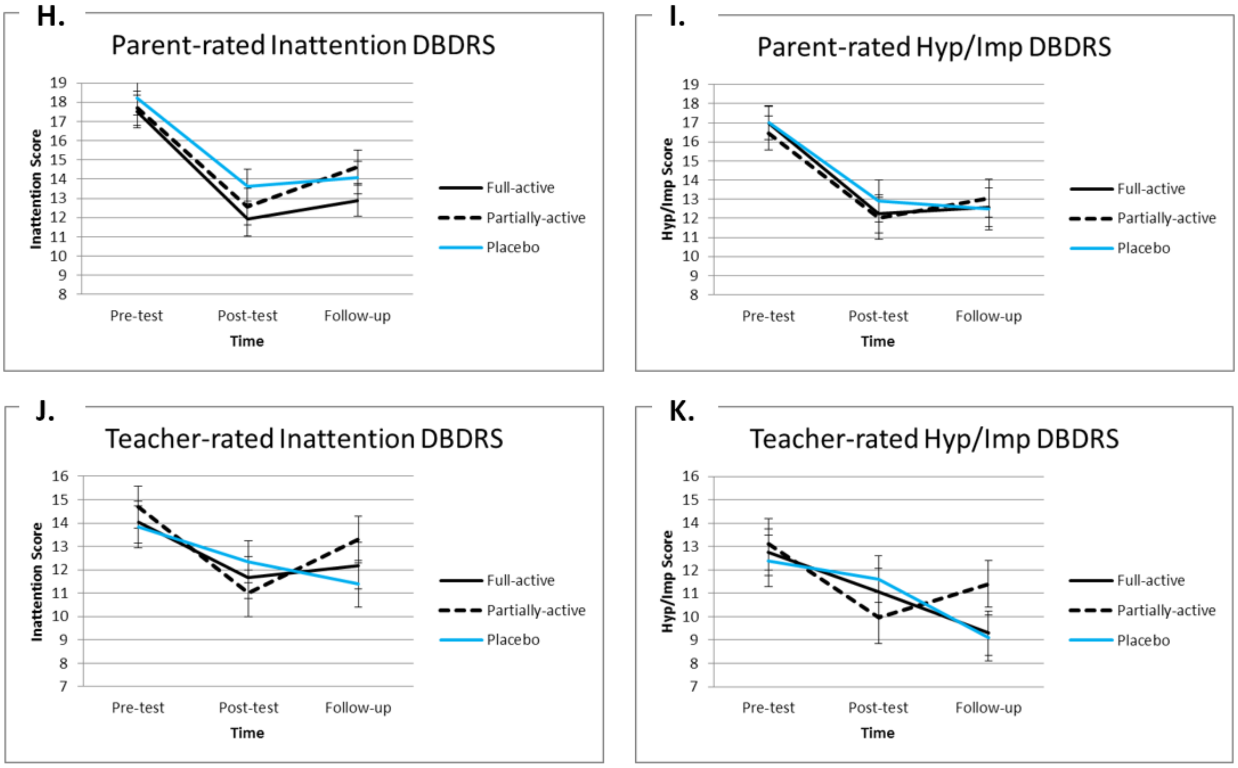


Fig. 4 Mean values and standard errors of the mean scores on the Inattention and Hyperactivity/ Impulsivity (Hyp/Imp) scales of the parent and the teacher versions of the Disruptive Behavior Disorder Rating Scale (DBDRS; H-K) on the pre-test, post-test and (3 months) follow-up of children in the three treatment groups

Parent-rated EF- and motivational behavior (BRIEF and SPSRQ-C). A 3x3 (Treatment condition x Time) repeated measures MANOVA with mean t-scores on the Inhibit-, Working Memory-, Shift-, Emotional Control-, Initiate-, Plan/Organize-, Organization of Materials-, and Monitor scales of the BRIEF, and the mean scores on the

Sensitivity to Punishment-, Impulsivity/Fun Seeking-, Reward Responsiveness-, and Drive scales of the SPSRQ-C as dependent variables, showed a main effect of Time, F (30,318) = 4.91, p < .001, η_p^2 = .32, no main effect of Treatment condition, F (30,146) = 1.08, p = .368, η_p^2 = .18, and no significant interaction between Treatment condition and Time, F (60,644) = .72, p = .942, η_p^2 = .06. The significant Time effect was further explored using simple contrasts:

These contrasts are presented in Table 2 and indicate that after training, parents reported a significant improvement on all scales of the BRIEF (EF behavior; except for the medium effect size on the Organization of Materials scale, all effect sizes were large) and on most scales of the SPSRQ-C (motivational behavior; effect sizes were medium). However, the non-significant Treatment x Time interaction indicates that these improvements did not differ between the Treatment conditions (in addition see the Treatment x Time contrasts in Table 2).

General problem behavior (DBDRS, PEDsQL, and HSQ). A 3x3 (Treatment condition x Time) repeated measures MANOVA with mean scores on the ODD and the CD scales of the parent and the teacher version of the DBDRS, the Psychosocial Health Summary score of the parent and the child version of the PEDsQL, and the mean severity score of the parent-rated HSQ as dependent variables, showed a main effect of Time, F (14,334) = 5.15, p < .001, η_p^2 = .18, a main effect of Treatment condition, F (14,162) = 1.83, p = .038, η_p^2 = .14, and no significant interaction between Treatment condition and Time, F (28,676) = 1.10, p = .337, η_p^2 = .04. The significant Time effect was further explored using simple contrasts:

These contrasts are presented in Table 2 and indicate that after training, parents reported a significant improvement on all general problem behavior indices (effect sizes ranged from medium to large), and teachers reported a significant improvement on the ODD scale of the DBDRS (medium effect size). However, the non-significant Treatment x Time interaction indicates that these improvements did not differ between the Treatment conditions (in addition see the Treatment x Time contrasts in Table 2). In contrast to their parents, children reported no significant difference in their Psychosocial Health Summary Score after training.

Treatment Responders

In addition to the overall means, the percentage of children who benefitted from training was calculated for each measure that showed significant main Time effects and/or Treatment condition x Time interactions on the pairwise comparisons of pre- and post-test scores and/or

pre- and follow-up test scores (see Table 2). On each of these measures children were either classified as responders or non-responders by using reliable change indices (Jacobson & Truax, 1991; Wise, 2004).[40] Results for each treatment condition are presented in Table 5. The pattern of these results strongly resembles the pattern of the mean results (see Table 5).

[40] Based on classification guidelines by Wise (2004), a participant was classified as responder when both the following criteria were met: (1) a reliable change index (RCI) of at least 1.28 (RCI was based on method of Jacobson & Truax, 1991), and (2) an improvement of scores of at least 1 standard deviation (Wise, 2004).

Table 5

Proportion of treatment groups showing improvement on performance measures and rating-scales (i.e., responders)

	Full-active Condition		**Partially-active Condition**		**Placebo Condition**	
	Pre vs. Post	Pre vs. FU	Pre vs. Post	Pre vs. FU	Pre vs. Post	Pre vs. FU
Domain and Measure	*% responders*	*% responders*	*% responders*	*% responders*	*% responders*	*% responders*
Performance Measures						
Stoptask (SSRT)	**41.9**	<u>**54.8**</u>	**35.7**	**35.7**	16.7	20.0
STROOP (interfence score)	9.7	22.6	21.4	10.7	14.6	6.7
CBTT-forward (total score)	**48.4**	**41.9**	17.9	17.9	13.3	13.3
CBTT-backward (total score)	**38.7**	29.0	17.9	3.6	10.0	16.7
Raven (total score)	12.9	19.4	10.7	14.3	16.7	16.7
ADHD Behavior						
P-DBDRS Inattention	<u>**51.6**</u>	**48.4**	<u>**53.6**</u>	**32.1**	**50.0**	**50.0**
P-DBDRS Hyp/Imp	**45.2**	**38.7**	**50.0**	**42.9**	**40.0**	**46.7**
T-DBDRS Inattention	29.0	**32.2**	**42.9**	28.6	23.3	30.0
T-DBDRS Hyp/Imp	16.1	**38.7**	25.0	25.0	20.0	30.0
EF- & Motiv. Behavior						
P-BRIEF Inhibit	**35.5**	**35.5**	25.0	25.0	26.7	**43.3**
P-BRIEF Working Memory	<u>**54.8**</u>	**41.9**	**39.3**	**32.1**	<u>**56.7**</u>	**50.0**
P-BRIEF Shift	25.8	**32.3**	17.9	25.0	**40.0**	**50.0**
P-BRIEF Emotional Control	**32.3**	**32.3**	14.3	21.4	**40.0**	**36.7**
P-BRIEF Initiate	**35.5**	**38.7**	**50.0**	**39.3**	**43.3**	30.0
P-BRIEF Plan/Organize	29.0	29.0	28.6	**35.7**	**33.3**	**33.3**
P-BRIEF Organiz. Materials	22.6	19.4	25.0	28.6	23.3	16.7
P-BRIEF Monitor	**48.4**	**48.4**	25.0	**32.1**	**53.3**	**46.7**
P-SPSRQ Punish. Sens.	12.9	9.7	3.6	3.6	23.3	13.3
P-SPSRQ Imp/Fun Seeking	22.6	16.1	25.0	14.3	10.0	13.3
P-SPSRQ Reward Respons.	16.1	22.6	21.4	10.7	10.0	3.3
Gen. Problem Behavior						
P-DBDRS ODD	**32.3**	19.4	10.7	10.7	30.0	20.0
P-DBDRS CD	6.5	3.2	25.0	14.3	10.0	13.3
T-DBDRS ODD	6.5	**32.3**	21.4	17.9	16.7	20.0
P-PEDsQL Psy.soc. Hlth.	<u>**51.6**</u>	**48.4**	25.0	21.4	**40.0**	**36.7**
P-HSQ Mean Severity Score	22.6	25.8	14.3	21.4	30.0	30.0

Note. BRIEF = Behavior Rating Inventory of Executive Function; CBTT = Corsi Block Tapping Task; CD = conduct disorder; DBDRS = Disruptive Behavior Disorder Rating Scale; FU = Follow-up-test (after 3 months); HSQ = Home Situations Questionnaire; Imp/Fun Seeking = Impulisivity/Fun Seeking; ODD = oppositional defiant disorder; Organiz. Materials = Organization of Materials; P- = Parent-rated; PEDsQL = Pediatric Quality of Life Inventory; Post = Post-test; Pre = Pre-test; Psy.soc. Hlth. = Psychosocial Health Summary Score; Punish. Sens. = Punishment Sensitivity; Reward Respons. = Reward Responsiveness; SPSRQ = Sensitivity to Punishment and Sensitivity to Reward Questionnaire for children; SSRT = Stop Signal Reaction Time; T- = Teacher-rated; **Bold number** = more than 30% responders; <u>**Bold + underlined number**</u> = more than 50% responders; Children were classified as responders based on reliable change indices (Jacobson & Truax, 1991; Wise, 2004).

7.4 Discussion

The aim of this study was to determine the short- and long-term effects of a gamified training intervention (BGB) that targets multiple EFs (visuospatial WM, response inhibition and cognitive flexibility) compared to a placebo version of the intervention on various outcome measures in children with ADHD combined-type. In addition, to determine the unique effect of the inhibition and cognitive flexibility training tasks, we compared a full-active condition (where WM, inhibition, and cognitive flexibility were all in training-mode) to a partially-active condition (where only inhibition and cognitive flexibility were in training-mode).

Results indicated that children in the full-active condition showed greater improvement on measures of visuospatial STM and WM than children in either the partially-active condition or the placebo condition (effect sizes ranged from medium to large). Compared to the placebo condition, inhibitory performance improved more in the full-active condition and the partially-active condition, and interference control improved more in the full-active condition (effect sizes were medium). However, no Treatment-condition x Time interactions were found for cognitive flexibility, verbal STM and WM, non-verbal complex reasoning, or child-rated psychosocial health, nor for any parent- or teacher-rated ADHD symptoms, EF behaviors, motivational behaviors, or general problem behaviors. Nonetheless, almost all measures showed significant Time-effects, including the teacher-ratings (effect sizes ranged from medium to large).

These findings suggest that improvements on inhibition and visuospatial STM and WM were specifically related to the type of treatment received. However, improvements on untrained EFs and behavior (*far-transfer* effects) were mostly nonspecific (i.e., only interference control improved more than in the placebo condition). As such, in this multiple EF training, mainly nonspecific treatment factors – as opposed to the specific effects of training EFs – seem related to the far-transfer effects on EF and behavior.

In many ways our findings are similar to those of previous placebo controlled (single) EF training studies in children with ADHD (Chacko et al., 2014; Green et al., 2012; Klingberg et al., 2005; Klingberg et al., 2002; Kray et al., 2012). Most of these studies find differential treatment effects on outcome measures of trained EFs (although Kray et al., 2012, as in the present study, found no significant differences on cognitive flexibility). However, such *near transfer* effects may not be surprising since many of these outcome measures are very similar to the training tasks themselves and improvement may be the result of a learned strategy instead of improved cognitive capacity (Thompson et al., 2013). Further, in most placebo controlled studies differential *far transfer* to untrained EF tasks has been limited, and

differential effects on parent- or teacher-rated behavior (e.g., ADHD or EF) are generally not found. Only Klingberg et al. (2005) found a differential effect of WM training on parent-rated ADHD. However, the placebo condition used in Klingberg et al., 2005 was considerably shorter in time than the training condition. This suggests a difference in parent involvement between the conditions, which may have interacted with the outcome of parent-rated ADHD behavior (e.g., through expectancy effects or inequality of parent-child interactions; see Chacko et al., 2013).

There are also several important differences between our findings and the findings of previous placebo controlled EF training studies. Although we used more stringent compliance criteria than most previous studies (i.e., completing 100% of the training sessions versus completing 80% of the training sessions), in our study only 3% of the participants failed to meet compliance criteria, whereas in previous studies 15-23% failed to meet compliance criteria. Since most previous studies also used an external reward system, a structured schedule for implementing the intervention, weekly contact with a coach, and performance feedback during training, the most obvious reason for this difference in compliance is the relatively strong gamification of BGB. This hypothesis is consistent with previous findings of increased time-on-training when EF training was gamified (Prins et al., 2011; also see Dovis et al., 2012), and with the finding that gaming increases the release of striatal dopamine (Koepp et al., 1998; Kühn et al., 2011), which is associated with increased motivation to continue playing and performing (Gray, 2010).

Moreover, in contrast to the previous placebo-controlled studies, we found a significant improvement on teacher-rated ADHD behavior (effect sizes ranged from medium to large). Although this improvement was unrelated to specific effects of the EF training (as it was also found in the placebo condition), it is still a remarkable finding. Some have argued that EF training studies only find Time effects on parent-ratings but not on teacher-ratings because teachers, in contrast to parents, are only minimally involved in training and thus may be less biased than parents (e.g., by their expectancies of the training outcome; Van der Oord et al., 2012). This suggests that generalization of improvement to teacher-ratings might represent relatively unbiased evidence of treatment induced changes in the child’s behavior. Nonetheless, it is unclear what caused this improvement. It seems unrelated to specific EF training effects, and the only nonspecific treatment factor that clearly distinguishes our study from previous studies appears to be the use of relatively strong gamification (i.e., teachers were not more involved than in previous studies). Is it possible that gamification somehow improved classroom behavior? For example, there is evidence that video game playing can

enhance various cognitive skills (e.g., attention; see Green & Bavelier, 2003). However, if playing video games by itself would be sufficient to improve classroom functioning in children with ADHD, it seems illogical that the participants in our study, who play commercial video games for 10 hours per week (see Table 1), did not improve before. Nonetheless, it may be that parents' positive attitude towards this particular game enhanced its positive effects. For example, sharing the joy of achievement in the game with his/her parents could have enhanced the child's appraisal of the game's positive feedback and its effect on his/her self-esteem beyond that of commercial video games (as many parents don't encourage children to indulge in commercial gaming). Although there is a link between parental praise and children's self-esteem (e.g., Felson & Zielinski, 1989), and self-esteem has been found to mediate the relationship between ADHD and classroom functioning (e.g., Shaw-Zirt, Popali-Lehane, Chaplin, & Bergman, 2005), future research should investigate this further. Furthermore, the gamification of BGB may also have impacted classroom functioning by enhancing children's motivation to comply with treatment. If children were more motivated to comply with treatment than in other EF training studies, which is consistent with the relatively high compliance rate in our study, there may have been less need for parents to discipline their children during training. Evidence suggests that decreased negative parental discipline mediates the effect of ADHD treatment (e.g., medication and behavior therapy) on teacher-rated ADHD behavior (Hinshaw, 2007). Future EF training studies should use larger samples and appropriate process measures to further investigate these potential mechanisms of mediation.

Although some previous EF training studies in children with ADHD have found differential effects on interference control (Kray et al., 2012; Johnstone et al., 2012[41]), our study is the first to find differential effects on response inhibition. In contrast to the placebo condition, response inhibition was improved in both the full-active condition and the partially-active condition, but no differences were found between these two experimental conditions. This suggests that a combined inhibition and cognitive flexibility training by itself (i.e., without WM) is sufficient to improve response inhibition in children with ADHD. Possibly, previous EF training studies investigating effects on measures of response inhibition in children with ADHD (Hoekzema et al., 2010; Johnstone et al., 2010; 2012) found no improvements because their intervention did not include an inhibition training task (i.e.,

[41] Although Klingberg et al. (2002; 2005) also found differential effects on the STROOP, they only used the incongruent trials as outcome measure. Therefore, baseline response times to congruent trials were not controlled for, which made it impossible to calculate the interference score.

Hoekzema et al. trained WM, cognitive flexibility, attention, planning and problem solving), or because their inhibition training task was based on a less appropriate response inhibition paradigm; the go/no-go task instead of the stop task (Johnstone et al., 2010; 2012). In contrast to the stoptask, the go/no-go task has been criticized as not functionally isolating inhibition (e.g., because of its interaction with selective attention and decision making, and the confounding effects of its prepotent response processes; see Nigg, 2006; Rubia, Smith, Brammer, & Taylor, 2003; Schachar, Tannock, & Logan, 1993). Nonetheless, since we did not investigate effects of the inhibition- and cognitive flexibility training separately, we can only speculate that the improvement on response inhibition was the result of our stop-task-based inhibition training. Additional research is needed to investigate this in more detail.

In contrast to our findings on other near transfer measures, no differential effects of EF training were found on the cognitive flexibility measure. This may be the result of the difference between the switch-cost (the index of cognitive flexibility) that was trained, and the switch-cost that was used as outcome measure of cognitive flexibility. Our outcome measure (the scaled contrast score on the TMT) measures *global* switch-cost (i.e., the difference between a block of switch-trials and blocks of non-switch trials), whereas the cognitive flexibility training focused on training *local* switch-cost (i.e., the difference between switch-trials and non-switch trials within a block of trials). Although, both types of switch-cost are considered valid measures of cognitive flexibility, evidence suggests that they tap somewhat different cognitive processes and can be differentiated on a neural level (Braver, Reynolds, & Donaldson, 2003; White & Shah, 2006). Therefore, it could be argued that our outcome measure of cognitive flexibility was in fact a measure of far transfer. Future studies should investigate this further using more varied measures of cognitive flexibility.

The fact that far transfer was also found in the placebo condition might not (only) be explained by nonspecific treatment effects (e.g., effects of expectancies, self-fulfilling prophecies, attribution, gamification, or improved parent-child interactions), but may be the result of actual cognitive training in the placebo condition. Although the cognitive load in our placebo condition was very low, it could be argued that the requisite of the placebo tasks to focus attention for a substantial amount of time was sufficient to improve cognitive control (e.g., attention) and the behavior of our participants. However, this appears inconsistent with the very limited improvement on EF performance in the placebo condition, and the lack of effects resulting from other activities that require prolonged focused attention (e.g., paying attention in school, playing [educational] video games).

Because no wait-list control condition was utilized, it is not possible to determine to which extent our findings relate to effects of multiple testing, the passage of time, or (nonspecific) treatment factors. However, a previous study investigating BGB (Van der Oord et al., 2012) found no improvement on parent- and teacher-rated ADHD and EF behavior in a wait-list control group, whilst they did find improvement in the group that was trained. This suggests that the current findings on ADHD and EF behavior are probably not attributable to mere passage of time or multiple testing.

In this study different EFs were trained simultaneously within the same training session. However, based on the current state of the literature it is unclear if this is indeed the best strategy for multiple EF training (i.e., there are no studies that directly investigate this). One could assume that training different EFs simultaneously is more effective (especially for transfer to daily life) than training one EF at a time (i.e., training each EF in separate sessions), because functioning in daily life also requires the use of multiple EFs at once. However, our results do not suggest that training three EFs per session (i.e., the full-active condition) has more effect on daily functioning than training two EFs per session (i.e. the partially-active condition). Future studies should further investigate this.

In the current study, far transfer effects were mostly nonspecific. However we only investigated overall group differences (i.e., disregarding potential subpopulations that show differential responses to treatment), and children were allocated to treatment conditions irrespective of their individual EF deficits. Therefore, before discarding EF training as potential treatment for children with ADHD, future studies should examine moderators (e.g., severity of EF deficits; teacher expectancies) and mediators of treatment success (e.g., improvement on EF performance; parental praise), and should investigate effects of individually tailored EF training (i.e., to make optimal use of the available training-time future studies should match training focus to the specific EF problems of each individual child). Furthermore, to increase chances of finding far-transfer that results from EF training specifically, training tasks should be made more ecologically valid (e.g., by using EF training tasks that resemble the complexity of problematic situations in daily-life) and should be intertwined with relevant real-life EF-taxing activities (e.g., completing chores in daily-life could be an additional goal in the EF training; for more suggestions see Gathercole, 2014). Finally, the domains of far transfer that were investigated in this study were limited to direct measures of performance and indirect measures of behavior (e.g., behavior as rated by parents, teachers or children). Future studies should also include direct measures of behavior. For example, a recent placebo-controlled WM training study (Green et al., 2012) found no

specific treatment effects on parent-rated behavior (teacher-rated behavior was not investigated), but found specific effects on aspects of experimenter-observed off-task behavior during an academic task.

In conclusion, our findings suggest that the training tasks of BGB have a specific and more facilitating effect on inhibition and visuospatial STM and WM than a placebo version of BGB. However, improvements on untrained EFs and behavior were mostly nonspecific. As such, in this multiple EF training, mainly nonspecific treatment factors – as opposed to the specific effects of training EFs – seem related to the far-transfer effects on EF and behavior.

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Appendix Chapter 7

The External Reward System

The standardized external reward system was the same for all participants. Its procedure was as follows: Children received a poster representing a map of all the areas in the game, and parents received 25 numbered envelopes (the numbers on the envelopes corresponded to the numbers of the training sessions). Parents were instructed to give the child an envelope after each completed training session (regardless of previous arguments or bad behavior). Each envelope contained two numbered stickers that could be pasted on corresponding numbers on the map. One sticker represented a game character that the child befriended in the training session, and the other sticker represented one of the inventions that was created in the training session. In this way the poster was used as an external representation of training achievement (see Fig. A). Every 5th envelope contained two extra rewards: a medal or reward ribbon and a certificate-sticker (that could be pasted on the poster). These extra rewards were used to emphasize the completion of each of the five training weeks.

Fig. A The reward system: an overview of the medals and reward ribbons and the map with all the stickers (photograph courtesy of Arnold Brakenhoff)

Chapter 8

Summary and general discussion

The goal of this doctoral thesis was to gain insight into the effects of reinforcement on the assessment and training of executive functioning (EF) in children with ADHD. This was investigated in six empirical chapters. First, a summary of these six chapters is provided, followed by the general discussion and the clinical implications of our findings. Finally, we discuss directions for future research.

8.1. Summary of main findings

Theories of ADHD suggest that deficits in executive functioning (EF) are at the core of the ADHD-syndrome, and play a pivotal role in explaining the problems children with ADHD encounter in daily life (e.g., Barkley, 2006; Nigg, 2006; Rapport, Chung, Shore, & Isaacs, 2001). However, there are also theories suggesting that these deficits in EF are the result of, or at least strongly interact with motivational deficits in children with ADHD (i.e., an abnormal sensitivity to reinforcement; Haenlein & Caul, 1987; Sergeant et al., 1999; also see Sagvolden et al., 2005; Sonuga-Barke, 2003). Visuospatial working memory is considered one of the most impaired EFs in children with ADHD (Martinussen, et al., 2005; Willcutt et al., 2005; 2012), and it's impairment has been associated with deficits in attention, hyperactivity, and impulsivity (Burgess et al., 2010; Kofler et al., 2010; Raiker et al., 2012; Rapport et al., 2009; Tillman et al., 2011). Nonetheless, the interaction between motivational deficits and visuospatial working memory performance was never investigated in children with and without ADHD. Therefore, in chapter 2 the effects of different reinforcers on visuospatial working memory performance were investigated in children with combined subtype ADHD and typically developing controls (aged 9-12). A visuospatial working memory task was administered in four reinforcement conditions: feedback-only, feedback + 1 euro, feedback + 10 euros, and a computer-game version of the task. Results indicated that with feedback-only, children with ADHD performed worse on the working memory measure than controls (large effect size). Additional incentives (1 euro, 10 euros, and gaming) only improved performance in children with ADHD, not in controls. However, these incentives were unable to 'normalize' working memory performance in children with ADHD (effect sizes of differences between ADHD and controls still ranged from medium to large). Only in children with ADHD task performance decreased over time (the task took about 20 minutes to complete), but the strongest incentives (10 euros and gaming) normalized their persistence of performance, whereas 1 euro had no such effect. It was concluded that: (1) both executive and motivational deficits give rise to visuospatial working memory deficits in combined subtype ADHD, (2) problems with task-persistence in children with combined subtype ADHD result

primarily from motivational deficits, (3) reinforcement intensity can be a confounding factor and should be taken into account in ADHD-reinforcement studies and clinical practice (e.g., assessment), and (4) gaming can be a cost-effective way to maximize performance in children with combined subtype ADHD.

Chapter 2 indicated that, aside from their motivational deficits, visuospatial working memory is impaired in children with ADHD. Nonetheless, working memory is a multicomponent system consisting of short-term memory and a central executive (Baddeley, 2007). Therefore, deficits in either or both short-term memory and the central executive may account for working memory impairments in children with ADHD. Given the relevance of working memory for the understanding and treatment (see chapters 6 and 7) of ADHD, interest in identifying which of the specific working memory components are impaired in children with ADHD, has increased in recent years. However, previous working memory-component studies do not account for the effects of motivational deficits on the components of working memory in children with ADHD. Therefore, in chapter 3 we examined the effects of a standard level of reinforcement (feedback-only) and a high level of reinforcement (feedback + 10 euros) on the visuospatial working memory-, visuospatial short-term memory-, and the central executive performance of children with combined subtype ADHD and typically-developing controls (aged 8-12). With standard reinforcement the short-term memory, central executive, and working memory performance of children with ADHD was worse than that of controls (effect size was medium for short-term memory, small for the central executive, and large for working memory). High reinforcement improved the short-term memory and working memory performance in children with ADHD, but not in controls. Nonetheless, high reinforcement did not normalize the short-term memory and working memory performance of children with ADHD (effect sizes of differences between ADHD and controls were still medium). High reinforcement did not appear to improve the central executive-related performance of children with ADHD and controls. It was concluded that: (1) motivational deficits have a detrimental effect on both the visuospatial working memory and short-term memory performance of children with combined subtype ADHD, and (2) aside from motivational deficits, both the visuospatial short-term memory and the central executive of children with combined subtype ADHD are impaired, and give rise to their deficits in visuospatial working memory.

The two most prevalent and valid diagnostic subtypes of ADHD are the combined subtype (ADHD-C) and the predominantly inattentive subtype (ADHD-I; Gomez, et al., 1999; Willcutt et al., 2012; Wolraich et al., 1998). Although ADHD-C and ADHD-I are

characterized by distinct patterns of symptomatic behavior, associated features and demographics (e.g. see Milich et al., 2001), it is unclear whether these two subtypes have different underlying deficits with regard to motivation and the components of visuospatial working memory (Diamond, 2005; Willcutt et al., 2012). Therefore, in chapter 4 we looked beyond combined subtype ADHD by investigating the interplay between motivational processes and the components of visuospatial working memory in different ADHD subtypes. Effects of a standard (feedback-only) and a high level of reinforcement (feedback + 10 euros) on visuospatial working memory-, short-term memory-, and central executive performance were examined in children with ADHD-I, children with ADHD-C, and typically-developing controls (aged 9-12). With standard reinforcement, central executive and working memory performance in both ADHD subtypes was worse than in controls (effect sizes were medium for the central executive and large for working memory). However, the short-term memory performance of children with ADHD-I was, in contrast to that of children with ADHD-C, not significantly different from controls (effect size was small for ADHD-I and medium for ADHD-C). High reinforcement improved short-term memory and working memory performance in both ADHD subtypes, but not in controls. Nonetheless, high reinforcement did not normalize the short-term memory and working memory performance of children with ADHD-C, nor the working memory performance of children with ADHD-I (effect sizes of differences between ADHD and controls were still medium). High reinforcement did not appear to improve the central executive-related performance of children with ADHD and controls. Short-term memory and working memory performance was worse in children with ADHD-C than in children with ADHD-I, whilst central executive-related performance did not differ. Reinforcement effects were equally pronounced in both ADHD subtypes. It was concluded that: (1) both subtypes have equally pronounced motivational deficits, which have detrimental effects on their visuospatial short-term memory and working memory performance, and (2) in contrast to children with ADHD-C, children with ADHD-I seem unimpaired on visuospatial short-term memory; only an impaired central executive and motivational impairments appear to give rise to their deficits in visuospatial working memory.

Although chapter 4 primarily focused on differences *between* ADHD subtypes, there is also evidence for heterogeneity *within* these subtypes (e.g., Fair et al., 2012; Sonuga-Barke et al., 2010). Therefore, in chapter 5 we specified the subgroups within these ADHD subtypes based on their cognitive (i.e., visuospatial working memory and short-term memory) and motivational impairments. We investigated the prevalence and diagnostic validity of impairments in visuospatial working memory, visuospatial short-term memory, and

reinforcement sensitivity in children with ADHD-C and ADHD-I. Typically developing controls were used as reference group (i.e., children with ADHD were characterized as impaired if they scored below the 10% worst scoring controls). For this study we used the dataset from the studies described in chapters 3 and 4. Results indicated that deficits in working memory and short-term memory were more prevalent in children with ADHD-C (58.1% impaired on working memory; 40.7% impaired on short-term memory), than in children with ADHD-I (33.3% impaired on working memory; 18.5% impaired on short-term memory) or controls (9.7% impaired on working memory; 9.7% impaired on short-term memory). In children with ADHD-I, only working memory impairments, not short-term memory impairments, were more prevalent than in controls. Deficits in reinforcement sensitivity were not common (only 22% was impaired) and equally prevalent in both subtypes. Deficits in working memory and/or short-term memory were not associated with deficits in reinforcement sensitivity. Children with ADHD-C who were classified as impaired on working memory, short-term memory and/or reinforcement sensitivity had more teacher-rated inattention symptoms, were more likely to use ADHD medication, and had lower IQ scores than children with ADHD-C who were not impaired on these indices. Only the indices of working memory and short-term memory showed acceptable diagnostic validity, with both sensitivity and specificity being ≥ 70% (as was recommended by Glascoe & Squires, 2007), to distinguish children with ADHD-C from controls. However, none of the indices showed acceptable diagnostic validity to distinguish children with ADHD-I from controls, or to distinguish between the ADHD subtypes. It was concluded that: (1) the majority of children with ADHD-C is impaired on visuospatial working memory, (2) in children with ADHD-I, short-term memory deficits are not more common than in typically developing children, (3) within both ADHD-subtypes only a minority of children has an abnormal sensitivity to reinforcement, and (4) visuospatial memory and reinforcement sensitivity seem to represent independent neuropsychological domains.

Chapters 6 and 7 focused on training EFs in children with ADHD, and on using reinforcement (i.e., gamification) to improve motivation and performance during training, and enhance the trainings' efficacy. In chapter 6 we examined the effects of adding game elements to a standard computerized working memory training. Children with ADHD (aged 7-12; no specific ADHD subtype was selected) were randomly assigned to either a gamified visuospatial working memory training or a regular (relatively stripped-down) visuospatial working memory training. Both groups completed three weekly training sessions. Children using the game training showed higher motivation (i.e., more voluntary training time), better

training performance (i.e., more completed training trials and fewer errors), and more post-training improvement on a visuospatial working memory task than children using the regular training. The superior efficacy of the game condition remained significant even after covarying for the number of completed training trials. It was concluded that gamification of a visuospatial working memory training can improve motivation and training performance in children with ADHD, and can enhance the efficacy of training.

The aim of the double-blind, placebo-controlled study described in chapter 7 was to determine the near- and far transfer effects of a *gamified* training intervention (Braingame Brian) that targets multiple EFs. Children with combined subtype ADHD (aged 8-12) were randomized to either a *full-active* condition where visuospatial working memory, response inhibition and cognitive-flexibility were trained, a *partially-active* condition where response inhibition and cognitive-flexibility were trained and the working memory training-task was presented in placebo-mode, or to a full *placebo* condition. Short-term and long-term (3-months) effects of this 25 session, home-based computer-training were evaluated on multiple outcome domains. During training compliance was high (only 3% failed to meet compliance criteria). After training, visuospatial short-term memory and working memory performance improved more in the full-active condition than in the partially-active- or placebo-condition (effect sizes ranged from medium to large). Compared to the placebo-condition, inhibitory performance improved more in the full-active- and partially-active condition, and interference control improved more in the full-active condition (effect sizes were medium). No Treatment-condition x Time interactions were found for cognitive-flexibility, verbal working memory, complex-reasoning, nor for any parent-, teacher-, or child-rated ADHD behaviors, EF-behaviors, motivational behaviors, or general problem behaviors. Nonetheless, almost all measures showed main Time-effects, including the teacher-ratings (effect sizes ranged from medium to large). It was concluded that: (1) improvements on inhibition and visuospatial short-term memory and working memory were specifically related to the type of treatment received (i.e., *near transfer*), (2) improvements on untrained EFs and behaviors (*far transfer*) appeared mostly nonspecific (i.e., only interference control improved more than in the placebo condition), and (3) as such, in this multiple EF-training, mainly nonspecific treatment factors – as opposed to the specific effects of training EFs - seem related to far transfer effects found on EF and behavior.

8.2 General Discussion

8.2.1 Working Memory and Motivational Deficits

In chapters 2, 3, and 4 it was consistently found that higher levels of reinforcement improved performance in children with ADHD (both in ADHD-C and ADHD-I), but not in controls. This suggests that for typically-developing children, providing feedback-only constituted sufficient reinforcement to reach optimal performance, while this was clearly not the case for children with ADHD-C or ADHD-I.[42] This is in line with theories suggesting that children with ADHD are characterized by an abnormal sensitivity to reinforcement (ADHD-C; e.g., Haenlein & Caul, 1987; Sergeant et al., 1999) and by a disposition to be more easily under-aroused compared to typically-developing children (ADHD-I; Diamond, 2005), and contradicts theories stating that motivational abnormalities characterize the combined subtype only (e.g., Sagvolden et al., 2005).

Furthermore, our findings support the notion that these motivational deficits interact with cognitive functioning in children with ADHD-C (e.g., Sonuga-Barke, 2011) and ADHD-I (e.g., Diamond, 2005), and are in line with models that emphasize the intertwined nature of executive control and motivation to control (Castellanos, Sonuga-Barke, Milham, & Tannock, 2006; Gladwin, Figner, Crone, & Wiers, 2011; Sonuga-Barke, Sergeant, Nigg, & Willcutt; 2008). Although results from chapters 2-4 indicate that additional high reinforcement improved working memory-related performance more in children with ADHD than in typically-developing children (except for central executive performance; for a detailed discussion see chapter 3), high reinforcement did not 'normalize' their performance (although it did normalize their persistence of performance; see chapter 2). This suggests that motivational factors can only partially explain the working memory-related impairments in children with ADHD-C and ADHD-I. Our findings are therefore consistent with previous studies (that did not control for these motivational factors) showing that children with ADHD-C are impaired on both components of working memory (e.g., Alderson et al., 2010*;* Rapport et al., 2008; Rhodes, Park, Seth, & Coghill, 2012), and with the notion that visuospatial

[42] Here we assume that the typically-developing children were highly motivated in both reinforcement conditions, whereas the children with ADHD were only highly motivated in the 10 euros condition. This assumption is substantiated by participants' reports described in chapter 4: After both reinforcement conditions were administered, children were asked what they thought of the task with feedback-only (FO) and of the task with 10 euros. In line with our assumption, children in both ADHD groups were less positive about the task in the FO condition (40% reported that the FO task was fun) than about the task in 10 euros condition (80% reported that the 10 euros task was fun), whereas typically-developing children were positive about the tasks in both reinforcement conditions (72.5% reported that the FO task was fun and 80% reported that the 10 euros task was fun; for more details see appendix 4.2 in chapter 4).

working memory truly is a core neurocognitive deficit in children with ADHD-C (Rapport et al., 2001). In addition, these findings, and the fact that we found no significant short-term memory deficit in children with ADHD-I, support Diamond's suggestion that children with ADHD-I are especially impaired on the central executive component, but not on the short-term memory component of working memory (Diamond, 2005).

These conclusions from chapters 2-4 are complemented and further specified by the findings in chapter 5. For example, in this chapter it was found that in children with ADHD-I, only working memory impairments, not short-term memory impairments, were more prevalent than in typically-developing children. Further, it was found that, when we controlled for motivational deficits, 58% of the children with ADHD-C were impaired on visuospatial working memory. This suggests that visuospatial working memory impairments are at least as prevalent in children with ADHD-C as other 'key' neuropsychological dysfunctions (prevalence of inhibition, 45-51%; reaction time variability, 44-48%; delay aversion, 32-56%; e.g., Nigg et al., 2005; Sonuga-Barke et al., 2010; Solanto et al., 2001), and are more prevalent than phonological working memory impairments (27-35% impaired; Lambek et al., 2011).[43] It is also consistent with the notion that impaired visuospatial working memory is a core causal executive process in a majority of children with ADHD-C (Rapport et al., 2001). Although less prevalent than working memory impairments, almost half of the ADHD-C group was impaired on short-term memory, suggesting that short-term memory impairments may also affect a substantial part of the ADHD-C population. Furthermore, although both theory (e.g. Haenlein & Caul, 1987; Sergeant et al., 1999) and research (Luman et al., 2005; Luman, Tripp, & Scheres, 2010; also see chapter 2-4) suggest that an abnormal sensitivity to reinforcement is characteristic of children with ADHD on a group level, we found that this motivational impairment, apart from being a valid and distinct impairment, is actually not so common among these children (only 22% were classified as impaired).

On the one hand the results from chapter 5 suggest that a substantial part of the ADHD population is indeed impaired on visuospatial working memory, visuospatial short-term memory, and/or reinforcement sensitivity. However, at the same time, these results support models and previous findings which suggest that ADHD is a neuropsychologically heterogeneous disorder that cannot be characterized by a single core dysfunction (Biederman et al., 2004; Fair et al., 2012; Lambek et al., 2010; 2011; Nigg et al., 2005; Pineda et al., 2007;

[43] Note that most of these studies did not adequately control for the motivational deficits in children with ADHD whilst assessing these *other key neuropsychological dysfunctions*, suggesting that the prevalence of these dysfunctions may be overestimated.

Sjöwall, Roth, Lindqvist, & Thorell, 2013; Sonuga-Barke et al., 2010). This point is further substantiated by the absence of significant co-occurrence between impairments in reinforcement sensitivity and impairments in visuospatial working memory and short-term memory. This absence of associations across motivational and memory domains does not only highlight the neuropsychological heterogeneity in ADHD, but also supports recent evidence suggesting separable neuropsychological subtypes in ADHD (e.g., Fair et al., 2012; Sonuga-Barke et al., 2010; De Zeeuw et al., 2012). Nonetheless, it must be noted that this absence of associations between deficits in motivation and memory was also found in controls. This suggests that the neuropsychological heterogeneity in ADHD may be a derivative of normal variation (see also Fair et al., 2012).

8.2.2 Effects of Gamification

The findings from chapter 2 suggest that gamification of an EF task (making a task more attractive by using game mechanics and visuals) can optimize mean performance and persistence of performance in children with ADHD. Furthermore, results from chapter 6 show that gamification of an EF training for children with ADHD can improve their motivation and performance during training, and enhances the trainings' efficacy. This is further substantiated by the results of the *gamified*, 25-session, multiple EF training (Braingame Brian) that was described in chapter 7. We found that treatment compliance in that placebo-controlled study was relatively high compared to the compliance rates of previous placebo-controlled EF training studies (Chacko et al., 2014; Green et al., 2012; Klingberg et al., 2005; Klingberg et al., 2002; Kray et al., 2012): Although we used more stringent compliance criteria than most previous studies (i.e., completing 100% of the training sessions versus completing 80% of the training sessions), in our study only 3% of the participants failed to meet compliance criteria, whereas in previous studies 15-23% failed to meet compliance criteria. Since most previous studies also used an external reward system, a structured schedule for implementing the intervention, weekly contact with a coach, and performance feedback during training (for more details see chapter 7), the most obvious reason for this difference in compliance is the relatively strong gamification of Braingame Brian. The findings from chapters 2, 6, and 7 seem in line with evidence suggesting that gaming increases the release of striatal dopamine (Koepp et al., 1998; Kühn et al., 2011; for a review on dopamine deficits in children with ADHD see Tripp and Wickens, 2008), promoting long-term potentiation of neural connections within the striatum (Reynolds et al., 2001), which is

suggested to improve motivation to continue playing and performing, and one's ability to learn (Gray, 2010, e.g., during EF training).

In addition, findings from chapter 7 might even suggest that gamification can enhance far transfer effects of treatment in children with ADHD. In contrast to previous placebo-controlled EF training studies (Chacko et al., 2014; Green et al., 2012; Klingberg et al., 2002; 2005; Kray et al., 2012), our study showed a significant improvement on teacher-rated ADHD behavior. Although this improvement was unrelated to specific effects of the EF training (as it was also found in the placebo condition), it is still a remarkable finding. Some have argued that EF training studies only find Time effects on parent-ratings but not on teacher-ratings because teachers, in contrast to parents, are only minimally involved in training and thus may be less biased than parents (e.g., by their expectancies of the training outcome; Van der Oord et al., 2012). This suggests that generalization of improvement to teacher-ratings might represent relatively unbiased evidence of treatment induced changes in the child's behavior. Although this improvement was unrelated to specific EF training effects, it might be related to the only nonspecific treatment factor that clearly distinguishes our study from previous studies: Gamification. Is it possible that gamification somehow improved classroom behavior? For example, there is evidence that video game playing can enhance various cognitive skills (e.g., attention; see Green & Bavelier, 2003). However, if playing video games by itself would be sufficient to improve classroom functioning in children with ADHD, it seems illogical that the participants in our study, who play commercial video games for 10 hours per week (see Table 1 of chapter 7), did not improve before. Nonetheless, it may be that parents' positive attitude towards this particular game enhanced its positive effects. For example, sharing the joy of achievement in the game with his/her parents could have enhanced the child's appraisal of the game's positive feedback and its effect on his/her self-esteem beyond that of commercial video games (as many parents don't encourage children to indulge in commercial gaming). Although this was not specifically investigated in our study, there is a link between parental praise and children's self-esteem (e.g., Felson & Zielinski, 1989), and self-esteem has been found to mediate the relationship between ADHD and classroom functioning (e.g., Shaw-Zirt, Popali-Lehane, Chaplin, & Bergman, 2005). Furthermore, the gamification of Braingame Brian may also have impacted classroom functioning by enhancing children's motivation to comply with treatment. If children were more motivated to comply with treatment than in other EF training studies, which is consistent with the relatively high compliance rate in our study, there may have been less need for parents to discipline their children during training. Although this was not specifically

investigated in our study, evidence does suggest that decreased negative parental discipline mediates the effect of ADHD treatment (e.g., medication and behavior therapy) on teacher-rated ADHD behavior (Hinshaw, 2007).

8.2.3 Effects of Training Multiple EFs

In many ways our findings from the multiple EF training study described in chapter 7 (which targeted visuospatial working memory, response inhibition, and cognitive flexibility) are similar to those of previous placebo controlled (single) EF training studies in children with ADHD (Chacko et al., 2014; Green et al., 2012; Klingberg et al., 2002; 2005; Kray et al., 2012). Most of these studies find differential treatment effects on outcome measures of trained EFs (although Kray et al., 2012, like us, found no significant differences on cognitive flexibility). However, such *near transfer* effects may not be surprising since many of these outcome measures are very similar to the training tasks themselves and improvement may be the result of a learned strategy instead of improved cognitive capacity (Thompson et al., 2013). Further, in most studies differential *far transfer* to untrained EF tasks has been limited, and differential effects on parent- or teacher-rated behavior (e.g., ADHD or EF) are generally not found. Only Klingberg et al. (2005) found a differential effect of working memory training on parent-rated ADHD. However, the placebo condition used in Klingberg et al., 2005 was considerably shorter in time than the training condition. This suggests a difference in parent involvement between the conditions, which may have interacted with the outcome of parent-rated ADHD behavior (e.g., through expectancy effects or inequality of parent-child interactions; see Chacko et al., 2013).

There are also several important differences between our findings and the findings of the previous placebo controlled studies (i.e., Chacko et al., 2014; Green et al., 2012; Klingberg et al., 2002; 2005; Kray et al., 2012). First of all, treatment compliance was relatively high in our study, which underlines the benefits of using gamification in computerized interventions for children with ADHD. Further, in contrast to previous placebo-controlled training studies, our study showed a significant improvement on teacher-rated ADHD behavior. Although this improvement was unrelated to specific effects of the EF training (as it was also found in the placebo condition), it does suggest relatively unbiased evidence of 'real' treatment induced changes in the child's behavior (as teachers were minimally involved in treatment; for a more detailed discussion see the previous section on gamification). Finally, our study is the first to find differential effects on response inhibition. In contrast to the placebo condition, response inhibition was improved in both the full-active

condition and the partially-active condition, but no differences were found between these two experimental conditions. This suggests that a combined inhibition and cognitive flexibility training by itself (i.e., without working memory) is sufficient to improve response inhibition in children with ADHD. Possibly, previous EF training studies investigating effects on measures of response inhibition in children with ADHD (Hoekzema et al., 2010; Johnstone et al., 2010; 2012) found no improvements because their intervention did not include an inhibition training task (i.e., Hoekzema et al. trained working memory, cognitive flexibility, attention, planning and problem solving), or because their inhibition training task was based on a less appropriate response inhibition paradigm; the go/no-go task instead of the stop task (Johnstone et al., 2010; 2012). In contrast to the stoptask, the go/no-go task has been criticized as not functionally isolating inhibition (e.g., because of its interaction with selective attention and decision making, and the confounding effects of its prepotent response processes; see Nigg, 2006; Rubia, Smith, Brammer, & Taylor, 2003; Schachar, Tannock, & Logan, 1993). Nonetheless, since we did not investigate effects of the inhibition- and cognitive flexibility training separately, we can only speculate that the improvement on response inhibition was the result of our stop-task-based inhibition training. Additional research is needed to investigate this in more detail.

In conclusion, the findings from chapter 7 suggest that the training tasks of Braingame Brian have a specific and more facilitating effect on inhibition and visuospatial short-term memory and working memory than a placebo version of this training. However, transfer to untrained EFs and behaviors was mostly nonspecific (with the exception of interference control). As such, in this multiple EF training, mainly nonspecific treatment factors – as opposed to the specific effects of training EFs – seem related to the far-transfer effects on the EF and behavior of children with ADHD.

8.3 Clinical Implications

Professionals, parents and teachers should be aware that in situations that are motivating enough for typically-developing children, both children with ADHD-I and ADHD-C are fairly likely (in about 22% of the cases) to perform sub-optimally on working memory related tasks and functioning (e.g., keeping information in mind, reasoning, problem solving, goal-directed behavior, planning, etc.). For example, if one tries to assess math skills, reading performance, or IQ (which have all been related to working memory performance; see Titz & Karbach, 2014) in a child with ADHD under regular reinforcement conditions, it is fairly likely that this child's performance will be confounded by deficits in motivation (i.e., his/her score will be

the combined result of cognitive and motivational processes). To prevent sub-optimal performance and to enable utilization and assessment of their full cognitive abilities, children of both ADHD subtypes should be motivated as strongly as possible (e.g., by using game-like strategies/formats and reward systems). However, even when children with ADHD are optimally motivated, a majority of children with ADHD-C and about one third of children with ADHD-I will still show impairments on visuospatial working memory-related tasks and functioning. These considerations are consistent with the clinical efficacy of evidence-based interventions such as behavioral parent and teacher training. These interventions (Pelham & Fabiano, 2008; Evans et al., 2013) aim at improving behavioral control in children with ADHD by teaching parents and teachers to use token (reward) systems and techniques to unburden the working memory of these children (e.g., providing reminders and a structured environment). We suggest that these interventions (including psycho-education) could be even more effective if they would focus more explicitly on the specific neuropsychological impairments of the individual child with ADHD (i.e., chapter 5 suggests separable neuropsychological subtypes in ADHD). For example, only a minority of children with ADHD-C may require an intensive reward system, whereas a majority of these children require strategies to unburden working memory (and have less need for an additional intensive reward system). Furthermore, to reduce the working memory-related problems of children with ADHD-I (e.g., being forgetful in daily activities; having trouble following through on instructions), it seems especially important to minimize demands on their central executive (e.g., by providing children with only one task at a time, giving them simple instructions, and avoid interrupting them while they work): Due to a lack of attentional resources in their central executive, normal increases in attentional demands (i.e. ‘working’ with stored information) will presumably strongly impair utilization of the information that is stored in their probably intact short-term memory.

Nonetheless, clinicians/diagnosticians should realize that although all indices that were investigated in chapter 5 (visuospatial working memory, visuospatial short-term memory, and reinforcement sensitivity) discriminated significantly between children with ADHD-C and TD children, only the working memory and short-term memory measures showed clinically acceptable diagnostic validity, with both sensitivity and specificity being ≥70% (as was recommended by Glascoe & Squires, 2007). In addition, based on these guidelines, none of the indices showed acceptable diagnostic validity to distinguish children with ADHD-I from TD children, or to distinguish between the ADHD subtypes. Furthermore, when it comes to distinguishing children with ADHD-C from TD children, the diagnostic

validity of ADHD rating scales is, at this point, still much better (with correct overall classification rates of 90-95%; Conners, 1999) than that of any neuropsychological task (including visuospatial working memory or short-term memory measures). As such, measures of visuospatial working memory, visuospatial short-term memory or reinforcement sensitivity are not the best choice for making DSM-oriented ADHD diagnoses in children (especially not for diagnosing ADHD-I). That said, a majority of children with ADHD-C is characterized by a visuospatial memory or motivational impairment, and assessment of these impairments may (independently)[44] provide information about possible causal mechanisms of the ADHD behavior of an individual child (e.g., the association between his/her low working memory and his/her classroom inattention problems), and can help clinicians choose the best approach for treatment. For example, it may help clinicians choose the best treatment approach within behavioral parent- and teacher training (e.g., using intensive reward systems versus techniques to unburden working memory), or may help determine the relevance of a neuropsychological training program (like short-term memory or working memory training) for an individual child with ADHD. In line with this, our results imply that interventions such as Cogmed working memory training, of which there is debate as to whether mainly short-term memory is trained (e.g., Shipstead et al., 2012), should focus more on training the central executive, especially in children with ADHD-I. Still, the far transfer effects of these kind of interventions for children with ADHD may be unrelated to the improvement of EF (see chapter 7).

In the multiple EF training Braingame Brian, most far transfer effects on EF and behavior were unrelated to the specific effects of training EFs (as these effects were also found in the placebo condition). However, although these far transfer effects were mostly nonspecific, effect sizes ranged from medium to large (even 3-months after training) and the generalization of improvement to teacher-ratings might represent relatively unbiased evidence of treatment induced changes in the child’s behavior. Therefore, in our opinion one should not view this intervention as ineffective for children with ADHD, but as a treatment that might have an actual effect for yet unknown reasons. As the reasons for the far transfer effects are yet unclear, we would not recommend the use of Braingame Brian as a stand-alone intervention in clinical practice. However, we encourage researchers to further elucidate these nonspecific treatment factors.

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[44] the absence of overlap between memory and reinforcement sensitivity suggests that the combined assessment of these domains may contribute to improved neuropsychological differentiation of ADHD.

Finally, our results from chapters 2, 6 and 7 imply that, especially for children with ADHD, the use of game-like motivational strategies at home, or using computer gaming in schoolwork (educational games), computerized testing and computerized interventions could be a cost-effective way to optimize motivation (e.g., like 10 euros and in contrast to 1 euro or feedback-only, gamification was able to normalize task persistence in children with ADHD), performance and learning.

8.4 Directions for Future Research

In the study presented in chapter 7, far transfer effects were mostly nonspecific. However, we mainly focused on overall group differences (i.e., disregarding potential subpopulations that show differential responses to treatment), and children were allocated to treatment conditions irrespective of their individual EF deficits. Therefore, before discarding EF training as potential treatment for children with ADHD, future studies should examine moderators (e.g., severity of EF deficits; teacher expectancies) and mediators of treatment success (e.g., improvement on EF performance; parental praise), and should investigate effects of individually tailored EF training (i.e., to make optimal use of the available training-time future studies should match training focus to the specific EF problems of each individual child). Furthermore, to increase chances of finding far transfer that results from EF training specifically, training tasks should be made more ecologically valid (e.g., by using EF training tasks that resemble the complexity of problematic situations in daily-life) and should be intertwined with relevant real-life EF-taxing activities (e.g., completing chores in daily-life could be an additional goal in the EF training; for more suggestions see Gathercole, 2014). Nonetheless, even if these kind of adaptations result in more far transfer effects, it would still be difficult to determine if these effects are indeed caused by improved EF capacity. For example, on the one hand it could imply that improving EF capacity can only impact daily-life functioning (far transfer) if children learn how to use their additional EF capacity outside the training setting. However, it could also suggest that EF training is more effective because children learn more relevant strategies, without improving their cognitive capacity. Further, the domains of far transfer that were investigated in chapter 7 were limited to direct measures of performance and indirect measures of behavior (e.g., behavior as rated by parents, teachers or children). Future studies should also include direct measures of behavior. For example, a recent placebo-controlled working memory training study (Green et al., 2012) found no specific treatment effects on parent-rated behavior (teacher-rated behavior was not

investigated), but found specific effects on aspects of experimenter-observed off-task behavior during an academic task.

In addition, we suggest that evidence-based interventions such as parent and teacher interventions (Pelham & Fabiano, 2008) could also be more effective if they would focus more explicitly on the specific neuropsychological impairments of the individual child with ADHD (see the previous section for a detailed discussion). Existing parent and teacher training programs should be adapted accordingly, and their effectiveness should be compared to the regular versions of these training programs.

Our results from chapters 2, 6 and 7 imply that, especially for children with ADHD, the use of game-like motivational strategies could be a cost-effective way to optimize motivation, performance and learning. However, from our studies it is not clear which of the various elements of the game format (e.g., stimulating animation, variation, gameplay, upgrades, competition) specifically contributed to these optimizations. For example, we used expensive 3D graphics for the gamification of Braingame Brian (chapter 7), whereas relatively inexpensive 2D graphics were used for the game condition in chapter 2 and for the game training in chapter 6. While the impact of this difference in graphics on our research budget was clear, we don’t know what the impact was on our outcome measures. Future studies should systematically vary and rate these game elements and their influence on performance to be able to employ gamification as efficient and effective as possible.

Finally, it is clear from our studies that motivational deficits can confound the working memory-related performance of children with ADHD. Therefore, in EF research more motivating (e.g., gamified) test-batteries should be used and standardized to enable valid assessment of the EF capacities of children with ADHD.

Samenvatting

ADHD is een zeer erfelijke, neurobiologische ontwikkelingsstoornis (Nikolas & Burt, 2010), die wereldwijd naar schatting 2-9% van de kinderen treft (Skounti, Philalithis, & Galanakis, 2007). Kinderen met ADHD hebben vaak moeite om hun aandacht vast te houden, zijn chaotisch en slordig, snel afgeleid, vergeetachtig, raken regelmatig hun spullen kwijt, praten veel, zijn vaak druk, bewegelijk, ongeduldig, opdringerig en impulsief (American Psychiatric Association, 2000; 2013). Dit verstoort hun leren en presteren op school, hun relaties met anderen binnen en buiten het gezin, en heeft vaak een negatieve invloed op het zelfbeeld van deze kinderen (Barkley, 2006). Ook op volwassen leeftijd zorgt ADHD voor problemen in het dagelijkse functioneren, onder andere in het gezin, op het werk en in sociale relaties (Barkley et al., 2008). Dit proefschrift gaat over de interactie tussen twee neuropsychologische processen die verondersteld worden ten grondslag te liggen aan de problemen van kinderen met ADHD: executief functioneren en motivatie. Het begrijpen van deze processen is cruciaal voor vroegtijdige onderkenning, adequate psycho-educatie en effectieve behandeling en ziektemanagement van ADHD.

Executief Functioneren en Motivatie

Veel van de problemen die kinderen met ADHD in het dagelijkse leven ervaren zouden het resultaat zijn van tekorten in hun executieve functioneren (Barkley, 2006; Nigg, 2006; Rapport et al., 2001). Executieve functies (EF) zijn cognitieve controleprocessen die noodzakelijk zijn voor het reguleren van onze gedragingen, gedachten en emoties; ze stellen ons in staat tot zelfcontrole. Onderzoek laat zien dat tekorten in EF vaak samengaan met afwijkingen in aandacht, hyperactiviteit en impulsiviteit, en met problemen in het academische functioneren (zie o.a. Biederman et al., 2004; Burgess, Depue, Ruzic, Willcutt, Du, & Banich, 2010; Crosbie et al., 2013; Kofler, Rapport, Bolden, Sarver, & Raiker, 2010; Titz & Karbach, 2014). Uit meta-analyses (Martinussen et al., 2005; Willcutt et al., 2005; 2012) blijkt dat kinderen met ADHD met name tekorten hebben in EF zoals gedragsinhibitie, cognitieve flexibiliteit en visuospatieel werkgeheugen. Het visuospatiële werkgeheugen is het meest beperkt bij kinderen met ADHD, en wordt gedefinieerd als het vermogen om relevante visuospatiële informatie actief in het geheugen vast te houden en deze informatie als het nodig is te manipuleren of te reorganiseren (te ‘werken’ met de informatie; Baddeley, 2007).

Volgens een andere belangrijke theoretische benadering hangen ADHD-gerelateerde problemen samen met tekorten in motivatie (Haenlein & Caul, 1987; Sergeant et al., 1999; zie verder Sagvolden et al., 2005; Sonuga-Barke, 2003). Kinderen met ADHD zouden op neuraal niveau minder worden gestimuleerd door bekrachtiging (o.a. beloningen) dan kinderen met een normale ontwikkeling (waarschijnlijk door een dopaminerge afwijking). Hierdoor zouden kinderen met ADHD doorgaans onvoldoende gemotiveerd raken om op eenzelfde niveau te presteren als normale kinderen. Sommige theoretici suggereren dat ook de afwijkende EF prestatie van kinderen met ADHD het gevolg is van, of tenminste sterk wordt beïnvloed door deze motivationele tekorten: onder standaard test omstandigheden zouden kinderen met ADHD, in tegenstelling tot kinderen met een normale ontwikkeling, onvoldoende gemotiveerd raken om tot een optimale prestatie te komen op EF taken. Dit zou vervolgens ten onrechte de suggestie wekken dat kinderen met ADHD EF tekorten hebben; aan deze suboptimale prestatie ligt immers een motivationeel tekort ten grondslag.

Opvallend genoeg was deze interactie tussen motivationele tekorten en de EF die het meest beperkt lijkt bij kinderen met ADHD (het visuospatieel werkgeheugen) bij aanvang van mijn promotie nog niet onderzocht bij kinderen met- en zonder ADHD. De onderzoeken die worden gepresenteerd in de hoofdstukken van dit proefschrift zijn dan ook vooral opgezet om meer inzicht te krijgen in deze interactie.

Samenvatting van de Hoofdstukken in dit Proefschrift

In **hoofdstuk 2** worden de effecten van verschillende bekrachtigers op het visuospatieel werkgeheugen onderzocht bij kinderen met het gecombineerde subtype van ADHD (kinderen met problemen in aandacht, hyperactiviteit en impulsiviteit) en kinderen met een normale ontwikkeling (controle kinderen). De kinderen waren tussen de 9 en 12 jaar oud. Er werd een visuospatiële werkgeheugentaak afgenomen onder vier bekrachtigingscondities: *feedback-only* (d.w.z. alleen standaard feedback: een groene krul bij een correcte respons en een rood kruis bij een incorrecte respons), *feedback + 1 euro* (de deelnemer wordt verteld dat hij/zij 1 euro kan verdienen als hij/zij goed genoeg presteert op de taak), *feedback + 10 euro's* (de deelnemer wordt verteld dat hij/zij 10 euro's kan verdienen als hij/zij goed genoeg presteert op de taak), en een *game versie* van de taak (de taak is vormgegeven als een computerspel).

Uit de resultaten bleek het volgende: met feedback-only presteerden kinderen met ADHD slechter op de werkgeheugentaak dan de controle kinderen (groot effect). Extra bekrachtigers (1 euro, 10 euro's en gaming) verbeterden alleen de prestatie van kinderen met ADHD, maar niet de prestatie van controle kinderen. Dit suggereert dat kinderen met ADHD,

in tegenstelling tot controle kinderen, suboptimaal presteerden in de feedback-only conditie (zie figuur 3 in hoofdstuk 2). Dit is in lijn met theorieën die suggereren dat kinderen met ADHD minder worden gestimuleerd door bekrachtiging dan kinderen met een normale ontwikkeling. De extra bekrachtigers waren echter niet in staat om de werkgeheugenprestatie van kinderen met ADHD te 'normaliseren' (effectgroottes van de prestatieverschillen tussen de ADHD groep en de controle groep waren ondanks de extra bekrachtigers nog steeds medium tot groot). Dit suggereert dat de werkgeheugentekorten van kinderen met ADHD niet volledig verklaard kunnen worden door hun motivationele afwijkingen. De werkgheugentaak duurde ruim 20 minuten en er werd daarom ook gekeken naar het effect van de bekrachtigers op de stabiliteit van de taakprestatie over tijd: alleen bij kinderen met ADHD verslechterde de taakprestatie over tijd. Maar met de sterkste bekrachtigers (10 euro's en gaming) konden zij hun taakprestatie even stabiel houden als normaal ontwikkelende kinderen, terwijl 1 euro dit effect niet had (zie figuur 4 in hoofdstuk 2).

Er werd geconcludeerd dat: (1) zowel executieve als motivationele tekorten bijdragen aan de visuospatiële werkgeheugen tekorten van kinderen met het gecombineerde subtype van ADHD (ADHD-C), (2) problemen van kinderen met ADHD-C met het volhouden van hun prestatie vooral het gevolg zijn van motivationele tekorten, (3) de intensiteit van de bekrachtiging een belangrijke factor is om mee te wegen bij het beoordelen van testresultaten van kinderen met ADHD-C[45], en (4) gamificatie kan een kostenefficiënt middel zijn om de prestatie van kinderen met ADHD-C te optimaliseren (het effect van de game conditie was immers even groot als het effect van de 10 euro conditie).[46]

Hoofdstuk 2 geeft aan dat het visuospatieel werkgeheugen beperkt is bij kinderen met ADHD-C, zelfs als je controleert voor hun motivationele tekorten. Werkgeheugen bestaat echter uit meerdere componenten: *korte termijn geheugen* en een *central executive* (Baddeley, 2007). Het korte termijn geheugen maakt het mogelijk om informatie gedurende een korte periode vast te houden in het geheugen. De central executive is een mentaal controle systeem dat ons in staat stelt om de informatie in het korte termijn geheugen te superviseren, te controleren en te manipuleren. Omdat het werkgeheugen uit meerdere componenten bestaat is

[45] Bij het testen van kinderen met ADHD bestaat er namelijk een grotere kans dan bij kinderen met een normale ontwikkeling dat men niet alleen het construct meet dat men wil te meten (bijv. werkgeheugen, IQ of academische vaardigheden), maar dat de prestatie mede wordt bepaald door motivationele tekorten.

[46] Clinici zullen begrijpen dat deze resultaten een indirecte verklaring bieden voor de effectiviteit van ouder- en leerkrachttrainingen. Deze interventies (Pelham & Fabiano, 2008) hebben als voornaamste doel om ouders en leerkrachten te leren hoe ze beloningsystemen en technieken om het werkgeheugen te ontlasten (bijv. het bieden van reminders en een gestructureerde omgeving) kunnen inzetten om de gedragsproblemen van kinderen met ADHD te verminderen.

het mogelijk dat tekorten in één of in beide componenten de werkgeheugen problemen van kinderen met ADHD-C veroorzaken. Gezien het belang van het werkgeheugen voor ADHD, is de interesse in het identificeren van de componenten van het werkgeheugen die beperkt zijn bij kinderen met ADHD de laatste jaren toegenomen. In eerder onderzoek hiernaar houdt men echter geen rekening met de interactie tussen de componenten van het werkgeheugen en de motivationele tekorten van kinderen met ADHD. In **hoofdstuk 3** hebben we daarom onderzoek gedaan naar de effecten van een standaard niveau van bekrachtiging (feedback-only) en een hoog niveau van bekrachtiging (feedback + 10 euro's) op de prestaties van kinderen met ADHD-C en controle kinderen (leeftijd 8-12 jaar) op taken die het visuospatiële werkgeheugen, het visuospatiële korte termijn geheugen en de central executive meten.

Uit de resultaten bleek het volgende: met feedback-only was de werkgeheugen prestatie, de korte termijn geheugen prestatie en de central executive prestatie van kinderen met ADHD-C slechter dan de prestatie van controle kinderen (dit effect was groot voor het werkgeheugen, medium voor het korte termijn geheugen en klein voor de central executive). Extra bekrachtiging (10 euro's) zorgde voor een verbetering van de werkgeheugen prestatie en de korte termijn geheugen prestatie bij kinderen met ADHD-C, maar niet bij controle kinderen (zie figuur 4 in hoofdstuk 3). Dit hoge niveau van bekrachtiging zorgde er echter niet voor dat de werkgeheugen prestatie en de korte termijn geheugen prestatie van kinderen met ADHD normaliseerden (effectgroottes van de prestatieverschillen tussen de ADHD groep en de controle groep waren nog steeds medium). Het hoge niveau van bekrachtiging zorgde verder in geen van de groepen voor een verbetering van de central executive prestatie.

Op basis hiervan werd geconcludeerd dat: (1) de motivationele tekorten van kinderen met ADHD-C zowel een negatieve invloed hebben op hun visuospatiële werkgeheugen prestatie, als op hun visuospatiële korte termijn geheugen prestatie, en (2) kinderen met ADHD-C, behalve motivationele tekorten, zowel tekorten hebben in hun visuospatiële korte termijn geheugen als in hun central executive; beide componenten dragen bij aan de visuospatiële werkgeheugentekorten van kinderen met ADHD-C.

De twee meest voorkomende en valide diagnostische subtypes van ADHD zijn het gecombineerde subtype (ADHD-C) en het overwegend onoplettend subtype (ADHD-I; kinderen met vooral aandachtproblemen en weinig tot geen symptomen van hyperactiviteit en impulsiviteit; Gomez, et al., 1999; Willcutt et al., 2012; Wolraich et al., 1998). Deze twee subtypen worden gekenmerkt door verschillen in symptomatisch gedrag (bijv. hyperactief en impulsief gedrag), geassocieerde eigenschappen (bijv. opstandig gedrag) en demografische kenmerken (bijv. gender ratio; Milich et al., 2001). Het is echter onduidelijk of kinderen met

ADHD-I en ADHD-C verschillen op het gebied van motivationele tekorten of tekorten van de componenten van het visuospatiële werkgeheugen (Diamond, 2005; Willcutt et al., 2012). In **hoofdstuk 4** hebben we daarom onderzoek gedaan naar de effecten van een standaard niveau van bekrachtiging (feedback-only) en een hoog niveau van bekrachtiging (feedback + 10 euro's) op de prestaties van kinderen met ADHD-I, ADHD-C en controle kinderen (leeftijd 9-12 jaar) op taken die het visuospatiële werkgeheugen, het visuospatiële korte termijn geheugen, en de central executive meten.

Uit de resultaten bleek het volgende: met feedback-only waren de werkgeheugen prestaties en central executive prestaties in beide ADHD groepen slechter dan de prestaties in de controle groep (de effecten waren groot voor het werkgeheugen en medium voor de central executive). Echter, de korte termijn geheugen prestaties van kinderen met ADHD-I waren, in tegenstelling tot de korte termijn geheugen prestaties van kinderen met ADHD-C, niet slechter dan de prestaties van controle kinderen (het effect was klein voor ADHD-I en medium voor ADHD-C). Extra bekrachtiging (10 euro's) zorgde voor een betere werkgeheugen- en korte termijn geheugen prestatie bij kinderen met ADHD-I en kinderen met ADHD-C, maar niet bij controle kinderen (zie figuur 2 in hoofdstuk 4). Dit hoge niveau van bekrachtiging zorgde echter niet voor een normalisering van de werkgeheugen prestatie en de korte termijn geheugen prestatie van kinderen met ADHD-C, noch van de werkgeheugen prestatie van kinderen met ADHD-I (effectgroottes van de prestatieverschillen tussen de ADHD groepen en de controle groep waren nog steeds medium). Extra bekrachtiging zorgde verder in geen van de groepen voor een verbetering van de central executive prestatie. Hoewel kinderen met ADHD-I betere werkgeheugen prestaties en korte termijn geheugen prestaties lieten zien dan kinderen met ADHD-C, waren hun central executive prestaties niet verschillend. Extra bekrachtiging had op beide ADHD groepen een vergelijkbaar effect (d.w.z. de relatieve vooruitgang in prestatie als gevolg van extra bekrachtiging was niet verschillend).

Op basis hiervan werd geconcludeerd dat: (1) beide ADHD subtypen gekenmerkt worden door een verminderde gevoeligheid voor bekrachtiging, (2) deze motivationele tekorten een negatieve invloed uitoefenen op de visuospatiële werkgeheugen- en korte termijn geheugen prestaties van deze kinderen, (3) de ernst van deze motivationele tekorten niet lijkt te verschillen tussen de ADHD subtypen, en (4) kinderen met ADHD-I, in tegenstelling tot kinderen met ADHD-C, geen tekorten lijken te hebben in hun korte termijn geheugen; de

tekorten in hun visuospatiële werkgeheugen lijken te worden veroorzaakt door hun beperkte central executive en hun verminderde gevoeligheid voor bekrachtiging.[47]

Hoewel hoofdstuk 4 vooral gericht is op de verschillen *tussen* ADHD subtypen, is er ook bewijs voor heterogeniteit *binnen* de subtypen (Fair et al., 2012; Sonuga-Barke et al., 2010). In **hoofdstuk 5** hebben we daarom, binnen deze ADHD subtypen, subgroepen onderscheiden op basis van hun cognitieve- (visuospatieel werkgeheugen en korte termijn geheugen) en motivationele tekorten. Bij kinderen met ADHD-C en kinderen met ADHD-I werd de prevalentie en diagnostische validiteit van tekorten in visuospatieel werkgeheugen, visuospatieel korte termijn geheugen en bekrachtigingsgevoeligheid onderzocht. Hierbij werden kinderen met een normale ontwikkeling als referentiegroep gebruikt (kinderen met ADHD werden als 'beperkt' geclassificeerd als zij slechter scoorden dan de 10% slechtst scorende controle kinderen). In dit onderzoek hebben we gebruik gemaakt van de datasets die staan beschreven in hoofdstuk 3 en 4.

Uit de resultaten bleek het volgende: tekorten in werkgeheugen en korte termijn geheugen[48] kwamen vaker voor bij kinderen met ADHD-C (58.1% beperkt op werkgeheugen; 40.7% beperkt op korte termijn geheugen) dan bij kinderen met ADHD-I (33.3% beperkt op werkgeheugen; 18.5% beperkt op korte termijn geheugen). Bij kinderen met ADHD-I kwamen alleen de werkgeheugen tekorten, maar niet de tekorten in korte termijn geheugen, vaker voor dan bij controle kinderen. Slechts een minderheid van de kinderen met ADHD werd gekenmerkt door tekorten in bekrachtigingsgevoeligheid, en deze tekorten kwamen in beide subtypen even vaak voor (in beide subtypen was slechts 22% beperkt; zie figuur 2 in hoofdstuk 5). Tekorten in werkgeheugen en/of korte termijn geheugen hingen niet samen met tekorten in bekrachtigingsgevoeligheid. Kinderen met ADHD-C die beperkt waren op werkgeheugen, korte termijn geheugen en/of bekrachtigingsgevoeligheid hadden meer aandachtproblemen, gebruikten vaker ADHD-medicatie (d.w.z. in het dagelijkse leven; tijdens het testen mochten kinderen geen medicatie gebruiken) en hadden een lager IQ dan kinderen met ADHD-C die op geen van deze maten beperkt waren. Alleen de werkgeheugen- en korte termijn geheugen maten hadden voldoende diagnostische validiteit om kinderen met ADHD-C te kunnen onderscheiden van controle kinderen (sensitiviteit en specificiteit waren

[47] Dit suggereert dat als kinderen met ADHD-I zo min mogelijk hoeven te werken met hun geheugen (bijv. doordat er een vaste structuur te geboden wordt) en zo veel mogelijk worden gemotiveerd (bijv. doordat er gebruik wordt gemaakt van een beloningsysteem), dat ze dan niet gehinderd zouden moeten worden door korte termijn geheugen gerateerde problemen (zoals vergeetachtigheid).

[48] Om de negatieve invloed van de motivationele tekorten op de EF prestaties zoveel mogelijk te verminderen, werden alleen de scores uit de hoge bekrachtigingscondities (10 euros) gebruikt om de prestaties op werkgeheugen en korte termijn geheugen te bepalen.

≥ 70%; Glascoe & Squires, 2007). Verder had geen van de maten voldoende diagnostische validiteit om kinderen met ADHD-I te kunnen onderscheiden van controle kinderen, of om onderscheid te kunnen maken tussen kinderen met ADHD-I en kinderen met ADHD-C.

Op basis hiervan werd geconcludeerd dat: (1) het merendeel van de kinderen met ADHD-C tekorten heeft op visuospatieel werkgeheugen, (2) korte termijn geheugen tekorten niet vaker voorkomen bij kinderen met ADHD-I dan bij kinderen met een normale ontwikkeling, (3) in beide ADHD subtypen slechts een minderheid van de kinderen een verminderde gevoeligheid voor bekrachtiging laat zien, en (4) tekorten in visuospatieel werkgeheugen en bekrachtigingsgevoeligheid onafhankelijke neuropsychologische domeinen vertegenwoordigen.[49]

Hoofstuk 6 en 7 richtten zich op het trainen van EF bij kinderen met ADHD. Het ging hierbij in bijzonder om het effect dat bekrachtiging (d.w.z. *gamificatie)*[50] heeft op de motivatie en prestatie tijdens de training en op de resultaten na afloop van de training. In **hoofdstuk 6** werden de effecten van gamificatie van een standaard gecomputeriseerde visuospatiële werkgeheugentraining onderzocht. Kinderen met ADHD (leeftijd 7-12 jaar; er werd geen specifiek ADHD subtype geselecteerd) werden random toegewezen aan: (1) een gegamificeerde visuospatiële werkgeheugentraining (waarbij de training was vormgegeven als een computerspel), of (2) een standaard (relatief ‘kale’) visuospatiële werkgeheugentraining. Beide groepen hebben vervolgens drie wekelijkse trainingssessies doorlopen.

Uit de resultaten bleek het volgende: kinderen die de gegamificeerde training deden waren meer gemotiveerd (besteden vrijwillig meer tijd aan de training), hadden betere prestaties tijdens de training (meer voltooide trainingstrials met minder fouten) en lieten na afloop van de training meer verbetering zien op een visuospatiële werkgeheugentaak dan kinderen die de standaard training deden. Dit superieure effect van de gegamificeerde training bleef zelfs significant nadat er was gecontroleerd voor het aantal voltooide trainingstrials. Op basis hiervan werd geconcludeerd dat gamificatie van een visuospatiële werkgeheugentraining de motivatie en trainingsprestatie van kinderen met ADHD kan verbeteren, en dat het bovendien in staat is om het effect van de training te vergroten.

[49] Dit suggereert dat je met een maat voor bekrachtigingsgevoeligheid een subgroep binnen de ADHD populatie kan identificeren die niet zichtbaar wordt als je alleen werkgeheugen meet: gecombineerde assessment van deze domeinen zou daarom de neuropsychologiche diagnostiek van ADHD kunnen verbeteren.

[50] Gamificatie is het toevoegen van mechanics en visuals die doorgaans worden gebruikt om computerspellen aantrekkelijk te maken.

In de dubbelblinde, placebogecontroleerde studie die staat beschreven in **hoofdstuk 7** werden de nabije- en verre generalisatie effecten onderzocht van een gegamificeerde EF trainingsinterventie (Braingame Brian). Braingame Brian bestaat uit 25 sessies van ongeveer 45 minuten (verspreid over 5 tot 6 weken), wordt thuis uitgevoerd en richt zich op het trainen van meerdere EF om zo de gedragsproblemen van kinderen met ADHD te verminderen. Kinderen met ADHD-C (leeftijd 8-12 jaar) werden random toegewezen aan één van de volgende drie condities: (1) een *volledig-actieve* conditie waarin visuospatieel werkgeheugen, gedragsinhibitie[51] en cognitieve flexibiliteit[52] werden getraind, (2) een *deels-actieve* conditie waarin alleen gedragsinhibitie en cognitieve flexibiliteit werden getraind, en de werkgeheugentraining in placebo-modus werd aangeboden, of (3) een *volledige-placebo* conditie. De korte- en lange termijn effecten (na 1 week en na 3 maanden) van deze gegamificeerde EF training werden op meerdere gebieden onderzocht (o.a. EF taakprestatie, ADHD gedrag, en algemeen probleem gedrag).

Uit de resultaten bleek het volgende: De therapietrouw tijdens de training was hoog (97% van de kinderen heeft alle 25 trainingsessies volledig doorlopen). Na de training bleken de visuospatiële korte termijn geheugen prestatie en de visuospatiële werkgeheugen prestatie meer verbeterd in de volledig-actieve conditie dan in de deels-actieve conditie en de placebo conditie (effecten waren medium tot groot). Verder verbeterde gedragsinhibitie meer in de volledig-actieve conditie en de deels-actieve conditie, dan in de placebo conditie (effecten waren medium). Interferentie controle (een andere EF die voor- en na de training gemeten werd) verbeterde meer in de volledig-actieve conditie dan in de placebo conditie (medium effect). Dergelijke interactie effecten (behandelconditie x meetmoment) werden echter niet gevonden voor de testscores op cognitieve flexibiliteit, verbaal werkgeheugen en complex redeneren, noch voor het door ouders-, leerkracht- of kind-gerapporteerde ADHD gedrag, EF gedrag, motivationele gedrag, of algemeen probleem gedrag (m.a.w. eventuele veranderingen op deze maten tussen de voor- en nameting waren niet afhankelijk van het type behandelconditie dat was doorlopen). Ondanks dat veranderingen op deze maten niet afhankelijk waren van het type behandelconditie, werd er op vrijwel al deze maten

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[51] Gedragsinhibitie is het vermogen om een in gang gezette reactie te stoppen voordat deze tot uitvoer wordt gebracht. Gedragsinhibitie geeft ons daarmee de mogelijkheid om te 'denken' voordat we 'doen'.

[52] Cognitieve flexibiliteit omvat twee vaardigheden: (1) het vermogen om gedragingen, gedachten of emoties te onderdrukken wanneer deze niet meer gewenst zijn (bijvoorbeeld omdat de situatie is veranderd), en (2) het vermogen om vervolgens over te schakelen op alternatieve gedragingen, gedachten of emoties die op dat moment meer passend of gewenst zijn. Cognitieve flexibiliteit stelt ons daarmee in staat om ons adequaat en op tijd aan te passen in veranderende situaties.

vooruitgang gevonden tussen de voormeting en de nametingen[53], zelfs op de leerkracht maten[54] (effecten waren medium tot groot).

Op basis hiervan werd geconcludeerd dat: (1) de actieve trainingstaken van Braingame Brian een groter effect hebben op het visuospatieel werkgeheugen, het visuospatieel korte termijn geheugen en de gedragsinhibitie van kinderen met ADHD dan een placebo versie van de training, (2) deze effecten afhankelijk zijn van het specifiek soort training dat wordt gevolgd (bijv. alleen als werkgeheugen wordt getraind, verbetert de werkgeheugenprestatie; dit zijn daarom slechts nabije generalisatie effecten), (3) vooruitgang van ongetrainde EF en gedragingen (d.w.z. verre generalisatie) vooral een non-specifieke en nog onbekende oorsprong lijkt te hebben (alleen het effect op interferentie controle was gerelateerd aan een specifieke behandelconditie), en dus (4) dat in deze EF training niet de verbetering van werkgeheugen en gedragsinhibitie, maar vooral non-specifieke behandelfactoren samen lijken te hangen met de verre generalisatie effecten op EF en gedrag.

Voor een inhoudelijke discussie van de resultaten verwijs ik u graag naar de ‘General Discussion’ in hoofdstuk 8 (paragraaf 8.2).

[53] In een eerdere studie naar Braingame Brian (Van der Oord et al., 2012) vondt men geen vooruitgang in een wachtlijst conditie, maar wel in een actieve trainingsconditie. Dit suggereert dat de hierboven gevonden vooruitgang meer is dan alleen een test-hertest effect.

[54] Dit is de eerste placebo-gecontroleerde EF trainingsstudie waarin dergelijke leerkracht effecten worden gevonden. Dit is vooral interessant omdat leerkrachten minder bij de behandeling betrokken zijn dan ouders (de interventie vindt immers niet op school plaats), hierdoor zijn scores van de leerkracht mogelijk minder vatbaar voor placebo effecten. Een effect dat wordt gerapporteerd door de leerkracht zou daarom eerder op een ‘echte’ verandering duiden.

References

A

Aarts, E., van Holstein, M., & Cools, R. (2011). Striatal dopamine and the interface between motivation and cognition. *Frontiers in Psychology, 2*, 163.

Alderson, R. M., Rapport, M. D., Hudec, K. L., Sarver, D. E., & Kofler, M. J. (2010). Competing core processes in attention-deficit/hyperactivity disorder (ADHD): Do working memory deficiencies underlie behavioral inhibition deficits? *Journal of Abnormal Child Psychology, 38,* 497–507.

Alloway, T. P., Elliott, J., & Place, M. (2010). Investigating the relationship between attention and working memory in clinical and community samples. *Child Neuropsychology: a Journal on Normal and Abnormal Development in Childhood and Adolescence, 16,* 242–254.

Altman, D. G., & Bland, J. M. (2005). Treatment allocation by minimisation. *BMJ (Clinical Research Ed.), 330,* 843.

American Psychiatric Association (2000). *Diagnostic and statistical manual of mental disorders, 4th revised edition (DSM-IV-TR).* Washington, DC: American Psychiatric Association.

American Psychiatric Association (2013). *Diagnostic and statistical manual of mental disorders, 5th edition (DSM-V).* Washington, DC: American Psychiatric Association.

B

Baddeley, A. D. (1986). *Working Memory.* London: Clarendon Press.

Baddeley, A. D. (2003). Working memory: Looking back and looking forward. *Nature Neuroscience, 4,* 829–839.

Baddeley, A. D. (2010). Working memory. *Current Biology, 20,* R136–140.

Baddeley, A. D. (2007). *Working memory, thought and action.* Oxford: Oxford University Press.

Baddeley, A. D., & Hitch, G. (1974). Working memory. In G. A. Bower (Ed.), *The psychology of learning and motivation* (Vol. 8, pp. 47–89). New York: Academic Press.

Barber, M. A., Milich, R., & Welsh, R. (1996). Effects of reinforcement schedule and task difficulty on the performance of attention deficit hyperactivity disordered and control

boys. *Journal of Clinical Child Psychology,* 25, 66–76.

Barkley, R. A. (1997). Behavioral inhibition, sustained attention, and executive functions: Constructing a unifying theory of ADHD. *Psychological Bulletin*, *121*(1), 65–94.

Barkley, R. A. (2006). *Attention-Deficit Hyperactivity Disorder. A Handbook for diagnosis and treatment (3d edn.).* New York: Guilford Press.

Barkley, R. A., Murphy, K. R., & Fischer, M. (2008). *ADHD in Adults. What the Science Says.* New York: Guilford Press.

Barkley, R. A., Edelbrock, C. (1987). *Assessing situational variations in children's behavior problems: The home and school situations Questionnaires*. In Prinz, R., editor. Advances in behavioral assessment of children and families (vol. 3). Greenwich, CT: JAI press. Pp. 157-176.

Bastiaansen, D., Koot, H. M., Bongers, I. L., Varni, J. W., & Verhulst, F. C. (2004). Measuring quality of life in children referred for psychiatric problems: Psychometric properties of the PedsQL TM 4.0 generic core scales. *Quality of Life Research*, *13*(2), 489–495.

Bauermeister, J. J., Barkley, R. a, Bauermeister, J. a, Martínez, J. V, & McBurnett, K. (2012). Validity of the sluggish cognitive tempo, inattention, and hyperactivity symptom dimensions: neuropsychological and psychosocial correlates. *Journal of Abnormal Child Psychology*, *40*, 683–697.

Beck, S. J., Hanson, C. A, Puffenberger, S. S., Benninger, K. L., & Benninger, W. B. (2010). A controlled trial of working memory training for children and adolescents with ADHD. *Journal of Clinical Child and Adolescent Psychology, 39*, 825–836.

Biederman, J., Monuteaux, M. C., Doyle, A. E., Seidman, L. J., Wilens, T. E., Ferrero, F., … Faraone, S. V. (2004). Impact of executive function deficits and Attention-Deficit/Hyperactivity Disorder (ADHD) on academic outcomes in children. *Journal of Consulting and Clinical Psychology, 72*, 757-766.

Braver, T. S., Reynolds, J. R., & Donaldson, D. I. (2003). Neural Mechanisms of Transient and Sustained Cognitive Control during Task Switching. *Neuron*, *39*(4), 713–726.

Burgess, G. C., Depue, B. E., Ruzic, L., Willcutt, E. G., Du, Y. P., & Banich, M. T. (2010). Attentional control activation relates to working memory in attention-deficit/hyperactivity disorder. *Biological Psychiatry, 67*, 632–640.

C

Carlson, C. L., Booth, J. E., Shin, M., & Canu, W. H. (2002). Parent-, teacher-, and self-rated

motivational styles in ADHD subtypes. *Journal of Learning Disabilities, 35,* 104–113.

Carlson, C. L., Mann, M., & Alexander, D. K. (2000). Effects of reward and response cost on the performance and motivation of children with AD/HD. *Cognitive Therapy and Research, 24,* 87–98.

Carlson, C. L., & Tamm, L. (2000). Responsiveness of children with attention deficit-hyperactivity disorder to reward and response cost: Differential impact on performance and motivation. *Journal of Consulting and Clinical Psychology, 68,* 73–83.

Castellanos, F. X., Sonuga-Barke, E. J. S., Milham, M. P., Tannock, R. (2006). Characterizing cognition in ADHD: beyond executive dysfunction. *Trends in Cognitive Sciences, 10,* 117–23.

Chacko, A., Bedard, A.-C., Marks, D. J., Feirsen, N., Uderman, J. Z., Chimiklis, A., … Ramon, M. (2014). A randomized clinical trial of Cogmed Working Memory Training in school-age children with ADHD: a replication in a diverse sample using a control condition. *Journal of Child Psychology and Psychiatry, and Allied Disciplines, 55*(3), 247–255.

Chacko, A., Feirsen, N., Bedard, A.-C., Marks, D., Uderman, J. Z., & Chimiklis, A. (2013). Cogmed Working Memory Training for Youth with ADHD: A Closer Examination of Efficacy Utilizing Evidence-Based Criteria. *Journal of Clinical Child and Adolescent Psychology : The Official Journal for the Society of Clinical Child and Adolescent Psychology, American Psychological Association, Division 53*, 1–15.

Cockcroft, K. (2011). Working memory functioning in children with attention-deficit/hyperactivity disorder (ADHD): A comparison between subtypes and normal controls. *Journal of Child & Adolescent Mental Health, 23,* 107–118.

Coghill, D. R., Rhodes, S. M., & Matthews, K. (2007). The neuropsychological effects of chronic methylphenidate on drug-naive boys with attention-deficit/hyperactivity disorder. *Biological psychiatry, 62,* 954–962.

Cohen, J. (1992). A power primer. *Psychological Bulletin*, *112*(1), 155–159.

Cohen, J. (1988). *Statistical power analysis for the behavioural sciences*. 2nd ed. Hillsdale (NJ): Lawrence Erlbaum.

Colder, C. R., & O'Connor, R. M. (2004). Gray's Reinforcement Sensitivity Model and Child Psychopathology: Laboratory and Questionnaire Assessment of the BAS and BIS. *Journal of Abnormal Child Psychology, 32*(4), 435–451.

Conners, C. K. (1999). Clinical use of rating scales in diagnosis and treatment of ADHD. *Pediatric Clinics of North America, 46,* 857–870.

Conway, A. R. A., Jarrold, C., Kane, M. J., Miyake, A., & Towse, J. (2007). Variation in working memory: An introduction. In A. R. A. Conway, C. Jarrold, M. J. Kane, A. Miyake, J. Towse (Eds.), *Variation in Working Memory*. Oxford: Oxford University Press.

Cools, R., & D'Esposito, M. (2011). Inverted-U-shaped dopamine actions on human working memory and cognitive control. *Biological Psychiatry, 69,* 113–125.

Cools, R., Gibbs, S. E., Miyakawa, A., Jagust, W., & D'Esposito, M. (2008). Working memory capacity predicts dopamine synthesis capacity in the human striatum. *Journal of Neuroscience, 28*, 1208–1212.

Corsi, P. M. (1972). Human memory and the medial temporal region of the brain. *Dissertation Abstracts International, 34*, 819B.

Costenbader, V., & Ngari, S. M. (2001). A Kenya Standardization of the Raven's Coloured Progressive Matrices. *School Psychology International*, *22*(3), 258–268.

Cowan, N. (1995). *Attention and memory: An integrated framework*. Oxford, England: Oxford University Press.

Crone, E. A., Jennings, J. R., & Van der Molen, M. W. (2003). Sensitivity to interference and response contingencies in attention-deficit/hyperactivity disorder. *Journal of Child Psychology and Psychiatry, 44,* 224–226.

Crosbie, J., Arnold, P., Paterson, a, Swanson, J., Dupuis, a, Li, X., … Schachar, R. J. (2013). Response inhibition and ADHD traits: correlates and heritability in a community sample. *Journal of Abnormal Child Psychology*, *41*(3), 497–507.

Cunningham, C. E., & Boyle, M. H. (2002). Preschoolers at Risk for Attention-Deficit Hyperactivity Disorder and Oppositional Defiant Disorder: Family, Parenting, and Behavioral Correlates. *Journal of Abnormal Child Psychology, 30*(6), 555–569.

D

Delaney, H. D., & Maxwell, S. E. (1981). On Using Analysis of Covariance in Repeated Measures Designs. *Multivariate Behavioral Research, 16*, 105–123.

Delis, D. C., Kaplan, E., & Kramer, J. H. (2007). *Delis-Kaplan Executive Function System: Examiner's Manual*, *Trial Making Test.* San Antonio, TX: Harcourt Assessment.

Demurie, E., Roeyers, H., Baeyens, D., & Sonuga-Barke, E. J. S. (2011). Common alterations in sensitivity to type but not amount of reward in ADHD and autism spectrum disorders. *Journal of Child Psychology and Psychiatry*, *52,* 1164-1173.

Dennis, M., Francis, D. J., Cirino, P. T., Schachar, R., Barnes, M. A., & Fletcher, J. M. (2009). Why IQ is not a covariate in cognitive studies of neurodevelopmental disorders. *Journal of the International Neuropsychological Society: JINS, 15,* 331–343.

Derefinko, K. J., Adams, Z. W., Milich, R., Fillmore, M. T., Lorch, E. P., & Lynam, D. R. (2008). Response style differences in the inattentive and combined subtypes of attention-deficit/hyperactivity disorder. *Journal of abnormal child psychology, 36,* 745–758.

Diamond, A. (2005). Attention-deficit disorder (attention-deficit/hyperactivity disorder without hyperactivity): a neurobiologically and behaviorally distinct disorder from attention-deficit/hyperactivity disorder (with hyperactivity). *Development and Psychopathology, 17,* 807–825.

Van Dongen-Boomsma, M., Vollebregt, M. A., Buitelaar, J. K., & Slaats-Willemse, D. (2014). Working memory training in young children with ADHD: a randomized placebo-controlled trial. *Journal of Child Psychology and Psychiatry, and Allied Disciplines*, in press.

Dovis, S., Geurts, H., Ponsioen, A., Ten Brink, E., Van der Oord, S., & Prins, P. J. M. (2008b). *Executive function training tasks: Inhibition and cognitive flexibility. Theoretical background and parameters.* Task force ADHD & computer. Amsterdam, the Netherlands: University of Amsterdam.

Dovis, S., Ponsioen, A., Geurts, H., Ten Brink, E., Van der Oord, S., & Prins P. J. M. (2008a). *Executive function training tasks: Working memory. Theoretical background and parameters*. Task force ADHD & computer. Amsterdam, the Netherlands: University of Amsterdam.

Dovis, S., Van der Oord, S., Wiers, R. W., & Prins, P. J. M. (2012). Can motivation normalize working memory and task persistence in children with attention-deficit/hyperactivity disorder? The effects of money and computer-gaming. *Journal of Abnormal Child Psychology, 40,* 669–681.

Dovis, S., Van der Oord, S., Wiers, R. W. & Prins, P. J. M. (2013). What part of working memory is not working in ADHD? Short-term memory, the central executive and effects of reinforcement. *Journal of Abnormal Child Psychology, 41*, 901-917.

Dovis, S., Van der Oord, S., Wiers, R. W. & Prins, P. J. M. (2014). ADHD subtype differences in reinforcement sensitivity and visuospatial working memory. *Journal of Clinical Child and Adolescent Psychology*, in press (available online ahead of print).

Douglas, V. (1999). Cognitive control processes in attention-deficit hyperactivity disorder. In Quay, H., Hogan, A., eds. *Handbook of disruptive behavior disorders* New York: Kluwer Academic Publishing/Plenum, pp. 105–138.

Douglas, V. I., & Parry, P. A. (1994). Effects of reward and non-reward on frustration and attention in attention deficit disorder. *Journal of Abnormal Child Psychology, 22,* 281–302.

Durstewitz, D., & Seamans, J. K. (2002). The computational role of dopamine D1 receptors in working memory. *Neural Networks, 15,* 561–572.

Durstewitz, D., & Seamans, J. K. (2008). The dual-state theory of prefrontal cortex dopamine function with relevance to catechol-o-methyltransferase genotypes and schizophrenia. *Biological Psychiatry, 64,* 739–749.

Durston, S., van Belle, J., & de Zeeuw, P. (2011). Differentiating frontostriatal and fronto-cerebellar circuits in attention-deficit/hyperactivity disorder. *Biological Psychiatry*, *69*, 1178–1184.

E

Egberink, I. J. L., Vermeulen, C. S. M., & Frima, R. M. (2014) COTAN review 2002, STROOP. Available: http://www.cotandocumentatie.nl/test_details.php?id=102. Accessed 5 January 2014.

Egeland, J., Aarlien, A. K., & Saunes, B. K. (2013). Few effects of far transfer of working memory training in ADHD: a randomized controlled trial. *PloS One*, *8*(10), e75660.

Eiraldi, R. B., Power, T. J., & Nezu, C. M. (1997). Patterns of comorbidity associated with subtypes of attention-deficit hyperactivity disorder among 6- to 12-yr-old children. *Journal of the American Academy of Child & Adolescent Psychiatry, 36,* 503–514.

Engle, R. W., Tuholski, S. W., Laughlin, J. E., & Conway, A. R. A. (1999). Working memory, short-term memory, and general fluid intelligence: A latent-variable approach. *Journal of Experimental Psychology: General*, *128*, 309–331.

Emes, C. E. (1997). Is Mr Pac Man eating our children? A review of the effect of video games on children. *Canadian Journal of Psychiatry. Revue Canadienne de Psychiatrie*, *42*(4), 409–414.

Van Es, S. (2007). *Treating ADHD with a computer game. Effects of a computerized working memory training on executive functions and ADHD-symptoms in boys*. Unpublished masterthesis, University of Amsterdam.

Evans, S. W., Owens, J. S., & Bunford, N. (2013). Evidence-Based Psychosocial Treatments for Children and Adolescents with Attention-Deficit/Hyperactivity Disorder. *Journal of Clinical Child and Adolescent Psychology : The Official Journal for the Society of Clinical Child and Adolescent Psychology, American Psychological Association, Division 53*, 1–25.

F

Fair, D. A., Bathula, D., Nikolas, M. A., & Nigg, J. T. (2012). Distinct neuropsychological subgroups in typically developing youth inform heterogeneity in children with ADHD. *Proceedings of the National Academy of Sciences of the United States of America*, *109,* 6769–6774.

Felson, R. B., & Zielinski, M. A. (1989). Children's Self-Esteem and Parental Support. *Journal of Marriage and the Family*, *51*(3), 727.

Ferrin, M., & Vance, A. (2014). Differential effects of anxiety and depressive symptoms on working memory components in children and adolescents with ADHD combined type and ADHD inattentive type. *European Child & Adolescent Psychiatry*.

Field, A. (2005). *Discovering Statistics Using SPSS (2nd ed.)* London: SAGE Publications

Frank, M. J., Moustafa, A. A., Haughey, H. M., Curran, T., & Hutchison, K. E. (2007). Genetic triple dissociation reveals multiple roles for dopamine in reinforcement learning. *Proceedings of the National Academy of Sciences of the United States of America*, *104*, 16311–16316.

Furgueson, C., McGuffin, P., Greenstein, D., & Soffer, S. (1998). Efficacy of the WISC-III short form for children diagnosed with ADHD. *Archives of Clinical Neuropsychology, 13(1),* 10-13.

G

Gathercole, S. E. (2014). Commentary: Working memory training and ADHD - where does its potential lie? Reflections on Chacko et al. (2014). *Journal of Child Psychology and Psychiatry, and Allied Disciplines*, *55*(3), 256–257.

Gee, J. P. (2005). Learning by Design: Good Video Games as Learning Machines. *E-Learning*, *2*(1), 5–16.

Gladwin, T. E., Figner, B., Crone, E. A., & Wiers, R. W. (2011). Addiction, adolescence, and the integration of control and motivation. *Developmental Cognitive Neuroscience, 1,* 364-376.

Glascoe, F. P., & Squires, J. (2007). Issues with the new developmental screening and surveillance policy statement. *Pediatrics*, *119*, 861–863.

Gomez, R., Harvey, J., Quick, C., Scharer, I., & Harris, G. (1999). DSM-IV AD/HD: Confirmatory Factor Models, Prevalence, and Gender and Age Differences Based on Parent and Teacher Ratings of Australian Primary School Children. *Journal of Child Psychology and Psychiatry*, *40*(02), 265–274.

Gray, P. O. (2010). *Psychology*. 6th ed. New York: Worth Publishers. 674 p.

Green, C. S., & Bavelier, D. (2003). Action video game modifies visual selective attention. *Nature*, *423*, 534–537.

Green, C. T., Long, D. L., Green, D., Iosif, A.-M., Dixon, J. F., Miller, M. R., … Schweitzer, J. B. (2012). Will working memory training generalize to improve off-task behavior in children with attention-deficit/hyperactivity disorder? *Neurotherapeutics : The Journal of the American Society for Experimental NeuroTherapeutics*, *9*(3), 639–648.

Greenhill, L. L. (1998). Childhood attention deficit hyperactivity disorder: Pharmacological treatments. In P. E. Nathan, & J. Gorman (Eds.), *A guide to treatments that work* (pp. 42-64). New York: Oxford University Press.

Geurts, H., Luman, M., & van Meel, C. (2008). What's in a game: The effect of social motivation on interference control in boys with ADHD and autism spectrum disorders. *Journal of Child Psychology and Psychiatry, 49,* 848–857.

Geurts, H. M., Verté, S., Oosterlaan, J., Roeyers, H., & Sergeant, J. A. (2004). How specific are executive functioning deficits in attention deficit hyperactivity disorder and autism? *Journal of Child Psychology and Psychiatry, and Allied Disciplines*, *45*(4), 836–854.

Geurts, H. M., Verté, S., Oosterlaan, J., Roeyers, H., & Sergeant, J. A. (2005). ADHD subtypes: do they differ in their executive functioning profile? *Archives of Clinical Neuropsychology, 20,* 457–477.

Gioia, G. A., Isquith, P. K., Guy, S. C., & Kenworthy, L. (2000). Behavior Rating Inventory of Executive Function. Odessa, FL: Psychological Assessment Resources.

Gomez, R., Harvey, J., Quick, C., Scharer, I., & Harris, G. (1999). DSM-IV AD/HD: Confirmatory factor models, prevalence, and gender and age differences based on parent and teacher ratings of Australian primary school children. *Journal of Child Psychology and Psychiatry*, *40*, 265–274.

H

Hadwin, J. A., Brogan, J., & Stevenson, J. (2005). State anxiety and working memory in children: A test of processing efficiency theory. *Educational Psychology, 25,* 379–393.

Haenlein, M., & Caul, W. F. (1987). Attention Deficit Disorder with Hyperactivity: A Specific Hypothesis of Reward Dysfunction. *Journal of American Academy of Child and Adolescent Psychiatry 26*(3), 356-362.

Halperin, J. M., Marks, D. J., Bedard, A.-C., Chacko, A., Curchack, J. T., Yoon, C. a, & Healey, D. M. (2013). Training executive, attention, and motor skills: a proof-of-concept study in preschool children With ADHD. *Journal of Attention Disorders*, *17*(8), 711–721.

Hammes, J. G. W. (1978) *De Stroop Kleur-Woord Test* (The Stroop Color-Word Test). Lisse, The Netherlands: Swets and Zeitlinger.

Hinshaw, S. P. (2007). Moderators and mediators of treatment outcome for youth with ADHD: understanding for whom and how interventions work. *Journal of Pediatric Psychology*, *32*(6), 664–675.

Hoekzema, E., Carmona, S., Ramos-Quiroga, J. A., Barba, E., Bielsa, A., Tremols, V., … Vilarroya, O. (2011). Training-induced neuroanatomical plasticity in ADHD: a tensor-based morphometric study. *Human Brain Mapping*, *32*(10), 1741–1749.

Hoekzema, E., Carmona, S., Tremols, V., Gispert, J. D., Guitart, M., Fauquet, J., … Vilarroya, O. (2010). Enhanced neural activity in frontal and cerebellar circuits after cognitive training in children with attention-deficit/hyperactivity disorder. *Human Brain Mapping*, *31*(12), 1942–1950.

Holmes, J., Gathercole, S. E., & Dunning, D. L. (2009). Adaptive training leads to sustained enhancement of poor working memory in children. *Developmental Science*, *12*(4), F9–15.

Holmes, J., Gathercole, S. E., Place, M., Alloway, T. P., Elliott, J. G., & Hilton, K. A. (2010). The Diagnostic Utility of Executive Function Assessments in the Identification of ADHD in Children. *Child and Adolescent Mental Health*, *15*, 37–43.

Huang-Pollock, C. L., Mikami, A. Y., Pfiffner, L., McBurnett, K. (2007). ADHD subtype differences in motivational responsivity but not inhibitory control: evidence from a reward-based variation of the stop signal paradigm. *Journal of Clinical Child and Adolescent Psychology, 36,* 127–136.

I

Iaboni, F., Douglas, V. I., & Baker, A. G. (1995). Effects of reward and response costs on inhibition in AD/HD children. *Journal of Abnormal Child Psychology, 104*, 232–240.

Iaboni, F., Douglas, V. I., & Ditto, B. (1997). Psychophysiological response of AD/HD children to reward and extinction. *Psychophysiology, 34*, 116–123.

J

Jacobson, N. S., & Truax, P. (1991). Clinical significance: A statistical approach to defining meaningful change in psychotherapy research. *Journal of Consulting and Clinical Psychology*, *59*(1), 12–19.

Johnstone, S. J., Roodenrys, S., Blackman, R., Johnston, E., Loveday, K., Mantz, S., & Barratt, M. F. (2012). Neurocognitive training for children with and without AD/HD. *Attention Deficit and Hyperactivity Disorders*, *4*(1), 11–23.

Johnstone, S. J., Roodenrys, S., Phillips, E., Watt, A. J., & Mantz, S. (2010). A pilot study of combined working memory and inhibition training for children with AD/HD. *Attention Deficit and Hyperactivity Disorders*, *2*(1), 31–42.

K

Karatekin, C. (2004). A test of the integrity of the components of Baddeley's model of working memory in attention-deficit/hyperactivity disorder (ADHD). *Journal of child psychology and psychiatry, and allied disciplines*, *45*, 912–926.

Kasper, L. J., Alderson, R. M., & Hudec, K. L. (2012). Moderators of working memory deficits in children with attention-deficit/hyperactivity disorder (ADHD): a meta-analytic review. *Clinical Psychology Review*, *32*(7), 605–617.

Kessels, R. P. C., van den Berg, E., Ruis, C., & Brands, A. M. A. (2008). The backward span of the Corsi Block-Tapping Task and its association with the WAIS-III Digit Span. *Assessment*, *15*(4), 426–434.

Kessels, R. P. C., van Zandvoort, M. J., Postma, A., Kappelle, L. J., & de Haan, E. H. (2000). The Corsi Block-Tapping Task: standardization and normative data. *Applied Neuropsychology*, *7*(4), 252–258.

Kittler, J. E., Menard, W., & Phillips, K. A. (2007). Weight concerns in individuals with body dysmorphic disorder. *Eating behaviors*, *8*, 115–120.

Klingberg, T. (2010). Training and plasticity of working memory. *Trends in Cognitive Sciences*, *14*(7), 317–324.

Klingberg, T., Fernell, E., Olesen, P. J., Johnson, M., Gustafsson, P., Dahlström, … Westerberg, H. (2005). Computerized training of working memory in children with ADHD: A randomized, controlled trial. *Journal of the American Academy of Child and Adolescent Psychiatry, 44*, 177-186.

Klingberg, T., Forssberg, H., & Westerberg, H. (2002). Training of working memory in children with ADHD. *Journal of Clinical and Experimental Neuropsychology, 24*(6), 781–791.

Koepp, M. J., Gunn, R. N., Lawrence, a D., Cunningham, V. J., Dagher, a, Jones, T., … Grasby, P. M. (1998). Evidence for striatal dopamine release during a video game. *Nature*, *393*(6682), 266–268.

Kofler, M. J., Rapport, M. D., Bolden, J., Sarver, D. E., & Raiker, J. S. (2010). ADHD and working memory: The impact of central executive deficits and exceeding storage/rehearsal capacity on observed inattentive behavior. *Journal of Abnormal Child Psychology, 38,* 149–161.

Kohls, G., Herpertz-Dahlmann, B., & Konrad, K. (2009). Hyperresponsiveness to social rewards in children and adolescents with attention-deficit/hyperactivity disorder (ADHD). *Behavioral and Brain Functions, 5,* 20.

Konrad, K., Gauggel, S., Manz, A., & Scholl, M. (2000). Lack of inhibition: A motivational deficit in children with attention deficit/hyperactivity disorder and children with traumatic brain injury. *Child Neuropsychology, 6,* 286–296.

Kort, W., Compaan, E. L., Bleichrodt, N., Resing, W. C. M., Schittekatte, M., Bosmans, M., Vermeir, G., & Verhaeghe, P. (2002). *WISC-III NL Handleiding*. (Dutch Manual). Amsterdam: NIP.

Kray, J., Karbach, J., Haenig, S., & Freitag, C. (2012). Can task-switching training enhance executive control functioning in children with attention deficit/-hyperactivity disorder? *Frontiers in Human Neuroscience*, *5*, 180.

Kühn, S., Romanowski, A., Schilling, C., Lorenz, R., Mörsen, C., Seiferth, N., … Gallinat, J. (2011). The neural basis of video gaming. *Translational Psychiatry*, *1*, e53.

L

Lambek, R., Tannock, R., Dalsgaard, S., Trillingsgaard, A., Damm, D., & Thomsen, P. H. (2010). Validating neuropsychological subtypes of ADHD: how do children with and without an executive function deficit differ? *Journal of Child Psychology and Psychiatry*, *51*, 895–904.

Lambek, R., Tannock, R., Dalsgaard, S., Trillingsgaard, A., Damm, D., & Thomsen, P. H. (2011). Executive dysfunction in school-age children with ADHD. *Journal of Attention Disorders*, *15*, 646–655.

Lawrence, V., Houghton, S., Tannock, R., Douglas, G., Durkin, K., & Whiting, K. (2002): ADHD outside the laboratory: Boys' executive function performance on tasks in videogame play and on a visit to the zoo. *Journal of Abnormal Child Psychology, 30*, 447-462.

Logan, G. D., Schachar, R. J., & Tannock, R. (1997). Impulsivity and Inhibitory Control. *Psychological Science*, *8*(1), 60–64.

Loo, S. K., Hale, T. S., Macion, J., Hanada, G., McGough, J. J., McCracken, J. T., & Smalley, S. L. (2009). Cortical activity patterns in ADHD during arousal, activation and sustained attention. *Neuropsychologia*, *47,* 2114–2119.

Loo, S. K., Humphrey, L. A., Tapio, T., Moilanen, I. K., McGough, J. J., McCracken, J. T., … Smalley, S. L. (2007). Executive functioning among Finnish adolescents with attention-deficit/hyperactivity disorder. *Journal of the American Academy of Child and Adolescent Psychiatry*, *46*, 1594–1604.

Luman, M., Oosterlaan, J., & Sergeant, J. A. (2005). The impact of reinforcement contingencies on ADHD: A review and theoretical appraisal. *Clinical Psychology Review*, *25*, 183-213.

Luman, M., Oosterlaan, J., & Sergeant, J. A. (2008). Modulation of response timing in ADHD, effects of reinforcement valence and magnitude. *Journal of Abnormal Child Psychology*, *36*, 445-456.

Luman, M., Tripp, G., & Scheres, A. (2010). Identifying the neurobiology of altered reinforcement sensitivity in ADHD: A review and research agenda. *Neuroscience and Biobehavioral Reviews*, *34,* 744–54.

Luman, M., van Meel, C. S., Oosterlaan, J., & Geurts, H. M. (2012). Reward and punishment sensitivity in children with ADHD: validating the Sensitivity to Punishment and Sensitivity to Reward Questionnaire for children (SPSRQ-C). *Journal of Abnormal Child Psychology*, *40*(1), 145–157.

Luman, M., Van Meel, C. S., Oosterlaan, J., Sergeant, J. A., & Geurts, H. M. (2009). Does reward frequency or magnitude drive reinforcement-learning in attention-deficit/hyperactivity disorder? *Psychiatry Research*, *168*, 222–229.

M

Martinussen, R., Hayden, J., Hogg-Johnson, S., & Tannock, R. (2005). A meta-analysis of working memory impairments in children with attention-deficit/hyperactivity disorder. *Journal of the American Academy of Child and Adolescent Psychiatry, 44,* 377-384.

Marusiak, C. W., & Janzen, H. L. (2005). Assessing the working memory abilities of ADHD children using the Stanford-Binet Intelligence Scales, fifth edition. *Canadian Journal of School Psychology, 20,* 84–97.

Mayes, S. D., Calhoun, S. L., Chase, G. A., Mink, D. M., & Stagg, R. E. (2009). ADHD subtypes and co-occurring anxiety, depression, and oppositional-defiant disorder: Differences in Gordon diagnostic system and Wechsler working memory and processing speed index scores. *Journal of Attention Disorders, 12,* 540–550.

McInerny, R. J., & Kerns, K. A. (2003). Time reproduction in children with ADHD: Motivation matters. *Child Neuropsychology, 9,* 91–108.

McNab, F., Leroux, G., Strand, F., Thorell, L., Bergman, S., & Klingberg, T. (2008). Common and unique components of inhibition and working memory: an fMRI, within-subjects investigation. *Neuropsychologia*, *46*, 2668–2682.

Van der Meere, J., Hughes, K. A., Börger, N., & Sallee, F. R. (1995). The effect of reward on sustained attention in AD/HD children with and without CD. In J. A. Sergeant (Ed.), *European approach to hyperkinetic disorder* (pp. 241–253). Zurich, Switzerland: Fotorotar.

Michel, J. A., Kerns, K. A., & Mateer, C. A. (2005). The effect of reinforcement variables on inhibition in children with ADHD. *Child Neuropsychology, 11*, 295-302.

Milich, R., Balentine, A. C., & Lynam, D. R. (2001). ADHD combined type and ADHD predominantly inattentive type are distinct and unrelated disorders. *Clinical Psychology: Science and Practice, 8,* 463–488.

N

Nakamura, K., & Hikosaka, O. (2006). Role of dopamine in the primate caudate nucleus in reward modulation of saccades. *The Journal of Neuroscience: the official journal of the Society for Neuroscience, 26,* 5360–5369.

Neuman, R. J., Sitdhiraksa, N., Reich, W., Ji, T. H.-C., Joyner, C. a, Sun, L.-W., & Todd, R. D. (2005). Estimation of prevalence of DSM-IV and latent class-defined ADHD subtypes in a population-based sample of child and adolescent twins. *Twin Research and Human Genetics : The Official Journal of the International Society for Twin Studies*, *8*(4), 392–401.

Nigg, J. T. (2006). *What causes ADHD? Understanding what goes wrong and why*. New York: Guilford Press.

Nigg, J. T., Willcutt, E. G., Doyle, A. E., & Sonuga-Barke, E. J. S. (2005). Causal heterogeneity in Attention-Deficit/Hyperactivity Disorder: Do we need neuropsychologically impaired subtypes? *Biological Psychiatry, 57*, 1224-1230.

O

Oosterlaan, J., Scheres, A., Antrop, I., Roeyers, H., & Sergeant, J. A. (2000). *Vragenlijst voor Gedragsproblemen bij Kinderen (VvGK)* (Dutch translation of the DBD Rating Scale). Lisse, The Netherlands: Swets & Zeitlinger.

Oosterlaan, J., & Sergeant, J. A. (1998). Effects of reward and response cost on response inhibition in AD/HD, disruptive, anxious, and normal children. *Journal of Abnormal Child Psychology*, *26,* 161–174.

Van der Oord, S., Ponsioen, A.J.G.B., Geurts, H.M., Ten Brink, E.L., & Prins, P.J.M. (2012). A pilot study of the efficacy of a computerized executive functioning remediation training with game elements for children with ADHD in an outpatient setting: Outcome on parent- and teacher-rated executive functioning and ADHD behavior. *Journal of Attention Disorders.*

Ota, K., & DuPaul, G. (2002). Task engagement and mathematics performance in children with ADHD: Effects of supplemental computer instruction. *School Psychology Quarterly, 17*, 242–257.

P

Pasini, A., Paloscia, C., Alessandrelli, R., Porfirio, M. C., & Curatolo, P. (2007). Attention and executive functions profile in drug naive ADHD subtypes. *Brain Development*, *29,* 400–408.

Pelham, W. E., & Fabiano, G. A. (2008). Evidence-based psychosocial treatment for ADHD: An update. *Journal of Clinical Child and Adolescent Psychology, 37,* 184-214.

Pelham, W. E., Gnagy, E. M., Greenslade, K. E., & Milich, R. (1992). Teacher rating of DSM-III-R symptoms for disruptive behavior disorders. *Journal of Clinical Child Psychology, 8,* 259–262.

Pessoa, L. (2009). How do emotion and motivation direct executive control? *Trends in Cognitive Sciences*, *13*(4), 160–6.

Pfiffner, L., Barkley, R., & DuPaul, G. (2006). *Treatment of ADHD in school settings*. In Barkley, R. A., Eds. *Handbook of attention deficit hyperactivity disorder*, 3rd ed. New York: Guilford Press.

Pineda, D. A., Puerta, I. C., Aguirre, D. C., García-Barrera, M. A., & Kamphaus, R. W. (2007). The role of neuropsychologic tests in the diagnosis of ADHD. *Pediatric Neurology*, *36*, 373–381.

Pleysier, S., Wydooghe, B. (2007). *Game-over? Over game- en filmgeweld, angst en onzekerheid* (Game-over? On game- and film violence, anxiety and uncertainty). Antwerp, Belgium: Garant.

Pribram, K. H., & McGuinness, D. (1975). Arousal, activation, and effort in the control of attention. *Psychological Review*, *82*, 116–149.

Prins, P. J. M., Ten Brink, E., Dovis, S., Ponsioen, A., Geurts, H. M., de Vries, M., & Van der Oord, S. (2013). “Braingame Brian”: Toward an Executive Function Training Program with Game Elements for Children with ADHD and Cognitive Control Problems. *Games for Health Journal*, *2*(1), 44–49.

Prins, P. J. M., Dovis, S., Ponsioen, A. J. G. B., Ten Brink, E., & Van der Oord, S. (2011). Does computerized working memory training with game elements enhance motivation and training efficacy in children with ADHD? *Cyberpsychology, Behavior, and Social Networking*, *14(3)*, 115-122.

R

Raiker, J. S., Rapport, M. D., Kofler, M. J., & Sarver, D. E. (2012). Objectively-measured impulsivity and attention-deficit/hyperactivity disorder (ADHD): Testing competing predictions from the working memory and behavioral inhibition models of ADHD. *Journal of Abnormal Child Psychology*, *40*, 699–713.

Rapport, M. D., Alderson, R. M., Kofler, M. J., Sarver, D. E., Bolden, J., & Sims, V. (2008). Working memory deficits in boys with attention-deficit/hyperactivity disorder (ADHD): The contribution of central executive and subsystem processes. *Journal of Abnormal Child Psychology*, *36*, 825–837.

Rapport, M. D., Bolden, J., Kofler, M. J., Sarver, D. E., Raiker, J. S., & Alderson, R. M. (2009). Hyperactivity in boys with attention-deficit/hyperactivity disorder (ADHD): A

ubiquitous core symptom or manifestation of working memory deficits? *Journal of Abnormal Child Psychology, 37,* 521–534.

Rapport, M. D., Chung, K. M., Shore, G., & Isaacs, P. (2001). A conceptual model of child psychopathology: Implications for understanding attention-deficit/hyperactivity disorder (ADHD) and treatment efficacy. *Journal of Clinical Child Psychology –Special Edition,* 30, 48–58.

Rapport, M. D., Orban, S. a, Kofler, M. J., & Friedman, L. M. (2013). Do programs designed to train working memory, other executive functions, and attention benefit children with ADHD? A meta-analytic review of cognitive, academic, and behavioral outcomes. *Clinical Psychology Review*.

Rapport, M. D., Tucker, S. B., DuPaul, G. J., Merlo, M., & Stoner, G. (1986). Hyperactivity and frustration: The influence of control over and size of reward in delay gratification. J*ournal of Abnormal Child Psychology, 14,* 191–204.

Raven, J. C., Court, J. H., Raven, J. (1995). *Coloured Progressive Matrices*. Oxford, UK: Oxford Psychologists Press.

Reynolds, J. N., Hyland, B. I., & Wickens, J. R. (2001). A cellular mechanism of reward-related learning. *Nature, 413*(6851), 67–70.

Rhodes, S. M., Park, J., Seth, S., & Coghill, D. R. (2012). A comprehensive investigation of memory impairment in attention deficit hyperactivity disorder and oppositional defiant disorder. *Journal of child psychology and psychiatry, and allied disciplines*, *53,* 128–137.

Rhodes, S. M., Coghill, D. R., & Matthews, K. (2004). Methylphenidate restores visual memory, but not working memory function in attention deficit-hyperkinetic disorder. *Psychopharmacology, 175,* 319–330.

Rose, E. J., & Ebmeier, K. P. (2006). Pattern of impaired working memory during major depression. *Journal of Affective Disorders*, *90,* 149–161.

Rubia, K., Smith, A. B., Halari, R., Matsukura, F., Mohammad, M., Taylor, E., & Brammer, M. J. (2009). Disorder-specific dissociation of orbitofrontal dysfunction in boys with pure conduct disorder during reward and ventrolateral prefrontal dysfunction in boys with pure ADHD during sustained attention. *The American Journal of Psychiatry, 166,* 83–94.

Rubia, K., Smith, A. B., Brammer, M. J., & Taylor, E. (2003). Right inferior prefrontal cortex mediates response inhibition while mesial prefrontal cortex is responsible for error detection. *NeuroImage*, *20*(1), 351–358.

Rutledge, K. J., van den Bos, W., McClure, S. M., & Schweitzer, J. B. (2012). Training cognition in ADHD: current findings, borrowed concepts, and future directions. *Neurotherapeutics : The Journal of the American Society for Experimental NeuroTherapeutics*, *9*(3), 542–558.

S

Sagvolden, T., Johansen, E. B., Aase, H., & Russell, V. A. (2005). A dynamic developmental theory of attention-deficit/hyperactivity disorder (ADHD) predominantly hyperactive/impulsive and combined subtypes. *The Behavioral and Brain Sciences*, *28,* 397–419.

Sagvolden, T., & Sergeant, J. A. (1998). ADHD – from brain functions to behavior. *Behavioural Brain Research*, *94,* 1-10.

Sarkis, S. M., Sarkis, E. H., Marshall, D., & Archer, J. (2005). Self-regulation and inhibition in comorbid ADHD children: An evaluation of executive functions. *Journal of Attention Disorders, 8,* 96–108.

Sattler, J. M. (2001). *Assessment of children: Cognitive applications* (4th edn.). San Diego, CA: Author.

Schachar, R. J., Tannock, R., & Logan, G. (1993). Inhibitory control, impulsiveness, and attention deficit hyperactivity disorder. *Clinical Psychology Review*, *13*(8), 721–739.

Schatz, D. B., & Rostain, A. L. (2006). ADHD with comorbid anxiety: A review of the current literature. *Journal of Attention Disorders*, *10,* 141–149.

Schecklmann, M., Ehlis, A.-C., Plichta, M. M., Dresler, T., Heine, M., Boreatti-Hümmer, A., … Fallgatter, A. J. (2013). Working memory and response inhibition as one integral phenotype of adult ADHD? A behavioral and imaging correlational investigation. *Journal of Attention Disorders*, *17*(6), 470–82.

Schellig, D. (1997). *Block-Tapping-Test*. Lisse: The Netherlands: Swets and Zeitlinger.

Scheres, A., Lee, A., Sumiya, M. (2008). Temporal reward discounting and ADHD: Task and symptom specific effects. *Journal of Neural Transmission*, *115,* 221–226.

Scheres, A., Milham, M. P., Knutson, B., Castellanos, F. X. (2007). Ventral striatal hyporesponsiveness during reward anticipation in attention-deficit/hyperactivity disorder. *Biological Psychiatry, 61,* 720–724.

Scheres, A., Oosterlaan, J., & Sergeant, J. A. (2001). Response inhibition in children with DSM-IV subtypes of AD/HD and related disruptive disorders: The role of reward. *Child Neuropsychology*, *7,* 172–189.

Scheres, A., Tontsch, C., Thoeny, A. L., & Kaczkurkin, A. (2010). Temporal reward discounting in attention-deficit/hyperactivity disorder: the contribution of symptom domains, reward magnitude, and session length. *Biological psychiatry, 67,* 641–648.

Sergeant, J. A., Oosterlaan, J., & Van der Meere, J. (1999). Information Processing and Energetic Factors in Attention-Deficit/Hyperactivity Disorder. In H. C. Quay & A. E. Hogan (Eds.), *Handbook of disruptive behavior disorders* (pp. 75-104). New York: Kluwer Academic/ Plenum Publishers.

Shaffer, D., Fisher, P., Lucas, C. P., Dulcan, M. K. & Schwab-Stone, M. E. (2000). NIMH Diagnostic Interview Schedule for Children version IV (NIMH DISC-IV): Description, differences from previous versions, and reliability of some common diagnoses. *Journal of the American Academy of Child and Adolescent Psychiatry, 39*, 28-38.

Shanahan, M., Pennington, B., & Wilcutt, E. (2008). Do motivational incentives reduce the inhibition deficit in ADHD? *Developmental Neuropsychology, 33*, 137-159.

Shaw, R., Grayson, A., & Lewis, V. (2005). Inhibition, ADHD, and computergames: the inhibitory performance of children with ADHD on computerized tasks and games. *Journal of Attention Disorders, 8(4),* 160-168.

Shaw, R., & Lewis, V. (2005). The impact of computer-mediated and traditional academic task presentation on the performance and behaviour of children with ADHD. *Journal of Research in Special Educational Needs*, *5*(2), 47–54.

Shaw-Zirt, B., Popali-Lehane, L., Chaplin, W., & Bergman, A. (2005). Adjustment, social skills, and self-esteem in college students with symptoms of ADHD. *Journal of Attention Disorders*, *8*(3), 109–120.

Shiels, K., Hawk Jr., L. W., Lysczek, C. L., Tannock, R., Pelham Jr., W. E., Spencer, S. V., … Waschbusch, D. A. (2008). The effects of incentives on visual-spatial working memory in children with Attention-deficit/Hyperactivity Disorder. *Journal of Abnormal Child Psychology, 36*, 903-913.

Shipstead, Z., Hicks, K. L., & Engle, R. W. (2012). Cogmed working memory training: Does the evidence support the claims? *Journal of Applied Research in Memory and Cognition*, *1*(3), 185–193.

Shipstead, Z., Redick, T. S., & Engle, R. W. (2012). Is working memory training effective? *Psychological Bulletin*, *138*, 628–654.

Sjöwall, D., Roth, L., Lindqvist, S., & Thorell, L. B. (2013). Multiple deficits in ADHD: executive dysfunction, delay aversion, reaction time variability, and emotional deficits. *Journal of Child Psychology and Psychiatry*, *54*, 619–627.

Skounti, M., Philalithis, A., & Galanakis, E. (2007). Variations in prevalence of attention deficit hyperactivity disorder worldwide. *European Journal of Pediatrics, 166*(2), 117–123.

Solanto, M. V. (1990). The effects of reinforcement and response cost on a delayed response task in children with attention deficit hyperactivity disorder: A research note. *Journal of Child Psychology and Psychiatry, 31,* 803–808.

Solanto, M. V., Abikoff, H., Sonuga-Barke, E. J., Schachar, R., Logan, G. D., Wigal, T. L., … Turkel, E. (2001). The Ecological Validity of Delay Aversion and Response Inhibition as Measures of Impulsivity in AD/HD. *Journal of Abnormal Child Psychology*, *29*, 215–228.

Solanto, M. V., Wender, E. H., & Bartell, S. S. (1997). Effects of methylphenidate and behavioral contingencies on sustained attention in Attention-Deficit Hyperactivity Disorder: A test of the reward dysfunction hypothesis. *Journal of Child and Adolescent Psychopharmacology, 7*(2), 123–136.

Sonuga-Barke, E. J. S. (2002). Psychological heterogeneity in AD/HD – a dual pathway model of behaviour and cognition. *Behavioral and Brain Research*, *130*, 29-36.

Sonuga-Barke, E. J. S. (2003). The dual pathway model of AD/HD: An elaboration of neuro-developmental characteristics. *Neuroscience & Biobehavioral Reviews, 27,* 593–604.

Sonuga-Barke, E. J. S. (2011). Editorial: ADHD as a reinforcement disorder - moving from general effects to identifying (six) specific models to test. *Journal of child psychology and psychiatry, and allied disciplines*, *52*, 917–918.

Sonuga-Barke, E. J. S., Bitsakou, P., & Thompson, M. (2010). Beyond the dual pathway model: Evidence for the dissociation of timing, inhibitory control, and delay-related impairments in attention-deficit/hyperactivity disorder. *Journal of the American Academy of Child and Adolescent Psychiatry, 49,* 345–355.

Sonuga-Barke, E. J. S., Dalen, L., & Remington, B. (2003). Do executive deficits and delay aversion make independent contributions to preschool attention-deficit/hyperactivity disorder symptoms? *Journal of the American Academy of Child and Adolescent Psychiatry*, *42*(11), 1335–1342.

Sonuga-Barke, E. J. S., Sergeant, J. A, Nigg, J. T, Willcutt, E. G. (2008). Executive dysfunction and delay aversion in ADHD: nosological and diagnostic implications. *Child and Adolescent Psychiatric Clinics of North America*, *17,* 367-384.

Soreni, N., Crosbie, J., Ickowicz, A., & Schachar, R. J. (2009). Stop signal and Conners' continuous performance tasks: test--retest reliability of two inhibition measures in ADHD children. *Journal of Attention Disorders*, *13*(2), 137–143.

Slusarek, M., Velling, S., Bunk, D., & Eggers, C. (2001). Motivational effects of inhibitory control in children with ADHD. *Journal of the American Academic of Child and Adolescent Psychiatry, 40*(3), 355-363.

Smidts, D. P., Huizinga, M. (2009). *BRIEF executieve functies gedragsvragenlijst: Handleiding* (BRIEF Dutch manual). Amsterdam, The Netherlands: Hogrefe Uitgevers.

Smith, A. B., Taylor, E., Brammer, M., Toone, B., & Rubia, K. (2006). Task-specific hypoactivation in prefrontal and temporoparietal brain regions during motor inhibition and task switching in medication-naive children and adolescents with attention deficit hyperactivity disorder. *The American Journal of Psychiatry*, *163*(6), 1044–1051.

Steinberg, L., Albert, D., Cauffman, E., Banich, M., Graham, S., & Woolard, J. (2008). Age differences in sensation seeking and impulsivity as indexed by behavior and self-report: evidence for a dual systems model. *Developmental Psychology, 44,*1764–1778.

Strand, M. T., Hawk, L. W., Bubnik, M., Shiels, K., Pelham, W. E., & Waxmonsky, J. G. (2012). Improving working memory in children with attention-deficit/hyperactivity disorder: The separate and combined effects of incentives and stimulant medication. *Journal of Abnormal Child Psychology, 40,* 1193-1207.

Ströhle, A., Stoy, M., Wrase, J., Schwarzer, S., Schlagenhauf, F., Huss, … Heinz, A. (2008). Reward anticipation and outcomes in adult males with attention-deficit/hyperactivity disorder. *Neuroimage, 39,* 966–972.

Swanson, H. L. (2008). WM and intelligence in children: What develops? *Journal of Educational Psychology*, *100*, 581–602.

T

Tabachnick, B. G., Fiddell, L. S. (2001). *Using multivariate statistics*. 4th ed. Boston: Allyn & Bacon.

Tannock, R. (1997). Television, videogames, and ADHD: Challenging a popular belief. *The ADHD Report, 5*, 3–7.

Thompson, T. W., Waskom, M. L., Garel, K.-L. A., Cardenas-Iniguez, C., Reynolds, G. O., Winter, R., … Gabrieli, J. D. E. (2013). Failure of working memory training to enhance cognition or intelligence. *PloS One, 8*(5), e63614.

Tillman, C., Eninger, L., Forssman, L., & Bohlin, G. (2011). The relation between working memory components and ADHD symptoms from a developmental perspective. *Developmental Neuropsychology, 36,* 181–198.

Titz, C., & Karbach, J. (2014). Working memory and executive functions: effects of training on academic achievement. *Psychological Research*, in press.

Toplak, M. E., Connors, L., Shuster, J., Knezevic, B., & Parks, S. (2008). Review of cognitive, cognitive-behavioral, and neural-based interventions for Attention-Deficit/Hyperactivity Disorder (ADHD). *Clinical Psychology Review*, *28*(5), 801–23.

Tripp, G., & Alsop, B. (1999). Sensitivity to reward frequency in boys with attention deficit hyperactivity disorder. *Journal of Clinical Child Psychology, 28,* 366–375.

Tripp, G., & Alsop, B. (2001). Sensitivity to reward delay in children with attention deficit hyperactivity disorder (AD/HD). *Journal of Child Psychology and Psychiatry, 42,* 691–698.

Tripp, G., & Wickens, J. R. (2008). Research review: dopamine transfer deficit: A neurobiological theory of altered reinforcement mechanisms in ADHD. *Journal of Child Psychology and Psychiatry, and Allied Disciplines*, *49*, 691–704.

V

Vance, A., Ferrin, M., Winther, J., & Gomez, R. (2013). Examination of spatial working memory performance in children and adolescents with attention deficit hyperactivity disorder, combined type (ADHD-CT) and anxiety. *Journal of Abnormal Child Psychology*, *41*(6), 891–900.

Varni, J. W., Seid, M., & Kurtin, P. S. (2001). PedsQL^{TM} 4.0: Reliability and Validity of the Pediatric Quality of Life Inventory^{TM} Version 4.0 Generic Core Scales in Healthy and Patient Populations. *Medical Care, 39*(8), 800–812.

W

Wåhlstedt, C., Thorell, L. B., & Bohlin, G. (2009). Heterogeneity in ADHD: neuropsychological pathways, comorbidity and symptom domains. *Journal of Abnormal Child Psychology*, *37*, 551–564.

Walsh, N. D., Williams, S. C. R., Brammer, M. J., Bullmore, E. T., Kim, J., Suckling, J., . . . Fu, C. H. Y. (2007). A longitudinal functional magnetic resonance imaging study of verbal working memory in depression after antidepressant therapy. *Biological Psychiatry, 62,* 1236–1243.

Wechsler, D. (1958). *The Measurement and Appraisal of Adult Intelligence* (4th edn.) Baltimore (MD): Williams & Witkins.

Wechsler D. (1991) *Wechsler Intelligence Scale for children. 3rd Edition (WISC-III).* San Antonio (TX): Psychological Corporation.

Wechsler, D. (1997). *Wechsler Adult Intelligence Scale—3rd Edition (WAIS-III)*. San Antonio (TX): Harcourt Assessment.

White, H. a, & Shah, P. (2006). Training attention-switching ability in adults with ADHD. *Journal of Attention Disorders*, *10*(1), 44–53.

Willcutt, E. G., Doyle, A. E., Nigg, J. T., Faraone, S. V., & Pennington, B. F. (2005). Validity of the executive function theory of attention-deficit/hyperactivity disorder: A meta-analytic review. *Biological Psychiatry, 57,* 1336–1346.

Willcutt, E. G., Nigg, J. T., Pennington, B. F., Solanto, M. V., Rohde, L. A., Tannock, R., … Lahey, B. B. (2012). Validity of DSM–IV attention deficit/hyperactivity disorder symptom dimensions and subtypes. *Journal of Abnormal Psychology, 121,* 991-1010.

Willcutt, E. G., Pennington, B. F., Chhabildas, N. A., Friedman, M. C., & Alexander, J. (1999). Psychiatric comorbidity associated with DSM-IV ADHD in a nonreferred sample of twins. *Journal of the American Academy of Child and Adolescent Psychiatry, 38,* 1355–1362.

Wise, E. A. (2004). Methods for analyzing psychotherapy outcomes: a review of clinical significance, reliable change, and recommendations for future directions. *Journal of Personality Assessment*, *82*(1), 50–9.

Wolraich, M. L., Hannah, J. N., Baumgaertel, A., & Feurer, I. D. (1998). Examination of DSM-IV criteria for attention deficit/hyperactivity disorder in a county-wide sample. *Journal of Developmental & Behavioral Pediatrics*, *19*,162–168.

Wong, C. G., & Stevens, M. C. (2012). The effects of stimulant medication on working memory functional connectivity in attention-deficit/hyperactivity disorder. *Biological Psychiatry*, *71*(5), 458–466.

Z

De Zeeuw, P., Weusten, J., van Dijk, S., van Belle, J., & Durston, S. (2012). Deficits in cognitive control, timing and reward sensitivity appear to be dissociable in ADHD. *PloS One*, *7*, e51416.

Curriculum Vitae

Sebastiaan Dovis was born on February 22, 1982 in Zaandam. After receiving a propaedeutic diploma in Social work, he started studying Psychology at the University of Amsterdam in 2001. In 2008 he received his M.Sc. degree in Clinical Psychology (cum laude) and started working in the lab of prof. dr. Pier Prins. From 2009 to 2014 he carried out his PhD research at the Clinical Psychology department and the Developmental Psychology department of the University of Amsterdam, with prof. dr. Pier Prins, prof. dr. Saskia van der Oord, and prof. dr. Reinout Wiers as his advisors. Currently Sebastiaan works as a postdoctoral researcher and lecturer at the department of Developmental Psychology of the University of Amsterdam. He also teaches the course ‘Psychology of effective games’ at the department of Information studies of the University of Amsterdam.

List of Publications

Dovis, S., Van der Oord, S., Huizenga, H.M., Wiers, R.W. & Prins, P.J.M. (2014). Prevalence and diagnostic validity of motivational impairments and deficits in visuospatial short-term memory and working memory in ADHD subtypes. *European Child & Adolescent Psychiatry*, in press (available online ahead of print).

Dovis, S., Van der Oord, S., Wiers, R.W. & Prins, P.J.M. (2014). ADHD subtype differences in reinforcement sensitivity and visuospatial working memory. *Journal of Clinical Child & Adolescent Psychology,* in press (available online ahead of print).

Prins, P.J.M., Brink, E. Ten, **Dovis, S.**, Ponsioen, A.J.G.B., Geurts, H.M., Vries, M. de, & Van der Oord, S. (2013). "Braingame Brian": Toward an Executive Function Training Program with Game Elements for Children with ADHD and Cognitive Control Problems. *Games for Health Journal, 2* (1), 44-49.

Ten Brink, E., **Dovis, S.**, Ponsioen, A.J.G.B., Geurts, H.M., Van der Oord, S., Vries, M. de, & Prins, P.J.M. (2013). Braingame Brian: Een executieve functietraining met game-elementen voor kinderen met ADHD. In C. Braet & S.M. Bögels (Eds.), *Protocollaire behandelingen voor kinderen en adolescenten met psychische klachten 2* (pp. 85-113). Amsterdam: Uitgeverij Boom.

Dovis, S., Van der Oord, S., Wiers, R.W. & Prins, P.J.M. (2013). What part of working memory is not working in ADHD? Short-term memory, the central executive and effects of reinforcement. *Journal of Abnormal Child Psychology, 41* (6), 901-917.

Dovis, S., Van der Oord, S., Wiers, R.W., & Prins, P.J.M. (2012). Can motivation normalize working memory and task persistence in children with Attention Deficit/Hyperactivity Disorder? The effects of money and computer gaming. *Journal of Abnormal Child Psychology, 40* (5), 669-681.

Verbeken, S., Braet, C., **Dovis, S.**, Ponsioen, A.J.G.B., Prins, P.J.M., Ten Brink, E., & Van der Oord, S. (2011). Training van werkgeheugen en inhibitie bij kinderen en adolescenten met obesitas. *Psychopraktijk*, *3* (5), 20-22.

Prins, P.J.M., **Dovis, S.**, Ponsioen, A., ten Brink, E., & Van der Oord, S. (2011). Does computerized working memory training with game elements enhance motivation and training efficacy in children with ADHD? *Cyberpsychology*, *Behavior and Social Networking*, *14*(3), 115–22.

Prins, P.J.M., **Dovis, S.**, Ponsioen, A.J.G.B., & Ten Brink, E. (2007). Nieuwe generaties, nieuwe media: ADHD behandelen met een computergame. *Kind & Adolescent Praktijk*, *6* (4), 148-155.

Submitted

Dovis, S., Van der Oord, S., Wiers, R.W. & Prins, P.J.M. (accepted pending minor revisions). Improving Executive Functioning in Children with ADHD: Training Multiple Executive Functions within the Context of a Computer Game. A randomized double-blind placebo controlled trial. *PloS One.*

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