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Effects of physical activity on executive function and motor performance in children with ADHD

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ABSTRACT

Children with Attention-Deficit/Hyperactivity Disorder (ADHD) often show major deficits in motor and cognitive abilities. Pharmacological treatment is commonly used to reduce ADHD symptoms. However, non-pharmacologic treatment methods would be preferred by parents, children and psychiatrists. Physical activity (PA) has been demonstrated to improve cognitive functioning in healthy populations. It can be hypothesized that there are similar beneficial effects in children with ADHD, however, very little is known about this issue. The purpose of the present study was to determine whether PA improves cognitive performance in children with ADHD.

A total of 43 children with ADHD (32 boys and 11 girls) aged between seven and 12 years took part in the study. To investigate whether potential effects on executive functioning depend on the kind of PA, two different 12-week training programs were implemented. The study-design consisted of two experimental groups (EG1, $n = 13$; EG2, $n = 14$) and a wait-list control group (CG, $n = 16$). Participants in EG1 took part in a training which focused on the abilities ball handling, balance and manual dexterity. Participants in EG2 group were trained in sports without a specific focus. The children in the CG group received no intervention. Participants completed assessments of working memory (WM) and motor performance before, immediately after the first training week and one week after the last session. After the 12-week intervention period, several measures of the EG1 and EG2s significantly improved over time. Furthermore, between group comparisons demonstrated significant improvements in both EG1 and EG2 compared to the CG in variables assessing WM performance and motor performance. These findings support the hypothesis that long-term PA has a positive effect on executive functions of children with ADHD, regardless of the specificity of the PA. The outcomes indicated that regular PA can be used as a complementary or alternative non-pharmacologic treatment for ADHD.

1. Introduction

Attention-Deficit/Hyperactivity Disorder (ADHD) affects 3–7% of the school-aged population, which makes it the most prevalent psychological disorder of childhood (Polanczyk, de Lima, Horta, Biederman, & Rohde, 2007; Wohnhas-Baggerd, 2008). In addition to primary problems of ADHD (i.e. impulsivity, hyperactivity, and inattention), affected children often reveal deficits in executive functions (EF) (Shoemaker et al., 2011; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005; Yang

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et al., 2011). EFs, are often described as the top-down control of cognitive processes and consist of the components working memory (WM), response inhibition, and set shifting. Several studies with ADHD children have demonstrated significant deficits in WM and the ability to inhibit responses (Alloway, 2011; Biedermann et al., 2008; Brocki, Randall, Bohlin, & Kerns, 2008). ADHD is most often treated pharmacologically using methylphenidate. Due to the proven effectiveness and the high response rate it is often the first choice of available treatment methods (Bedard, Martinussen, Ickowicz, & Tannock, 2004; Holmes et al., 2010; Klingberg et al., 2005). Yet, there are numerous side effects such as headache or lack of appetite. For this reason, many parents are searching for alternative treatment methods. In addition to cognitive impairments, children with ADHD often experience deficits in motor abilities. These motor impairments are reflected in a delayed motor coordination, sluggish gross motor movements and poor graphomotor ability (Barkley, Edwards, Laneri, Fletcher, & Metevia, 2001; Fliers et al., 2008; Kramann, 2008; Pitcher, Piek, & Hay, 2003; Willcutt et al., 2005). Research has shown that particularly children between six and nine years of age are affected and that there are no gender-related differences (Fliers et al., 2008; Meyer & Sagvolden, 2006; Polderman, Van Dongen, & Boomsma, 2011). Although the effect of a pharmacologic treatment on motor functions has been investigated in some studies, there is no conclusive evidence supporting a positive effect of stimulant medication on motor deficits in children with ADHD (Stray, Stray, Iversen, Ruud, & Ellersten, 2009; Harvey et al., 2007).

1.1. Correlation between executive functions and motor skills/physical activity

The relationship between motor performance and cognitive performance has been demonstrated in healthy children (Piek et al., 2004). The study examined a total of 238 subjects (121 boys, 117 girls) aged between six and 15 years with the aim to explore the association between inattention, specific domains of EF and motor ability. The measurements included tasks assessing response inhibition, WM, the ability to plan and motor ability. The authors found a strong association between attention and motor coordination and several weak significant relationships between motor ability and EF tasks. A clinical sample of children with developmental coordination disorder (DCD), who suffer from deficits in fine and gross motor coordination, was investigated by Alloway (2011). Having found these motor deficits alongside significant impairments in WM performance, lead to the conclusion that there is a relationship between EF and motor abilities in these children as well. There are only few investigations addressing this issue in children with ADHD, yet. For example, Davis, Pass, Finch, Dean, and Woodcock (2009) found a strong correlation between sensory-motor functioning and cognitive processing in 67 children with ADHD children. Unfortunately, due to the lack of assessments of individual EF domains it was not possible to make any statements concerning a correlation between each domain and motor abilities. To close this knowledge gap, we examined the relationship between EF and motor performance in children with ADHD (Ziereis & Jansen, 2014). Fifty children (39 boys, 11 girls) aged between 7 and 12 years ($M = 8.95$, $SD = 1.43$) were assessed in EF performance and motor abilities. Each child was tested in an individual test session with a duration of one and a half hours. In order to measure verbal and visuo-spatial WM performance, two tasks of the "Hamburg-Wechsler-Intelligenztest für Kinder – IV" (Hawik – IV) (digit span forward/ backward and letter–number-sequencing) and the "Corsi-block-tapping test" were used (Pagulayan, Busch, Medina, Bartock, & Krikorian, 2006; Petermann & Petermann, 2010). The "Go/No-Go Task" was chosen to measure inhibition control and the "Movement Assessment Battery for Children" (M-ABC 2) (Petermann, 2008) was used to assess motor abilities. The results showed a significant positive correlation between WM and motor performance in children with ADHD. Specifically, it emerged that WM performance is connected to the motor abilities catching and aiming, manual dexterity and balance. No relationship was found between inhibition control and motor performance.

The relationship between cognition and physical activity (PA) has already been investigated extensively. Sibley and Etnier (2003) summarized the results of 44 studies pertaining to PA and cognition in children. The obtained value for the overall effect size (ES) of 0.32 is significant and indicates a positive relationship between PA and cognitive performance in general. Padilla, Pérez, and Adrés (2013, 2014) explored whether a high level of physical fitness can be associated with better inhibitory abilities or a higher WM capacity. The results found in both investigations support an association between long-term exercise, inhibitory abilities, and WM capacity. Unfortunately, there is a paucity of studies addressing this issue in children with ADHD. Gapin and Etnier (2010) measured PA (using an accelerometer) and the performance in four EF tasks of 18 boys with ADHD (M age = 10.61). The authors did not find any significant correlations, but merely a tendency toward a positive relationship between the extent of PA and particular domains of EF.

1.2. Effects of physical activity on executive functions

Because EF is related to motor skills and PA, one can hypothesize that improved motor abilities or an increased PA could lead to enhanced EF. This hypothesis has been supported in a non-clinical population of children and adolescents by Best (2010). Best (2010) summarized experimental studies that investigated the effects of aerobic exercise on EF tasks. In his review he distinguished studies which focused on long-term exercises and studies which determined the immediate effects of exercise. The review demonstrated improvements in EF by short-term as well as long-term exercises and suggested a transient facilitation of EF by single bouts of aerobic exercise and enduring improvements to EF after a continued participation in aerobic exercise. Although Sibley and Etnier (2003) suggested "that any type of physical activity will ultimately benefit cognitive performance" (p. 252), Best (2010) concluded that further research examining different forms of exercise and their impact on EF is necessary. Furthermore, he suggested that "the interaction of aerobic activity alone influences EF, but that the interaction of aerobic activity and cognitive engagement has an even stronger effect" (Best, 2010,

p. 347). Budde, Voelcker-Rehage, Pietraßyk-Kendziorra, Ribeiro, and Tidow (2008) assessed the influence of an acute bout of coordinative exercise (CE) on cognition in 115 healthy adolescents aged 13–16 years. The participants consciously chose CE, because "coordinative exercise is known to involve an activation of the cerebellum which besides motor functions influences a variety of neurobehavioral systems including attention, working memory, and verbal learning and memory" (Budde et al., 2008, p. 220). The recruited children completed five different CE for 1.75 min each, selected from special coordinative training forms for soccer and exercises from the Munich Fitness Test (Rusch & Irrgang, 1994). At the same time, the control group (CG) completed a normal sport lesson for 10 min. An attention test was used before and immediately after 10 min of CE respectively leisure sport in order to assess acute effects on neuropsychological performance in the areas of attention and concentration. Although the results revealed an improved performance in both groups, the progression in the CE group was significantly higher. The authors concluded that short bouts of exercise with a focus on coordinative skills could enhance attention in healthy individuals. Furthermore, they pointed out that attention "can be seen as a predictor for efficient cognitive control and academic performance" (Budde et al., 2008, p. 222). The issue whether regular aerobic exercise benefits particular executive functioning in healthy populations, was addressed in a review of Guiney and Machado (2013). Although the reviewed literature indicated beneficial effects on several EF domains in young and older adults, the authors stated that "In children, working memory capacity is the only executive function shown to benefit from chronic exercise,. . ." (Guiney & Machado, 2013, p. 84).

Davis et al. (2011) tested 171 overweight 7- to 11-year-old children to examine the effect of exercise on EFs. A standardized psychological battery assessing cognition had to be completed by the children at the beginning and after 13 week of intervention. The exercise program included activities like running games, jump rope, and modified basketball and soccer games. Each day the children either participated in a single session or two exercise sessions of 20 min length. The authors found that regular aerobic exercise over a period of 3 months improved cognitive performance in overweight children, regardless of the provided intervention dose.

A literature overview concerning comparable investigations of clinical populations suffering from ADHD was created by Gapin, Labban, and Etnier (2011). The authors reviewed published and unpublished research investigating the effects of PA on cognitive performance and behavior in ADHD samples. Firstly, they mentioned the already established, beneficial effects of long-term and acute PA on cognitive performance in healthy subjects. Secondly, the authors noted that "there is a relatively large literature addressing the effects of PA on the cognitive abilities of older adults at risk for cognitive decline" (Gapin et al., 2011, p. 70). Moreover, the authors cited a lack of research exploring potential benefits of PA in participants who have behavioral and cognitive impairments, such as children with ADHD. They hypothesized that those subjects might have even greater cognitive benefits than those without ADHD. Before some relevant studies were listed, Gapin et al. emphasized that not all of the mentioned investigations have been published, that they were often lacking a CG as well as an ADHD-sample which was clinically diagnosed. Medina, Netto, and Muszkat (2009) examined the effects of an acute, high intensity PA on cognitive performance in boys with ADHD. After a 30-min exercise on a treadmill, participants improved significantly in sustained attention. The results indicated that more physically active children perform better in WM, inhibition and processing speed tasks compared to more inactive children. However, more research is required to substantiate these results. In particular, more experimental studies including more rigorous designs and clinically diagnosed populations are needed in order to gain adequate power. The latest study addressing the effects of PA on EF in an ADHD sample assigned 30 children to either an aquatic exercise or a waiting CG and assessed inhibition control and motor abilities prior and after an 8-week exercise intervention (Chang, Hung, Huang, Hatfield, & Hung, 2014). One particular main group effect indicated that an exercise program involving both quantitative and qualitative exercise characteristics facilitates the restraint inhibition component of behavioral inhibition in children suffering from ADHD.

1.3. Goal of this study

Children with ADHD often experience deficits in motor abilities and EF. Although an improvement of these deficits can be achieved by pharmacological treatments, parents increasingly ask for non-pharmacological alternatives due to numerous side effects. The positive relationship between EF and motor abilities and between EF and PA in healthy and few clinical samples may suggest that an improvement of motor abilities and increased PA could affect EF performance in a positive way. Studies examining the impact of PA on EFs in healthy subjects strengthened this suggestion by indicating significant positive effects on certain EF domains. The lack of research and the suggestions of Gapin et al. (2011) concerning further investigations combined with the parents' demands for alternative treatment methods led us to the current intervention study. The aim of this study was to determine whether there are beneficial effects of PA on EF in children with ADHD. Furthermore, we considered the question whether the kind of PA has an impact on these effects. Based on the correlations found in our previous research (Ziereis & Jansen, 2014), we focused on training of catching and aiming, balance and manual dexterity for one of our two experimental groups (EG1). The PA program of the second exercise group (EG2) included sports with low demands on the mentioned abilities. In this context, we further investigated the short-term and the long-term effects of PA on EF performance. Because no significant relationship between inhibition control and motor skills was found in our previous investigation (Ziereis & Jansen, 2014), this study did not include measurements of response inhibition. We hypothesized cognitive improvements in all WM variables for both EGs, whereas the waiting CG would remain at the pre-test level. Due to the previously found correlations between manual dexterity/catching and aiming and EF performance

(Ziereis & Jansen, 2014), we additionally hypothesized a greater improvement in each WM variable after a short-term as well as after a long-term intervention in the EG1 compared to the EG2.

2. Materials and methods

2.1. Participants

A sample of 43 children diagnosed with ADHD (32 boys and 11 girls) between the ages of seven and 12 years ($M = 9.45$, $SD = 1.43$) took part in the study. Families were either invited to participate by their child's psychiatrist or were recruited from a local child and youth psychiatric practice. The medical diagnosis of ADHD was made by a resident child psychiatrist according to the criteria of *the International Statistical Classification of Diseases and Related Health Problems* (ICD-10) (Dilling, Mambour, & Schmidt, 1991). Clinical interviews with children, parents and teachers as well as rating scales like the "Fremdbeurteilungsbogen für Aufmerksamkeitsdefizit-/Hyperaktivitätsstörungen" (FBB-ADHS) (Döpfner, Lehmkuhl, & Steinhausen, 2006) or the "Testbatterie zur Aufmerksamkeitsprüfung für Kinder" (KITAP) (Zimmermann, Gondan, & Fimm, 2002) were, among others, used as diagnostic methods. All children, regardless of whether they were diagnosed as a predominantly inattentive (ADHD-PI), as a predominantly hyperactive-impulsive (ADHD-HI), or as a combined (ADHD-C) subtype of ADHD were included in the study. None of the children were treated with stimulant medication e.g. methylphenidate at the time of testing. Children with an IQ of less than 85, gross sensory or motor problems, the diagnosis of mental retardation rather than the diagnosis of autism, schizophrenia, epilepsy or the history of other neurological problems were excluded from the study. A pediatrician ascertained these criterions. Children were randomly assigned randomized either to one of two EGs (EG1 = 13, EG2 = 14) or to a waiting CG ($n = 16$). Prior to testing the groups did not differ significantly in age, BMI, and weekly hours of sport activities (cf. Table 1). Written informed consent was obtained from all parents as well as assent was received from all children before testing. The entire investigation continued for 14 weeks and took place between April and July 2013.

2.2. Materials

2.2.1. Working memory measures

The digit span (forwards/backwards) and the letter–number-sequencing task of the HAWIK – IV (Petermann & Petermann, 2010) were used to assess verbal WM performance.

The digit span-task (test–retest reliability $r = 0.84$) includes series of numbers, which are orally presented to the child. Each span length is to be managed two times. The span increases from two to nine numbers and must be repeated by the child in the same order in which it was presented. The test is being completed in forward- and backward-condition with different spans. A correct answer is rated with one point. The total score is converted in an age-adjusted index-score.

In the subtest letter–number-sequencing the experimenter reads a predetermined sequence of letters and numbers to the child. These sequences are to be repeated by the child, naming the letters in alphabetical order subsequently to the numbers in ascending order. For each correct repetition the child receives one point and the test is terminated after three incorrect answers. The achieved number of points is converted in a standardized index-score. The calculated index-score "working memory" is made up of the two index-scores achieved in the previously mentioned subtests. The test–retest reliability is $r = 0.91$ (Petermann & Petermann, 2010).

To measure visuo-spatial WM performance, the Corsi block tapping test was used (Pagulayan et al., 2006). The test apparatus includes a board containing nine cubes labeled from one to nine on one side, which is positioned between the child and the experimenter. Only the experimenter can see the numbers on the cubes of the board. During the task the child is asked to repeat predetermined sequences which have been tapped by the experimenter. The span increases after three sequences of the same length. The sequence length reached at least two times is the taken measure. After reproducing the sequences in the same order, the child has to complete the test repeating the sequences in the reverse order.

Table 1
Anthropometrical and fitness variables.

Variables	Group						$F(1,43)$	p
	Experimental group 1 ($n = 13$)		Experimental group 2 ($n = 14$)		Control group ($n = 16$)			
	Mean	*SD*	Mean	*SD*	Mean	*SD*		
Age (years)	9.2	1.3	9.6	1.6	9.5	1.4	.302	.741
Body mass index (BMI) (kg/cm^2)	18	2.4	18.4	2.4	18.7	2.4	.197	.822
Activities in a sports club (h/week)	1.3	1.7	0.9	1.5	1.1	1.2	.277	.759
Leisure sports (h/week)	4.8	5.2	4.2	2.8	4.5	2.5	.092	.913

2.2.2. Motor performance measures

The M-ABC 2 was chosen to measure motor performance (Petermann, 2008). The test-battery is designed to assess motor abilities in children between 3 and 16 years, containing a separation in three age bands (3–6, 7–10, and 11–16 years). The battery measures the overall motor performance and separately assesses main motor abilities such as manual dexterity, catching and aiming, and static and dynamic balance. For the age band 7–10 years: manual dexterity was measured using "placing pegs", "threading lace", "drawing trail"; catching and aiming was measured using "catching with two hands" and "throwing a bean bag onto a mat"; and static and dynamic balance was measured using "walking heel-to-toe forwards" and "hopping on mats". Children of the age band 11–16 were asked to complete subtests "turning pegs", "triangle with nuts and bolts" and "drawing trail" (manual dexterity), "catching with one hand" and "throwing a ball at wall mounted target" (ball skills), and "two board balance", "walking toe-to-heel backward" and "zig zag hopping" (balance).

After completion of the test, a total motor score and separate scores for manual dexterity, catching and aiming, and static and dynamic balance were assigned. The test–retest reliability is $r = 0.80$ (Petermann, 2008).

2.3. Procedure

The current study included a 12-week PA intervention program with two EGs participating in the program and a waiting control group. Informed consent was obtained of the parents before testing.

Children were tested individually one week prior to the start and one week after the last session. Children of the EGs were also assessed immediately after the first session. The measures described above were administered in a single session of one and a half hours and were conducted in a room at the University of Regensburg's Institute of Sport Science (EGs) or in a room at the surgery of the child and youth psychotherapist (CG). After the children were familiarized with the prepared room, they were asked to sit down facing the investigator at a table and were provided with a short description of the procedure. Standardized instructions of the tests were given to each participant and a practice trial was performed to ensure the child had an understanding of the tests.

The test session started with the tasks digit span (forwards/backwards) and letter–number-sequencing in order to measure verbal WM performance. Subsequently, the participant was asked to complete the Corsi block tapping test. After the series of cognitive tests, which lasted about forty-five minutes, the motor test was conducted. The subtests measuring manual dexterity, catching and aiming, and static and dynamic balance were carried out in the previously listed order. The motor test battery took approximately thirty minutes.

After the first week, in which the parents were informed and the 43 children were pre-tested by the experimenter, the intervention program started. Each child was assigned to a group containing up to five children. Boys and girls were mixed. Each of the six groups (three of the EG1 and three of the EG2) were instructed by two coaches. Prior to the start of the program, the coaches received training and practice in the implementation of the program to ensure reliable administration of the intervention and assessment procedures. All coaches were experienced in working with children or teaching physical activities.

The intervention included a single session of 60 min per week for each group. Although it was taken into consideration through personal experience that the intensity levels for both EGs were equivalent, no appropriate method was used to ensure this. Hence, it is not possible to make any statements about the exact intensity of the conducted program contents, which differed between the EGs. Figs. 1 and 2 show detailed overviews of both exercise programs. The intervention took place at facilities of the University of Regensburg's Institute for Sport Science between four and six o'clock in the afternoon.

Exercise program of the EG 1

EG 1			
week 1	week 2	week 3	week 4
parental information	catching, throwing and bouncing	balance training	acrobatics
pre-test	post-test 1		
week 5	week 6	week 7	week 8
targeting and throwing	tennis	slacklining*	juggling
week 9	week 10	week 11	week 12
beachvolleyball and -handball	juggling	slacklining*	coordinative exercises
week 13	week 14		
throwing and catching	post-test 2		

*Note. slacklining: a practice in balance that uses nylon or polyester webbing tensioned between two anchor points

Fig. 1. Exercise program of the EG1.

Exercise program of the EG 2

EG2								
week 1			week 2			week 3		week 4
parental information			sport games -relay races			swimming		swimming
pre-test			post-test 1					
week 5			week 6			week 7		week 8
wrestling games			climbing			climbing		orienteering
week 9			week 10			week 11		week 12
sport games -			gymnsatics			gymnastics -		track and fiel
relay races						trampoline		long jump
week 13			week 14					
track and field -			post-test 2					
sprint, hurdling								

Fig. 2. Exercise program of the EG2.

Immediately after the first session, each child was asked to complete the cognitive and motor tests to assess potential short-term effects of PA and coordinative exercises.

Exactly one week after the last session, each child of both EGs was individually assessed for long-term training effects. Children in the CG were post-tested 12 weeks after their individual pre-test without attending any sessions during the 12-week intervention period. The assessment tools and the duration of the post-tests did not differ from the pre-test sessions. Children who attended less than nine training sessions were excluded statistical analyses. A final total of 12 participants were included in EG1 (3 girls and 9 boys) and 11 children were included in EG2 (2 girls and 9 boys). The whole intervention program took place from mid-April until end of July 2013.

2.4. Statistical analysis

Prior to the analysis of cognitive and motor variables, a one-way analysis of variance (ANOVA) was conducted to determine whether the anthropometrical and fitness status of the three groups differed significantly. No differences were found between the groups. A second one-way ANOVA was used to compare pre-test measurements. No significant differences were found with the exception of lower CG performance in the variable Corsi block tapping forward compared to the EGs.

The first set of analyses compared all pre- and post-test (post session 1) outcomes of the EGs in order to assess potential short-time effects of PA and CEs. Therefore a series of 2×2 repeated measures ANOVAs with condition (EG1 vs. EG2) as a between-subjects factor and time (pre- vs. post-test 1) as a within-subjects factor was conducted.

The second set of 3×2 repeated measures ANOVAs was implemented determining long-time effects of PA on EF and motor abilities. In this case, we considered the within-subjects factor time with pre- and post-test 2 as well as group as a between-subjects factor (EG1, EG2, and CG). All previously mentioned cognitive outcome measures were analyzed. Due to significant group differences in the pre-test levels of the variable Corsi block tapping forward, the covariate "pre-test score" was included in the calculation. Following the ANOVAs, post hoc Tukey-Tests were undertaken if significant differences were observed. Statistical significance was assessed at alpha = .05.

3. Results

3.1. Short-term effects of PA on executive functioning

The analysis of measurements gained in the post-test 1 showed a significant main effect of time for the variable catching and aiming, $F(1,25) = 7.540$, $p < .05$, $\eta^2 = .23$. No other significant results were obtained.

3.2. Long-term effects of PA on executive functioning

Analysis of post-test 2 measurements demonstrated several significant results. There were three significant main effects of time for the following variables: (1) index-score WM, $F(1,33) = 17.800$, $p < .001$, $\eta^2 = .35$ (cf. Fig. 3), (2) digit-span forward, $F(1,33) = 24.261$, $p < .001$, $\eta^2 = .43$ (cf. Fig. 4), and (3) letter–number-sequencing, $F(1,33) = 6.128$, $p < .05$, $\eta^2 = .15$ (cf. Fig. 6). Furthermore, we found significant group $\times$ time interactions for the variables: (1) index-score WM, $F(2,33) = 10.075$, $p < .001$, $\eta^2 = .38$ (cf. Fig. 3), (2) digit span backward, $F(2,33) = 3.438$, $p < .05$, $\eta^2 = .17$ (cf. Fig. 5), and (3) letter–number-sequencing, $F(2,33) = 5.851$, $p < .01$, $\eta^2 = .26$ (cf. Fig. 6). Even though the initial ANOVAs showed significant interaction

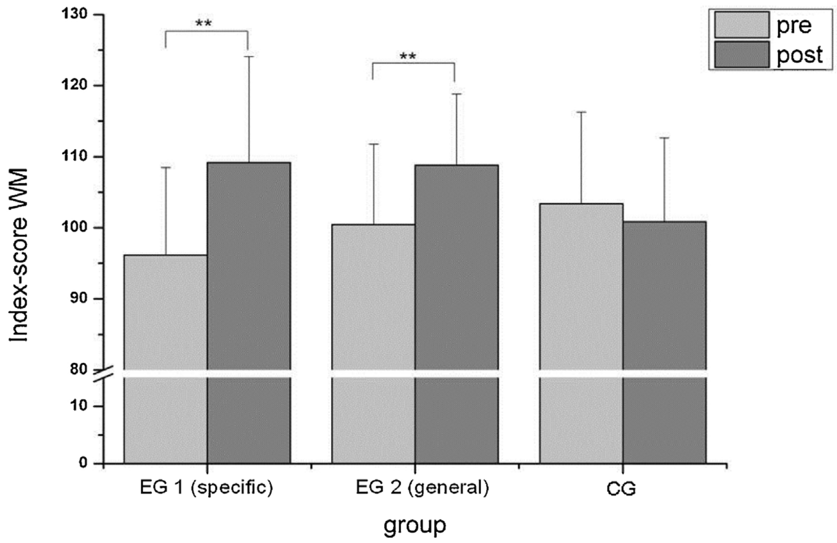

Fig. 3. Index-score WM at pre- and post-test in the experimental groups (EG1, EG2) and the control group (CG).

effects, the post hoc Tukey-Tests did not reveal any significant differences between each combination of both factors group and time.

The analysis of the motor measures yielded two significant group × time interactions for the variable catching and aiming, $F(2,33) = 8.197$, $p < .01$, $\eta^2 = .33$ (cf. Fig. 7) and for the variable total score M-ABC, $F(2,33) = 9.925$, $p < .001$, $\eta^2 = .38$ (cf. Fig. 8). The comparisons of individual groups (i.e. EG1 vs. CG, EG2 vs. CG, EG2 vs. CG, and EG1 vs. EG2) are separately analyzed through post hoc Tukey-Tests. These tests did not show significant differences between the EG1 and the EG2, the EG1 and the CG, and the EG2 and the CG for all motor-related variables.

4. Discussion

It was the aim of the current study to investigate the effects of physical activity (PA) on cognitive functioning, especially executive functions (EF) and motor performance in children with ADHD. We developed two 12-week PA programs with focus on specific versus unspecific PA. Results of a previously conducted study (Ziereis & Jansen, 2014) and results of Budde et al. (2008) suggested to specifically train catching and aiming, manual dexterity and balance (i.e. experimental group 1; EG1). In order to differentiate both training groups, we consciously focused the content of the other training group (EG2) on

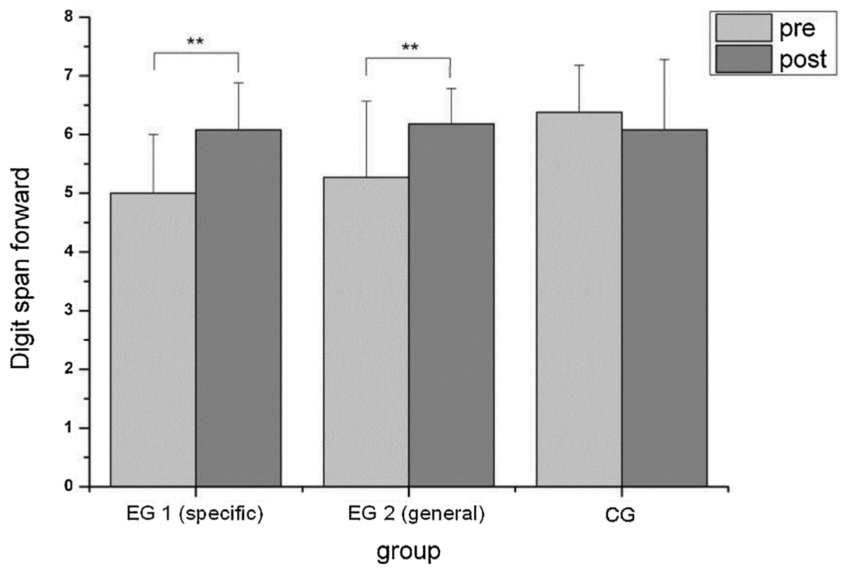

Fig. 4. Digit span forward at pre- and post-test in the experimental groups (EG1, EG2) and the control group (CG).

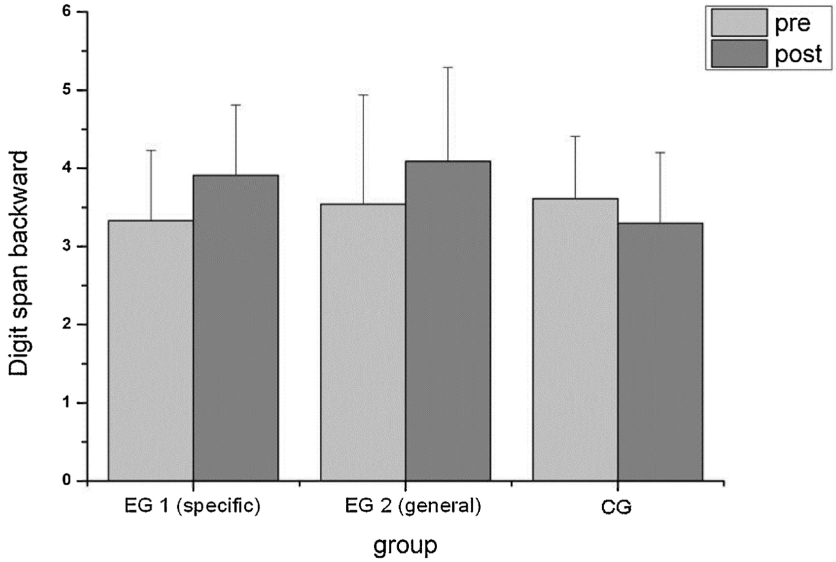

Fig. 5. Digit span backward at pre- and post-test in the experimental groups (EG1, EG2) and the control group (CG).

PA with low demands on the aforementioned abilities. The data obtained from the EGs and the waiting control group (CG) after the 12 weeks of intervention showed several significant changes in EF performance and motor development over time. The discussion will focus on EF measures and the results concerning cognitive performance.

The analysis for potential short-term effects on EF did not reveal significant differences between both EGs. Hence, we did not find any support for improved EF following a single session of PA.

There are several significant positive effects on EF performance following the 12 weeks of intervention. Unfortunately, these effects occurred in a first set of ANOVAs, but are missing when the groups were analyzed separately. A reason for the lack of significant results in the post hoc tests could be the low statistical power of the investigation. Due to this lack of power, we also considered the descriptive results as well as the effect sizes when interpreting the current findings.

Firstly, we found a significant interaction effect for the variable index-score WM, which includes all verbal WM measures. Similar findings were found for the variables of the corresponding subtests digit span backward and letter–number-sequencing. The corresponding figures (Figs. 3, 5 and 6) showing improvements in the EG-performances as well as decreases in the CG-performances. Although we could not show this in our statistical analysis, an improvement in the EGs compared to the CG can be supposed for the variables index-score WM, digit-span backward and letter–number-sequencing. These

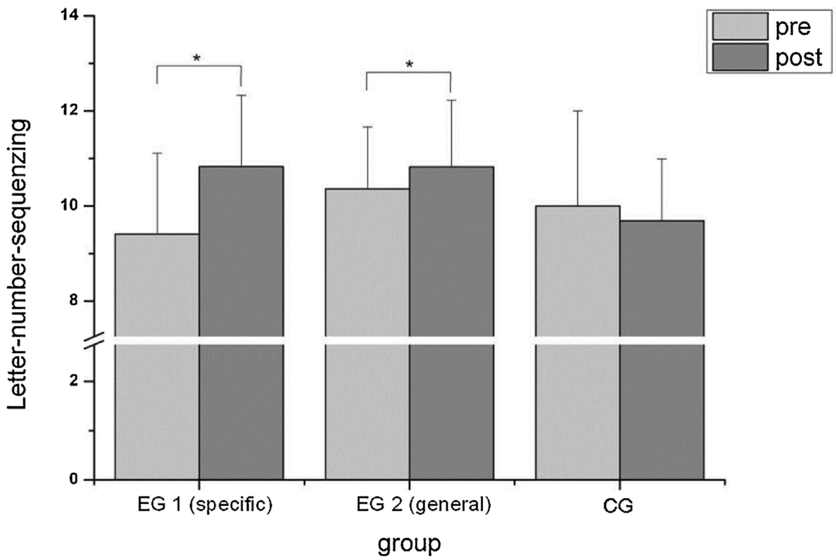

Fig. 6. Letter–number-sequencing at pre- and post-test in the experimental groups (EG1, EG2) and the control group (CG).

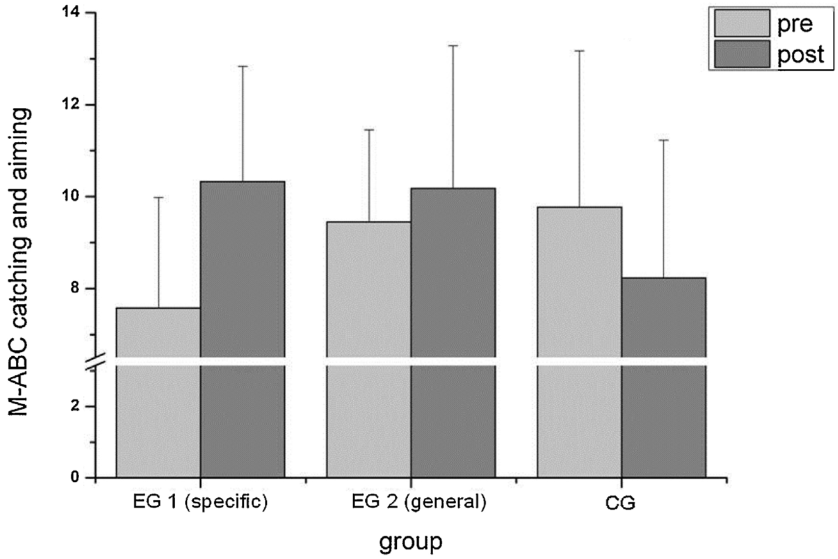

Fig. 7. Catching and aiming (M-ABC) at pre- and post-test in the experimental groups (EG1, EG2) and the control group (CG).

findings are partly consistent with those found in non-clinical populations of children and adolescents (Best, 2010). Best (2010) examined studies investigating immediate and long-term effects of PA on EF and found EF improvements in both cases. Although we did not find any short-term effects, we are able to confirm the positive effects of PA on EFs for children with ADHD after the 12-week intervention. Furthermore, we considered Best's claim for further research in investigating different forms of exercise. We developed a training program focused on manual dexterity, catching and aiming, and balance (EG1) as well as a program offering sports with low or no demands on these abilities (EG2). Before conducting the training programs, we hypothesized greater improvements in children participating in the EG1 compared to EG2. Yet, due to no significant differences between the EGs, we had to assume that both groups improved equally. This result underlines Sibley and Etnier's (2003) suggestion "that any type of physical activity will ultimately benefit cognitive performance" (p. 252). Unfortunately, it is inconsistent with the findings of Budde et al. (2008), which show significant greater effects on cognition in healthy adolescents after an acute bout of coordinative exercise (CE) compared to a normal sports lesson. Consequently, further research on different types of PA and different training frequencies is required.

The improvements in WM performance of the children with ADHD after the 12-week PA intervention are similar to the findings of Davis et al. (2011) who investigated a population of overweight children and found significant benefits of exercise on EF. However, a direct comparison is difficult because Davis et al. (2011) measured planning ability and did not include

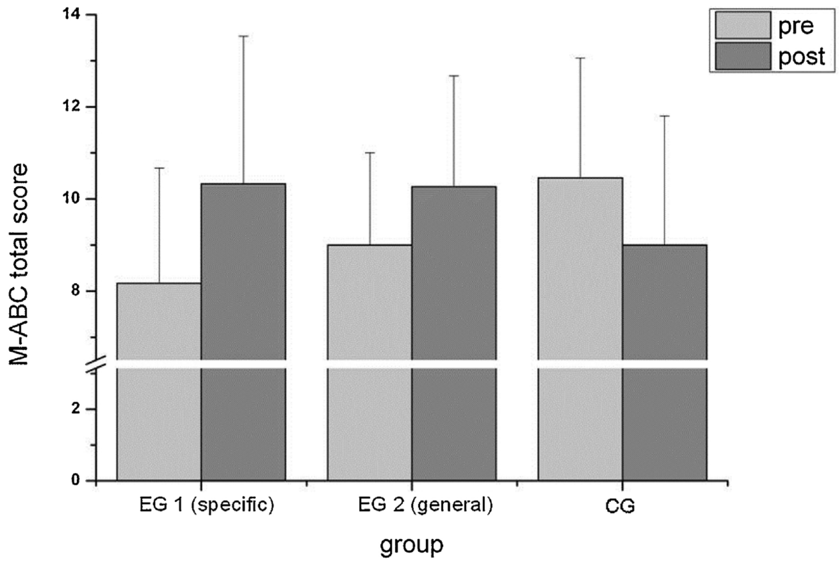

Fig. 8. M-ABC total score at pre- and post-test in the experimental groups (EG1, EG2) and the control group (CG).

WM as an outcome measure. Further support for our current results comes from Gapin and Etnier (2010) who assessed the amount of regular PA of boys with ADHD with an accelerometer and demonstrated significantly better performances in WM, inhibition and processing speed in physically active children compared to more inactive ones.

In conclusion, the results obtained in the present study reinforced the findings of previous research which indicated that PA would have positive effects on EF in children with ADHD. The results support the hypothesis of an improvement in EFs caused by increased PA. Due to missing significant outcomes after a single session of PA, this conclusion can only be applied to long-term PA. Furthermore, the findings do not lend support to the hypothesis of greater EF improvement in EFs after a training of caching and aiming, manual dexterity, and balance compared to a training without such a focus.

Gapin et al. (2011) state that there is a lack of preliminary research exploring such potential benefits of PA in a population with ADHD. Despite the limited research, Gapin et al.'s (2011) conclusion states beneficial effects of PA on cognitive performance in ADHD affected children. Furthermore, they suggests "that PA might be an effective supplement to medication..." (p. 73).

5. Limitations

The current study contains a waiting CG but lacks a CG receiving an alternative intervention program including, for example, relaxation or stretching exercises. Yet, such an additional CG is necessary to determine the amount at which ongoing care and social integration alone can influence the results. Furthermore, the study investigated only three domains of EF, verbal and visuo-spatial WM, and the ability of inhibition control. Thus, we are not able to draw any conclusion about planning ability and its relationship to motor performance. Another limiting factor is the use of only one task per EF domain or sub-domain in most cases. A direct comparison with the few existing results which were gained with other assessment tools is not feasible. In order to further substantiate our hypothesis, future research dealing with the issue "Executive functioning and motor performance in children with ADHD" should use a wider range of EF assessment tools that include multiple assessment per EF subdomain.

6. Conclusion

The current study succeeded in supporting the hypothesis of positive effects of long-term PA on several EFs in children with ADHD. In particular, we have found significant improvements in tasks assessing verbal WM performance after participating in a 12-week PA program. No significant differences between a specific and non-specific training program were found. Thus, we have found no evidence that supports an advantage of either approach. In addition, the investigation revealed the potential of long-term PA to improve motor abilities of ADHD children. Although future research regarding the effect of PA on cognition in children with ADHD is of great importance, the recent findings already demonstrate the huge substantial potential of PA as an adjunct treatment method. Administering PA with each pharmacological treatment could potentially lead to better outcomes or a reduced need of long-term pharmacological intake.

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