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Reaction Performance Improvement in Children with ADHD through Adapted Physical Activity – A Pilot Study

Erhöhung der Reaktionsfähigkeit bei Kindern mit ADHS durch angepasste körperliche Aktivität – Eine Pilotstudie

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Summary

- **Background:** This study investigates the efficacy of an adapted physical activity program on reaction performance in children with attention deficit hyperactivity disorder (ADHD).
- **Methods:** Study participants consist of 37 children with ADHD aged 8 -11 years old, were divided into intervention and control groups. The intervention consisted of a 60-minute adapted physical exercise program occurring two times per week for eight weeks. This intervention program, which combined both aerobic and perceptual-motor exercise characteristics, was designed with a diverse set of exercise games. Two tests of joystick were employed: a simple reaction time test (SRT), and a four-choice reaction time test (CRT).
- **Results:** Our results showed that whole group (pretest: 808±243 ms; posttest: 714±197 ms, $p<0.05$), boys (pretest: 764±277 ms; posttest: 685±228 ms, $p<0.05$), and girls (pretest: 918±56 ms; posttest: 788±51 ms, $p<0.05$) had reduced CRT in the intervention group but not in the control group, and there was no significant change in the variability of SRT and CRT in all groups.
- **Conclusion:** Our study found that the adapted physical exercise used in this study influenced the performance of a sensory-dependent cognitive task of children with ADHD. This confirms that exercise can be a useful intervention tool for these children, especially those who are looking to improve these aspects of their executive functions and complicated sensorimotor ability.

Zusammenfassung

- **Hintergrund:** Diese Studie untersucht den Einfluss von angepasster körperlicher Aktivität auf die Reaktionsfähigkeit von Kindern mit Aufmerksamkeitsdefizit-/ Hyperaktivitätsstörung (ADHS).
- **Methode:** Die Teilnehmer, 37 Kinder mit ADHS im Alter von 8 bis 11 Jahren, wurden in eine Interventions- und eine Kontrollgruppe aufgeteilt. Die Interventionsgruppe absolvierte zweimal in der Woche ein 60-minütiges Sport-Programm über einen Zeitraum von acht Wochen. Dieses Interventionsprogramm ist eine Kombination aus Ausdauer-, Wahrnehmungs- und Koordinationstraining, das mit einer Reihe von Übungsspielen entwickelt wurde. Mit dem Joystick-Reaktionsmessgerät wurde die einfache Reaktionszeit (SRT) und die Wahlreaktionszeit (CRT) gemessen.
- **Ergebnisse:** Die Ergebnisse zeigten, dass die Wahlreaktionszeit im Unterschied zur Kontrollgruppe in der gesamten Interventionsgruppe reduziert war (Vortest: 808±243 ms; Nachtest: 714±197 ms, $p<0.05$). Dieses Ergebnis war unabhängig vom Geschlecht: Jungen (Vortest: 764±277 ms; Nachtest: 685±228 ms, $p<0.05$) und Mädchen (Vortest: 918±56 ms; Nachtest: 788±51 ms, $p<0.05$). Zudem gab es keine signifikanten Abweichungen der Variabilität von einfacher Reaktionszeit und Wahlreaktionszeit in allen Gruppen.
- **Schlussfolgerung:** Unsere Studie zeigte, dass die angepasste körperliche Bewegung die Leistung der sensorischen abhängigen kognitiven Funktionen von Kindern mit ADHS beeinflussen kann. Die Studie bestätigt, dass Bewegung eine effektive Interventionsmethode für Kinder mit ADHS sein kann, was insbesondere für Aspekte der Exekutivfunktion zutrifft, welche komplizierte sensomotorische Fähigkeiten verbessert.

KEY WORDS:
Exercise Games, Information Processing, Executive Function, Reaction Time

SCHLÜSSELWÖRTER:
Übungsspiele, Informationsverarbeitung, Exekutive Funktion, Reaktionszeit

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Introduction

Attention deficit hyperactivity disorder (ADHD), a neuropsychiatric disorder characterized by developmentally inappropriate symptoms of inattention, impulsivity, and motor restlessness, is among the most common childhood neurobehavioral disorders, and often persists into adolescence and adulthood (1). The multifactorial causation of ADHD leads to a heterogeneous profile of psychopathology, neurocognitive disorder and abnormalities in the function and structure of the brain (2). ADHD exhibits a complex combination of developmental challenges involving medical problems, low academic performance, and impaired interpersonal relationships (3). Along with inattention, impulsivity, and hyperactivity, the main outcome of ADHD is the deficit of inhibition functions, › which makes the selective/continuous attention or the response system react abnormally when receiving outside stimuli (4). A consistent marker of cognitive function disorder in ADHD is inhibition-related processes such as executive motor inhibition or response inhibition (2). One of the key cognitive impairments in ADHD involves a dysfunction that interrupts or inhibits behaviors that are no longer appropriate (5). Recent studies found that children with ADHD have more problems inhibiting a prepared response than age-matched controls in a stop signal task, hence revealing a response inhibition deficit that often is exhibited in eye movement. Previous study has confirmed that children with ADHD have trouble garnering visual attention resources and experience limited eye movement coordination. These weaknesses might lead to reduced perceptual motor coordination and poor concentration (6). Also, the deficit of inhibition and impulsive control in cases of oculomotor control and visual attention in children with ADHD could be caused by dysfunctions of the anterior cingulate cortex frontostriatal circuitry, dorsolateral PFC (7), and basal ganglia (8).

Along with various cognitive impairments, some studies have confirmed the association between ADHD and sensorimotor harm (9) and deficits in performing fine motor movements. The hyperactivity syndrome reduces the ability to regulate motor behavior, where hyperactive children show less control in terms of preparation, time, and adjustment (10). The moment-to-moment variability in behavior of ADHD children may also be central to the dysfunction (5, 11), where most children with ADHD display cognitive ability imbalances. The prevalence of school-age children with ADHD in Taiwan, where this study took place, is about 6-12 percent (12), which is much higher than in Western countries, which is about 5 percent (2, 13).

Use of Physical Activity and Other Methods to Treat ADHD

The potential of physical activity as a treatment for ADHD is supported by empirical findings, where it has been shown to positively impact many of the same neurobiological factors that are implicated in ADHD (14). Physical activity intends to improve basic perceptual and motor skills by the performance of structured movement activities. Some studies have shown positive consequences for physical activity, primarily on behavioral and emotional difficulties (15). Others found that the employment of moderate-high intensity and aerobic physical activity combined with cognitive demand could promote brain growth, which leads to the improvement of inhibition and executive function in children with ADHD (16, 17, 18). But the majority of previous studies have focused on acute exercise and its effects on the inhibition function in children with ADHD (19, 20, 21). Relatively few studies have investigated the effects of chronic exercise on the precision of motor performance in children with ADHD, where long-term physical activity effects on reaction performance of children with ADHD still remains unclear. The purpose of this study is thus to analyze the effects of eight-weeks of a moderate physical activity program on reaction ability of children with ADHD.

Numerous influential studies on the effect of vigorous exercise on mental function (22) and cognition (23) have been conducted. An EEG study showed that increased motor competence in people with ADHD was associated with less deviant cortical activity in the resting state as measured by theta to beta ratio, and that motor competence moderated the relationship between moderate–to-vigorous physical activity and theta to beta ratio after controlling for age (17). Moreover, an acute exercise study showed that, both aerobic exercise and coordinative exercise led to improvement in inhibitory control, the allocation of attentional resources, and reduction in reaction time in children with ADHD.

Yet some studies have indicated that aerobic exercise is more effective than coordinative exercise in reducing the inhibitory control deficits that persist in children with ADHD (20). In analyzing studies that assessed the effects of exercise on adults' cognitive performance, Tomporowski and colleagues (2008) found that exercise-induced arousal not only changes information-processing speed, but also under certain conditions may facilitate problem solving and decision making. In addition to aerobic exercise-induced awakening, sensory processes are involved in stimulus detection (24).

While there is no cure for ADHD, there is broad agreement that intervention for children with ADHD should be multidisciplinary and long lasting (25). This means that drugs and counseling along with physical exercise are commonly used to manage the condition. The most commonly prescribed drug for treatment of ADHD is the stimulant methylphenidate (Ritalin®). While it is reasonably effective, not all children with ADHD respond favorably to the drug (26). Specifically, stimulant medications have negative side-effects for certain children, such as sleeplessness, appetite loss (27), and growth suppression . Moreover, some of the currently effective medications for ADHD have catecholaminergic effects, resulting in an increase in heart rate and blood pressure (28).

Due to these potential problems, it is important to search for alternative treatment options, such as non-stimulant drugs, counseling, exercise and education services. Furthermore, the aim of this preliminary study was to expand current knowledge by examining the effects of Adapted physical activity program, which combined both aerobic and perceptual-motor exercise characteristics, on the reaction performance in children with ADHD.

Methods

Study Participants

The study participants (N=37) consist of 27 boys with ADHD and 10 girls with ADHD (combined type), recruited from the Child & Adolescent Psychiatric Clinic in Taipei City, Taiwan. To rule out the comorbid condition, all children in this study were given a structured clinical interview found in the Diagnostic and Statistical Manual of Mental Disorders, fifth edition (DSM-V) by a pediatric psychiatrist (13). The intervention group included 15 boys (9.2±0.8 years old) and 6 girls (8.9±1.0 years old), and control group included 12 boys (8.9±0.8 years old) and 4 girls (9.9±0.9 years old). The criteria for eligible children with ADHD were only right-handed children who were reported to be free of neurological disorders, and those identified through the questionnaire to have the following diseases were excluded: organic brain injury, development, or psychiatric symptoms/diagnosis, including intellectual disability, sensory impairments, cerebral palsy, brain injury, epilepsy, anxiety, depression, obsessive-compulsive disorder, pervasive developmental disorder, tic disorders, and cardiovascular heart disease. The children had to complete more than 90 percent of the physical exercise program. This research was approved by the National Taiwan Sport University's Human Research Ethics Board, and informed consent was obtained from all of the participating children and their parents for the physical exercise program used in this study.

Table 1

Reaction time measures in intervention and control group of whole group before and after 8 weeks sensorimotor training; SRT=simple reaction time test; CRT=-complex reaction time tasks; *p<0.05; displayed are mean ± SD.

WHOLE GROUP	INTERVENTION			CONTROL		
	Pretest	Posttest	Effect Size	Pretest	Posttest	Effect Size
SRT	696±427	637±314	0,32	536±112	548±103	0,12
CRT	808±243	714±197*	1,16	691±133	656±119	0,28
Variability of SRT	257±329	252±202	0,02	152±57	214±105*	0,60
Variability of 4CRT	308±233	274±228	0,23	206±133	272±248	0,22

Table 2

Reaction time measures in intervention and control group in boys before and after 8 weeks sensorimotor training; SRT=simple reaction time test; CRT=complex reaction time tasks; *p<0.05; displayed are mean ± SD.

BOYS	INTERVENTION			CONTROL		
	Pretest	Posttest	Effect Size	Pretest	Posttest	Effect Size
SRT	650±497	578±352	0,38	530±109	545±106	0,18
CRT	764±277	685±228*	0,98	710±139	650±128	0,48
Variability of SRT	280±387	232±22	0,18	157±56	215±95*	0,62
Variability of 4CRT	302±248	279±242	0,14	238±143	246±263	0,03

Table 3

Reaction time measures in intervention and control group in girls before and after 8 weeks sensorimotor training; SRT=simple reaction time test; CRT=complex reaction time tasks. *p<0.05; displayed are mean ± SD.

GIRLS	INTERVENTION			CONTROL		
	Pretest	Posttest	Effect Size	Pretest	Posttest	Effect Size
SRT	812±159	784±120	0,14	552±130	554±104	0,01
CRT	918±56	788±51*	0,19	642±115	669±105	0,22
Variability of SRT	198±116	302±164	0,39	137±65	212±142	0,55
Variability of 4CRT	324±226	259±221	0,87	121±31	339±214	0,11

Reaction Performance Assessment

The subjects sat in front of a computer monitor with a 12-inch screen. Using a joystick control, they were required to move the joystick in the same direction as the screen displayed. The time of the screen signal (arrow) varied in a uniform random distribution of between 3 to 9 seconds. Two tests were employed: a simple reaction time test (SRT), and a four-choice reaction time test (CRT). There were a total 20 steps (5 up, 5 left, 5 down, and 5 right) and the total duration of the response test was 260 seconds. A 3-second blank screen on a monitor was displayed between each of the two steps. The reaction time is defined as the elapsed time between the display of an arrow and the subject's response. The sampling rate of the signal record was 1000 Hz.(29). The differential method was used to locate the time points of arrow display and subject response. The differential data of 40 and 75 were the arrow display and subject response, respectively.

Adapted Physical Exercise Program

The adapted physical exercise program was conducted by an instructor with a professional background in this program, implemented with an instructor-to-student ratio of 1:4. The program consisted of eight consecutive weeks of two sessions per week (16 sessions in total) at a Perceptual-Motor room in a primary school. Due to the children with ADHD having weak attention spans as well as lack of patience, the physical exercise program was designed with a diverse set of exercise games. Each session lasted 60 minutes and consisted of five stages:

- 5-minute warm-up period (dynamic stretching);
- 20-minute moderate-intensity interval training;
- 20-minute perceptual-motor exercise;
- 10-minute group dynamic game; and
- 5-minute cool-down period.

The participants took the reaction performance test before and after the intervention period.

The moderate-intensity interval training was chosen based on evidence that this form of exercise may improve cardiovascular fitness, one of the potential mechanisms associated with exercise and neuropsychological function as well as its intensity appropriateness of the intensity for children with ADHD (18). This kind of perceptual-motor movement exercise encompasses training in whole body reaction performance, rhythmic ability, and visuomotor coordination (30). In the whole-body reaction performance training, the children responded to a range of more or less complex signals by short-sprint running or jumping as fast as possible. These signals could be in audio, visual, or tactile form. The movement tasks were often changed. The children were instructed to move as fast as possible towards a 10 to 15 meter distanced target (31). ›

The rhythmic training consisted of body movements forward, backward, and sidewise (as these movements are found to facilitate vestibular stimulation) (15) combined with different perceptive stimulations (audio, visual, tactile, and proprioceptive information) (31). Additionally, auditory orientation and vestibular stimulation training were included.

Statistical Analysis

The present study recorded the visual reaction performance data using built-in software, SPSS 17.0, to analyze the effect of adapted physical exercise on reaction performance of the ADHD group and the control group. Analyses of the effects of sensorimotor training on simple and choice reaction time were compared in a pre-posttest design. The reaction performance parameter, including simple reaction time/ variability, and choice reaction time/ variability, were compared with the student T-test. The prominent standard of the statistical test was α=.05.

Results

The study recorded the reaction performance of the participants with the visual reaction time test (Table 1, 2 and 3). The SRT in the intervention group (pretest: 696±427 ms; posttest: 637±314 ms, p>0.05) and the control group (pretest: 536±112 ms; posttest: 548±103 ms, p>0.05) showed no significant differences. However, though the whole group's CRT was found reduced in the intervention group (pretest: 808±243 ms; posttest: 714±197 ms, p<0.05), no considerable differences were detected in the control group. The variability of SRT and CRT in the whole group suggests no significant difference between the pre-test and post-test in the intervention group. The boys' SRT showed no significant reduction after adapted physical exercise program in the intervention group (pretest: 650±497 ms; posttest: 578±352 ms, p>0.05). The boys' SRT in the control group also showed no significant difference between pretest and posttest (p>0.05). The boys' CRT significantly decreased in the intervention group (pretest: 764±277 ms; posttest: 685±228 ms, p<0.05), but no significant decrease was detected in the control group (pretest: 710±139 ms; posttest: 650±128 ms, p>0.05). There was no significant difference between pretest and posttest in the girls' SRT of both groups. Girls' CRT was found to be significantly reduced in the intervention group (pretest: 918±56 ms; posttest: 788±51 ms, p<0.05), but no considerable differences were detected in the control group. On one hand, the variability of SRT in the boys' group demonstrates no significant difference between pretest and posttest in the intervention group, but the variability of SRT in the control group significantly increased (pretest: 157±56; posttest: 215±95, p<0.05). On the other hand, there was no difference between pretest and posttest in the girls group for the variability of SRT. The boys and girls groups thus showed no determinable difference in the variability of CRT after eight weeks.

Discussion

In investigating the effects of physical exercise on children with ADHD, after assessing visual simple reaction time and visual choice reaction time, we observed a passive effect of adapted physical exercise on reaction performance. Our results suggest that there is a benefit in employing physical exercise for both visual attention control and sensorimotor performance in children with ADHD.

Specifically, the average reaction times were reduced in all reaction tasks after the eight week-intervention. This may be due to the fact that information perception and processing were more efficient after employing physical exercise, however. The main finding is the significant decrease in CRT not only in whole group, but also in boys/ girls with ADHD after eight weeks of training. This result could confirm that adapted physical exercise has a better effect in complex tasks (CRT) than in simple tasks (SRT). These results also support the findings of other studies showing positive effects of exercise training on the sensorimotor difficulties (10, 18) and several executive functions (18, 32) in children with ADHD. For example, one study extended the previous research by utilizing an aquatic-based moderate-intensity exercise program that involved both aerobic and coordination skill training, where motor skills of ADHD children significantly improved following an eight-week, multifaceted exercise program (18). Researchers also found out that ADHD children with higher levels of muscular endurance and aerobic capacity had shorter reaction times (31) and larger P3 amplitudes in EEG compared to less fit ADHD children (33). It is possible, therefore, that exercise and physical activity could not only build up physical fitness and positive self-esteem/ self-confidence in the children with ADHD by practicing exercise, but other neuropsychological mechanisms such as the exercise-associated increases in basal ganglia volume and prefrontal cortex activation (34, 35).

The increased level of arousal induced by physical activity mediates the increased response speed and accuracy. Children who are more physically fit perform cognitive tasks more rapidly, and display patterns of neurophysiologic activity indicative of larger mobilization of brain resources, than do less fit children (36). Current influential study has shown that aerobic exercise also increases the availability of dopamine and norepinephrine in synaptic clefts of brain(37) and high intensity exercise increased lactate levels and lactate infusion at rest can increase central BDNF levels (38). Further, changes due to exercise include the maintenance of cerebral vasculature and enhancement in angiogenesis and neurogenesis, which all serve to improve neuroplasticity and positively affect cognitive abilities (37).

Impacts of exercise could improve the learning context experience for children with ADHD. The type of exercise task carried out by the child may mediate the interaction between cognitive function and sensorimotor training (36). The whole-body reaction to performance training (including short sprint running and jumping in our study) could be due to short-term high intensity training, where short-term maximal aerobic exercise that could improve executive function. These effects of sensorimotor training showed more significant improvements in the difficult task than simple tasks in children with ADHD.

In this case, the variability of reaction time means the stability of reaction performance. Most intervention groups had a mean decrease in variability of reaction time after eight weeks of training, but the variability of reaction time of the control groups increased. Consequently, the reaction performance of boys with ADHD in the control group demonstrate significant instability. It could be that children with higher fitness engaged in more proactive control in the mostly incongruent condition. It seems that better fitness is associated with a more flexible shift between reactive and proactive modes of cognitive control to adapt to varying tasks (35). The control groups could limit their fitness and sensorimotor performance without exercise intervention, thus leading to an increased instability in reaction performance.

Our findings suggest there is a positive effect of physical exercise on reaction performance and visual attention control of children with ADHD. An effective exercise prescription for children depends on various components, such as types of exercise modality, exercise intensity, dose–response relationships, time delay effects and design of exercise game. Therefore, in order to expand and further the understanding of effective exercise prescriptions, it is believed more researches have to be down to explore the complicated relationship among exercise design, executive function, and the social skills for ADHD children.

Conclusion

In summary, the adapted physical exercise program used in this study influenced the performance of a sensory-dependent cognitive task of children with ADHD. Our findings confirm that exercise can be a useful tool for these children, especially those who are looking to improve these aspects of their executive functions and complicated sensorimotor ability. Moreover, adapted physical exercise can be integrated into other intervention programs for ADHD children. We therefore strongly recommend more moderate exercise training in public and private schools' adapted physical education courses for ADHD children. The adapted physical exercise should not only improve sensorimotor ability, but also increase the child's confidence and amend communication skills and social interactions, a fruitful topic for future research.

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Conflict of Interest

The authors have no conflict of interest.

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