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Cognitive Control and Motivation in Children with ADHD: How Reinforcement Interacts with the Assessment and Training of Executive Functioning

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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.

[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.