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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

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Abstract

Objective: This pilot study tested the short- and long-term efficacy (9 weeks follow-up) of an executive functioning (EF) remediation training with game elements for children with ADHD in an outpatient clinical setting, using a randomized controlled wait-list design. Furthermore, in a subsample, that is, those treated with methylphenidate, additive effects of the EF training were assessed. **Method:** A total of 40 children (aged 8-12 years) were randomized to the EF training or wait-list. The training consisted of a 25-session training of inhibition, cognitive flexibility, and working memory. Treatment outcome was assessed by parent- and teacher-rated EF, ADHD, oppositional deviant disorder, and conduct disorder symptoms. **Results:** Children in the EF training showed significantly more improvement than those in the wait-list condition on parent-rated EF and ADHD behavior in the total sample and in the subsample treated with methylphenidate. Effects were maintained at follow-up. **Conclusion:** This pilot study shows promising evidence for the efficacy of an EF training with game elements. *(J. of Att. Dis. 2014; 18(8) 699-712)*

Keywords

ADHD, child, executive functioning, cognitive, training

ADHD is one of the most common disorders among school-aged children with a prevalence of 3% to 7% in the general population (*Diagnostic and Statistical Manual of Mental Disorders* [4th ed., text rev.; *DSM-IV-TR*]; American Psychiatric Association [APA], 2000). Currently, there are several theoretical approaches explaining ADHD.

First, ADHD has been characterized as an executive functioning (EF) disorder (e.g., Barkley, 1997). Executive functions are cognitive control functions, enabling rule-governed behavior. Compared with normal control children, children with ADHD are most deficient on tasks measuring the executive functions working memory (WM), behavioral inhibition, and cognitive flexibility (e.g., Cepeda, Cepeda, & Kramer, 2000; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005; Wu, Anderson, & Castiello, 2006). WM is the ability to retain information online during a delay and then making a response based on that internal representation (Baddeley, 1992, 2000). Visual spatial WM is considered the most important neuropsychological deficit in children with ADHD (Nigg, 2006). Inhibition is defined as inhibition of an overlearned, competing, or disrupting response (Barkley, 1997). Prepotent inhibition (inhibition of an ongoing response) is most disturbed in ADHD (Sergeant, Geurts, &

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Oosterlaan, 2002). Cognitive flexibility is the ability to shift to different thoughts or actions depending on situational demands (Monsell, 2003).

Others, however, typify children with ADHD as primarily having an abnormal sensitivity to reinforcement (Sagvolden, Aase, Zeiner, & Berger, 1998), because children with ADHD react differently to reward and punishment as compared with normal control children (Luman, Oosterlaan, & Sergeant, 2005). Although reinforcement contingencies have a positive impact on the task performance and motivation of children with ADHD and normal controls, this is more pronounced in children with ADHD (Dovis, Van der Oord, Wiers, & Prins, 2012a; Haenlein & Caul, 1987; Luman et al., 2005). High-intensity reinforcement has shown to be effective in improving task performance in ADHD and, compared with normal control children, 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. As 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, the attention span of children with ADHD will be very limited (Luman et al., 2005). Adding external incentives in a game-like fashion to a potentially boring task may help children with ADHD optimize their motivational state and normalize their cognitive performance (Dovis et al., 2012a; Geurts, Luman, & Van Meel, 2008).

A feature that may increase children's motivation is adding computer game elements to tasks. Parents, teachers, and clinicians have reported that children with ADHD, when playing a computer game, can sustain attention, concentrate for longer periods, and behave less impulsively (Barkley, 2006). In addition, studies show enhanced cognitive performance on EF tasks due to adding gaming elements to these tasks (Dovis et al., 2012b; Houghton et al., 2004; Lawrence et al., 2002; Prins, Dovis, Ponsioen, Ten Brink, & Van der Oord, 2011). In a recent study, we have found that children with ADHD were more motivated for an EF task (visuospatial WM) with game elements, compared with the same EF task without game elements; the children voluntarily played the task with game elements longer even without adult supervision; furthermore, after only three EF-training sessions, children in the gaming training condition showed a significantly better result on the EF task than children in the nongaming training condition (Prins et al., 2011).

There are several theoretical explanations for this enhanced motivation due to gaming in children with ADHD. Adding game elements to computerized tasks may heighten children's arousal/activation state, which may promote optimal performance (Houghton et al., 2004). In addition, the immediate reward for performance that is provided, and the fact that the child does not experience a delay of gratification, may lengthen their attention span and may reduce unwanted interfering hyperactive-impulsive behavior (Barkley, 2006; Houghton et al., 2004). Finally, video game play may promote the release of striatal dopamine (Koepp et al., 1998). As the dopamine system is thought to be deficient in ADHD (e.g., Knutson, Fong, Adams, & Hommer, 2001; Knutson, Fong, Bennett, Adams, & Hommer, 2003; Luman, Tripp, & Scheres, 2010), playing computer games may temporarily increase dopaminergic tone, which may in turn temporarily enhance arousal and cognitive control functions (Houghton et al., 2004).

To date, psychosocial treatments (behavioral and/or cognitive behavioral), treatment with stimulants (mostly methylphenidate), and their combination are considered empirically supported for school-age children with ADHD (Van der Oord, Prins, Oosterlaan, & Emmelkamp, 2008). Psychosocial treatments for ADHD focus on the parents, the teacher, and the child, for example, with variants of (cognitive) behavioral therapy. Thus far, cognitive-behavioral treatment of the child has received little empirical support in comparison with medication treatment and behavioral parent and teacher training (Van der Oord et al., 2008). Clearly, there is a need for new effective interventions that focus directly on the child and which specifically focus on improving executive dysfunctioning. There is increasing evidence for the efficacy of training these executive function deficits in children with ADHD (Beck, Hanson, Puffenberger, Benninger, & Benninger, 2010; Holmes, Gathercole, Place, et al., 2009; Karbach & Kray, 2009; Klingberg et al., 2005; Klingberg, Forssberg, & Westerberg, 2002; White & Shah, 2006), in children with poor WM (Holmes, Gathercole, & Dunning, 2009), and in preschoolers without ADHD (Thorell, Lindqvist, Nutley, Bohlin, & Klingberg, 2009).

To date, most evidence has been found for the trainability of WM (Holmes, Gathercole, Dunning, 2009; Holmes, Gathercole, Place, et al., 2009; Klingberg et al., 2002; Klingberg et al., 2005; Thorell et al., 2009). Klingberg and colleagues (2005) showed that in nonmedicated children with ADHD, without comorbidity, a computerized WM training improved not only the trained visuospatial WM but training effects also generalized to other nontrained executive functions, such as verbal WM, response inhibition, and complex reasoning. Furthermore, there was a significant reduction of parent-rated inattention and hyperactivity/impulsivity symptoms (no effects on teacher ratings). These positive effects at posttest were maintained at 3 months' follow-up. A recent study with a within-group design (Holmes, Gathercole, Place, et al., 2009) showed that in children with ADHD, while medication (methylphenidate) alone significantly improved visuospatial WM, additional training of WM resulted in even more improvement in visuospatial WM and showed improvements in nontrained executive functions (visuospatial short-term memory, verbal short-term memory, and verbal WM), but effects on ecologically valid ratings of ADHD behavior (parent and teacher ratings) were not assessed. Recently, Beck and colleagues (2010) conducted a wait-list controlled trial of a WM training in children with ADHD and WM problems, including children with comorbid diagnoses and medication. They showed that parental ratings of ADHD and EF improved, but no significant effects on teacher ratings of ADHD behavior were found.

Fewer studies have been conducted on the trainability of inhibition and cognitive flexibility (Karbach & Kray, 2009; Thorell et al., 2009; White & Shah, 2006). Preschool children (without ADHD) trained on inhibition showed a significant improvement on most of the trained tasks, but there was no generalization effect of this training to tasks measuring WM or attention. This may be due to the training task used; within the training task, the level of inhibition was not adapted to the level of the child. This individually adaptable task difficulty has shown to be crucial in improving WM through training (Klingberg, 2010). There is much less known about how to best adapt task difficulty individually in inhibitory control tasks (Thorell et al., 2009).

In the current study, we developed a new way to adapt task difficulty in an inhibitory control task (see the Method section; Dovis, Geurts, et al., 2008) by individually adapting the window of responding for each child, so the time in which can be stopped was individually adapted during the task. A pilot study has shown training effects of this inhibition training in children with ADHD (Dovis, Van der Oord, Wiers, & Prins, 2012b).

In addition, cognitive flexibility possibly can be trained (Karbach & Kray, 2009; White & Shah, 2006). One recent study in a normal sample of children, adolescents, and adults showed transfer of task-switching training to nontrained switching tasks. Moreover, after this task-switching training, children showed improved interference control, and verbal and spatial WM, suggesting generalization of training to other EF (Karbach & Kray, 2009). Adults with ADHD show improved task-switching abilities on trained and nontrained tasks after a task-switching training of two sessions of 30 min only (White & Shah, 2006). To date, however, task-switching training studies in children with ADHD are lacking.

Treatment with methylphenidate is one of the evidence-based treatments for children with ADHD (Van der Oord et al., 2008). In clinical practice, often children are encountered who are treated with methylphenidate, but who still have symptoms and need additional treatment. Most studies on the effectiveness of WM training are conducted with children who do not have a history of methylphenidate use (Klingberg, 2010; Klingberg et al., 2005). There is only one study that evaluated the additive value of WM training next to methylphenidate (Holmes, Gathercole, Place, et al., 2009); this study showed that above the effects of methylphenidate, WM training showed additional effects not only on the improvement of visual spatial WM but also on the improvement of other cognitive functions. Although Beck et al.'s (2010) sample included children on methylphenidate, they did not separately assess the effects of the WM training in the medicated children only.

In the current pilot study, we investigated the effectiveness of a 5- to 6-week intensive EF training embedded in a game world in children with ADHD. The training not only aims to improve WM capacity but also response inhibition and cognitive flexibility by directly training all three cognitive processes (see Method). Outcomes are parent and teacher ratings of EF and ADHD, oppositional deviant disorder (ODD), and conduct disorder (CD) symptoms. We expected our EF training at posttest, compared with a wait-list control condition, to be effective in improving EF and ADHD behavior and effects to be maintained at 9-week follow-up. Exploratively, we also assessed effects of our executive function training in a subsample of the participating children, who were also treated with methylphenidate.

Method

Participants

A total of 56 children, between 8 and 12 years old, were recruited from two outpatient mental health clinics in the Netherlands. All children, who were currently receiving treatment or who had received treatment for ADHD at these outpatient clinics, were sent an information letter about the research project. They were invited to attend an information session and were asked to participate. Inclusion criteria for participation were a *DSM-IV* (4th ed.; APA, 1994) diagnosis of ADHD established with the parent version of the Diagnostic Interview Schedule for Children (DISC-IV; Ferdinand, Van der Ende, & Mesman, 1998; Shaffer, Fisher, Lucas, Dulcan, & Schwab-Stone, 2000; see "Selection Measures"), and an estimated full-scale IQ of 80 or above, as established with a short version of the Dutch Wechsler Intelligence Scale for Children–Revised (WISC-III; Kort et al., 2002). Exclusion criteria were inadequate mastery of the Dutch language by the child or both parents and use of atomoxetine. Before participation, parents gave their written informed consent. Then the selection procedure was conducted (DISC-IV/WISC-III). Shortly before the beginning of the treatment, after the pretest, participants were randomly (using random number generators by person blind to study) assigned to either the wait-list condition or to the active treatment condition. Randomization was stratified on gender and use of medication. During treatment and during the wait-list period, the dose of methylphenidate was kept stable (no change of methylphenidate dose was allowed), and children and parents were not allowed to initiate or participate in other psychosocial treatments.

Selection Measures

DISC. The ADHD, ODD, and CD sections of the DISC-IV parent version was administered by a trained clinical child psychologist. The DISC-IV is a structured diagnostic interview that generates *DSM-IV* diagnoses and has adequate reliability and validity (Ferdinand et al., 1998; Shaffer et al., 2000).

WISC-III, short version. Four subtests of the Dutch WISC-III (Kort et al., 2002) were administered: Vocabulary, Block Design, Information, and Picture Completion. In children with ADHD, these subtests correlate highly with full-scale IQ (Furgueson, McGuffin, Greenstein, & Soffer, 1998).

Outcome Measures

Behavior Rating Inventory of Executive Functioning (BRIEF; Gioia, Isquith, Guy, & Kenworthy, 2000). A Dutch parent-rated version of the BRIEF (Smidts & Huizinga, 2009) was used as outcome measure. The 75-item BRIEF assesses executive functions and contains eight subscales: Inhibit, Shift, Emotional Control, Initiate, Working Memory, Plan/Organize, Organization of Materials, and Monitor. The first three scales form the "behavior regulation factor" and the remaining five the "meta-cognition index." In addition, a total score is computed. The BRIEF differentiates between different psychiatric disorders (Gioia, Isquith, Kenworthy, & Barton, 2002), and internal consistency and test–retest reliability are good (Smidts & Huizinga, 2009). For this study, we used the subscales Inhibit, Shift, Working Memory, the Meta-Cognition Index, and the Total Scale as dependent variables.

Disruptive Behavior Disorder Rating Scale (DBDRS). The DBDRS (Pelham, Gnagy, Greenslade, & Milich, 1992) assesses *DSM-IV* disruptive behavior disorder symptoms. The DBDRS consists of 42 items and contains four subscales: Inattention, Hyperactivity/Impulsivity, Oppositional Deviant Disorder, and Conduct Disorder. Parents and teachers rate the child's behavior on a 4-point Likert-type scale ranging from 0 (*not at all*) to 3 (*very much*). Adequate reliability and validity have been reported for the Dutch translation of the DBDRS (alpha range = .88–.94; Oosterlaan et al., 2008). Higher scores indicate more severe symptoms. Dependent variables were scores on the Inattention, Hyperactivity/Impulsivity, ODD, and CD subscales.

Treatment

The intervention is a training of three EFs, visuospatial WM, inhibition, and cognitive flexibility, embedded in a game world (Prins et al., 2010). The game is called "Braingame Brian," named after the main character of the game "Brian." The game consists of 25 training sessions of about 40 min. Each session contains two blocks (of about 15 min) of the three training tasks of WM, inhibition, and cognitive flexibility in a fixed order. The first training task is a WM training task, the second an inhibition training task, and the third a cognitive-flexibility training task. Over a period of 5 weeks, the child trains and plays a total of 25 sessions. Each day of training, the child does not play more than 1 session of 40 min. After each block of training tasks, the difficulty level of the training task is automatically adjusted to the child's level of performance. To enhance motivation, each completed block of training tasks results in an elaboration of the game world or extra powers for the main character Brian, with whom the child plays the game. Before, after, and between training tasks, the child can walk around in the game world. The game world gets more and more elaborate from the first to the last session, and every completed block results in extra powers for Brian. With these extra powers, he can create inventions to help people in his village, resulting in happier village people (the more Brian helps them, the more they smile). Thus, completing sessions does not only result in a more elaborate game world, more powers for Brian, but also in happier people in the village. The child plays the computer game at home. Every week a research assistant visits the child, and watches the child play a session, and answers possible questions about the game. Furthermore, the child keeps a diary of his or her experiences with the game.

The WM training. The WM training, embedded in the game world, combines different types of WM training (Dovis, Ponsioen, et al., 2008). It consists of five levels of training: (a) training of short-term memory, (b) training of short-term memory, updating and keeping information online, (c) training of short-term memory and manipulation/updating, (d) training of short-term memory and keeping information online during a delay, and (e) training of short-term memory and keeping information online and manipulation of information/updating. Each level is trained for 5 of the 25 sessions.

At each level, the training consists of a 4 × 4 grid of equally sized rectangles (Figure 1—Level 1 training of short-term memory). The rectangles light up in a random sequence. The rectangles light up for 900 ms, and after 500 ms, the next rectangle lights up. After each sequence, there is a 1,000-ms pause, after which the child has to reproduce the sequence by clicking the rectangles that have lit up in the requested sequence with the computer mouse. The child finishes a session if she or he has reproduced the required amount of sequences (Level 1: 68 sequences, Level 2: 52 sequences, Level 3: 62 sequences, Level 4: 62 sequences, Level 5: 62 sequences). During the training, the sequence length is adapted to the child's individual level of performance. If the child has fewer than 50% correct responses, the sequence length is shortened; more than 70% correct responses, the sequence length is

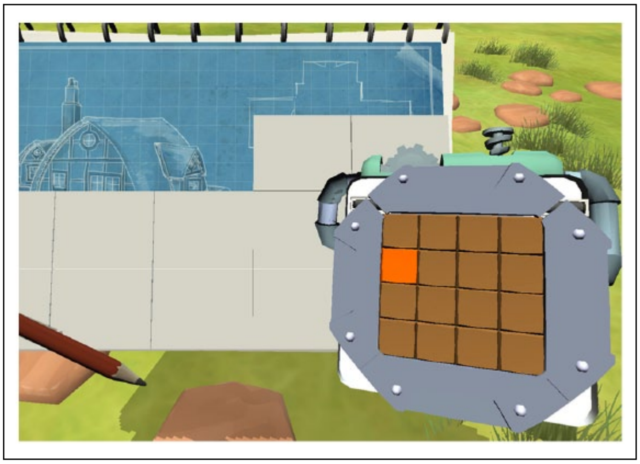

Figure 1. The working memory training.
Note: Tiles on the right light up in a random sequence; the child has to reproduce the order of the tiles; with every correct reproduced trial, the child sees more of the reward that can be earned in the game (here painting the house of the parents of the main character Brian).

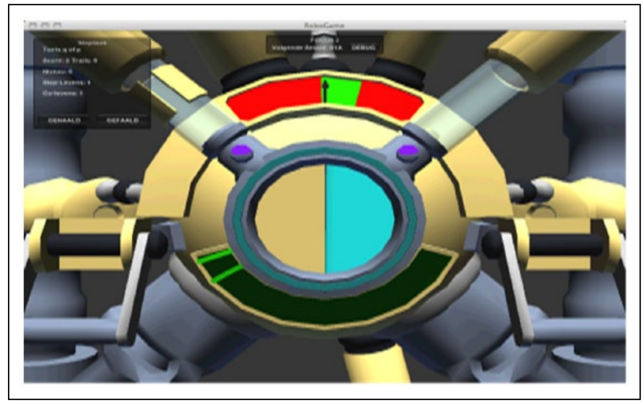

Figure 2. The inhibition training.
Note: The child has to press the right (*P*) or left (*Q*) key, depending on which half of the inner circle lights up; if the right half lights up blue, the *P* key has to be pressed, if left, the *Q* key (Go-trials). The child arrow (upper half of the machine) goes from the left to the right in the red area; the child has to respond when the arrow hits the green range. However, when the left or right half of the inner circle lights up red, the child has to refrain from responding (Stop-trials).

lengthened and between 50% and 70% correct responses, the sequence length stays the same.

The inhibition training. This task was designed to train prepotent response inhibition (Dovis, Geurts, et al., 2008). The task is visually designed as a factory in which the child has to respond as quick and accurately as possible to an arrow on a machine (Figure 2). In the first block of 10 trials (practice block), a blue stimulus lights up on the left or right side of the machine. If the stimulus lights up on the left, the child has to press the left button (*Q* key), and if the stimulus lights up on the right, the child has to press the right button (*P* key). It is not a matter of responding as quickly as possible, but to respond within a certain range; a stimulus at the top of the screen—that is, a bar colored green between 700 and 1,000 ms and red before 700 ms and after 1,000 ms (see Figure 2)—shows the range within which the child has to respond. The trials on which the child has to respond to the left or right within a certain range are the "Go-trials." In the training blocks of 52 trials, the Stop-trials are introduced: 25% of the trials are Stop-trials and 75% are Go-trials. In the Stop-trials, after presentation of the stimulus, a stop-signal is given (a tone, and the stimulus on the machine turns red); the child then has to inhibit his or her ongoing response. The time a child needs to stop his or her response is the Stop Signal Reaction Time; in the present training, the time in which it can be stopped is progressively shortened depending on the performance of the child; the presentation of the stop-signal is automatically adjusted to the level of the child's performance. After two incorrect responses, the stop-signal is presented earlier (25 ms earlier; thus the child has more time to "stop" his or her response), and after two correct responses, the stop-signal is presented later (25 ms later, that is, less time to "stop").

The cognitive-flexibility training. This task was designed (Dovis, Geurts, et al., 2008) to train cognitive flexibility and was based on the training described by Karbach and Kray (2009). The task is also designed as a factory, in which the child has to sort various objects according to the instruction given (Figure 3). The first two blocks of 10 trials are practice blocks. In the first block, the child is instructed to sort objects according to color, and in the second block according to shape (nonswitch trials). In the subsequent blocks, the child has to switch the rule of sorting the parts for 25% of the time, from color to shape, or from shape to color (switch trials); 75% of the time are nonswitch trials. First, a stimulus appears (the parts of the machine; thus a plunger or wheel, colored copper, or silver) on the screen; 600 ms after the appearance of this stimulus, a cue (to sort according to shape or color) appears at the top of the screen, and the child has 1,300 ms to respond (the time the child has to respond is displayed at the bottom of the screen). The interval to respond is adapted to the child's level of performance on the task; thus, after two correct responses, the interval to respond is shortened (with 50 ms); after two incorrect responses, the interval to respond is lengthened (with 50 ms). The switch cost is the time needed for switch trials subtracted from the time needed for nonswitch trials, and the training is intended to reduce the switch cost. If the child has more than 30% errors on switch or nonswitch trials, the child has to replay the test block.

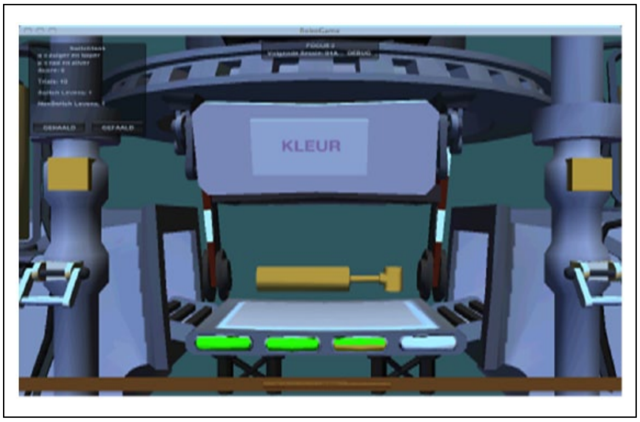

Figure 3. The cognitive-flexibility training.
Note: The shapes are either plungers or wheels, colored copper or silver. The child has to press the right (*P*) or left (*Q*) key to sort the parts of the machine into either the left (*Q* key) or the right (*P* key) side of the machine, depending on the instruction. The instruction for sorting is displayed in the middle top of the machine (here the child has to sort "color"). The green and yellow rectangles on the bottom of the machine display the time left to sort the parts.

Improvement of Inhibition, Cognitive Flexibility, and WM From First to Last Training Sessions

To validate whether the training actually improved task performance on the designated EF, in a subset of children (n = 11), the improvement on training performance from beginning to end of training was assessed. It was tested whether these children improved over time from the start of the training to the end of the training on their level of inhibition ("Stop-index"), cognitive flexibility ("Switch-index"), and WM ("WM-index"). For cognitive flexibility, a "Switch-index" was computed for each child, the percentage of correct switch trials divided by the mean reaction time on the switch trials. For inhibition for each child, a Stop-index was computed, the percentage of correct inhibition responses multiplied by difficulty level (individually adapted) divided by 100. For WM for each child as performance measure, a WM-index was computed (the total amount of sequences of a level divided by the correct amount of sequences of each level). All scores were transformed to z scores. For cognitive flexibility and inhibition, the mean performance on Blocks 2, 3, and 4 (start training) was compared to the mean performance on Block 48, 49, and 50 (end training) by paired t tests (all 25 EF-training sessions had two blocks of training). As WM had five levels, within each level, the performance of the start of the level (the mean performance of Blocks 2 and 3) was compared with the end of each level (the mean performance of the last two blocks) by paired t tests.

Paired t tests showed significant improvement from beginning to end of training for both the cognitive flexibility (M begin = −1.49, SD begin = 0.30, M end = 1.31, SD end = 0.46; t (10) = −25.21, $p < .01$) and the inhibition training (M begin = −1.83, SD begin = 0.24, M end = 0.92, SD end = 0.40; t (10) = 16.70, $p < .01$). For the WM training, all levels except for Level 4—due to technical problems—showed significant improvement from the beginning to the end of the level (Level 1: M begin = −1.41, SD begin = 0.21, M end = −0.78, SD end = 0.20; t (10) = −5.83, $p < .01$; Level 2: M begin = 0.87, SD begin = 0.30, M end = 1.61, SD end = 0.42; t (10) = −4.61, $p < .01$; Level 3: M begin = −1.44, SD begin = 0.17, M end = −0.48, SD end = 0.31; t (10) = −6.90, $p < .01$; Level 4: M begin = 0.57, SD begin = 0.24, M end = 0.62, SD end = 0.28; t (10) = −.83, $p > .01$; Level 5: M begin = −0.15, SD begin = 0.24, M end = 0.54, SD end = 0.28; t (9) = −8.12, $p < .01$).

Procedure

Children who were randomized to treatment were provided with a Macintosh computer at their homes. It was ensured that this computer was placed at a location with limited distractions. Furthermore, to limit distraction during training, children wore headphones, and no contact with the Internet or other software was possible on the computer. The pretest was conducted 1 week before the beginning of treatment: Parents and teachers completed questionnaires assessing behavior of their child, and children were assessed at the outpatient clinic. Participants in both conditions received the posttest after 6 weeks. In case children were randomized to the wait-list condition, after 6 weeks of waiting, they also participated in the treatment. A follow-up was conducted 9 weeks after the game training. The Ethics Committee of the university had approved the study.

A total of 56 children were recruited and 43 met selection criteria; 6 children did not receive a *DSM-IV* diagnosis of ADHD, as established with the DISC-IV, and 7 children had an estimated IQ score below 80, as established with the short version of the WISC-III. Of the remaining 43 children (age M = 9.79, SD = 1.04), 21 children were randomized to the treatment condition and 22 to the wait-list control condition. With regard to treatment adherence and dosage, every time the child played a session, this date and time was recorded on the database of the computer, and every week this was monitored by the research assistants. In all, 3 children in the experimental condition did not meet the criterion of having completed at least 20 of the 25 training sessions (see Klingberg et al., 2005); therefore, the scores of these children were not used in the analyses. Thus, the total n for the analyses was 18 for the treatment condition (12 taking medication and 6 not) and 22 for the wait-list control condition (17 taking medication and 5 not). Of these 40 children, 29 children had a diagnosis of ADHD Combined type, 7 of ADHD Inattentive type, and 4 the Hyperactive-Impulsive type. In total, 16 children (40%) showed comorbidity with

Table 1. Differences in Demographic Characteristics Between Children in the EF-Training Condition (EF Training) and the Wait-List Condition (Wait-List).

	EF training (n = 18)		Wait-list (n = 22)		F/χ^2
Age (*M*/*SD*)	10.00	.97	9.55	1.43	F = 1.79
IQ (*M*/*SD*)	101.11	12.32	103.36	12.86	F = 0.31
MPH-use (*n*/%)					χ^2 = .46
Yes	12	66.66%	17	77.27%	
No	6	33.33%	5	22.73%	
MPH-dose[a] (*M*/*SD*)	28.52	13.85	31.09	13.36	F = 0.24
Psychosocial treatment (*n*/%)					χ^2 = 1.20
Yes	5	29.41%	6	27.27%	
No	12	79.59%	15	68.18%	
Missing	0		1	4.55%	
Gender (*n*/%)					χ^2 =.34
Girls	2	11.11%	5	22.73%	
Boys	16	88.88%	17	77.27%	
DISC diagnosis (*n*/%)					χ^2 = 1.62
ADHD	12	66.66%	17	77.27%	
ADHD-I	3	16.67%	4	18.18%	
ADHD-H/I	3	16.67%	1	4.55%	
DISC diagnosis ODD (*n*/%)					χ^2 = .15
Yes	5	27.77%	11	50%	
No	13	73.33%	11	50%	
Experience games (*n*/%)					χ^2 = .38
A little	1	5.56%	2	9.09%	
Moderate	10	55.55%	15	68.18%	
A lot	7	38.89%	4	18.18%	
Missing	0	0%	1	4.55%	

Note: EF = executive functioning; MPH = methylphenidate; DISC = Diagnostic Interview Schedule for Children; ODD = oppositional deviant disorder.
$^*p < .05$. $^{**}p < .01$.
[a]Methylphenidate dose per day, in Methylphenidate immediate release equivalent doses.

ODD. In all, 11 participants had received other psychosocial treatments before starting the present treatment: 5 children had participated in a social skills training, 1 child had received a combined social skills training and a cognitive behavioral treatment for ADHD, 1 child had an intensive home-based behavioral parent training, 1 child had a yearlong after-school coaching for ADHD, 1 child had a yearlong after-school coaching for ADHD followed by a cognitive-behavioral treatment for ADHD, and 2 children had received regular consultations from a child psychologist.

Statistical Analyses

First, baseline differences between the EF game-training condition and the wait-list condition were tested using chi-square tests for categorical and ANOVAs for continuous variables. Then, differences between treatment conditions were tested with ANOVAs for repeated measures analyses with time of assessment as within factor (pretest, posttest) and treatment condition as between factor (wait-list or intervention). To assess long-term effects, for those children randomized to the intervention condition, a within-group ANOVA for repeated measures analyses was conducted with time as within factor (pre–post follow-up). Effect sizes (Cohen's η^2; Cohen, 1988) are reported for all analyses. Following Cohen's guidelines, effect sizes smaller than 0.06 were considered small, effect sizes between 0.06 and 0.14 were considered medium, and effect sizes above 0.14 were considered large. In case of missing items, if one item per subscale was missing, this item was replaced by the mean of the other items of the subscale. If more than one item was missing, this subscale was not used in the analyses. Furthermore, differences between treatment conditions were reanalyzed for the subsample of the children using methylphenidate (N = 29).

Results

First, ANOVAs and chi-square analyses tested for baseline differences and differences in demographic variables between treatment conditions (see Tables 1 and 2). There

Table 2. Baseline Differences Between Children in the EF-Training Condition (EF Training) and the Wait-List Condition (Wait-List).

	EF training (n = 18)		Wait-list (n = 22)		F
DBDRS parent (*M*/*SD*)					
IA	17.39	3.99	17.32	5.31	F = 0.00
H/I	15.78	3.78	15.23	5.39	F = 0.13
ODD	6.83	4.02	10.55	5.08	F = 6.35*
CD	1.39	1.69	2.52	3.34	F = 1.70
DBDRS teacher (*M*/*SD*)					
IA	14.33	6.88	13.09	7.12	F = 0.31
H/I	10.11	5.73	9.55	7.20	F = 0.07
ODD	4.39	5.26	5.82	6.24	F = 0.60
CD	1.27	2.12	0.94	1.73	F = 0.23
BRIEF parent (*M*/*SD*)					
Inhibition	22.39	3.45	23.24	4.17	F = 0.47
Cog flex	15.00	3.97	16.05	2.94	F = 0.89
WM	24.83	3.79	25.43	3.70	F = 0.24
Metacog	106.22	13.19	104.10	16.72	F = 0.19
Total	163.56	19.41	165.52	21.50	F = 0.09

Note: EF = executive functioning; DBDRS = Disruptive Behavior Disorder Rating Scale; IA = inattention, H/I = hyperactivity/impulsivity; ODD = oppositional deviant disorder; CD = conduct disorder; BRIEF = Behavior Rating Inventory of EF; Cog Flex = cognitive flexibility; WM = working memory; Metacog = metacognition.
*p < .05. **p < .01.

were no significant differences between treatment conditions on any of the demographics or baseline variables, except for scores on the parent-rated ODD scale of the DBDRS. This scale showed a significant difference between the treatment and wait-list condition. Therefore, we conducted repeated measures analyses of covariance with ODD as a covariate in all analyses. Outlier analysis showed no outliers on any of the variables.

ADHD Symptoms

The repeated measures covariance analyses showed significant interaction effects for the parent-rated DBDRS inattention and hyperactivity/impulsivity subscales, with large effect sizes. Children in the training condition showed a greater reduction in ADHD symptom behaviors (inattentive and hyperactive/impulsive behaviors) as reported by the parent compared with children in the wait-list condition. Two trends emerged; on the parent-rated ODD subscale (p = .08) and the teacher-rated inattention subscale (p = .08) of the DBDRS, both with medium effect sizes. Children in the treatment condition showed a greater reduction of ODD and inattentive behavior than did children in the wait-list group (see Table 3).

Executive Functions

For the BRIEF total score and for the metacognition factor, there were significant interaction effects, with large effect sizes. Children in the executive function training condition showed more improvement in EF (total score) and metacognition than children in the wait-list group. On the inhibition subscale of the BRIEF, a trend was found (p = .07), with a medium effect size (Table 3). Other subscales of the BRIEF did not show significant effects.

Subsample Treated With Medication

Results were reanalyzed for the children treated with medication (N = 29). There were no significant differences between the two conditions on any of the demographics or baseline variables; again only the parent-rated ODD scale of the DBDRS showed a significant difference between the treatment and wait-list condition, $F(1, 27) = 6.07$, $p < .05$. Therefore, again the ODD scale was used as a covariate in all analyses.

There were significant interaction effects, in the expected direction, on the parent-rated DBDRS Inattention and Hyperactivity subscales (large effect sizes; Table 4). In addition, the Total Scale, the Meta-Cognition Factor (both large effect sizes), and the Inhibition subscale (medium effect size) of the BRIEF showed significant interaction effects in the expected direction. Furthermore, the Cognitive-Flexibility subscale of the BRIEF showed a trend (p = .08) for the interaction effect (medium effect size) in the expected direction.

Long-Term Effects

Furthermore, repeated measures ANOVA's were conducted on parent- and teacher-rated questionnaires with

Table 3. Scores at Pretest, Posttest for Children in the EF-Training Condition (EF Training) and the Wait-List Condition (Wait-List).

	Pretest				Posttest							
	EF training		Wait-list		EF training		Wait-list					
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	Time	η^2	Time by group	η^2
DBDRS-P												
IA	17.47	4.09	16.86	4.97	12.76	5.12	16.90	6.56	$F(1, 35) = 1.32$	.04	$F(1, 35) = 11.95^{**}$	.25
H/I	16.12	3.60	14.90	5.30	11.82	4.13	14.81	5.87	$F(1, 35) = 0.03$	.00	$F(1, 35) = 9.68^{**}$	.22
ODD	7.06	4.02	10.05	4.62	5.47	4.05	9.86	5.25	$F(1, 35) = 2.04$	.06	$F(1, 35) = 3.31$[a]	.09
CD	1.41	1.73	2.35	3.33	1.41	2.32	1.95	3.25	$F(1, 34) = 1.24$	.04	$F(1, 34) = 0.00$	.00
DBDRS-T[b]												
IA	15.60	6.20	13.56	7.55	10.73	4.91	11.44	7.10	$F(1, 28) = 1.78$	.06	$F(1, 28) = 3.26$[a]	.11
H/I	11.40	5.18	9.94	7.44	8.20	3.67	9.31	6.85	$F(1, 28) = 0.03$	.00	$F(1, 28) = 2.15$	.07
ODD	4.57	5.81	4.93	6.25	3.50	4.66	4.60	6.43	$F(1, 26) = 0.00$	.00	$F(1, 26) = 1.50$	.06
CD	1.10	1.97	.50	.71	.20	.63	.20	.42	$F(1, 17) = 0.55$	.03	$F(1, 17) = 2.76$	.14
BRIEF												
Inhibition	22.39	3.45	23.00	4.13	20.56	2.97	23.05	4.22	$F(1, 35) = 0.04$	.00	$F(1, 35) = 3.49$[c]	.09
Cog Flex	15.00	3.97	15.85	2.87	14.44	3.29	15.70	3.63	$F(1, 35) = 0.81$	.02	$F(1, 35) = 0.91$	.03
WM	24.83	3.97	25.26	3.72	22.67	3.31	24.26	4.98	$F(1, 34) = 1.34$	.04	$F(1, 34) = 1.68$	.05
Metacog	106.22	13.19	103.15	16.57	97.22	13.10	102.00	17.55	$F(1, 35) = 0.89$	.03	$F(1, 35) = 6.80^{*}$	.16
Total	163.56	19.41	163.85	20.61	150.39	19.07	162.20	21.77	$F(1, 35) = 0.27$	.01	$F(1, 35) = 6.84^{*}$	.16

Note: EF = executive functioning; DBDRS = Disruptive Behavior Disorder Rating Scale; IA = inattention; H/I = hyperactivity/impulsivity; ODD = oppositional deviant disorder; CD = conduct disorder; BRIEF = Behavior Rating Inventory of EF; Cog Flex = cognitive flexibility; WM = working memory; Metacog = metacognition.
[a]Trend $p = .08$.
[b]Due to practical reasons, DBDRS-T was only administered to a subset of children at posttest ($N = 31$).
[c]Trend $p = .07$.
$^{*}p \leq .05$. $^{**}p \leq .01$.

time (pre–post follow-up) as within-group factor for those children who were immediately randomized to the EF game-training condition ($n = 18$). There were significant time effects for the parent-rated BRIEF and the parent- and teacher-rated DBDRS. Within-group contrasts showed significant improvement from pre to follow-up test for the Total Score, Meta-Cognition Factor, and the Inhibition subscale of the BRIEF (large effect sizes) and for the DBDRS subscales Inattention and Hyperactivity/Impulsivity, also with large effect sizes (Table 5).

Discussion

This pilot study is the first evaluation of a broad EF-remediation training with game elements for children with ADHD, referred to an outpatient clinical setting. A majority of children participating in the study were treated with methylphenidate and had comorbidity, optimizing the generalizability of the results to children with ADHD in regular clinical settings. Children who followed the EF-remediation training showed significant reductions in parent-rated ADHD behaviors and improvement in executive functions compared with children in the wait-list condition. These significant results were found both in our total sample, as in the subsample of children who were treated with methylphenidate. Furthermore, not only were effect sizes at posttest medium to large, but effects also appeared long lasting; at 9 weeks' follow-up, these significant reductions in ADHD behavior and improvement in executive functions were maintained.

In children with ADHD, not only WM but other executive functions are disturbed as well (Nigg, 2006). Although there is accumulating evidence for the effectiveness of WM training (for a review, see Klingberg, 2010), only few studies have investigated the effectiveness of training other important executive functions that are disturbed in ADHD, such as inhibition and cognitive flexibility (Karbach & Kray, 2009; Thorell et al., 2009; White & Shah, 2006). Our pilot study is the first to report on a training of the three executive functions most disturbed in ADHD, embedded in a game world. Using this broad training of executive functions, we did find positive effects of training on parent-rated ADHD symptoms and executive functions. Although we did find a trend toward significance on the Inhibition subscale of the BRIEF, we unexpectedly did not find positive effects of training on the WM and Set-Shifting subscales of the BRIEF. It may be that our broad training of EF may have trained all these executive functions to some degree,

Table 4. Scores at Pretest, Posttest for Children in the EF-Training Condition (EF Training) and the Wait-List Condition (Wait-List) Who Were Taking Medication at Pretest.

	Pretest				Posttest							
	EF training		Wait-list		EF training		Wait-list					
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	Time	η^2	Time by group	η^2
DBDRS-P												
IA	16.92	4.27	17.23	5.37	12.67	5.42	17.53	6.98	$F(1, 26) = 0.02$	.00	$F(1, 26) = 10.91^{**}$	.30
H/I	16.92	3.23	16.06	4.93	15.94	5.80	13.08	3.48	$F(1, 26) = 0.22$	.01	$F(1, 26) = 5.94^{*}$	.19
ODD	7.25	4.59	11.12	3.84	5.83	4.43	10.71	5.39	$F(1, 26) = 1.40$	.05	$F(1, 26) = 1.75$	.06
CD	1.25	1.60	2.81	3.56	1.42	2.61	2.31	3.55	$F(1, 25) = 1.01$	.04	$F(1, 25) = 0.00$	.00
DBDRS-T[a]												
IA	13.30	5.74	12.00	7.29	9.80	4.83	9.33	5.94	$F(1, 19) = 1.02$	.05	$F(1, 19) = 0.20$	.01
H/I	11.40	4.67	10.50	7.86	8.20	3.52	9.00	6.19	$F(1, 19) = 1.56$	.08	$F(1, 19) = 0.21$	.01
ODD	6.20	6.18	5.42	6.84	4.90	4.88	5.00	7.08	$F(1, 19) = 0.00$	.00	$F(1, 19) = 1.29$	.06
CD	1.50	2.51	.50	.76	.33	.82	.13	.35	$F(1, 11) = 0.49$	.04	$F(1, 11) = 2.48$	.18
BRIEF												
Inhibition	23.25	3.65	23.87	4.08	21.33	2.67	24.13	3.95	$F(1, 25) = 0.19$	.01	$F(1, 25) = 4.09^{*}$	.14
Cog Flex	15.75	4.49	16.81	2.23	14.67	3.60	16.63	3.46	$F(1, 25) = 2.27$	.08	$F(1, 25) = 3.26^{b}$	.12
WM	24.42	4.10	25.75	3.66	22.75	3.62	24.50	5.10	$F(1, 25) = 0.17$	.01	$F(1, 25) = 0.65$	.03
Metacog	104.92	14.56	105.31	17.38	96.67	14.87	103.75	18.83	$F(1, 25) = 0.05$	.00	$F(1, 25) = 6.10^{*}$	.20
Total	164.92	22.84	169.25	18.97	151.50	20.99	166.88	21.79	$F(1, 25) = 0.22$	.01	$F(1, 25) = 7.18^{**}$	.22

Note: EF = executive functioning; DBDRS = Disruptive Behavior Disorder Rating Scale; IA = inattention; H/I = hyperactivity/impulsivity; ODD = oppositional deviant disorder; CD = conduct disorder; BRIEF = Behavior Rating Inventory of EF; Cog Flex = cognitive flexibility; WM = working memory; Metacog = metacognition.
[a]Due to practical reasons, DBDRS-T was only administered to a subset of children at posttest ($N = 31$).
[b]$p = .08$.
$^{*}p \leq .05$. $^{**}p \leq .01$.

resulting in a significant improvement of overall executive functions—as found on the BRIEF total score—and ADHD behavior, but not enough for significant changes on these separate subscales.

Children with ADHD are heterogeneous in display of their symptoms, neurocognitive deficits, associated features, and response to treatment (e.g., Sonuga-Barke, 2003; Willcutt et al., 2005). For future studies, it is to further unravel which executive functions can be trained best, for which specific child, and to what extent the effects of these different types of cognitive training can be generalized to other cognitive functions and behavior problems (Thorell et al., 2009). In addition, possible motivating effects of the game environment used in the current training remains to be explored.

The generalizability of WM training effects to settings in which the WM problems and ADHD symptoms cause difficulty, such as school settings, is often questioned (Morrison & Chein, 2011). Furthermore, one could argue that parents are informants who may be biased in their ratings, because they were the main initiators for participation of their child in the study and were involved in motivating their child to do the EF training. Teachers are less biased and are not involved in the training. Other studies on WM training often have not found significant effects on teacher ratings of ADHD behavior (e.g., Beck et al., 2010; Klingberg et al., 2005). The fact that, in our study, we did find at posttest a trend toward significance in those children who participated in the EF training compared with children on the wait-list and the fact that we have found significant long-term effects on the teacher ratings is encouraging and suggests generalizability of our EF training effects to the behavior of the child in the school setting.

Klingberg (2010) suggests that extensive training (at least 8 hr) is necessary for a WM training to be effective. Compared with a much used other WM training program (Cogmed), our training program is of a substantially shorter duration (i.e., Cogmed: ±15 hr WM training, our program ±4 hr WM training). Nevertheless, we did find positive effects of our EF training program not only on the short term but also on the long term, suggesting long-lasting effects. However, dismantling research is necessary to examine whether the positive effects of the EF-remediation training are accounted for by the WM, the inhibition (also 4 hr of training), the set-shifting (4 hr) training, or the combination of the three training elements. Currently, we are conducting such a dismantling study (Dovis, Van der Oord, Wiers & Prins, 2012c).

Table 5. Scores at Pretest, Posttest, and Follow-Up Test for Children in the EF-Training Condition.

	Pretest		Posttest		Follow-up test					
	M	*SD*	*M*	*SD*	*M*	*SD*	Time	η^2	Pre-follow-up contrast	η^2
DBDRS-P										
IA	17.07	3.97	13.07	5.62	14.00	5.50	$F(2, 12) = 5.28^{*}$	.47	$F(1, 13) = 6.07^{*}$	.32
H/I	16.29	3.85	12.64	4.05	12.21	3.72	$F(2, 12) = 8.86^{**}$	.60	$F(1, 13) = 13.91^{**}$	.52
ODD	7.29	4.20	6.00	4.13	6.71	3.99	$F(2, 12) = 0.62$	.09	$F(1, 13) = 0.39$	.03
CD	1.64	1.82	1.71	2.46	1.43	1.87	$F(2, 12) = 0.14$	.02	$F(1, 13) = 0.14$	.02
DBDRS-T[a]										
IA	14.45	6.61	9.91	4.72	9.82	7.35	$F(2, 9) = 13.80^{**}$	.75	$F(1, 10) = 16.14^{**}$	.62
H/I	11.83	5.56	8.25	3.25	8.33	5.07	$F(2, 10) = 7.55^{*}$	.38	$F(1, 11) = 12.53^{**}$	.53
ODD	8.30	6.38	4.30	5.10	4.90	5.57	$F(2, 8) = 0.71$	.04	$F(1, 9) = 0.08$	.01
CD	1.43	2.30	.29	.76	.57	1.13	$F(2, 5) = 0.42$	.29	$F(1, 6) = 2.4$	.29
BRIEF										
Inhibition	22.42	3.55	20.82	2.83	20.05	3.47	$F(2, 15) = 4.91^{*}$	.40	$F(1, 16) = 10.18^{**}$	.39
Cog Flex	15.18	4.20	14.59	3.37	14.88	3.67	$F(2, 15) = 0.58$	.07	$F(1, 16) = 0.13$	.01
WM	24.88	3.90	22.82	3.34	23.82	3.59	$F(2, 15) = 2.96$	.28	$F(1, 16) = 2.33$	.13
Metacog	105.88	13.51	97.41	13.48	100.29	12.41	$F(2, 15) = 4.78^{*}$	.39	$F(1, 16) = 4.32^{*}$	.21
Total	163.47	20.00	151.29	19.25	153.53	19.80	$F(2, 15) = 4.59^{*}$	.38	$F(1, 16) = 5.79^{*}$	.27

Note: EF = executive functioning; DBDRS = Disruptive Behavior Disorder Rating Scale; IA = inattention; H/I = hyperactivity/impulsivity; ODD = oppositional deviant disorder; CD = conduct disorder; BRIEF = Behavior Rating Inventory of EF; Cog Flex = cognitive flexibility; WM = working memory; Metacog = metacognition.

[a]Due to practical reasons, DBDRS-T was only administered to a subset of children at post and follow-up test.

$^{*}p \leq .05$. $^{**}p \leq .01$.

In most WM treatment studies to date, the selected samples often are nonclinical (Holmes, Gathercole & Dunning, 2009; Klingberg et al., 2002; Klingberg et al., 2005; Thorell et al., 2009), do not have comorbidity (Klingberg et al., 2005), and/or have no medication history (Klingberg et al., 2005). A notable exception is the study by Beck et al. (2010). Similar to the results of Beck et al. (2010), our study shows positive results of an EF training in a clinical sample including children with medication and comorbidity. In contrast to Beck et al. (2010), in our study significant treatment effects were also reported in the subsample treated with methylphenidate, suggesting, similar to the study of Holmes, Gathercole, Place, et al. (2009), additive effects of EF training above methylphenidate treatment in our clinical sample of children. This is remarkable, because additive effects of the regular evidence-based treatments such as behavioral parent training to methylphenidate treatment is often not found (MTA Cooperative Group, 1999; Van der Oord et al., 2008).

Limitations

For this first pilot study of the EF training in this clinical sample of children with ADHD, who often had comorbidity, we deemed an active control group (e.g., a non adaptive training such as Klingberg et al., 2005 used) not feasible. A nonadaptive training has little challenge for the children, and anticipating on possible motivational problems in this clinical sample of children with ADHD, a wait-list was used as a control group. Therefore, nonspecific treatment effects in the EF-remediation training condition (such as attention of parents) were not controlled for. However, the trend on the Inattention scale of the teacher ratings in the EF training condition compared with the wait-list condition and our significant long-term effects on teacher ratings in the EF training condition do indicate toward true unbiased effects of the EF training.

In this first pilot study of our EF-remediation training with game elements, we evaluated the effects of our training as a fixed package on parent- and teacher-rated questionnaires. Thus, all children, regardless of their specific executive (dis)functioning profile, received a training of WM, inhibition, and cognitive flexibility, in this fixed order within the game environment. In future studies, effects of each separate training task (on, for example, neuropsychological measures), the order of training, and the game environment need to be unraveled. Furthermore, due to practical constraints (holidays within a treatment period), we were not able to collect all teacher data.

Furthermore, within our pilot study, the power for detecting differences, especially for teacher ratings, was low. Nevertheless, we did find (nearly) significant effects on the parent and teacher ratings of ADHD behavior. In addition, multiple statistical analyses were conducted, which increases the possibility of chance findings. Future studies should try to address these limitations and explore the effectiveness of this EF game training in an adequately powered sample.

As this was the first pilot study of our EF game training, we encountered a few technical problems. Although 18 children completed the game training, due to technical difficulties (i.e., computer data showed that the children did train the complete 25 sessions, but individual data of the training tasks were not saved on the hard disk), we were only able to obtain data from 11 to compute training performance over time. The main purpose for computing this performance over time was validating the training modules. The exploratory analyses of the 11 showed significant and sufficient evidence for validation of the training and improved training performance over time.

All in all, our pilot study shows promising evidence for the efficacy of a broad EF-remediation training in a clinically diagnosed sample of children with ADHD, of which a large proportion had comorbid disorders and a treatment history with methylphenidate. Future studies should further replicate these positive results in a larger sample and further disentangle these positive treatment effects to explore specific effects for each EF training (WM, inhibition, or cognitive flexibility), motivational aspects of the gaming environment, and ultimately, for which child, with their specific executive (dis)functioning profile, which EF training component would be most effective.

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