CYBERPSYCHOLOGY, BEHAVIOR, AND SOCIAL NETWORKING
Volume 14, Number 3, 2011

DOI: 10.1089/cyber.2009.0206

Does Computerized Working Memory Training with Game Elements Enhance Motivation and Training Efficacy in Children with ADHD?

Pier J.M. Prins, Ph.D.,[1] Sebastiaan Dovis, M.Sc.,[1] Albert Ponsioen, Ph.D.,[2]
Esther ten Brink, M.Sc.,[2] and Saskia van der Oord, Ph.D.[1,2]

Abstract

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

Introduction

CURRENT RESEARCH ON CHILDHOOD ADHD is based on two theoretical approaches: one focusing primarily on executive functioning[1] and the second on motivational variables.[2] In his comprehensive theory, Barkley[1] assumes that self-regulation deficits are at the core of the ADHD syndrome, and are related to executive functions (EFs) such as working memory (WM), response inhibition, and temporal processing. EFs play an important role in everyday life, such as paying attention in class, waiting one's turn to say or do something, and keeping track of homework. Children with ADHD exhibit significant impairments in WM and response inhibition.[3] WM has been defined as the ability to retain information during a delay and then to make a response based on that internal representation.[4] Visuospatial WM is considered the most important neuropsychological deficit in children with ADHD.[5]

A second approach to ADHD assumes an abnormal sensitivity to reinforcement.[6,7] Research has indicated that reinforcement contingencies, including reward, punishment/response cost, and (accuracy) feedback, as well as combinations of feedback and reward or response cost, have a positive impact on the task performance and motivation in both children with ADHD and controls. In a recent meta-analysis, Luman et al.[8] concluded that this effect is somewhat more prominent in children with ADHD: the high intensity of reinforcement appeared highly effective in ADHD, and children with ADHD prefer immediate over delayed reward. When reinforcers are powerful and frequent, the differences in behavior between children with ADHD and controls are expected to be minimal. Since reinforcement is highly associated with motivation, research suggests that an unusually low level of effort or intrinsic motivation accounts for the performance deficits in children with ADHD. When tasks are extremely boring, or without supervision, the attention span of children with ADHD will be very limited.[8] Adding external incentives to a potentially boring task may help children with ADHD optimize their motivational state and normalize their performance.[9]

Relatedly, Sergeant et al.[10] hypothesized that children with ADHD suffer from a nonoptimal energetic state explained in terms of the cognitive-energetic model (CEM), which is based on the assumption that information processing is influenced by both computational (process) factors and state factors such as effort, arousal, and activation. Effort, which is related to

[1]Department of Clinical Psychology, University of Amsterdam, Amsterdam, Netherlands.
[2]Mental Health Outpatient Center Lucertis/Dijk and Duin, Zaandam, Netherlands.

motivation, is conceived as the energy necessary to meet the demands of the task. Reinforcement contingencies are presumed to have their influence on effort. If children with ADHD suffer from a deficit in effort, performance may be poor due to a non-optimal energetic state. Since reinforcement is expected to activate effort, reinforcement will induce the necessary energy to meet the task demands. As a result, performance on cognitive tasks improves.[8] If state factors are manipulated by contextual changes, then, given the correct degree of incentive, increased activation and effort result in cortical stimulation and thus improvements in performance.[11]

As well as adding external incentives, a feature that has shown to increase an ADHD child's interest and motivation is the computerization of tasks.[12] Computer assisted instruction (CAI) programs typically include clear goals and objectives, highlighting of important material, and immediate feedback regarding response accuracy. Many—perhaps the more effective CAI programs—also have a *game-like format*.[12] Parents, teachers, and clinicians have reported that children with ADHD, when playing a computer game, can sustain attention, concentrate for longer periods of time, and behave less impulsively.[13]

A gaming format uses multiple sensory modalities (color, sounds, movement) and provides frequent, immediate feedback about quality/accuracy of performance (via graphics, sounds, and scoring). It further includes animated characters, narratives, colorful interactive environments, and player advancement through levels.[11] Gameplay is a complex, multi-requirement cognitive domain, and is known to be very motivating for children, including those with ADHD.[14,15] Tasks with a game format should promote optimal cognitive performance (relative to repetitive and boring experimental tests) in children with ADHD by providing external motivating contingencies just prior to and at the moment of responding. They should also heighten the activation/arousal state, which may further promote optimal performance.[16,17]

Ota and DuPaul[18] investigated the effects of CAI software with a game format on attending behavior and math performance of children with ADHD, relative to a written seatwork condition. The game format included games (activities), difficulty levels that adjusted to the child's ability, and rewards (points) earned throughout the game and provided following each correct response. Computer software with a game format strongly improved the attending behavior, time on-task, and task performance of the children, "presumably because of the stimulating nature of the stimuli and the immediate performance feedback." In another study, Lawrence et al.[17] found that boys with ADHD compared to controls were equally capable of inhibiting responses when playing a computer game. These studies suggest that computer gaming facilitates attention and impulse control.

Shaw et al. studied the influence of computer-game elements on the performance of children with ADHD.[19] In the first part of the study, children with ADHD and controls played two commercial computer games. In the second part, the children performed a computerized version of the Continuous Performance Test (CPT) and a Pokémon task. This task was similar to the CPT, but the target letters were in the form of Pokémon characters. Each child was instructed to catch as many Pokémons as they could. Results showed that the behavior of children with ADHD when using the commercial computer game (number of impulsive errors and the amount of attention) was similar to the behavior of controls. This result further supports the facilitating role of computer games on children's impulse control and attention. The findings of the second part of the study showed that children with ADHD made fewer impulsive errors and were more attentive on the Pokémon version of the CPT. In the control group, no difference was found between the two versions of the CPT.

Introducing game elements per se does not enhance performance; it may distract children from the main aim of the task. In a study by Shaw and Lewis,[11] adding animation did not enhance the attractiveness of a computer task; children with ADHD performed less well on a computerized task with game features. They reported that they were distracted by the animations. Perhaps they experienced problems in remembering the main aim of the task in the presence of more interesting stimuli. Or perhaps processing resources were allocated to more interesting surface features or distractions and not to task content.[11]

In summary, these findings suggest that to increase the chances of a child with ADHD maintaining concentration and attention and withholding impulsive behaviors and inappropriate behaviors, the child needs to be specifically motivated and stimulated. This is where the use of computerization and gaming seems to be critical.[11]

Recently, attempts have been made to train specific EF deficits with computerized training. Klingberg et al. successfully trained the WM of children with ADHD.[20] Fifty-three children with ADHD were randomly assigned to either computerized treatment or a comparison program. The treatment consisted of performing WM tasks implemented using a computer program (RoboMemo®), which included visuospatial WM tasks (remembering the position of objects in a 4×4 grid), as well as verbal tasks (remembering phonemes, letters, or digits). The children were trained for 5 weeks, with 90 trials on each training day. The level of difficulty was automatically adjusted on a trial-by-trial basis to match the WM span of the child on each task. After training, the children in the treatment condition not only performed better on a task measuring visuospatial WM (span-board task), but also on tasks assessing verbal WM (digit-span task), response inhibition (Stroop task), and complex reasoning (Raven task). Finally, a significant reduction in the number of parent-rated ADHD behaviors was found. The WM training of Klingberg et al. was computerized, including some animation and feedback, but without elaborate gaming elements. Based on previous research and clinical observations, it was expected that adding more game elements to computerized WM training would enhance its effects.

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

Method

Participants

Participants were 62 children from a suburban area, who had been referred to three outpatient mental-health clinics, and were on a waiting list for ADHD treatment. Inclusion criteria were: (a) meeting DSM-IV[21] diagnostic criteria for ADHD; (b) aged between 7 and 12 years; (c) a clinical score on the Attention Deficit and/or Hyperactivity/Impulsivity subscales of the Disruptive Behavior Disorder Rating Scale, parent and/or teacher version (see below); and (d) no use of medication on days of training. A total of 52 children (42 boys, 10 girls) met the inclusion criteria, with an average age of 9.47 years ($SD = 1.08$). Participants with ADHD on stimulant medication discontinued treatment for a minimum of 24 hours prior to the test sessions. Only participants on short-acting stimulants were included.

Controls were matched to participants with ADHD for age, gender, IQ, comorbid behavior disorders, dyslexia, and experience with computer gaming. Participants were then randomly assigned to either standard WM training ($n = 25$) or a game version of the training ($n = 27$). One child (control condition) dropped out before training, leaving a final sample of 51 children. Demographic information and baseline characteristics are shown in Table 1.

Screening and selection measures

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

Disruptive Behavior Disorders Rating Scale (DBDRS). The DBDRS[22] assesses DSM-IV disruptive behavior disorder symptoms in children between 6 and 12 years. It consists of 42 items and four subscales: inattention (nine items), hyperactivity/impulsivity (nine items), oppositional defiant (eight items), and conduct disorder (16 items). Items are scored by parents and teachers on a 4-point Likert scale, ranging from 0 = "not at all" to 3 = "very much". The maximum score on the ADHD subscales is 27. Higher scores indicate more severe symptoms. The Dutch translation has adequate reliability (α range = 0.88–0.94); validity and Dutch norms are available.[23]

Table 1. Demographics and Baseline Characteristics of Participants in the Computerized WM Game Training and Control Training

Variables	*Game* (n = 27)	*Control* (n = 24)
Mean age (years)	9.59 (1.12)	9.33 (1.05)
No. male (%)	21 (78%)	21 (88%)
DBDRS (parent version)		
– Attention deficit	15.30 (5.23)	15.08 (4.68)
– Hyperactivity/impulsivity	14.67 (5.45)	15.04 (4.96)
– ODD	7.74 (4.75)	8.38 (4.99)
– CD	1.85 (3.42)	1.88 (2.27)
DBDRS (teacher version)		
– Attention deficit	12.24 (7.24)	11.96 (5.97)
– Hyperactivity/impulsivity	11.38 (7.96)	11.21 (5.60)
– ODD	7.69 (4.84)	8.38 (4.99)
– CD	1.31 (3.28)	1.42 (1.64)
WISC III		
– Substitution	9.00 (3.20)	9.00 (2.50)
– Block design	10.74 (3.79)	9.83 (2.96)
– Vocabulary	11.85 (3.39)	10.83 (2.93)
Dyslexia	2 (7%)	2 (8%)
Computer-game experience	27 (yes)	24 (yes)
Hours per week	9.73 (4.91)	7.58 (5.02)
Memory span (CBTT)	4.96 (0.76)	4.96 (0.75)

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

Wechsler Intelligence Scale for Children III (WISC-III) short version. The WISC-III short version,[24,25] designed for children between the ages of 6 and 16 years, consists of five subtests: information, vocabulary, incomplete drawings, block design, and substitution. Scores of children with ADHD on this short version correlate highly ($r = 0.94$) with scores of children with ADHD on the complete version.[26] To reduce testing time, the full-scale IQ was estimated with three subtests: vocabulary, block design, and substitution.

Outcome measures

Corsi Block-Tapping Test. The Corsi Block-Tapping Test (CBTT)[27] assesses the capacity of visuospatial short-term memory and WM.[28] In the present study, the same test format (size of board and blocks, distances between blocks) was used as in Kessels et al.,[28] and the same scoring procedure was used as in Geurts et al.[29] The task consists of nine cubes (blocks of $30 \times 30 \times 30$ mm) that are positioned on a square board (225×225 mm). The blocks, numbered one through nine, are visible for the test leader only. The test leader taps a sequence of blocks, starting with a sequence of three blocks, which the child must repeat three times in the correct order (e.g., 1-2-3 > 1-2-3). If the child reproduces at least one of three sequences of a particular number of blocks correctly, the sequence is extended with one block to a maximum of eight blocks. After three successive errors within the same sequence length, the test is stopped. The last sequence length in which the child has reproduced at least two sequences correctly is considered his/her memory span. The minimum score on the CBTT is two and the maximum score is eight. The CBTT takes approximately 10 minutes, and was the main outcome measure in our study (see below).

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

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

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

Training conditions

Control training. In the computerized WM training without gaming elements, adapted from Klingberg et al.,[20] children were presented with a 4×4 grid consisting of 16 blue squares in rows of four against a black background. The squares lit up in random order, one after the other, and, as such, formed a sequence. The child had to reproduce this sequence by clicking with the computer mouse on the squares that lit up. The first sequence consisted of three squares that lit up. After two consecutive correct reproductions, the sequence increased by one square. After two consecutive incorrect reproductions, the sequence was shortened by one square. This upward and downward adjustment was the only form of "feedback" in this condition. No external visual or auditory feedback was given. This training format without explicit feedback and without gaming elements is similar to most neuropsychological assessment tasks. The minimal length of a sequence was two squares. Each square in a sequence lit up for 900 milliseconds and it took 500 milliseconds for the next square to light up. The next sequence automatically started 5 seconds after the child tried to reproduce the sequence. These trial and inter-trial times are similar to the Klingberg et al. study. During this control version of the WM training, in each training session of 30 minutes, the child could maximally reproduce 110 sequences. If the child did not interact with the mouse within 60 seconds, the time was recorded by the computer until the child interacted again. This was considered the absence time. Each participant was allowed to try out the training for a maximum of 5 minutes before the training began properly.

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

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

Materials

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

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

Procedure

The study consisted of an intake session and three successive training sessions, spaced 1 week apart. The study was approved by the Research Ethics Committee of the University of Amsterdam. After a description of the study, written informed consent was obtained from the parents, and each child gave verbal consent. Parents were then invited for an intake session. The DBDRS was mailed to the parents to give to the child's teacher to complete. During the intake session, the parents and child were interviewed with the intake questionnaire. Parents were then asked to complete the DBDRS, while the child was administered the WISCIII and the CBTT subtests. This session lasted 50 minutes. If the child met the inclusion criteria, he/she was randomly assigned—after matching—to one of the two conditions, and three training appointments were scheduled.

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

> The training is over and you did very well. I have to look at the results and you'll have to wait here for a short while. It'll take

> me about 15 minutes and then I'll come back. In the meantime you can do something for yourself. You may read the magazines or continue playing on the computer. It's up to you. I'll be in the hallway to look at the results.

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

Data analysis

First, pre-training group differences were tested using analysis of variance (ANOVA), and Chi-square tests were used for categorical variables. Second, training effects were examined with 2×3 (training: standard or game version×time: training sessions 1, 2, and 3) repeated measures ANOVAs. Bonferroni post-hoc analyses were conducted. Effect sizes for all analyses (partial η^2 and Cohen's d)[30] are reported. As the value of η^2 depends on the number and magnitude of other effects in the model, the partial η^2 is considered a practical alternative.[31] All analyses were conducted with SPSS statistical software (V14.0; SPSS, Inc., Chicago, IL).

Results

Pre-training comparisons and comparability of control and game training

At pre-training, the two training conditions were not significantly different in terms of demographic variables and baseline characteristics (Table 1). In the control condition, the length of sequences (i.e., level of difficulty) was automatically adjusted to the child's performance, while in the game condition the sequence length, which ranged between three and six squares, was presented in random order. A one-way ANOVA showed no significant difference between the average length of sequences in the two training conditions (*M* control = 4.12; *M* game = 4.02), $F(1, 44) = 0.28$, $p = 0.60$.

Participant responses relating to gaming familiarity were subjected to χ^2 analysis. No group differences were revealed for level of game familiarity, $\chi^2 = 0.788$, $df = 1$, $p = 0.375$.

Motivation

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

Absence time. The average time (seconds) that children were not using the mouse was recorded automatically. Four scores were calculated: absence time for each training session and total absence time over all three sessions (see Table 2). The maximum total absence time per training session was 1,800 seconds. A 2×3 (conditions×training sessions) ANOVA with repeated measures showed a significant main effect for conditions, $F(1, 44) = 81.41$, $p < 0.001$. More time of absence was found in the control condition than in the game condition. Further, a significant main effect for training sessions was found, $F(2, 88) = 6.45$, $p < 0.01$. There were no significant interactions. Bonferroni post hoc analyses showed that the average absence time in the first session ($M = 397.22$, $SD = 37.38$) was significantly shorter than in the third session ($M = 521.44$, $SD = 39.22$), $p < 0.05$. Over all three sessions, children in the control condition did not use the training for 42% of the time compared with 9% in the game condition.

Number of sequences. The average number of sequences per training session and the total number of performed sequences are presented in Table 3. The maximum number of sequences that could be reproduced in each conditions was 110 (based on the minimum amount of time needed to reproduce 10 sequences). A 2×3 (conditions×training sessions) ANOVA with repeated measures showed a significant main effect for conditions, $F(1, 44) = 27.45$, $p < 0.001$. Significantly more sequences were performed in the game condition than in the control condition. Further, a significant main effect for sessions was found, $F(2, 88) = 4.50$, $p < 0.01$. No significant interaction effect was found, $F(2, 88) = 0.60$, $p = 0.55$. Bonferroni post hoc analyses showed that the average number of sequences in session 3 ($M = 51.56$, $SD = 2.52$) was significantly smaller than in session 2 ($M = 58.58$, $SD = 2.85$), $p < 0.05$.

Exit questionnaire. Children in the game condition significantly endorsed more often that they: liked the task ($\chi^2 = 17.752$, $df = 2$, $p < 0.01$), would like to have the task at home ($\chi^2 = 21.359$, $df = 1$, $p < 0.01$), would like to do the task at home ($\chi^2 = 16.461$, $df = 1$, $p < 0.01$), and would often use the task at home ($\chi^2 = 14.206$, $df = 1$, $p < 0.01$).

TABLE 2. TOTAL ABSENCE TIME (SECONDS) AND ABSENCE TIME FOR EACH OF THE THREE TRAINING SESSIONS IN THE GAME CONDITION AND CONTROL CONDITION

	Condition	M	SD	n	F	η_p^2
Absence time, first session	Game	107.68	192.91	25	55.92*	0.560
	Control	666.76	309.34	21		
Absence time, second session	Game	189.04	278.84	25	43.16*	0.495
	Control	758.57	308.90	21		
Absence time, third session	Game	177.16	279.10	25	77.04*	0.636
	Control	865.71	247.07	21		
Absence time, total	Game	473.88	615.70	25	81.41*	0.649
	Control	2291.05	750.68	21		

*$p < 0.001$.

Table 3. Total Number of Performed Sequences and Number of Sequences During Each of the Three Training Sessions in the Game Condition and Control Condition

	Condition	M	SD	n	F	η_p^2
Performed sequences, first session	Game	66.48	14.42	25	21.47*	0.328
	Control	47.14	13.70	21		
Performed sequences, second session	Game	70.88	22.07	25	18.60*	0.297
	Control	46.29	15.22	21		
Performed sequences, third session	Game	62.12	20.65	25	17.53*	0.285
	Control	41.00	11.28	21		
Performed sequences, total	Game	199.48	47.46	25	27.45*	0.384
	Control	134.43	34.18	21		

*$p < 0.001$.

Training performance

Training performance was evaluated using the percentage of incorrect sequences per session and the percentage of incorrect sequences over all three sessions. Only sequences of three to six squares were included in this analysis because in the game training the sequences varied between three and six squares. A 2×3 (conditions×training sessions) ANOVA with repeated measures showed a significant main effect for conditions. Significantly fewer incorrect sequences over all three sessions together were reproduced in the gaming condition (31% in the game and 49% in the control condition), $F(1, 44) = 21.89$, $p < 0.001$. No significant main effect for sessions or an interaction effect was found.

Training efficacy

Working memory. A 2×2 (conditions×pre-/post-test) ANOVA with repeated measures showed a significant interaction effect for conditions and time, $F(1, 49) = 8.30$, $p < 0.01$, $d = 0.80$. Post hoc analysis showed that memory span in the game training condition significantly increased from pre- to post-test ($t = 3.075$, $df = 26$, $p < 0.01$), while no significant increase was found in the control training condition ($t = -1.072$, $df = 23$, $p = 0.29$, two-tailed; see Table 4).

The number of sequences performed significantly differed between the two conditions (see above) and was taken into consideration as a covariate. With the number of performed sequences covaried out (ANCOVA), group differences remained significant: the game condition remained superior to the control condition, $F(1, 48) = 5.887$, $p = 0.019$, $d = 0.66$.

Discussion

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

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

It is not clear from our study which of the various elements of the game format contributed to superior training efficacy. Different forms of feedback, animation, control over when to perform a trial (training at one's own pace), use of levels, and a long-term goal are all elements of the game format.[32] To determine the impact of these elements, future research should systematically vary these elements.

Interestingly, positive results in the game condition were found after only three sessions of 30 minutes, while other WM training programs are much longer. Klingberg et al.,[20] for example, used 25 sessions. By using a gaming format, fewer training sessions may be necessary for WM training to be effective.

The majority of participants in the present study were boys, with only a small number of girls ($n = 9$). At intake, all children, girls included, reported that they had a computer at home on which they could play games (PC, Playstation, Nintendo, or XBOX). In fact, boys reported that they played games for an average of 8.7 hours per week, while girls reported playing games for an average of 8.2 hours, indicating that the amount of time boys and girls with ADHD reported playing games at home did not differ greatly. Some authors have suggested that in the general population boys play games more frequently than girls.[33] Despite the fact that the number of girls in the present study was very small, it is remarkable that boys and girls with ADHD did not differ in

Table 4. Scores on the Corsi Block Tapping Test (CBTT) in the Game Condition and Control Condition

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

Note: WM, working memory.

the amount of self-reported game playing. Moreover, at the end of the training, we asked the boys and girls in the game condition questions such as: "Would you like to play this computer game at home?", "How did you like the game?", and "If you would have this game at home, how often would you play it?" Girls who had performed the game-training did not differ from the boys in their answers to these exit questions. Although the number of girls in the game condition was small (6 out of 27), this finding suggest that girls with ADHD did not evaluate the game as less attractive than boys with ADHD, even though the game training was typically boyish (e.g., warlike with shooting and explosions). Given the small number of girls in our sample, no definite conclusions on the gender variable can be drawn. Future studies may examine whether, indeed, girls with ADHD are more inclined to play games than girls without ADHD.

An interesting question relates to the real-life implications of the present findings. Would, for example, participating in game-like training have a "spill-over" or generalization effect on children's learning in non-preferred areas? Or, is the implication that non-preferred areas must be modified for children with ADHD to learn? Klingberg et al.[2] found that the positive effects of their WM training generalized to non-trained executive functions and even to ADHD-related behaviors as rated by parents in real life, suggesting a "spill-over" effect. Similarly, Holmes et al.[34] found that the effects of their WM training in a computerized game environment generalized to non-trained mathematical ability, which improved 6 months following WM training. In the present study, we did not evaluate generalization effects. However, some evidence for generalization of the effects of our brief game-like WM training was found in another study we recently conducted in our lab.[35] Boys with ADHD who were trained in the same brief, game-like WM training again showed substantial improvement in WM, but also improved on a non-trained EF (i.e., inhibition). Moreover, ADHD-related behaviors as rated by the parents on a standardized behavior questionnaire also significantly decreased after training. Clearly, the generalization issue is an important one in the area of the remediation of EF, and future studies should investigate which cognitive functions can be trained and to what extent the effects of cognitive training generalize to real-world learning situations.

The findings of the present study should be considered in light of several limitations. First, a number of the elements in the new game task were not controlled for in the control condition, such as not adjusting the difficulty level of the task on a trial-by-trial basis in the game condition. Instead, trials of varying difficulty were presented in random order in the game condition. In designing the present study, in our opinion, adjusting the difficulty level on a trial-by-trial basis, as was done in the Klingberg et al. study,[20] did not fit with a game-like format and would eventually result in frustration and possibly a decrease in motivation. We chose therefore to present the difficulty level in a way that was more similar to computer games: the child would have to adjust himself to the level of the game. Generally, the level is challenging but not too difficult, as the aim was to keep the child interested and motivated to do the sequences. Thus not adjusting the difficulty level of the task on a trial-by-trial basis was one of the game elements added to our WM training. Whether this element is a critical one in terms of the impact of a game version on WM training should be examined in future research. Despite this difference between the game and the control condition, it should be noted that this element did not differentially affect the level of difficulty of the two training conditions, as the length of sequences to be reproduced in the two conditions did not differ significantly. Second, no information on the stability of the effects is available as no follow-up assessments were conducted.

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

Acknowledgment

We thank Harold de Groot (Shosho, Amsterdam, Netherlands) for his game input, and Rosalie Knuvelder, Marjolein Drenth, Merel Beemsterboer, and Anoek Drieman for their contribution to the data collection.

Disclosure Statement

No competing financial interests exist.

References

1. Barkley RA. Behavioral inhibition, sustained attention, and executive functions: Constructing a unifying theory of ADHD. Psychological Bulletin 1997; 121:65–94.
2. Sagvolden T, Sergeant JA. Attention deficit/hyperactivity disorder—From brain functions to behavior. Behavioural Brain Research 1998; 94:1–10.
3. Willcut EG, Doyle AE, Nigg JT, et al. Validity of the executive function theory of attention deficit/hyperactivity disorder: A meta-analytic review. Biological Psychiatry 2005; 57:1336–46.
4. Baddeley AD. (1986) *Working memory.* London: Clarendon Press.
5. Nigg JT. (2006) *What causes ADHD? Understanding what goes wrong and why*. New York: Guilford Press.
6. Douglas V. (1999) Cognitive control processes in attention-deficit hyperactivity disorder. In Quay H, Hogan A, eds. *Handbook of disruptive behavior disorders* New York: Kluwer Academic Publishing/Plenum, pp. 105–38.
7. Sagvolden T, Johansen EB, Aase H, et al. A dynamic developmental theory of ADHD predominantly hyperactive/impulsive and combined type. Behavioral Brain Science 2005; 28:397–419.
8. Luman M, Oosterlaan J, Sergeant JA. The impact of reinforcement contingencies on ADHD: A review and theoretical appraisal. Clinical Psychology Review 2005; 25:183–213.
9. Shanahan M, Pennington B, Wilcutt E. Do motivational incentives reduce the inhibition deficit in ADHD? Developmental Neuropsychology 2008; 33:137–59.

10. Sergeant JA, Oosterlaam J, van der Meere J. (1999) Information processing and energetic factors in ADHD. In Quay H, Hogan A, eds. *Handbook of disruptive behaviour disorders.* New York: Plenum, pp. 75–104.
11. Shaw R, Lewis V. The impact of computer-mediated and traditional academic task presentation on the performance and behaviour of children with ADHD. Journal of Research in Special Educational Needs 2005; 5:47–54.
12. Pfiffner L, Barkley R, DuPaul G. (2006). *Treatment of ADHD in school settings*. In Barkley RA, ed. *Handbook of attention deficit hyperactivity disorder*, 3rd ed. New York: Guilford Press.
13. Barkley RA. (2006) *Attention-deficit hyperactivity disorder. A handbook for diagnosis and treatment.* 3rd ed. New York: Guilford Press.
14. Emes C. Is Mr Pac Man eating our children? A review of the effects of videogames on children. The Canadian Journal of Psychiatry 1997; 42:409–14.
15. Tannock R. Television, videogames, and ADHD: Challenging a popular belief. The ADHD Report 1997; 5:3–7.
16. Koepp MJ, Gunn R, Lawrence A, et al. Evidence for striatal dopamine release during a videogame. Nature 1998; 393:266–8.
17. Lawrence V, Houghton S, Tannock R, et al. ADHD outside the laboratory: Boys' executive function performance on tasks in videogame play and on a visit to the zoo. Journal of Abnormal Child Psychology 2002; 30:447–62.
18. Ota K, DuPaul G. Task engagement and mathematics performance in children with ADHD: Effects of supplemental computer instruction. School Psychology Quarterly 2002; 17:242–57.
19. Shaw R, Grayson A, Lewis V. Inhibition, ADHD, and computer games: The inhibitory performance of children with ADHD on computerized tasks and games. Journal of Attention Disorders 2005; 8:160–8.
20. Klingberg T, Fernell E, Olesen, PJ, et al. Computerized training of working memory in children with ADHD: A randomized, controlled trial. Journal of the American Academy of Child & Adolescent Psychiatry 2005; 44:177–86.
21. American Psychiatric Association. (2000) *Diagnostic and statistical manual of mental disorders, 4th revised edition (DSM-IV-R).* Washington, DC: American Psychiatric Association.
22. Pelham WE, Gnagy EM, Greenslade KE, et al. Teacher rating of DSM-III-R symptoms for disruptive behavior disorders. Journal of Clinical Child Psychology 1992; 8:259–62.
23. Oosterlaan J, Scheres A, Antrop I, et al. (2000) *Handleiding Vragenlijst voor Gedragsproblemen bij Kinderen (VvGK)* [*Manual of the Disruptive Behavior Disorder Rating Scale (DBDRS)*]. Lisse, Netherlands: Harcourt.
24. Wechsler D. (1991) *Wechsler Intelligence Scale for children.* 3rd ed. San Antonio, TX: Psychological Corporation.
25. Kort W, Compaan EL, Bleichrodt N, et al. (2002) *WISC-III NL Handleiding*. [Dutch Manual]. Amsterdam: NIP.
26. Furgueson C, McGuffin P, Greenstein D, et al. Efficacy of the WISC-III short form for children diagnosed with ADHD. Archives of Clinical Neuropsychology 1998; 13:10–13.
27. Corsi PM. Human memory and the medial temporal region of the brain. Dissertation Abstracts International 1972; 34:819B.
28. Kessels RP, van Zandvoort MJ, Postma A, et al. The Corsi block-tapping task: Standardization and normative data. Applied Neuropsychology 2000; 7:252–8.
29. Geurts HM, Verté S, Oosterlaan J, et al. How specific are executive functioning deficits in attention deficit hyperactivity disorder and autism? Journal of Child Psychology & Psychiatry 2004; 45:836–54.
30. Cohen J. (1988) *Statistical power analysis for the behavioural sciences*. 2nd ed. Hillsdale, NJ: Lawrence Erlbaum.
31. Tabachnick BG, Fiddell LS. (2001) *Using multivariate statistics*. 4th ed. Boston: Allyn & Bacon.
32. Gee JP. Learning by design: Good video games as learning machines. E-learning 2005; 2:5–16.
33. Pleysier S, Wydooghe B. (2007) *Game-over? Over game- en filmgeweld, angst en onzekerheid* [*Game-over? On game- and film violence, anxiety and uncertainty*]. Antwerp, Belgium: Garant.
34. Holmes J, Gathercole SE, Dunning DL. Adaptive training leads to sustained enhancement of poor working memory in children. Developmental Science 2009; 12:9–15.
35. Van Es S. Treating ADHD with a computer game. Effects of a computerized working memory training on executive functions and ADHD-symptoms in boys. Unpublished masters thesis, University of Amsterdam, 2007.

Address correspondence to:
Dr. Pier J.M. Prins
Department of Clinical Psychology
University of Amsterdam
Roetersstraat 15
1018 WB Amsterdam
Netherlands

E-mail: p.j.m.prins@uva.nl