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ORIGINAL ARTICLE / ОРИГИНАЛНИ РАД

Writing kinematics and graphic rules in children with ADHD

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SUMMARY

Introduction/Objective The aim of this study was to compare kinematic features and graphic rules of writing between children with attention deficit/hyperactivity disorder (ADHD) (with and without medical treatment) and typically developed children (TDC).

Methods In total, 55 children (26 with ADHD/ten subjects were on methylphenidate treatment and 29 TDC) completed a writing task on a digitizing board (in three repetitions; using non-inking stylus) which included a semicircle tracing, triangle, and letter copying. Kinematic features of movements in all tasks and graphic rules during a semicircle tracing were analyzed. Graphic rules were observed as expected movements (selecting the starting point and direction of tracing).

Results The values of kinematic parameter jerk were significantly larger in TDC group compared to all ADHD subjects (regardless of treatment) and increased constantly with semicircle task progression and repetition in both groups. Children with ADHD without methylphenidate treatment used overall slower movements compared to TDC. The tracing of children with ADHD taking methylphenidate was more automated (with less change in movement velocity and acceleration) compared to TDC. In ADHD group only, those with treatment traced faster and more automated compared to those without treatment. The majority of subjects used expected movements in semicircle tracing and this percentage increased with the task repetition (without difference between ADHD and TDC).

Conclusion Both children with ADHD and TDC used similar approach in the tracing task and were compliant with graphic rules. Methylphenidate treatment may positively influence writing kinematics in children with ADHD. Task repetition also influences writing.

Keywords: writing; ADHD; kinematic parameters; graphic rules; methylphenidate

INTRODUCTION

Writing is a sophisticated skill that combines cognitive, affective, and biomechanical processes [1, 2]. Writing skill develops with age and masters during elementary and high school [2, 3, 4]. Writing is still an important part of learning and education, and writing difficulties can negatively influence development [1, 2]. Due to its complexity, writing is very sensitive to different intrinsic (e.g., fine motor control, sensory modalities, attention, or working memory) and extrinsic factors (e.g. sitting position, chair height, writing surface color, or verbal instructions) [2, 3].

Writing movements can be divided into basic portions called strokes. A single stroke is defined as the time segment between two subsequent changes in direction during writing [5]. Specific kinematic parameters of writing can be derived from strokes and these are: on surface pressure, stroke speed, stroke duration, velocity, acceleration, jerk, number of velocity/acceleration direction alteration, hand in-air/on-surface time, horizontal/vertical/tangential velocity (acceleration/jerk) and others [6–10]. Various psychiatric and neurological disorders often have their own unique combination of kinematic parameters in particular writing task in which they deviate from healthy controls [6–11].

Certain rules are observed during writing, copying or tracing. These rules are observed as predictable movements, which form a sequence in writing simple or more complex shapes. They are called graphic rules and include starting (a preference to initiate writing by selecting certain location point), progression (a preference to write a segment in some direction), and horizontal rule (a tendency to draw horizontal line after the vertical or oblique) [12, 13]. Using these rules, we can predefine order/sequence of writing or tracing movements in writing task execution and potentially reveal which cognitive strategies children use in writing. By this approach, it is possible to detect children with writing difficulties [12].

Attention deficit/hyperactivity disorder (ADHD) is one of the most common neurodevelopmental disorders among children and adolescents with a worldwide prevalence ranging 5–7%, being more frequent among males [14]. Children with ADHD may have motor performance difficulties including writing

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impairment [1, 15, 16, 17]. Problems with attention span, fine motor control, error processing, visual-motor integration, motor planning, and working memory can all contribute to poorer writing performance in ADHD [1, 18, 19, 20]. Subjects with ADHD write less legible, poorer scaled, with more interruptions, using higher on-surface pressure and less automated movements for age compared to TDC, while writing can be influenced with stimulant medication [1, 18].

Both kinematic analysis and graphic rules are potential ways to assess writing characteristics, but only one study so far had combined these to detect children with writing difficulties [12]. Our research was organized in order to further analyze this particular approach in developmental disorders like ADHD. The aim was to determine whether and how writing of children with ADHD differs from TDC in kinematic features and graphic rules. In addition, we tested the influence of stimulant medications and task repetition onto writing performance.

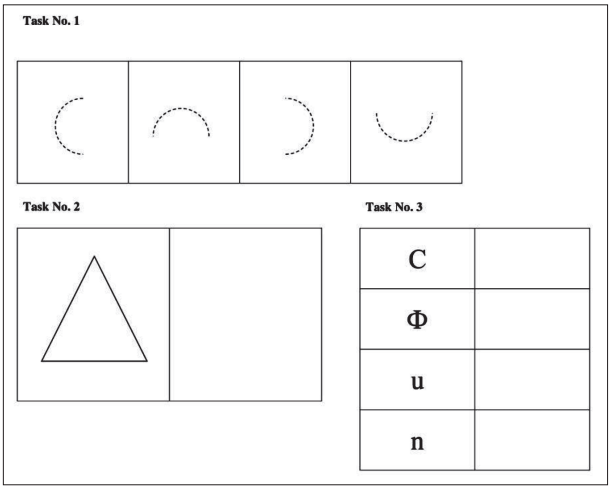

Figure 1. Examples of writing tasks; Task No. 1 – semicircle tracing task (semicircles from 1 to 4 with radius of 1.9 cm rotated in clockwise direction by 90°); Task No. 2 – triangle copying task (a – left edge, b – base and c – right edge); Task No. 3 – letter copying task (C – capital Cyrillic letter s, Ф – capital Cyrillic letter f, u and n are small latin leters)

METHODS

Participants

Data for the present study was collected from a clinical and community sample. The clinical sample, constituting the experimental group, included 26 children (mean age 10.5 ± 1.5 years; 21 (80.8%) boys; 24 (92.3%) right-handed) to whom was confirmed the diagnosis of ADHD according to the Diagnostic and Statistical Manual of Mental Disorders 5th edition (DSM–5) [21]. The experimental group was divided regarding medical treatment with psychostimulant drugs. Ten children (38.5 %) in the experimental group were taking extended-release methylphenidate (MTX) (OROS formulation; at dose 18 or 36 mg per day) and 16 subjects did not take medications. The community sample, constituting the control group, included 29 TDC (mean age 10.2 ± 0.4 years; 16 (55.2%) boys; 26 (89.7%) were right-handed). The majority of subjects preferred Serbian cursive Cyrillic script during writing. The exclusion criteria were the total IQ < 80 and the presence of any other neurological or psychiatric comorbidity.

An informed consent from parent/guardian was provided for all subjects. The study was approved by the Institutional Committee on Ethics.

Procedure

Following the previous study of Khalid et al. [12], 2010, this study considered a similar combination of tracing and copying tasks of semicircles, shapes, and letters and a digitizing writing board. The writing task considered the following (Figure 1): (1) a tracing of four semicircles (SC) rotated in clockwise direction (CW) by 90°, (2) a triangle copying, and (3) a letter copying, namely writing the capital Serbian Cyrillic letters S (C) and F (Ф), and small Serbian Latin letters u (y) and n (н) (selected to resemble previous semicircles by their shape). Tasks were repeated three times and each time with a different task order. For left-handed subjects, the test battery was adapted not to overlay their hand over the writing material ("mirror image"). In order to familiarize participants with the procedure, all subjects were first instructed to write (e.g. their name) on the writing board surface. The writing tasks were performed on a digitizing board (Intuos4 XL, sampling rate – 200 Hz, resolution – 0.25 mm) (Wacom®, Kazo, Japan) with stylus without ink trace. An A4 white paper sheet with printed tasks was placed on the writing surface under the transparent foil. A customized software platform for data acquisition was previously created using the LabVIEW® (National Instruments Co. Austin, TX, USA) software environment [22]. All subjects from the experimental group (ADHD) were tested in conditions resembling those in school, while the control group (TDC) was tested during school classes.

Data analysis

Kinematic parameters were analyzed from the data related to all writing tasks (Figure 1): the semicircle tracing (for each semicircle for three repetitions), triangle coping (for all triangle edges: a – left edge, b – base and c – right edge; in three repetitions), and letter coping (for all letters together only for the first repetition). The following kinematic parameters were analyzed (mean values and standard deviations): on surface pressure (P), velocity (V), acceleration (A), jerk (J), stroke time (ST), stroke speed (SS), number of changes in velocity (NCV) and number of changes in acceleration (NCA). For V, A and J, three vector components were analyzed: x – horizontal, y – vertical and t – tangential (Table 1). Kinematic parameters were extracted using a customized algorithm in Matlab® (Mathworks, Novi, MI, USA) [8, 9].

The difference in mean values for kinematics parameters between the experimental and control group were tested by the t-test for two independent groups (when the normality assumption is satisfied) and the Mann–Whitney

Table 1. Kinematic parameter details

Parameters	Abbreviation	Details
Pressure	P	The force that a stylus tip creates over the writing surface
Velocity*	V	The rate at which the position of a stylus changes with time
Acceleration*	A	The rate at which the velocity of a stylus changes with time
Jerk*	J	The rate at which the acceleration of a stylus changes with time
Stroke duration (time)	ST	The duration of the basic unit of writing movements
Stroke speed	SS	The length of a single stroke divided by the stroke time
Number of changes in velocity	NCV	The mean number of local extremes of the velocity
Number of changes in acceleration	NCA	The mean number of local extremes of the acceleration

* – velocity, acceleration, and jerk have three vector sub-components: x – horizontal; y – vertical; t – tangential [7]

U test (when the normality assumption is not satisfied). Categorical parameters were analyzed with χ^2 test. The level of statistical significance was set at a two-tailed p-value of 0.05. In addition, sustainability of statistically significant difference between groups through task repetitions was particularly addressed for each kinematic parameter.

In addition, graphic rules were analyzed from the data related only to the semicircle tracing task and included the starting point and the direction of tracing for each semicircle in each of the three task repetitions. These were called "expected movements" and were predefined for each of the semicircles [12]: for the first semicircle from top to the bottom – Counter Clock Wise (CCW), for the second from left to the right – Clock Wise (CW), for the third from top to the bottom – CW, and for the fourth from left to the right – CCW (Figure 2). Expected movement usage was considered as compliance with graphic rules.

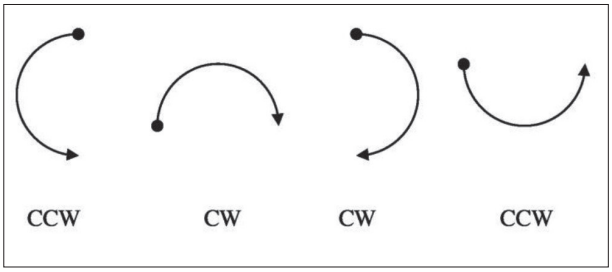

Figure 2. Expected movements in semicircle tracing; starting points (dots) and tracing directions (arrowheads) are shown; CW – clockwise; CCW – counter clockwise

RESULTS

Kinematic features

Semicircle tracing task

Compared to TDC, children with ADHD (all subjects regardless of stimulant treatment) traced semicircles with a lower NCA and had a lower Jt (tangential jerk) in each of the three task repetitions. Children with ADHD receiving MTX (n = 10) had lower NCA, NCV and Jt in comparison to TDC, where only NCA difference sustained through all three task repetitions (Table 2, section A). Children with ADHD not receiving MTX traced with lower SS, Vt and At and higher ST in the first two repetitions compared to TDC (Jt was lower in ADHD group in all repetitions) (Table 2, section A). In addition, in ADHD group only, those taking MTX wrote with higher Vt and lower ST, NCV and NCA compared to subjects without MTX (in all repetitions except for NCV) (Table 2, section B).

The Jt had sustainable trend of augmentation through semicircles and task repetitions in both ADHD (regardless of stimulant treatment) and TDC group (Figure 3; test statistics for the Mann–Whitney U test ranged from $U = 127$, $p < 0.001$ to $U = 429.5$, $p = 0.02$). Difference in Jt value between groups was reducing with task progression (Jt value rose faster in ADHD group).

Table 2. Kinematic parameter relations between study groups in semicircle tracing task

	Parameter		TDC														
			P	SS	ST	NCA	NCV	V			A			J			
		Rpt.						x	y	t	x	y	t	x	y	t	
A)	ADHD (all)	I	/	/	/	▼	/	/	/	/	/	/	/	/	/	▼▼	
		II	/	/	/	▼	/	/	/	/	/	/	/	/	/	▼	
		III	/	/	/	▼▼	/	/	/	/	/	/	/	/	/	▼	
	ADHD 1	I	/	/	/	▼	/	/	/	/	/	/	/	/	/	▼	
		II	/	/	/	▼	▼	/	/	/	/	/	/	/	/	/	
		III	/	/	/	▼▼	▼	/	/	/	/	/	/	/	/	/	
	ADHD 2	I	/	▼	▲	/	/	/	/	▼	/	/	▼	/	/	▼▼	
		II	/	▼	▲	/	/	/	/	▼	/	/	▼	/	/	▼▼	
		III	/	/	/	/	/	/	/	/	/	/	/	/	/	▼	
B)	Parameter		ADHD 2														
			P	SS	ST	NCA	NCV	V			A			J			
		Rpt.						x	y	t	x	y	t	x	y	t	
	ADHD 1	I	/	/	▼	▼	▼	/	/	▲▲	/	/	/	/	/	/	
		II	/	/	▼	▼	▼	/	/	▼	/	/	/	/	/	/	
		III	/	/	▼	▼	/	/	/	▼	/	/	/	/	/	/	

A) ADHD (all), ADHD 1 and ADHD 2 compared to TDC; B) ADHD 1 compared to ADHD 2 during successive semicircle tracing in three task repetitions; ADHD – attention deficit/hyperactivity disorder (all – all ADHD subjects, 1 – ADHD receiving methylphenidate treatment, 2 – ADHD without methylphenidate treatment); TDC – typically developed children; Rpt. – task repetition; shaded fields indicate statistically significant difference ($p < 0.05$); / - no statistically significant difference ($p > 0.05$); ▲ (▼) – indicates that parameter value is statistically higher (or lower) compared to A) TDC and B) ADHD 2; ▲▲ (▼▼) – indicates substantial statistical difference ($p < 0.01$); parameter abbreviations are defined in Table 1

Triangle copying task

In the first repetition, for b and c triangle edges, ADHD subjects (regardless of stimulant treatment) applied significantly larger pressure on the writing surface ($U = 511$, $p = 0.02$ and $U = 579$, $p = 0.01$ respectively) compared to TDC. This was not the case in second and the third task repetition where no statistically significant difference in pressure was documented ($p = 0.06$ - 0.14). Regarding other kinematic parameters, no significant difference was observed between study groups in neither task repetition.

Letter copying task

Only the first repetition was analyzed, and all ADHD subjects (regardless of stimulant treatment) were compared to TDC. It was found that Vt, SS and P were significantly higher in ADHD group compared to TDC ($U = 80798$, $p = 0.004$; $U = 80680$, $p = 0.004$; and $U = 81169$, $p = 0.002$ respectively).

Graphic rules

Comparing ADHD subjects (regardless of stimulant medication treatment) to TDC, those ADHD subjects taking stimulant medication to TDC and those ADHD without medical treatment to TDC; no statistically significant differences were observed regarding usage of expected movements. The same was observed when comparing ADHD subjects with stimulant medication to ADHD subjects without stimulants. There was a certain trend observed with task repetition where an increased number of subjects used expected movements (the most evident in TDC for the first and third semicircle and in ADHD with MTX treatment in the second semicircle). The usage of expected movements was the highest for the fourth semicircle and the lowest for the third semicircle in all groups (Figure 4).

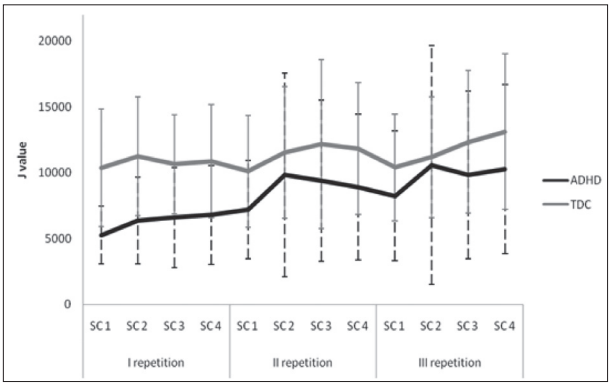

Figure 3. Observed increment in tangential jerk value with successive semicircles and task repetition; mean values and standard deviations are presented; there is a statistically significant difference between groups ($p < 0.05$); ADHD – attention deficit/hyperactivity disorder; TDC – typically developed children; J – jerk; SC – semicircle

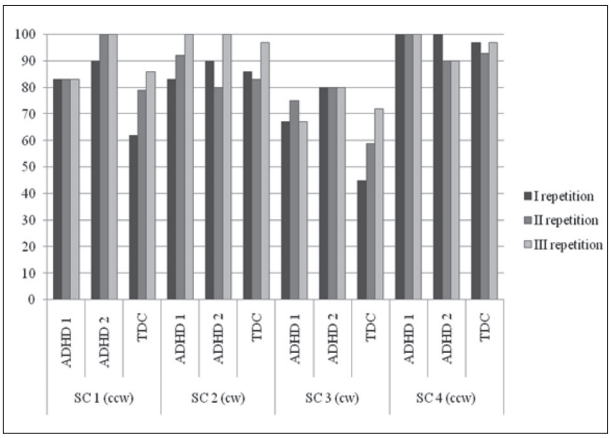

Figure 4. Percentage of subjects used expected movements for semicircle tracing in each task repetition; there is no statistically significant difference between groups ($p > 0.05$); ADHD 1 – subjects receiving methylphenidate treatment; ADHD 2 – subjects without methylphenidate treatment; TDC – typically developed children; SC_i i=1-4 – semicircles; cw – clockwise; ccw – counter clockwise.

DISCUSSION

In both ADHD (regardless of medication treatment) and control group, the Jt had sustainable trend of augmentation through semicircles and task repetitions (values were significantly higher in the control group but raised faster in the ADHD group). We could assume that, based on previous research, with the lack of visual guidance (no inking trace) TDC would be more careful during writing task, making saccadic ("jerky") movements with increased jerk value and in this manner decreasing possibility for error (missing tracing lines, under- or overwriting preset boundaries) [7, 15]. This could also result in decreased writing automation. In addition, the automation of writing movement is observed through changes in velocity and acceleration profile of writing movements (NCV and NCA values). The bigger NCV and NCA values are the lower writing automation is [7]. The opposite would be expected in ADHD group, less saccadic ("smoother"; with lower jerk) and more automated movements (with lower NCA and NCV) which could be due to disturbances in error monitoring [2, 15]. This was shown in our results for all ADHD subjects (regardless of stimulant medication treatment) and similar for ADHD taking stimulant medication. It was also observed that, with repetition, difference in jerk between study groups tends to decrease and ADHD subjects tend to trace as "jerky" as TDC. This could be in partial explained by better error processing with time and repetition. However, recent study has shown that ADHD subjects make from the beginning jerkier large-scale writing movements compared to TDC [19].

ADHD subjects without stimulant medication treatment traced semicircles with movements that were slower and of longer duration, but less saccadic compared to TDC. When these subjects were compared to ADHD subjects with a stimulant medication, they traced with the movements of longer duration and with lower velocity, but also less automated. Stimulant medication in subjects with ADHD modified writing kinematics compared to TDC improving overall movement speed, and this was not the case in group of ADHD subjects without stimulant medication.

This could be explained with the previous data showing that stimulant treatment could alleviate fine motor control impairment seen in ADHD with possible repercussion to writing movements [18, 23]. However, there is not much data on the influence of stimulant medications on motor functioning in ADHD, and should be interpreted with caution [18, 24]. MTX does improve ADHD symptoms in overall, but motor performance problems could remain [18, 25].

In the triangle-copying task, in the first repetition, subjects with ADHD applied significantly more pressure on writing surface (P) compared to TDC (but not in later repetitions). Although larger axial pressure on the writing surface was seen in ADHD [18], our result was not consistent with task repetition. Since no sustainable difference between groups was observed regarding all triangle edges and task repetition, we can assume that kinematic profile of shape copying in ADHD is similar to TDC.

In the letter-copying task, our results showed that V, SS, and P were significantly larger in ADHD group. This is to some instance in accordance with earlier research showing faster, poorly scaled writing movements with larger pressure in ADHD [17, 18]. Earlier research of writing in children with ADHD revealed that writing difficulties associated with attention problems are the consequence of both impaired graphemic buffer and kinematic motor production, and not of linguistic nature [26]. Based on this, we could assume that subjects with ADHD tend to make faster movements with more pressure on the surface compared to TDC and not due to the possibly accompanied dyslexia or dysgraphia, or the presence of comorbid developmental coordination disorder (DCD) [26, 27].

Our findings showed that there were no differences between children with ADHD and TDC when considering the expected movement usage (starting point and the direction of tracing as the main graphic rules). The lowest percentage of fulfilling graphic rules was in the third semicircle tracing. This result could be explained with greater "degrees of freedom" in tracing this semicircle as at the same time being a part of some letters (e.g. b or p, or Cyrillic small letter f – ф or r – р), which offers a possibility to start tracing from either end [13]. On the other hand, the highest percentage of fulfilling graphic rules was in the tracing of the fourth semicircle. It could be explained with the fact that the fourth semicircle resembles small cursive shape for the Cyrillic letter "i" (*и*). This letter is written and connected to other letters in words from left to right during writing (in Serbian language writing is from left to the right). In addition, most of our subjects preferred cursive script Cyrillic.

Subjects in both ADHD and TDC groups fulfilled expectations proposed by graphic rules with an observed increment of usage of expected movement with a task repetition [12]. This increment with task repetition in both ADHD and TDC groups represent a novel result in studies dealing with writing analysis. The largest percentage of non-preferred movement (opposite to graphic rules) seen in the first attempt can also be explained with the poor visual feedback (lack of inking trace). This finding could lead us to conclusion that both ADHD and TDC subjects have similar writing movement strategy in dealing with a simple tracing task.

Our study has some limitations. The writing was done using writing stylus without ink trace. It could influence results to some extent due to poor visual feedback during writing. Correlation between attention, behavior issues, and writing performance was not analyzed. The writing accuracy and overall legibility were not analyzed in the relations to the graphic rules and kinematic parameters.

CONCLUSION

Children with ADHD tended to make more automated writing movements with less jerk compared to TDC. It appeared that MTX treatment improved writing movement speed and automation in ADHD subjects, however these are preliminary data from a small number of subjects and should be further assessed. In more complex tasks, like triangle and letter copying, the kinematic difference was evident but not consistent. Both ADHD and TDC children were compliant with graphic rules in semicircle task. This study also showed importance of task repetition and its influence on writing. These specific kinematic traits found in children with ADHD could be used in clinical practice as an additional method in defying more subtle clinical presentations of ADHD, as well as to monitor effects of stimulant therapy. Addressing the limitations of the present study, further research is needed among children with ADHD in order to better understand specific cognitive approaches to writing and how to implement these in regular clinical practice.

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Кинематика писања и графичка правила код деце са хиперкинетским поремећајем са недостатком пажње (*ADHD*)

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САЖЕТАК

Увод/Циљ Циљ ове студије био је да упореди кинематичке карактеристике и графичка правила приликом писања деце са хиперкинетским поремећајем са недостатком пажње (*ADHD*) (са терапијом стимулансима и без ње) и код типично развијене деце (*TDC*).

Методе Анализирано је укупно 55 испитаника (26 са *ADHD*, од којих је 10 добијало метилфенидат, и 29 *TDC*). Испитаници су радили задатак са писањем на дигитализованој графичкој табли (у три понављања; писаљком без мастила). Задатак је укључивао подебљавање полукругова, прецртавање троугла и преписивање слова. Анализиране су кинематичке карактеристике свих покрета, као и графичка правила приликом подебљавања полукругова. Графичка правила су сагледавана кроз очекиване покрете писања (одабир почетне тачке и правац подебљавања).

Резултати Вредности параметра „трзај" биле су статистички значајно веће код *TDC* у поређењу са децом са *ADHD* и константно су расле у обе групе са израдом и понављањем задатка са полукруговима. Деца са *ADHD* без терапије метилфенидатом имала су спорије покрете писања у поређењу са *TDC*. Покрети подебљавања су били аутоматизованији (мање промена у брзини и убрзању) и са мањим трзајем код деце са *ADHD* на метилфенидату у поређењу са *TDC*. У групи деце са *ADHD*, она деца која су била на терапији подебљавала су брже и аутоматизованије у поређењу са децом без терапије. Већина испитаника користила је очекиване покрете за подебљавање полукругова и овај проценат је растао са понављањем задатка (није било разлике међу испитиваним групама).

Закључак Деца са *ADHD* као и *TDC* користе сличан приступ у подебљавању полукругова и придржавају се графичких правила. Третман метилфенидатом може утицати позитивно на кинематику писања код деце са *ADHD*. Понављање задатка такође утиче на писање.

Кључне речи: писање; *ADHD*; кинематички параметри; графичка правила; метилфенидат