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Can Motivation Normalize Working Memory and Task Persistence in Children with Attention-Deficit/Hyperactivity Disorder? The Effects of Money and Computer-Gaming

Sebastiaan Dovis · Saskia Van der Oord · Reinout W. Wiers · Pier J. M. Prins

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

Keywords ADHD · Working memory · Reinforcement · Executive functioning · Motivation · Computer gaming · Cognitive functioning · WM

Introduction

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

Alternative theories suggest that motivational deficits are a core problem in ADHD (e.g., Haenlein and Caul 1987; Sergeant et al. 1999). These theories state that children with ADHD are less stimulated by reinforcement than typically developing children (possibly due to a dopaminergic deficit)

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

Only one study has looked at the impact of reinforcement on the visual-spatial WM performance of children with ADHD (Shiels et al. 2008). This study showed that the performance of children with ADHD on a visual-spatial WM task without feedback, improved when feedback and incentives were added. However, due to the lack of a typically developing control group, it could not be determined whether this reaction to reinforcement is specific for children with ADHD, nor whether their WM performance could be normalized by reinforcement.

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

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

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

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

We compared the performance of children with- and without ADHD on a visual-spatial WM task in four reinforcement conditions: Feedback-only, feedback and a small monetary incentive (1 euro), feedback and a large monetary incentive (10 euros), and a computer game version of the task. We expected that, in the Feedback-only condition, children with ADHD would perform worse on the WM task compared to children without ADHD (Martinussen et al. 2005), that the difference in performance between children with- and without ADHD would be smaller in the incentive conditions (1 euro, 10 euros, and game) than in the Feedback-only condition (Sergeant et al. 1999), and that this difference would disappear in the high incentive condition (10 euros; Haenlein and Caul 1987; Slusarek et al. 2001). Finally, we expected that although the mean WM performance of children with ADHD would improve in all incentive conditions, only gaming would improve the persistence of performance over time in these children (Shaw et al. 2005; Solanto et al. 1997).

Method

Participants

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

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

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

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

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

Procedure

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

During each test session, two of the four reinforcement conditions (Feedback-only, 1 euro, 10 euros and gaming) of

Table 1 Means and standard deviations of group demographics and characteristics

Measure	Group					
	ADHD		Controls			
	(n=30)		(n=31)			
	M	SD	M	SD	F/χ^2	p
Gender (M : F)	23 : 7	–	18 : 13	–	2.39	0.12
Age (years)	11.0	1.2	11.0	1.1	0.00	1.0
FSIQ	103	19.4	111	19.7	2.90	0.09
DBDRS parent						
Inattention	19.5	3.4	2.9	2.7	444.3	<.001
Hyperactivity/Impulsivity	16.8	3.8	2.4	2.5	309.5	<.001
ODD	11.5	3.6	2.0	2.0	165.7	<.001
CD	2.0	2.1	0.2	0.5	22.1	<.001
DBDRS teacher						
Inattention	15.0	5.9	1.4	2.3	119.2	<.001
Hyperactivity/Impulsivity	12.1	7.7	1.3	1.9	48.1	<.001
ODD	7.0	3.4	0.6	0.9	84.2	<.001
CD	1.13	1.6	0.1	0.3	11.7	0.001
Weekly spendable income (in euros)	2.0	1.1	2.4	1.8	1.16	0.29
Computergame experience (hours per week)	4.9	3.9	4.4	2.9	0.34	0.56
Dyslexia (Yes : No)	6 : 24	–	2 : 28	–	2.46	0.12

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

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

The WM Task

The Chessboard Task[1] is a newly developed WM performance measure based on two WM tasks; the Corsi Block Tapping Task (Corsi 1972) and the subtest Letter-Number Sequencing from the Wechsler Adult Intelligence Scale (WAIS; Wechsler 1958). The task, described in Fig. 1, assesses the ability to both maintain and manipulate/reorganize visual-spatial information that is relevant for the task at hand. To make it easier to remember the instructions during the task a brief instruction ('first press green, then press blue, both in the same order as they were presented') was continuously visible in the corner of the screen. To ensure that every presented sequence had to be reorganized (engaging the central executive), the order of stimuli was random with the restriction that in every sequence at least one blue stimulus was presented before the last green stimulus. To ensure optimal attention of the participant during each trial, the task was self-paced (the participant had to click to start a trial). Every square that lit up was presented with the same brief tone. To prevent the use of strategies (e.g., positioning the mouse-cursor on one of the squares in the sequence to unburden WM) the mouse-cursor was not visible during sequence presentation. The difficulty level of the task was adaptive; the first sequence consisted of two stimuli and after two consecutive correct reproductions, the sequence was increased by one stimulus. After two consecutive incorrect reproductions, the sequence was shortened by one

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

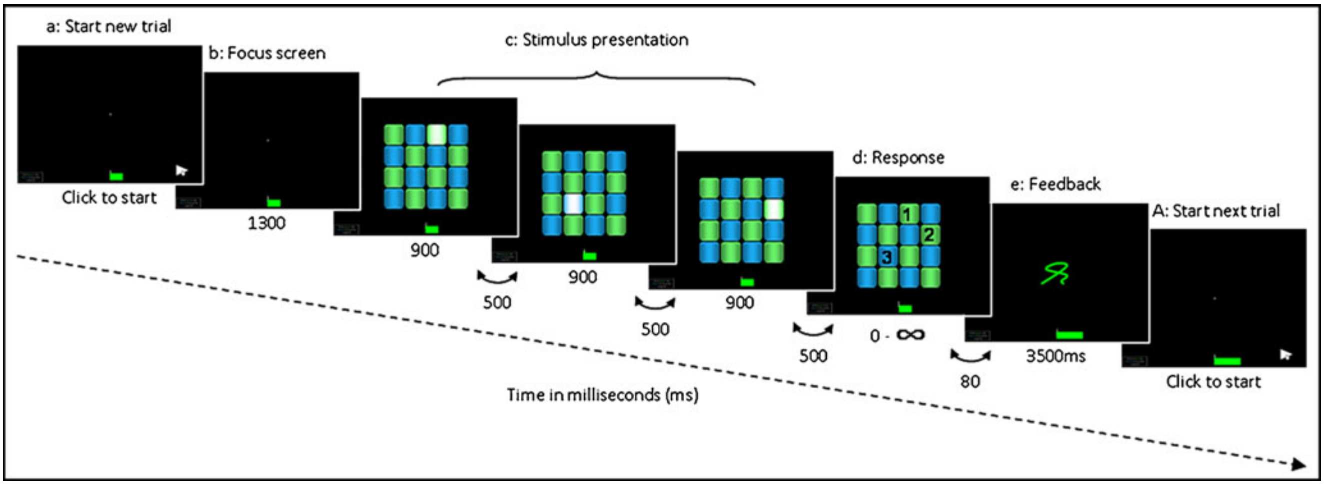

Fig. 1 A trial on the Chessboardtask. **a** To start a trial the arrowhead-button in the bottom-right corner of the screen has to be clicked. **b** Then the focus screen (a black screen with a little white cross) is presented. **c** Subsequently, a sequence of stimuli (squares that light up) is presented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

stimulus. The minimum sequence length consisted of two stimuli and there was no maximum sequence length. Because the difficulty level adapted to individual performance, the amount of positive and negative feedback received, was approximately the same (55% reward, 45% response-cost) for every child and in every condition.

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

In the game condition the WM-task was presented in the context of a computer-game. Game elements were added, such as varied and stimulating animation, gameplay, storylines, upgrades and competition. In this game the child had to save the world by using his or her Megabot (a big battle-robot) to conquer the various robot-enemy occupied levels. Levels could be conquered by destroying all occupying enemy-robots, without taking too much damage. To destroy an enemy-robot, complete an objective (rewards), or protect his or her Megabot from being damaged (response-cost) the child had to correctly reorganize the WM-task sequence that was presented (sequence presentation and type of feedback [e.g., immediate and consistent] was the same as in the other conditions; *see* Fig. 2b). With each level completion the child got higher in rank, and received upgrades (e.g., stronger armor). After 60 trials a screen was presented that indicated that the enemies surrendered, the player had won the game, and the game was over.

Dependent Measures Because the first 12 trials on the WM-task were needed to reach the child's optimal difficulty level, these trials were excluded from analysis. [2] WM performance in every reinforcement condition was measured by the mean sequence length of the last 48 trials. To study task performance over time, we divided the trials into three parts: early performance (mean sequence length on trials 13–20), middle performance (mean sequence length on trials 21–40) and later performance (mean sequence length on trials 41–60). [3]

Data Analysis

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

Results

Counterbalancing

Order effects were controlled for by counterbalancing the sequence in which the reinforcement conditions were presented. There were no significant differences between the two groups in the number of times the reinforcement conditions (FO, 1 euro, 10 euros and game) were administered first ($\chi^2(3)=0.05, p=0.997$), second ($\chi^2(3)=0.05, p=0.997$), third ($\chi^2(3)=0.18, p=0.981$) or last ($\chi^2(3)=0.05, p=0.997$).

Mean WM Performance

A 2×4 (group x reinforcement conditions) repeated-measures ANOVA with mean sequence length as dependent variable, showed a main effect of reinforcement condition, $F(3,177)=7.74$, $p<0.001$, $\eta_p^2=0.12$, a main group-effect, $F(1,59)=13.87$, $p<0.001$, $\eta_p^2=0.19$, and a significant interaction between reinforcement condition and group, $F(3,177)=3.69$, $p=0.01$, $\eta_p^2=0.06$ (*see* Fig. 3). To interpret this interaction, we used simple contrasts for the reinforcement effect. Compared to the FO condition, the difference in performance between the ADHD and control children was smaller when incentives were used; 1 euro, $F(1,59)=4.70$, $p=0.034$, $\eta_p^2=0.07$, 10 euros, $F(1,59)=9.85$, $p=0.003$, $\eta_p^2=0.14$, and gaming, $F(1,59)=4.34$, $p=0.040$, $\eta_p^2=0.07$. Other pair-wise differences in group effects were non-significant.

Differences between reinforcement conditions within each group were tested with paired t-tests. Compared to FO, incentives significantly improved the mean performance of children with ADHD (FO<1 euro, $t(29)=-2.86$, $p=0.008$; FO<10 euros, $t(29)=-3.98$, $p<0.001$; FO<game, $t(29)=-3.45$, $p=0.002$), but not of controls (FO=1 euro, $t(30)=-0.41$, $p=0.682$; FO=10 euros, $t(30)=-0.37$, $p=0.711$; FO=game, $t(30)=-1.92$, $p=0.070$). Differences between the incentive conditions were non-significant in both children with ADHD and controls.

Performance differences between the ADHD and control children in each reinforcement condition were tested in a multivariate analysis. Children with ADHD showed lower mean performance in the FO ($F(1,59)=19.57$, $p<0.001$, $\eta_p^2=0.25$), 1 euro ($F(1,59)=11.55$, $p=0.001$, $\eta_p^2=0.16$), 10 euros ($F(1,59)=6.11$, $p=0.016$, $\eta_p^2=0.09$) and game condition ($F(1,59)=9.35$, $p=0.003$, $\eta_p^2=0.14$), compared to controls. Even the mean performance of children with ADHD in the highest incentive conditions (10 euros and game) was significantly lower than the mean performance of controls in the FO condition (10 euros ADHD vs. FO Controls, $F(1,59)=5.99$, $p=0.017$, $\eta_p^2=0.09$; Game ADHD vs. FO Controls, $F(1,59)=5.93$, $p=0.018$, $\eta_p^2=0.09$) (*see* Fig. 3).

Time on Task

For the ADHD group, a 3×4 (time on task x reinforcement conditions) repeated-measures ANOVA showed a main effect of reinforcement condition, $F(3,87)=6.14$, $p=0.001$, $\eta_p^2=0.18$, a main effect of time on task, where performance decreased with time, $F(2,58)=3.47$, $p=0.038$, $\eta_p^2=0.11$, and a significant interaction between reinforcement and time on task, $F(6,174)=2.72$, $p=0.015$, $\eta_p^2=0.09$ (Fig. 4, left hand panel). In order to interpret this interaction, we used linear contrasts for the time on task effect and simple

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

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

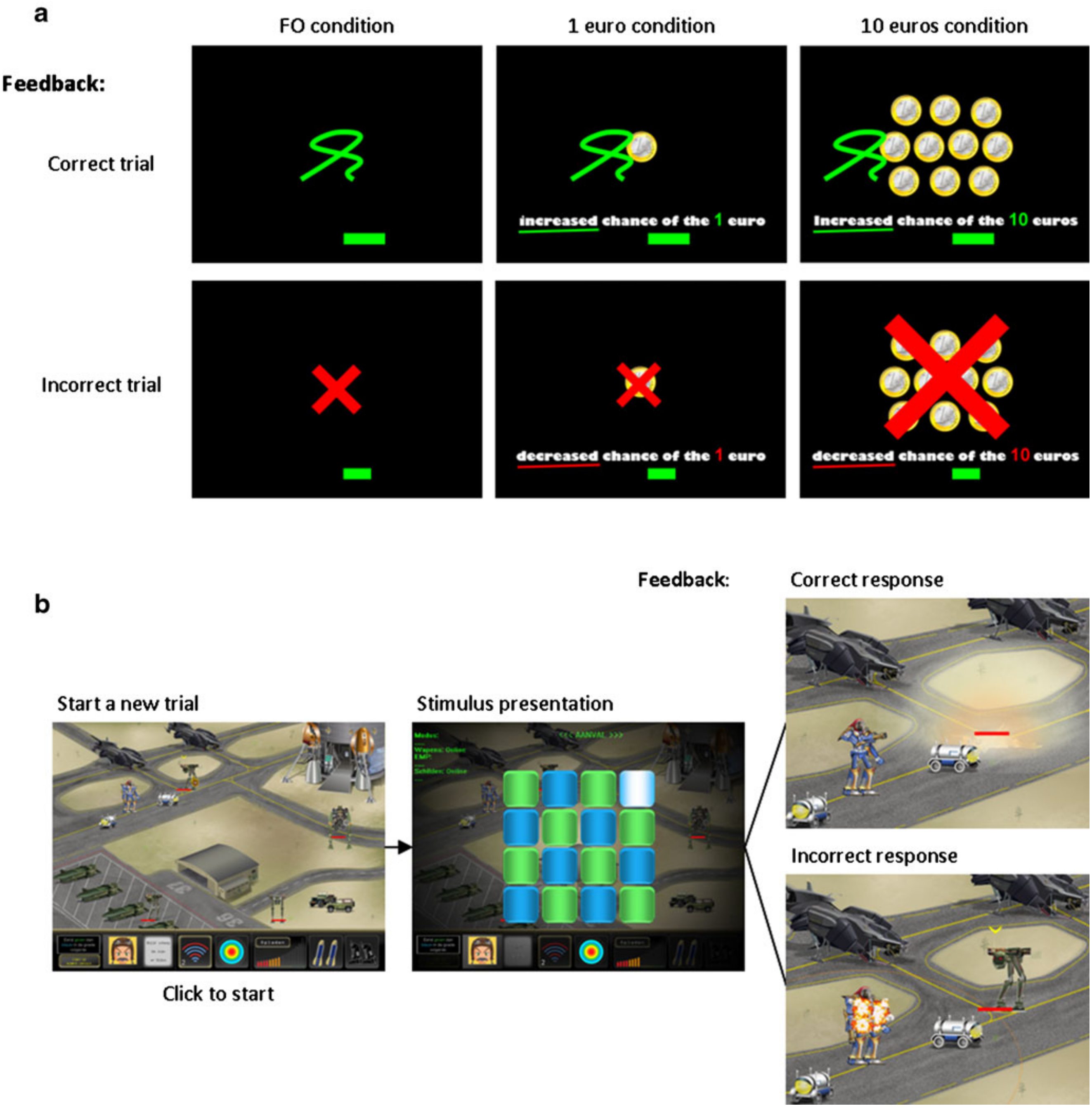

Fig. 2 **a** Visual feedback in the Feedback-Only (FO) and monetary conditions **b** A trial in the game condition. The Megabot stands on the left, the enemies to the right

contrasts for the reinforcement effect. In this way we examined whether the linear decrease in performance due to time on task differed between the reinforcement conditions. As compared to the FO condition, the linear decrease in performance was significantly less in the game condition, *F* (1,29)=8.80, $p=0.006$, $\eta_p^2=0.23$, and in the 10 euros condition, *F* (1,29)=7.49, $p=0.010$, $\eta_p^2=0.21$, but not in the 1 euro condition, *F* (1,29)=0.44, $p=0.511$, $\eta_p^2=0.02$. Other pair-wise condition differences in time on task effects were non-significant, except that the linear decrease in performance was less pronounced in the 10 euros condition as compared to the 1 euro condition, *F* (1,29)=4.31, $p=0.047$, $\eta_p^2=0.13$. These results indicate that only strong incentives (10 euros and gaming) can reduce time on task effects in the ADHD sample.

This effect of reinforcement intensity on time on task was not observed in control children. In this group, a 3×4 (time on task x reinforcement conditions) repeated-measures ANOVA

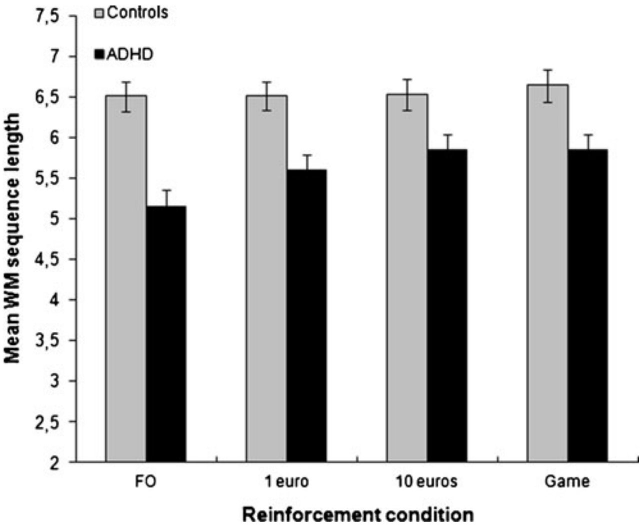

Fig. 3 Mean performance of children with ADHD and control children on the visual-spatial working memory (WM) task in the Feedback-only (FO), 1 euro, 10 euros, and Game condition

showed no main effect of reinforcement condition, $F\,(3{,}90)=1.16$, $p=0.330$, $\eta_p^2=0.04$, no main effect of time on task, $F\,(2{,}60)=1.17$, $p=0.317$, $\eta_p^2=0.04$, and no significant interaction between reinforcement and time on task, $F\,(6{,}180)=0.15$, $p=0.989$, $\eta_p^2=0.005$ (Fig. 4, right hand panel).

These results thus indicate that in the ADHD group there is a pronounced time on task effect which can only be diminished by providing strong incentives (1 euro was insufficient), whereas in the control group, this time on task effect was absent. This conclusion was further supported in a 2×3×4 (group x time on task × reinforcement conditions) repeated-measures ANOVA. Linear contrasts for the time on task effect and simple contrasts for the reinforcement effect indicated that the reduction of time on task effects in the 10 euro condition, as compared to the FO condition, and as compared to the 1 euro condition, was more pronounced in children with ADHD than in controls (10 euros vs FO: $F\,(1{,}59)=3.206$, $p=0.041$, $\eta_p^2=0.07$; 10 euros vs 1 euro: $F\,(1{,}59)=3.846$, $p<0.05$, $\eta_p^2=0.06$). Finally, four additional 3×2 (time on task x group) repeated-measures ANOVAs (one for each reinforcement condition) indicated that children with ADHD only showed a stronger decrease in performance over time than control children in the FO condition ($F\,(2{,}118)=3.31$, $p=0.040$, $\eta_p^2=0.05$) and in the 1 euro condition ($F\,(2{,}118)=3.97$, $p=0.021$, $\eta_p^2=0.06$), but not in the 10 euros condition ($p=0.671$) or in the game condition ($p=0.643$).

Discussion

This study examined the impact of different intensities and forms of reinforcement on the performance of children with combined-type ADHD and typically developing control children on a visual-spatial WM task. The present findings showed that children with ADHD performed worse on the WM task compared to control children, and although incentives improved the WM performance of children with ADHD, even the strongest incentives (10 euros and gaming) were unable to normalize their performance completely. Furthermore, unlike control children, children with ADHD showed a decrease in performance over time. However, the strongest incentives (10 euros and gaming) were able to normalize their persistence of performance, whereas small incentives (1 euro) had no effect. This suggests that, although motivational deficits might explain problems with persistence of performance in children with ADHD, it

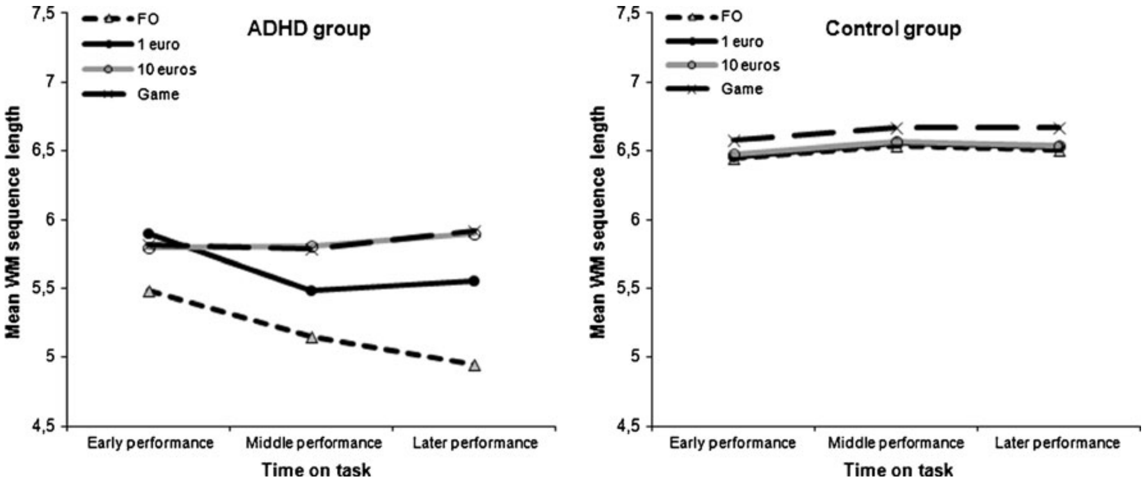

Fig. 4 Mean performance over time of children with ADHD, and control children on the visual-spatial working memory (WM) task in the Feedback-only (FO), 1 euro, 10 euros, and Game condition

cannot completely explain the aberrant visual-spatial WM performance of these children.

Compared to feedback-only, incentives improved performance in children with ADHD, but not in control children. This suggests that for typically developing children, providing feedback-only constituted sufficient reinforcement to reach optimal performance, while this was clearly not the case for children with ADHD. This is in line with the idea that children with ADHD have an abnormal sensitivity to reinforcement (e.g., Sergeant et al. 1999), and, more specifically, is consistent with the theory of Haenlein and Caul (1987) which suggests that children with ADHD require higher amounts of reward in order to perform optimally due to an elevated reward threshold. No support was found, however, for Haenlein and Caul's hypothesis that a large amount of reward would normalize performance in children with ADHD. That is, although the persistence of performance over time was normalized by high reinforcement, executive performance was still lower in children with ADHD. Our findings therefore support models that state that multiple deficits, both executive and motivational, give rise to ADHD (e.g., the dual pathway model, Sonuga-Barke 2002), and models that emphasize the intertwined nature of executive control and motivation to control (Castellanos et al. 2006; Gladwin et al. 2011; Sonuga-Barke et al. 2008).

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

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

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

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

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

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Appendix

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

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

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

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

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

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

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

If you have earned this 1 euro, you can take it home and do with it what you want:
The 1 euro is yours.

You can earn this 1 euro by performing well enough on this task

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

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

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

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

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

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