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GRAPHOMOTOR FUNCTIONS IN ADHD – MOTOR OR PLANNING DEFICIT? A MICROGENETIC APPROACH

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SUMMARY

Background: Attention Deficit Hyperactivity Disorder (ADHD) is the most common neurobehavioural disorder of childhood. Although graphomotor deficits are not listed as a diagnostic criterion for ADHD, they are very common. It remains unclear, however, whether this is caused by motor deficits or by problems in planning and organizing behavior.

Material/ Methods: The experimental group consisted of 30 boys with ADHD. The control group consisted of 30 boys with no deficits, matched in terms of age and IQ. The Clock Drawing Test (CDT), and the Rey-Osterrieth Complex Figure Test were used to analyze graphomotor and planning functions.

Results: As expected, the ADHD children achieved significantly lower scores on the Rey-Osterrieth Figure for both speed and accuracy, in both the copying and reproduction tasks.The ADHD children showed less complexity, along with a tendency to dislocate, rotate, or omit elements of the model. On the Clock Drawing Test, the ADHD children significantly more often drew the clock face incorrectly, and even when they did not, they more often indicated the wrong time. The strongest correlation was between the results on the Rey-Osterrieth Test and precision in drawing the clock face, both of which tasks are heavily dependent on graphomotor functions.

Conclusions: Children with ADHD exhibit diverse deficits of cognitive and behavioral processes, including graphomotor deficits. The latter seem to be associated with both disturbances of coordination and fine motor control resulting from hyperactivity and difficulties in the planning of writing, caused by executive dysfunction.

Key words: neurobehavioral disorders, Rey-Osterrieth figure, clock drawing test

INTRODUCTION

Attention deficit hyperactivity disorder (ADHD) is one of the most frequently diagnosed neurodevelopmental disorders among school-age children. Even so, there is little consistent information as to its frequency in the general population. In the United States, figures suggest that from 3% to 7% of children are hyperactive (APA, 2000); in England, less than 1%; in China, from 2% to 13% (Mann et al., 1992); in Poland, 6.6% (Kołakowski et al., 2007). The terminology in this area is also not uniform. In much of the world, the most common term is ADHD, which comes from the American Psychiatric Assocation's Diagnostic and Statistical Manual (DSM-IV-TR; APA, 2000), while in Europe the official term used by diagnosticians is "hyperkinetic disorder" (HK), which comes from the ICD-10 (WHO, 1992). Despite some differences, the diagnostic criteria in these two classifications are similar: psychomotor hyperactivity is characterized by difficulties in concentrating attention, excessive mobility, and impulsiveness, to a degree that impairs the child's functioning or is not proportional to his development. The full clinical picture of ADHD is a composite of all three symptoms, but these do not necessarily occur with equal force in particular cases, which is the basis for diagnosing the inattentive and impulsive-hyperactive subtypes of ADHD (APA, 2000). Research on the causes of ADHD points to a primarily genetic basis for this disorder. Most of the evidence indicates that there is a connection between ADHD and the genes associated with the dopaminergic, noradrenergic, and serotoninergic systems (Faraone et al., 2005). Moreover, thanks to the application of neuroimaging of brain structure and function, many anatomical anomalies have been found to be associated with specific patterns of abnormal information processing in children with ADHD (Castellanos et al., 2002).

The specific symptoms of ADHD become observable to others in various periods of the child's development (Barkley, 2006). The first perceptible symptom is hyperactivity, that is, motor activity that seems excessive in comparison to other children at the same stage of development. A hyperactive child is unable to sit in one place, cannot play quietly or rest, displays nervous movements of the hands and/or feet, is often excessively talkative and noisy. Unfortunately, increased mobility is not accompanied by a high level of motor efficiency: clumsiness is manifested in both large motor activities (jumping, running) and small (drawing, writing; Brossard-Racine et al., 2011a).

The next symptom to become observable is impulsiveness, which results primarily from deficits in inhibiting actions. The inhibition of behavior makes it possible to make rational decisions regarding the appropriate response to a stimulus or situation, instead of an immediate reaction, often automatic and inappropriate (Borkowska, 2008). Impulsiveness then presents itself as an inability to restrain an action and wait until the performance of the action will be easier or accepted by the environment. Impulsive children are conflict-prone: they are easily offended, it is hard for them to adapt to new situations, and they are often irritable (Pastwa-Wojciechowska, 2008). The stimuli that affect them provoke an immediate response, both motor and emotional, regardless of its appropriateness to the given situation.

Along with the commencement of schooling, problems with concentration of attention (that is, reduced ability to focus on the task at hand) become paramount. In the case of ADHD the duration of attention is very slight and distractibility is very high. This results in a reduced ability to concentrate on one phenomenon for a longer time (Borkowska & Tomaszewski, 2008). A child with disturbances of attention has problems with following instructions, since he does not listen carefully and does not remember what he was supposed to do, or in the middle of the task forgets what he was supposed to do.

However, children with ADHD must deal with many additional problems, among which are difficulties with social functioning (Lipowska & Dykalska-Bieck, 2010), various forms of disturbances in the development of language and communication skills (Lipowska et al., 2008; Jędrzejowska & Borkowska, 2011), and especially cognitive problems (Willcutt et al., 2005; Borkowska, 2008; Lipowska, 2011). In the neuropsychological diagnosis of ADHD considerable importance is attached to executive functions, memory, and of course attention (Barkley, 2006).

Graphomotor deficits are not listed among the diagnostic criteria for ADHD, but they occur very frequently (Borssard-Racine et al., 2011b). Poor handwriting, especially in the first years of school, is a frequent cause of academic failure. Both children with developmental dyslexia and children with ADHD often receive low grades for written work as a result of their illegible writing (Bogdanowicz, 2011). Research on the effectiveness of methylphenidate has found significant improvement in graphomotor functions after stimulatory pharmacotherapy, both in respect to the quality of the handwriting and its legibility and precision (Tucha et al., 2006). It should be emphasized, however, that many studies have found improvement in the concentration of attention, and reduced impulsiveness and distractibility in ADHD children who receive methylphenidate (Stasik et al., 2009). It would seem desirable, then, to examine the relationship of graphomotor functions in ADHD children with their abilities in planning and organizing material.

MATERIAL AND METHODS

The research was conducted in Poland in the years 2008-2009, with 60 children. The experimental group consisted of 30 boys from 4th to 6th grade, diagnosed with Attention-Deficit Hyperactivity Disorder (ADHD). The control group consisted of 30 boys with no deficits, matched to the clinical groups in terms of age (control group mean age M = 11.5; SD = 0.5; ADHD mean age M = 11.6; SD = 0.8) and handedness.

All of the participants were native Polish speakers and met the following criteria:

- average or above-average intelligence;
- standard educational opportunities;
- normal or corrected to normal visual and auditory acuity;

- no gross sensory deficit;
- no gross behavioral problems;
- no history of neurological disease.

The study was carried out individually with each child. IQ was assessed with the Wechsler Intelligence Scale for Children (WISC-R; Matczak et al., 2008). The mean IQ in the control group was 112.6 (SD = 11.5), and in the ADHD group, 107.92 (SD = 12.7). An interdisciplinary diagnosis of ADHD was given by qualified psychiatrists or psychologists.

In order to analyze graphomotor and planning functioning, we used the following instruments:

- the Rey-Osterrieth Complex Figure Test (Strupczewska, 1990),
- the Clock Drawing Test (CDT) (Cohen et al., 2000).

The intensity of the axial symptoms for ADHD was identified using the ADHD and Behavior Disturbances Diagnostic Questionnaire of Wolańczyk and Kołakowski (2005), which is based on the diagnostic criteria of both the ICD-10 and the DSM-IV-TR. This questionnaire consists of three parts, corresponding to the pathognomonic symptoms of ADHD: disturbances of attention, hyperactivity, and impulsiveness.

In my research I used the Rey-Osterrieth Complex Figure Test, as adapted by Strupczewska (1990), which refers to developmental norms expected for children in the Polish population. After more than 60 years of widespread application of this test, there has been much empirical research justifying its application in the neuropsychological diagnosis of children (Atkinson & Nardini, 2008). The child's task was to copy the figure without time limitations. The construction of the Rey-Osterrieth figure facilitates the isolated reproduction of its elements, while it is harder to arrange them in such a way that they form a whole. Its structure requires attention, analysis and organized perception. The test was conducted in two phases. In the first phase (copying), the task was to make an exact copy of the figure from the model. Then, three minutes after the completion of the first phase, without prior warning, the examiner asked the subject to make another copy of the figure, this time from memory (reproduction). In both phases the time needed to make the drawing was measured. The interpretation and evaluation of both drawings (copying and reproduction) is done on the basis of three criteria: the type of reproduction (based on a qualitative analysis), the number of points obtained, and the drawing time.

The Clock Drawing Test is an easy to administer instrument of neuropsychological diagnosis. Initially this test was used primarily to diagnose constructive apraxia, and until the mid-1980s it was applied most often to diagnose visuospatial disturbances caused by parietal lesions (Freedman et al., 1994). Since that time the Clock Drawing Test has become a standard screening instrument to test for dementia in persons with suspected neurodegenerative diseases (Pontin & Giovannini, 2004). It is one of the most important tests used to evaluate visuo-spatial orientation and orientation in time (Wolf-Klein et al., 1989; Pachalska & MacQueen, 2005; Pachalska, 2008). Although most of the research on the accuracy of this test has been done in relation to the diagnosis of dementia, there are more and more reports indicating its usefulness in diagnosing cognitive functions in normally developing children (Dilworth et al., 2004) and children with cognitive difficulties resulting from developmental disorders (Eden et al., 2003; Wang et al., 2007). In 2009 the Clock Drawing Test was added to the fourth edition of the Wechsler Memory Scale (WMS-IV; Wechsler, 2009). The clock drawing test has been found to be sensitive to disturbances in visuospatial perception, graphomotor skills, verbal reasoning, and executive functioning, and can be used to track frontal lobe maturation in children (Kibby et al., 2007).

The procedure itself is relatively simple. The subject is asked to draw a clock face with all 12 numbers, and then minute and hour hands indicating a particular time. In my research I used the evaluation system proposed by Sunderland et al. (1989). If the drawing of the entire clock is generally correct the subject receives from 6 to 10 points. If the drawing of the clock face is disturbed, the subject gets from 1 to 5 points. For completely correct performance the subject can receive a maximum of 10 points; if the subject makes no attempt or the performance is impossible to interpret, the minimum score of 1 point is assigned.

RESULTS

To begin with, the performance of the ADHD children and the controls was compared on the various tests measuring both graphomotor ability and executive functions. As expected, on the Rey-Osterrieth Complex Figure Test, which involves copying a complex figure displayed on a drawing (first while looking at it, and then from memory), the ADHD children obtained significantly lower results, both when copying (t=2.3; p=0.026) and reproducing from memory (t=2.1; p=0.038; see Fig. 1).

The application of the Rey-Osterrieth Complex Figure Test also provides data on the speed of performance, both when copying and when reproducing the model (see Fig. 2). The children from the control group made their drawings faster than the ADHD children, both copying (t=2.4; p=0.019) and reproducing (t=2.7; p=0.010). This result takes on particular importance when compared to the data regarding the precision of the drawings, which was significantly lower among the ADHD children.

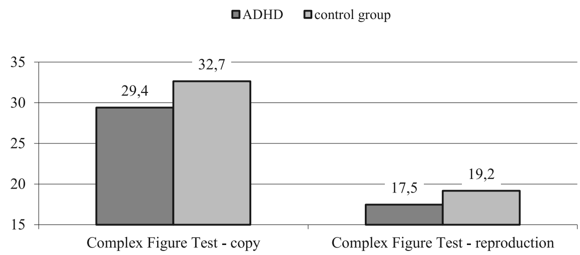

Fig. 1. Comparison of results in the Rey-Osterrieth Complex Figure Test

The qualitative analysis of the drawings made it possible to classify them to one of the seven types described by Osterrieth (cited by Strupczewska, 1990). In the group of ADHD children I tested, the most common type (46%) was type 4 – that is, details placed side by side with no attention to essential elements - followed by type 3 (20%) - that is, a general shape that consists of particular elements drawn into the outside contour of the figure. As compared to the control group, the drawings of the ADHD children were characterized by a low level of complexity, but also a tendency to dislocate or even omit elements, or to rotate constitutive elements of the model.

An example is given in Fig. 3. The subject first copied the figure (a), inexactly and three times faster (0'42") than the average time for the ADHD group (2'71"). The reproduction from memory (b) was also done three times faster than the norm for the ADHD group (0'31"; ADHD average: 1'57"). These short performance times may be a reflection of the child's impulsiveness. Qualitative analysis of the copy and the reproduction shows a lack of planning, no analysis of the task, and little concentration, either on the model or on the task at hand. The re-

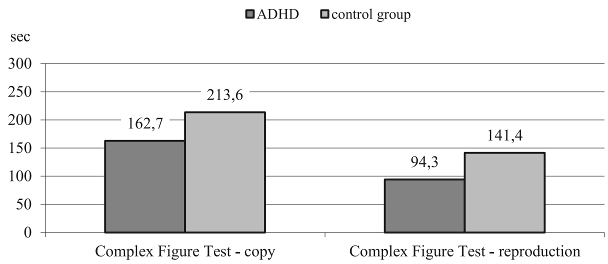

Fig. 2. Comparison of performance time in the copying and reproduction tasks from the Rey-Osterrieth Complex Figure Test

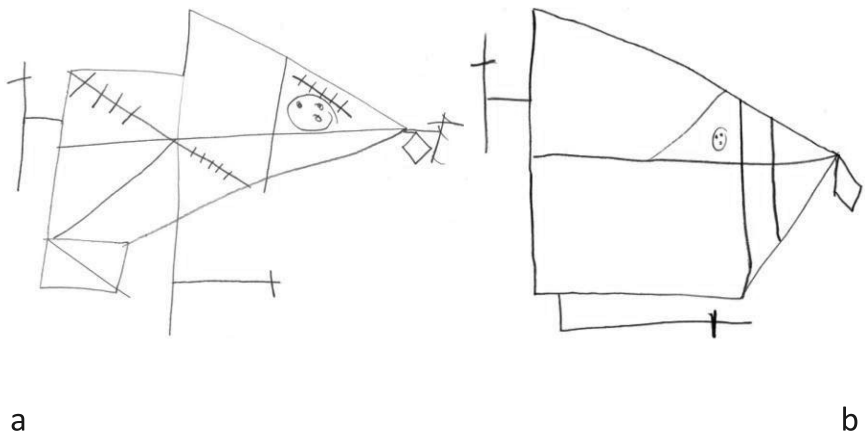

Fig. 3. An example of performance on the Rey-Osterrieth Complex Figure Test , by a subject with ADHD (age 11;11). Copy (a) and reproduction (b).

production from memory is simplified, which suggests deficits of visuo-spatial memory.

In analyzing the results from the Clock Drawing Test, which involves drawing a clock face that shows a particular time given by the examiner, I found significant differences between the two groups, both in drawing hands specifying the given time ($t=2.1$; $p=0.038$) and in drawing the clock face and numbers ($t=3.8$; $p=0.000$). The ADHD children significantly more often drew the time incorrectly on a correctly drawn clock face, and also committed more errors on the clock face itself (see Fig. 4).

The most common type of error in the control group was drawing 10:22 instead of 10:27, whereas the ADHD children, in addition to marking the wrong time, also placed the numbers incorrectly on the clock face.

An example is given in Fig. 5. In the first effort to draw the clock, the subject drew the clock imprecisely, and neglects the left side of the clock face. He quickly noticed his mistake, however, and began trying to correct it. The second clock

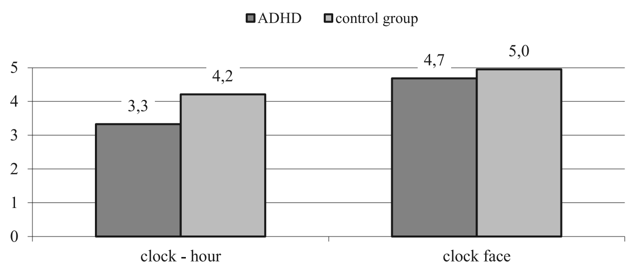

Fig. 4. Comparison of results in the Clock Drawing Test

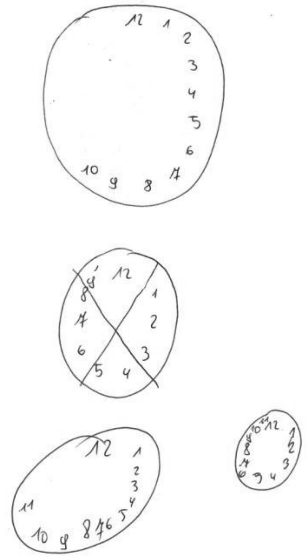

Fig. 5. Example of a clock drawn by a boy with ADHD (four attempts)

was made more carefully, but there was still no planning in the placement of the numbers. The subject realized the problem, but since he could not repair it, he crossed it out. The third clock was virtually a copy of the first, again with no planning of number placement. Realizing that he had failed again, he drew a fourth and final clock. This time, the clock face was drawn more or less correctly, but the excessive concentration on this part of the task caused the subject to omit the second part: drawing the hands.

The correlations among the results of the various tests were also analyzed. The strongest correlation occurred between the level of performance in copying the Rey-Osterrieth Complex Figure and precision in drawing the clock face ($r=0.37$; $p=0.029$). Both these tasks involve a high level of graphomotor ability.

DISCUSSION

The results of my research clearly point to a significantly lower level of performance on these two tests by the ADHD children, who performed much worse on both tests, which require drawing. Although particular attention should be paid to the poor execution of the drawings, which is obviously caused by impaired visuomotor coordination (Westerberg et al., 2004), the role of planning deficits in the deformation of the drawings cannot be ignored.

The poor execution of drawings in the Rey-Osterrieth Complex Figure Test is generally regarded as a factor of neurological deficits; however, it may also result from disturbances of functions that are specific for the performance of graphic tasks, and are associated with posterior regions of the brain (Pachalska, 2008), as well as non specific deficits resulting from problems in the organization and planning of tasks, which may be the result of the frontal lobe dysfunctions (Przybylski & Oszwa, 2008).The qualitative analysis of the drawings indicates not only serious problems with visuospatial functions in terms of analysis and synthesis, but also difficulties with the organization of material. Type 4 drawings, which were the most common in the ADHD group, are characteristic of normal development for children at the age of 8 years; research done by Waber and Bernstein (1995) indicated that among children with learning disabilities, performance in this respect does not change much until adolescence.

In the attempt to reproduce the complex figure from memory in the Rey-Osterrieth Complex Figure Test, the ADHD children performed significantly worse than the control group. Although reproduction is a task much less often studied in research on ADHD (Sami et al., 2003), in the present study its results significantly differentiated the ADHD children from the control group. Also, research comparing the functioning of ADHD children to that of children with dyslexia has emphasized impaired recall of the graphic design by hyperactive children (Lipowska, 2011). The correlation between ADHD and impaired recollection of graphic designs has also been found in neuroimaging research, where a correlation has been noted between test results and developmental asymmetry of the caudate nucleus (Mataró et al., 1997), an anomaly which has been described as characteristic for ADHD (Castellanos et al., 2003). Grodzinsky and Barkley (1999) believe that the results from the reproduction task of the Rey-Osterrieth Complex Figure Test can be useful in the differential diagnosis of ADHD and other neurodevelopmental disorders. Research on adults with ADHD has also indicated a low level of reproducing drawings from memory (Schreiber et al., 1999).

The significantly lower results point to problems in the domain of working memory, part of which is the so-called "visuospatial sketch." According to Barkley (2006), a deficit of nonverbal working memory is a key element in the pathomechanism of ADHD. In his opinion, working memory is the capacity to maintain an internal representation of information in the mind, which can be used to control a later response. Nonverbal working memory is responsible for maintaining a coherent picture of visual impressions and is essential to the process of acquiring and automating complex motor behavior patterns. Both deficits in nonverbal working memory and reduced graphomotor ability may cause children with ADHD to obtain significantly lower results in a task requiring the reproduction of a drawing from memory.

In the Clock Drawing Test, the ADHD children were especially prone to drawing the clock face incorrectly. The method of drawing the clock and the types of errors committed by the ADHD children point to deficits associated with the right hemisphere, which manifest themselves in disturbances of the selectivity of attention, working memory, and executive functions. The most common errors involved failure to use the left side of the clock face and placing the numbers mostly on the right side. This way of drawing, in a healthy population, is characteristic primarily for younger children, and seems to be related to the continuing process of frontal lobe maturation (Cohen et al., 2000). Particular attention should be drawn to the fact that the children in the control group began by placing on the clock face the numbers designating the quarter hours (3, 6, 9, 12), and then marking the remaining numbers in relation to them. This logical procedure was not observed among the ADHD children, which constitutes yet another argument in favor of the thesis that the low level of execution of drawings among ADHD children results to a large extent from executive dysfunction (cf. also Shallice et al., 2002; Pachalska et al., 2007).

The process of symptom formation responsible for the heterogeneity and changeability of behavioral disturbances in ADHD children is explained by Fig. 6, which illustrates the bidirectional transition from emotion to mentation and action (details in Brown & Pachalska 2003). The state of arousal in the mind, which in a healthy brain can be reinforced or inhibited by the executive functions, cannot be controlled in the brains of ADHD children (details in Pachalska et al., 2011). Thus the behavior which these children exhibit can be diverse, variable, and capricious, depending on a whole range of factors both structural and functional in nature (details in Lipowska 2011).

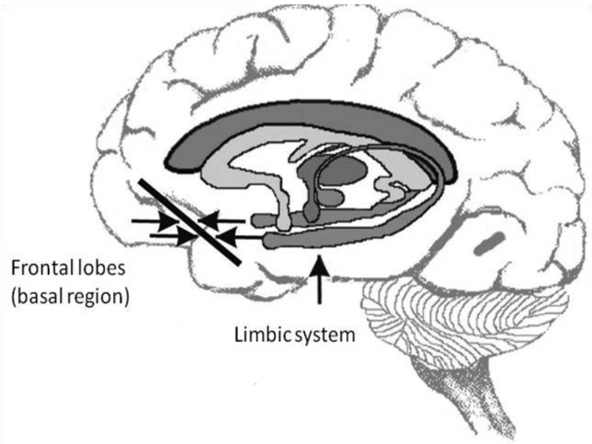

Fig. 6. The bidirectional transition from emotion to mentation and action (Pachalska, 2008)

CONCLUSIONS

Children with ADHD exhibit diverse deficits of cognitive and behavioral processes, including graphomotor deficits. The latter seem to be associated with both disturbances of coordination and fine motor control resulting from hyperactivity and difficulties in the planning of writing, caused by executive dysfunction.

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