10.12663/PSYHUNG.2.2014.2.4

VESTIBULAR REGULATION IN CHILDREN WITH ADHD: A NEUROPSYCHOLOGICAL PERSPECTIVE

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Abstract

In childhood, the maturation of central nervous system processes is manifested in the efficacy and enhancement of regulatory processes such as motoric and behavioural regulatory processes. This study aims to demonstrate the delayed regulation processes found in children with ADHD compared to an adjusted control group, via the instrumental examinations of the balance system. The immaturity of regulatory processes in children with ADHD hinders effective adaptation to their environment and the execution of purposive movements. Prefrontal maturation delay, however, does not merely manifest in the regulation of movement; it could also cause behavioural and emotional difficulties as well.

Keywords: ADHD ▪ neuro-motor maturity ▪ regulation of balancing ▪ visuomotor skills ▪ maturation of executive functions

Kivonat

A központi idegrendszeri folyamatok érése gyermekkorban a szabályozó folyamatok hatékonyságában, javulásában mutatható ki, így a mozgás és viselkedésszabályozásban. Jelen vizsgálatunkban, arra teszünk kísérletet, hogy az egyensúly szabályozás műszeres vizsgálata révén, ADHD-s gyerekeknél a szabályzó folyamatok elmaradását igazoljuk azonos életkorú kontrollcsoporthoz viszonyítva. A szabályozó folyamatok éretlensége a hiperaktív/figyelemzavaros gyerekeknél a célvezérelt mozgások kivitelezésének nehezítettségét okozza, és csökkenti a hatékony környezeti alkalmazkodást. A prefrontális kéreg érésének elmaradása pedig nemcsak a mozgásszabályozás, hanem a magatartás és érzelemszabályozás nehézségeiben is megnyilvánul.

Kulcsszavak: ADHD ▪ mozgásérettség ▪ egyensúlyszabályozás ▪ vizuomotoros képességek ▪ végrehajtó funkciók érése

MOTOR ACTS, MATURATION OF THE NERVOUS SYSTEM AND COGNITIVE DEVELOPMENT

The role of motor acts in cognitive development in childhood has been a central theme since Piaget (Piaget, 1936,1963,1977; Piaget and Inhelder 2004). Nowadays, many studies investigate the relationship between neuro-motor maturity, maturity of the nervous system, and the formation of cognitive functions. Son and Meisels (2006), in their large sample study, showed and proved statistically that motor skills, especially visuomotor skills, predict mathematical and reading skills (Son & Meisels, 2006, Meaisels, Donnelly & Lambourne, 2011). Researchers examining the relation between motor regulation and the maturation of the nervous system (Kakebeeke et al., 2013; Largo et al., 2001) examined the maturity of basic movements with specific motor trials (Zurich Neuromotor Assessment) between the age of 5 and 18 along two indicators, namely the speed of execution and involuntary associated movements. They presumed that dynamic and static balance tests and tasks require visuomotor coordination as basic movement. According to their results, the speed of motor execution reaches its idiosyncratic level at about the age of 10 which corresponds to the formation of the idiosyncratic level of the speed of nerve impulses that can be considered as a general factor of Wechsler-type intelligence scales. During motor execution, involuntary associated movements of contralateral limbs show a declining tendency with age, but are still present in puberty. In visuomotor tests, they were present at approximately 10% after the age of 10, even in adulthood. Thus, motor or balance regulation can be an appropriate predictor of the maturity of central nervous system processes. This is in accordance with research demonstrating that in children with ADHD, increased involuntary associated movements of the contralateral extremities are present in motor coordination (Shaw, 2011).

In ADHD, besides its diagnostic criteria (i.e. impulsivity, inattention, hyperactivity), there are significant problems with motor coordination (Watemberg et al., 2007, F. Földi, 2003, 2005). Motor symptoms can mainly be detected in dexterous fine motor skills and in the balance system (Piek et al., 1999; F. Földi 1998). Involuntary associated movements are significant in fine motor skills (Shaw, 2011), thus the inhibition of contralateral movements is inappropriate.

Children with ADHD do not show difference in the speed of movements compared to their peers, only when the accuracy of movements is also involved in a particular task (Eliasson et al., 2004).

In ADHD the immaturity of regulatory processes is manifested not only in motor regulation but in behavior regulation as well. Mental functions that are needed to be able to reach aims and targets are coordinated by the frontal lobe.

Frontal lobe is the center of the most complex cognitive functions, such as will, self-consciousness, self-regulation, control of behavior and thinking, and motivational processes. It is connected to the organization of inner states and deliberate action. It functions as coordinator of sensory input, thinking and actions, especially when new and constantly changing information are present. These functions are represented in the dorsolateral area of the prefrontal lobe (PFL), while the involvement of the lateral premotor (LPA) and supplementary motor areas (SMA), and the parietal lobe is involved in spatial and temporal organization. The regulation and planning of motor acts are organized through multiple, hierarchical steps: motor neurons, ventral spinal roots, motor nuclei of the midbrain (mesencephalon), cerebellum, thalamus in the diencephalon, basal ganglia and the frontal lobe. The primary motor cortex is responsible for the representation and execution of basic movements, while the premotor cortex is responsible for the execution of more complex direction-guided and purposive movements (Fuster, 1999).

Studies mention five processing loops related to PFL (Weiner, 1997; Fuster, 1999), three of them are of significance in ADHD: dorsolateral, orbitofrontal and medial loops. The dorsolateral loop is related to working memory, purposive behavior, self-regulation, planning, motivation, spontaneity, and response inhibition. In the acquisition and selection of behavior, it is the orbitofrontal area that plays the most important role; its damage mainly influences emotional and behavior regulation, and, as a consequence, disinhibition, impulsivity, and hyperactivity as well. The medial processing loop has a role in the initiation and organization of movements, and contributes to emotional regulation and motivation, as well.

In ADHD, the immaturity of regulatory processes was proven by many studies (F. Földi 2004, Shaw, 2011) investigating the balance system, the associated involuntary movements, and the position the contralateral limb, especially when executing fine movements. This study aims at demonstrating a difference in balance regulation via a stabilometer.

Stabilometric balace system examination study

Stabilometer is mainly used in the selection and skill examination of athletes. According to our hypotheses, with this instrument, we can measure the level of balance regulation more precisely and ascertain whether there are any differences between children diagnosed with ADHD and an age-adjusted control group. Even though previous studies have already demonstrated that the immaturity of the balance system can be identified in children with ADHD, their research methods included subjective elements (Piek et al., 1999; F. Földi 1998).

Hypotheses

1. In children with ADHD, the indicators of static balance are weaker than those of the control group. Thus, in a standing position, the fluctuation of the center of the mass of the body is more significant than in the non-ADHD control group. The maintenance of balance requires constant muscular coordination. This constant muscular coordination is required in straight posture and in movement execution alike, which supposes the parallel functioning of agonist and antagonist muscles. This parallel functioning is based on the interconnections of the γ cells that can be found among the motor neurons of the ventral spinal cord. On one hand, they regulate muscle spindles, the impulses reaching the muscles, and the level of muscle contraction, on the other, they get facilitative and inhibitory innervation from both cortex and subcortex nuclei (extrapiramidal system). In children with ADHD, difficulties of keeping balance are manifested in trying to keep straight posture by wider movements because of the immaturity of muscle tone regulation. Nota bene, however, that this nerval immaturity is connected not only to the balance system but to the cerebellum as well.

2. The purposive transposition of the body mass (dynamic balance) is also weaker in children with ADHD, as their performance in movement execution is inaccurate.

Method

The stabilometer is an instrument for registering the fluctuation of the center of mass of the human body. The instrument is a board of 60x60 centimeters; its four corners are fixed on springs. The instrument is connected to a computer that calculates the fluctuation of the center of mass of the body in centimeters. During the examination, children are asked to solve two

1. Static balance: Romberg test (standing tall, legs together, arms reaching forward)
   a) with opened eyes
   b) with eyes closed for 20 seconds. A computer calculates the fluctuation of the center of mass of the body in centimeters in both cases.

2. Dynamic balance: shifting the center of mass of the body according to the task shown on the screen, while the child is able to check visually the correct execution of the given task.
   a) Tree: a Christmas tree is shown on the screen and candies are to be touched by transposing the posture, i.e. shifting the center of the mass of the body. The computer registers the duration of the execution.
   b) Mouse: a mouse and a hole are shown on the screen and the mouse is needed to be led into the hole by transposing the posture i.e. shifting the center of the mass of the body. The computer registers the duration of the execution.
   c) Blackboard: the blackboard on the screen is needed to be painted with a paintbrush. The percentage of the "painted' surface is registered by the computer. The paintbrush is moved by transposing the posture, i.e. shifting the center of the mass of the body.

Participants

14 children with ADHD took part in the study. Their age was between 8 and 9 (mean=8.6), gender ratio: 4 girls and 10 boys. The diagnosed children were examined at the Neurological Ward of Buda Area Pediatric Hospital (n=7), and at the Institute of Psychology of Special Education of Eötvös Loránd University (n=7). The gender ratio represents the gender distribution of ADHD. The age and gender-adjusted control group was chosen from the second-year pupils of a primary school in Budapest (age mean 8,8 years, gender: 10 boys, 4 girls).

Results

	ROMBERG OPENED EYES	ROMBERG CLOSED EYES	TREE (SECONDS)	MOUSE (SECONDS)	BLACKBOARD %
Mean (ADHD)	11.25 cm	11.16 cm	8.66 sec	4.75 sec	63.5%
Mean (Control)	7.3 cm	9.1 cm	9.2 sec	3.9 sec	63.5 %
Level of significance	p<0.05	n.a.	n.a.	n.a.	n.a.

Table 1. Results of the stabilometric tests in the ADHD and control group.

As it can be seen from Table 1, that there are indeed differences between the performances of the groups, the one and only trial that yielded the exact same results was the blackboard trial (we discuss it later). *The two-tailed T-test showed a significant difference in the opened eyes Romberg test ($p<0,05$).*

1. According to the first hypothesis, the static balance indicators of children with ADHD are weaker than that of the control group: the Romberg test with opened eyes showed a significant difference between the two groups. It is worth to mention that in the Romberg test *there is no difference between the opened and closed eyes trials in children with ADHD*. Moreover, they, albeit slightly, performed better with closed eyes.
2. Regarding our second hypothesis, it became evident that dynamic balance (i.e. shifting the center of the mass of the body) showed no significant difference between the two groups.

Regarding each subtest:

2/a. Touching the candles on the Christmas tree: 8.66 seconds could be observed in the ADHD group and 9.2 seconds in the control group. This shows that the speed of movement is equal in both groups. Thus, the delay of maturity is not manifested in the speed of movements. These results are in accordance with the results from Eliasson et al. (2004), that children with ADHD show no difference in the speed of movements.

2/b. Leading the mouse into the mouse hole: 4.6 seconds, and 3.9 seconds, respectively. In the ADHD group, the length of the execution of visually guided purposive movements (speed and accuracy of movements) seems to be elongated, because of lack of accuracy, since the first task (2/a) showed that the hyperactive group outperforms the control group. Regarding targeting movements, performances in the ADHD group is impaired, in accordance with the results of the study of Eliasson and colleagues (2004).

2/c. The two groups did not show any differences in the blackboard painting performance task. There was a significant difference in the extension of movements (unfortunately, this proved unmeasurable by the computer), children with ADHD could not mind the frame of the blackboard, the painting was extended to the whole screen. Their movements were oversized. The execution of movements was reminiscent of little children coloring drawings, as they are likewise unable to mind the frames of their drawings.

DISCUSSION

Our results confirm that in children with ADHD, the immaturity of central nervous system processes can be identified in the field of balance (Piek et al., 1999, F. Földi 1998); however, they do not show difficulties in the speed of movements (Eliasson et al., 2004). Moreover, besides difficulties in balance regulation, our results confirm difficulties in utilization of visual information. While moving, visual information increases the accuracy of movements, as it helps to find the right extent of movements by feedback mechanisms, i.e. if it is oversized, visual information reduces its extension. This visual feedback cannot be observed in children with ADHD (there was a child who solved the task jumping on the board). Even though the efficacy can be questioned, the results were the same: children with ADHD needed considerably more energy to solve the same task. Visual information helps maintaining balance and a straight posture, and this is why Romberg tests with opened and closed eyes were used during the neurological examinations. Postural and kinetic reflexes are based on the extended connections among balance nerves (nervus vestibularis), palleocerebellum, cranial motor nuclei of the ocular motor muscles, reticular formation, spinal cord, and cortex. Damage of these connections manifests in the pendulum motion of the eye when looking out (oscillation, oscillatio). The nystagmus that appears in a resting position or when looking sideways, is composed of slow and fast components of different directions, the slow component being the indicator of vestibular damage. Pathological nystagmus should be differentiated from physiological nystagmus, as the latter is based on the connection between the balance and visual system. It is necessary for the perception of moving objects, and that of standing objects when the body itself is moving. The physiological nystagmus is based on the vestibulo-ocular reflex, thus the lack of this reflex indicates the damage of opticomotor system. This nystagmus is caused by rotational movements when it is directed opposite to the direction of the rotation, so it has a compensatory function. Studies investigating eye movement responses to rotational movements identified that this phenomenon is present in newborns, but fast responses appear at around three month of age, therefore it is connected to the maturity of the nervous system. In accordance with this, we think that out results confirm that in children with ADHD these processes are immature. Our results show the lack of integration between the balance system, areas responsible for eye movements, and the cerebellum. Problems with utilization of visual information in a standing position and problems with the execution of purposive movements also refer to this.

Visuovestibular and cerebellar impulses that regulate eye movements influence spatial orientation, whereas fast eye movement responses influence orientation and adaptation to the situation. Exploration of the environment happens through visual activity. The frontal gaze field (Br.8.) ensures scanning by maintaining eye fixation.

The role of the dual visual system:

Magnocellular (dorsal) system from V1 to the parietal visual area: it is important for localization and motion perception.

Parvocellular (ventral) to temporal areas: recognition, identification, identification of colors.

The differentiation between the two systems can be found in the frontal lobe as well. Dorsolateral prefrontal: localization of motion, ventrolateral prefrontal: pattern recognition. Execution of voluntary purposive movements is realized by visual guidance and control. The coordination of movement planning and required eye movements can be connected to the visual areas of the dorsal parietal lobe. During attentional processing necessary for executing movements, the dominant activity of the corresponding areas is connected to response organization; the cooperating regions constitute a functional unit.

The selection of the target object requires the activity of the inferotemporal areas, and localization requires the activity of the posterior parietal areas, thus when executing a purposive movement, the coordination of the anterior and posterior attentional systems is needed. Moreover, this process is supplemented by the activity of the motivational and motor systems.

According to our study, in children with ADHD, the lack of the integration of visual and motor system, and the problem of the coordination of the anterior (frontal) and posterior (parietal) attentional systems can be identified. The study also showed that the immaturity of the frontal lobe is manifested in the problems with functions connected to the medial processing loop (planning and initiation of movements), and, at the same time, it indicates problem of emotional and motivational regulation in children with ADHD, as these processes are connected to the same brain areas.

BIBLIOGRAPHY

Donnelly, J. E., & Lambourne, K. (2011). Classroom-based physical activity, cognition, and academic achievement. *Preventive Medicine,* 52, S36-S42.

Eliasson, A., Rosblad, B., & Forssberg, H. (2004). Disturbances in programming goal-directed arm movements in children with ADHD. *Developmental Medicine & Child Neurology, 46*(1), 19-27.

F. Földi, R. & Tomasovszki, L. (2003). A Rey-féle Összetett Figura és Felismerési Próba neuropszichológiai alkalmazási lehetőségei. Ideggyógyászati Szemle 56(3-4), 82-91.

F. Földi, R. (2004). A neuropszichológiai vizsgálatok jelentősége a tanulási és viselkedészavarok diagnosztikájában. *Pszichológiai Szemle, 59*(1), 19-40.

F. Földi, R (2005). A hiperaktivitás organikus és lelki háttere. Comenius Bt. Pécs.

Fuster JM. (1999). *The prefrontal cortex: Anatomy, physiology and neuropsychology of the frontal lobe* (3rd edition). Lippicott-Raven, Philadelphia.

Kakebeeke, T. H., Caflisch, J., Chaouch, A., Rousson, V., Largo, R. H., & Jenni, O. G. (2013). Neuromotor development in children. Part 3: motor performance in 3- to 5-year-olds. *Developmental Medicine & Child Neurology, 55*(3), 248-56.

Largo, R. H., Caflisch, J. A., Hug, F., Muggli, K., Molnar, A. A., & Molinari, L. (2001). Neuromotor development from 5 to 18 years. Part 1: timed performance. *Developmental Medicine & Child Neurology, 43*(7), 436–443.

Normandeau,S., & Larrivée,S. (1998). Risk and protective factors in the cognitive development of low birthweigt children. Paper presented at the Satellite Meeting of the 8th International Child Neurology Congress, Vienna.

Piek, J., Pitcher, T., & Hay, D. (1999). Motor coordination and kinaesthesis in boys with attention deficit-hyperactivity disorder. *Developmental Medicine & Child Neurology, 41*(1), 159-165.

Piaget, J. (1936/1977). *L'origine de l'intelligence chez l'enfant.* Delachaux et Niestlé, Neuchatel, Paris.

Piaget, J. (1963). *The origins of intelligence in children.* W.W. Norton & Company, Inc., New York.

Posner, M. I. (1993). Attention befor and during the decade of the brain. In D.E.Mayer, S:M:Kornblum (eds.), *Attention and Performance* XIV., MIT Press, Cambbridge: Mass.

Rouke, B. P. (1987). Neuropsychology of learning disabilities. Guilford, New York

Shaw, G. (2011). This Way In: ADHD Causes Motor Skill Problems. *Neurology Now*, 7(3), 13-14.

Schneider, W. & Shiffrin, R.M. (1977). Controlled and automatic information processing: I. Detection, search and attention. *Psychological Review, 84*(1), 1-66.

Watemberg, N., Waiserberg, N., Zuk, L., & Lerman-Sagie, T. (2007). Developmental coordination disorder in children with attention-deficit-hyperactivity disorder and physical therapy intervention. *Developmental Medicine and Child Neurology, 49*(12), 920-925.

Weiner J D. (1997). The connections of the primate subthalamic nucleus: Indirect pathways and the open-interconnected scheme of basal ganglia-thalamocortical circuitry. *Brain Research Reviews, 23*(1), 62-78.

Willcutt, E.G. (2012). The prevalence of DSM-IV attention-deficit/hyperactivity disorder: a meta-analytic review. *Neurotherapeutics,* 9(3), 490-499.