COGNITIVE ABILITIES IN CHILDREN WITH ADHD, COMORBID EPILEPSY AND TYPICALLY DEVELOPED CHILDREN

Edmunds Vanags[1], Ņikita Bezborodovs[2,3], Līga Riekstiņa[1],
Armands Zelčs[1], Lelde Ūlupe[1], Dana Skara[1], Ance Vecgrāve[1],
Marta Celmiņa[3], Jurģis Strautmanis[3]

[1] University of Latvia, Latvia

[2] Rīga Stradins University, Department of Psychiatry and Narcology

[3] Children's Clinical University Hospital, Epilepsy and Sleep Medicine Centre

ABSTRACT

The aim of the study was to assess the differences in cognitive abilities compared across clinical and control groups. It was hypothesized that differences between groups would be small or non-existant, due to rather heterogeneous clinical profiles. And they could be partially explained by participants' age as cognitive abilities develop over time. Further analysis of the sample was performed by creating cognitive ability profiles of the participants. The study used data from the project "Development of a Screening Method for Children with ADHD and CSWS in Children aged 7–15", and included data from 97 children, which were divided into 3 groups: ADHD, combined ADHD and epilepsy and control group. For assessing cognitive abilities an extended battery of executive and other cognitive computerized tests were used: Stroop Color and Word Test, Digit Span Test, Symbol Digit Modalities Test, and Continious Performance Test. The analysis of cognitive ability profiles reveals a wide range of heterogeneity in both clinical and control groups. It revealed that children with ADHD and combined ADHD and epilepsy have more profiles with lower cognitive abilities compared to control group. Some children with ADHD have similar cognitive profiles to those of typically developed children, suggesting that in some cases there may be a small difference in cognitive performance between ADHD and typically developed children.

Keywords: ADHD, cognitive abilities, executive functions, attention deficit and hiperactivity syndrome, epilepsy

Introduction

Attention Deficit Hyperactivity Disorder (ADHD) is the most commonly diagnosed mental health disorder in children and adolescents (Willcutt, 2012). This disorder often is associated with impairment of executive functions (Magnus et al., 2021), as well as non-executive functions (Song,

2015), like sustained and selective attention (Song et al., 2012) and processing speed (Willcut et al., 2005). The impairment of different cognitive abilities is considered to be one of the most important features of ADHD (Kofler et al., 2019). But despite the fact that children with ADHD suffer from delayed development of the fronto-striato-parietal and fronto-cerebellar networks that are responsible for cognitive functioning (Rubia, 2013), not all of children with ADHD will express them (Nigg et al., 2005; Willcut et al., 2005; Friedmann et al., 2016). Although impairment of cognitive abilities can be grouped into several subgroups when viewed in a clinical population, the heterogeneity of symptoms, clinical outcomes, and behavior at the individual level can differ significantly (Karalunas & Nigg, 2020).

Researchers have attempted to identify and classify symptoms through statistical analysis and create profiles of children with ADHD based in different domains (Bergwerff et al., 2019; Costa Dias et al., 2015; Fair et al., 2012), but to date, no universal and exhaustive classification has been established that could classify all children in distinct subgroups (Bergwerff et al., 2019). This subtyping of ADHD was an attempt to address clinical heterogeneity; however, variation in clinical symptoms, behavior and expressions is significant even within one subtype, and similar variation is also expected in the etiology and pathophysiology of the disorder (Fair et al., 2012; Karalunas et al., 2014; Nigg & Casey, 2005). DSM-V includes 3 subtypes of ADHD, based on the primary symptoms – predominantly Inattentive, predominantly Hyperactive-Impulsive, and Combined type (APA, 2013). ADHD is usually diagnosed based on the number, severity and duration of symptoms observed by parents or carers and teachers. Biological or etiological parameters are generally not taken into account when making the diagnosis. Studies and clinical trials in psychiatry are mainly based on the assumption that the diagnostic criteria that appear in DSM represent homogeneous population of disorder. If these criteria are strictly applied, such a categorical comparison of individuals or groups may not take into account subtle phenotypic variations. And it may pose a risk that children who do not show a sufficient number of symptoms or whose symptoms are not observed by their parents do not receive diagnosis and help even though they suffer from cognitive ability impairments and related issues.

In recent years, the dimensions of emotional, behavioral, and cognitive functioning in children with ADHD have been studied to better understand the etiology of ADHD to improve clinical outcome (Karalunas & Nigg, 2020). Researchers have begun to pay more attention to the impact of various factors on ADHD and how neurobiological pathways can contribute to the development of symptoms of external (behavioral) and latent (neurocognitive) disorders (Zeeuw et al., 2012).

Epilepsy is a chronic, neurological disorder, the main symptom is spontaneous, repeated seizures (Shneker & Fountain, 2003) resulting from an sudden increase in electrical activity between neurons (Bromfield, Cavazos & Sirven, 2006). Some children with epilepsy also have memory and speech impairment, difficulty concentrating, hyperactivity, irritability, other mental disorders or behavioral disorders (Yuan, Li & Zhong, 2015). Due to epilepsy causing exacerbate pre-existing cognitive impairment, patients with epilepsy are more prone to cognitive and behavioral deficits (Motamedi & Meador, 2003). Patients with epilepsy most often suffer from memory impairment, especially short-term memory due to seizure-induced changes in the temporal lobe and hippocampus (van Rijckevorsel, 2006).

The aim of this study is to assess the differences in impairment of several cognitive abilities compared across clinical and control groups using a novel evaluation platform. It was hypothesized that due to rather heterogeneous clinical profiles, differences between groups would be small or non-existant. And the existing differences could be partially explained by participants age. And to better understand the heterogeneity of cognitive abilities in all groups, further analysis by developing unique cognitive profiles of the participants was explored.

Methods

Participants

The study used data from the project "Development of a Screening Method for Children with ADHD and CSWS (continuous spike-wave syndrome) in Children aged 7–15". First the clinical groups (ADHD and combined ADHD and epilepsy) were recruited through CCUH (Children's Clinical University Hospital). And after a social media campaign on Facebook.com was started, asking parents with children to participate in a scientific study. The capmpaign was active from March, 22 – August, 28, 2021. Initially 519 applications for participating in the study were recieved. After a follow-up e-mail with information about the study and a phone call about the instructions 151 children performed the testing from which 97 were consistent for this study.

A Facebook campaign inviting parents / legal guardians to join the study without any monetary incentives for rewarding participation was chosen for the selection and enrollment of participants for the study due to epidemiological restrictions of COVID-19. The campaign lasted from 22nd of March to 28th of August 2021. Together 519 applications were received and all of these received emails containing full information about the study, its goals and testing procedure. In the end, 151 successfully completed the testing procedure due to initial screening (children's age, ability to read, access to the computer, attention or behavioral difficulties and if a child

had a diagnosis) or participants dropping out. To ensure equal testing conditions, Calls with each parent or legal guardian participating in the study were arranged to explain the process of the remote testing and all the instructions and necessary preparations in order to achieve the most equal conditions for testing. Exploro.lv platform was used to carry out the remote testing. From these, due to ambiguity of their clinical symptoms, 97 were used for the data analysis.

Due to the epidemiological restrictions of COVID-19, the testing was conducted remotely using exploro.lv test platform. The researchers sent an email to the parents and legal guardians with information about the study and its goals, detailed instructions for testing. Calls with each parent or legal guardian participating in the study were arranged to explain the process of the remote testing and all the instructions and necessary preparations in order to achieve the most equal conditions for testing.

The children were divided into relevant groups by either clinical diagnosis in case of Epilepsy and ADHD groups or by Conner's ADHD index subscale results (clinical group if over 75 T, control group if under 58 T) in case of ADHD or control groups. Overall, 97 children were enrolled in the study separated into three groups as follows: ADHD ($n = 51$, $M = 10.12$, $SD = 0.45$, 72.5% boys), ADHD and epilepsy ($n = 12$, $M = 9.9$, $SD = 1.95$, 75 boys), and control group ($n = 34$, $M = 9.13$, $SD = 1.80$, 73.5% boys).

Instruments

1) Finger Tapping Test. To assess motor and psychomotor functioning, Finger Tapping test (FTT, Reitan, 1959, modification by Vanags, Ekmanis, 2018) was used. Participants are asked to tap the "Space" button with their index finger as fast as possible first with the left hand, then – with their right hand. For each hand there are 3 attempts each lasting for 10 seconds with 3 seconds rest between each.

2) Stroop Color and Word Test *(SCWT,* Stroop, 1935, modification Vanags & Ekmanis, 2018). The test consists of 3 parts with congruent, non-congruent and control stimuli. In the first part the participant must press a key each time when the color name appears on the screen. In the second part the participant must press a key only when the color name matches the color of the word. During the third part the participant must press a key only when the color name does not match the color of the word. The reaction time and missed reactions or incorrect reactions for each step are calculated.

Three test indicators were used: reaction time measuring information processing speed and visual attention from the first step. The average number of correct responses from the second and third steps, which reflects the ability of working memory, inhibitory control and selective attention (Strauss et al., 2006). From the third step the number of incorrect clicks was

used as a measure to reflect impairments in inhibitory control (cognitive inhibition) (Sørensen et al., 2013)

3) Digit Span Test *(*Terman, 1916, modification Vanags, Ekmanis, 2018) was used to measure working memort abilities. The test consists of two parts: (1) a series of numbers that must be memorized and entered in the required field in the order in which they were displayed, and (2) a series of numbers that must be memorized and entered in the required field in the reverse order in which they were displayed. Each string of numbers is displayed once, and with every step one digit is added to the string.

This study used the number of all correctly entered digits as a measure of an individual's short-term memory capacity (Jarrold & Towse, 2006).And the number of digits entered correctly in the opposite order reflects an individual's working memory abilities (switching, manipulation, and dual processing) (Beblo et al., 2004).

4) Symbol Digit Modalities Test (SDMT, Smith, 1968), modification Vanags, Ekmanis, 2018). On the top of the screen are 2 rows – the first contains numbers, the second corresponding symbols. The test taker must fill in the corresponding number for each symbol that appears on the screen. For example, the symbol "@" is given, for which the corresponding number is "1", then when the symbol "@" appears, the respondent must press the number "1", Errors cannot be corrected, the participant must continue till the time limit ends.

Indicators of visual processing and motor speed, visual attention were measured with the SDMT. Most traditional measures of information processing speed also require a motor response to facilitate performance (Low et al., 2017). At the most basic level, information processing speed should encompass at least two main domains, one of which would be the speed of any primary non-motor/cognitive activity (e. g. perceptual speed for attentional activation or auditory processing speed) and the other of motor or physical activity (e. g. psychomotor speed or reaction time). This goes also for Symbol Digit Modalities test, where the individual has to fill the empty box as quickly as possible with the relevant symbol – both motor speed and the ability to switch their attention from the given sample to the empty box and back are required, and the speed of information processing is also important.

5) Computerized CPT test (Sonuga-Barke et al., 2008, modification by Vanags & Ekmanis, 2018). The continuous performance test allows the evaluation of sustained and selective attention, impulsivity, or inability to slow down their response (Sonuga-Barke et al., 2008). During the test, various letters are displayed on the screen and the participant must press the spacebar each time when a letter that is not "b" is being displayed and restrain their reaction to press the button when the letter "b" appears. The test continues for 2 minutes.

6) Demographic survey. Each parent or legal guardian filled the demographic survey about child's age, ability to read, ADHD and epilepsy diagnosis (if applicable).

7) Conner's Parent Rating scale (Conners et al. 1998). The question-naire consists of 80 statements and 13 subscales. Answers to statements about the child should be given according to the child's behavior during the last month. Statements are on a Likert scale from 0 to 3, where 0 is "Not at all (very seldom, never)", 1 is "A little (sometimes)", 2 is "Quite a lot (often, quite a lot)" and 3 is "Very (very often)'. In order to more accurately divide children into the clinical or control group, a subscale of this survey – the ADHD index – was used.The scoring was performed according to the test manual and established cutoff points for possible and likely ADHD (less than 58 standardized T-score for control group and more than 75 standardized T-score for ADHD group).

Based on the available literature, while describing each test used and its obtained scores, the cognitive abilities they mostly measure were also described. For the most part, cognitive tests measure various cognitive abilities in general, but to make it easier to navigate the cognitive ability indicators obtained from the tests were conceptualized.

In the further statistical calculations, the description of the results, the discussion part and the conclusions, these conceptualized names of the indicators of cognitive abilities will be used, which can be seen in Table 1.

Table 1. Cognitive domains and test variables used to measure them and and abbreviations for profile analysis presented in the second part of the results.

Variable from test	Cognitive ability domain
SDMT correct answer mean response time	Information processing and motor speed – A, a
SDMT incorrect number of answers	Visual attention – B, b
DST amount of numbers in forwards	Visual short-term memory – C, c
DST number of numbers in backwards	Visual working memory – D, d
SCWT mean response time	Information processing speed – E, e
SCWT 2nd and 3rd step mean correct number of answers	Working memory, inhibition, selective attention – F, f
SWCT 2nd and 3rd step mean incorrect number of answers	Inhibition control (cognitive inhibition) – G, g
CPT number of impulse taps	Inhibition control (response inhibition) – H, h
CPT number of correct taps	Selective and sustained attention – I, i

Procedure

The study used data from the project "Development of a screening method for children with ADHD and CSWS in children aged 7–15 years". This project was implemented in collaboration with students and researchers of the University of Latvia (UL) and CCUH specialists. Permission for the research was received from the Ethics Commission of the UL (Institute of Cardiology and Regenerative Medicine) and CCUH. Parents were able to enroll their children in the study through a survey that gathered the first information needed to make a selection (age, literacy, diagnoses made, child's difficulties, computer availability, etc.). Also, the procedure of the study and its goals have been agreed with the representatives of the study participants through informed consent, which was sent by email. In the face of the epidemiological situation in the country (Covid-19 restrictions), testing was moved to a remote environment. The testing took place via the exploro.lv platform, where the necessary cognitive test battery, informative data survey and ADHD Conner's parent survey were created. Detailed testing instructions were developed, which were sent to the email provided by the parents and then discussed individually with each child's parent in order to achieve the most equal conditions for testing. After an in-depth presentation of the testing protocol, a link to the test battery created by exploro.lv was sent to the parents. The testing of the children was administered by the parents. The parent or legal guardian filled demographic survey and Conner's parent survey. After the testing was completed the parent had the chance to report whether there were circumstances that could have left a negative impact on child's testing results, e. g. the sibling run into the room.

Results

ANCOVA analysis

Descriptive statistics for all variables used for calculating results can be seen in Table 2. To test our hypothesis, ANCOVA was used with variable age as a covariate. All assumptions (normality, linearity, homogeneity, independent sample*s)* were met supporting the choice of this method.

First, a Spearman's Rho coefficient was calculated to find which dependent variables correlate with age of participants (see Table 3). Five of nine variables showed statistically significant correlation with age of which three were positive ones (Visual short-term memory $r = .43$, $p < .001$, Visual working memory $r = .427$ $p < .001$, Executive functions $r = .262$, $p < .001$), and two negative ones (Motor speed, $r = -.686$, $p < .001$, Information processing speed, $r = -.51$, $p < .001$).

These five variables were then put into ANCOVA model (see Table 3) with variable age as a covariate.

Table 2. Descriptive statistics for the visual attention, information processing and motor speed, visual short-term memory, visual working memory, inhibition control, information processing speed, working memory, inhibition and selective attention, inhibition control, selective and sustained attention variables used in the study

Variable	M	SD
Visual attention	1,77	1,86
Information processing and motor speed	2933,35	1196,21
Visual short-term memory	26,34	10,31
Visual working memory	20,88	9,83
Inhibition control	2,29	4,48
Information processing speed	377,02	142,64
Working memory, inhibition, selective attention	21,42	3,39501
Inhibition control	2,5256	3,31117
Selective and sustained attention	191,60	4,24

Table 3. Spearman's Rho for age and information processing and motor speed, visual attention, visual short-term memory, visual working memory, information processing speed, working memory, inhibition variables

	Spearman's rho	p	Lower 95% CI	Upper 95% CI
Information processing and motor speed	–0.69***	< .001	–0.76	–0.59
Visual attention	0.06	0.42	–0.09	0.22
Visual short-term memory	0.43***	< .001	0.28	0.55
Visual working memory	0.43***	< .001	0.29	0.55
Information processing speed	–0.51***	< .001	–0.62	–0.38
Working memory, inhibition, selective attention	0.26***	< .001	0.11	0.40
Inhibition control	–0.04	0.65	–0.19	0.12
Inhibition control	–0.06	0.49	–0.22	0.11
Selective, sustained attention	0.01	0.94	–0.16	0.17

Note: ***$p < .001$

Table 4. Between-subjects tests for information processing and motor speed, visual short term memory, visual working memory, information processing speed and working memory, inhibition and selective attention variables and age as a covariate

Variable		*F*	*df*	*w2*
Information processing and motor speed	groups	3.101	2	.03
	age	36.134***	1	.36
Visual short-term memory	groups	0.77	2	.00
	age	8.38*	1	.08
Visual working memory	groups	0.18	2	.00
	age	6.16*	1	.05
Information processing speed	groups	0.71	2	.00
	age	12.089**	1	.52
Working memory, inhibition, selective attention	groups	4.23*	2	.06
	age	6.51*	1	.05

Note: *$p < .05$; **$p < .01$, ***$p < .001$

As can be seen from Table 3, significant between group differences were observed only for the working memory, inhibition and selective attention ($F_{(2, 93)} = 4.23$, $p < .05$, $w^2 = .06$), however effect size is small. For the rest of the variables, no significant between group differences were found. When controlling for age, the model seems to explain all five of the variables: Information processing and motor speed ($F_{(1, 93)} = 36.13$, $p < .001$, $w^2 = .36$), visual short-term memory ($F_{(1, 93)} = 8,38$, $p < 0.05$, $\omega^2 = 0,08$), visual working memory ($F_{(1, 93)} = 6,16$, $p = 0,015$, $w^2 = 0,05$), information processing speed ($F_{(1, 93)} = 12,09$, $p = .001$, $w^2 = .11$) and working memory, inhibition, selective attention ($F_{(1, 93)} = 6.51$, $p < .05$, $w^2 = 0.05$. The biggest effect size can be observed for information processing and motor speed ($\omega^2 = .36$) and working memory, information processing speed ($\omega^2 = .52$)

Cognitive profiles

Cognitive profiles of all participants across groups were created based on an example by Fried and Nesse (2015). First, seven cognitive domains were defined and all the participants' test scores evaluated. For the basis of evaluation percentiles were used with cut-off points on 14th and 86th percentile. If an individual score in one of the cognitive domains was higher than 86th or lower than 14th percentile, depending on how the variable is scored, it was marked as a high presence of dysfunction. The result of

this analysis can be seen below in Table 5 where all the found variations of cognitive profiles are presented. Lowercase letter indicates non-existent dysfunction in a particular cognitive domain, while the uppercase letter indicates dysfunction found in one of the cognitive domains. Cognitive domains used and their assignment to letters can be seen in Table 1.

Table 5. Frequencies of cognitive ability profiles for ADHD, combined ADHD and epilepsy and control group.

Cognitive ability profiles	ADHD group	Control group	ADHD and Epilepsy group
abcdefghi	18	13	5
abcdefghI	4		1
abcdefgHi	3	1	
abcdefGhi	3	1	
abcdEfghi	3	1	
aBcDefghi	2		
AbCDefghi	2		
abcdefgHI	1		
abcdeFGhi	1		
abcdEfghI	1		
abcdEFGhi	1		1
abcDefGhi		1	
abcDefGHi	1		
abCdefghi		2	
abCdefgHi	1	1	
abCdefGhi		1	
abCdefghI		1	
abCdeFGHI	1		
abCDefghi	1		1
abCDEfgHi			1
aBcdefghi	1	2	
aBCdefghi		1	
aBcdefghI		2	
aBcdefGhi		1	
aBcdefgHi	1		
aBcdefgHI	1		
aBcDefgHI		1	
aBcdeFGhi	1		
aBcdeFGHi	1		
AbcDefghi		1	

Continued from previous page

Cognitive ability profiles	ADHD group	Control group	ADHD and Epilepsy group
Abcdefghi	1	1	
ABcdEfghi		1	
ABcdEfGhi			1
AbcdEFghi			1
AbCdEFghi	1		
AbCDEfGhi			1
AbcDEfghi		1	
AbCDeFGHi	1		

Results show a wide range of heterogeneity in all 3 groups. There were 23 unique cognitive ability profiles (out of 512 possible profile combinations) in the ADHD group. In Figure 1 can be seen the frequencies of cognitive ability impairment in all three groups. The most common is the cognitive ability profile without pronounced cognitive impairment – 18 children, which make up 35% of the sample, 15 children (30%) have only one low cognitive ability, 8 children (16%) have 2 low scores, 6 children (12%) 3 low scores, 2 children (4%) 4 low scores. Only one child has 5 low cognitive abilities and one child has 6 low cognitive abilities. Apart from the profile without cognitive impairment, only 6 other combinations of profiles are repeated among several children, and 4 of these were with only 1 lower cognitive ability. The other 16 cognitive ability profiles, which account for 32% of all ADHD sample profiles, are unique, with different combinations of cognitive ability indicators for each child.
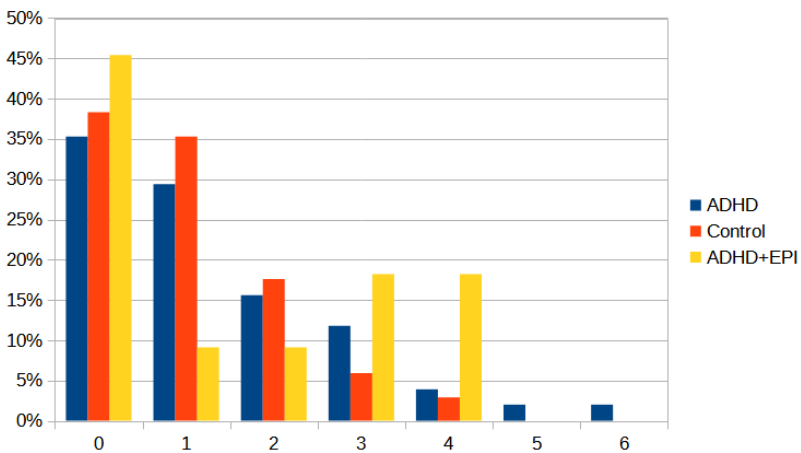

Figure 1. Frequencies of cognitive ability impairment in ADHD, combined ADHD and epilepsy and control groups

Looking at the ADHD and Epilepsy group with the lowest numbers ($n = 12$), 5 children (42%) have profiles without cognitive impairment, 1 child has a low score, just as 1 child has two low scores, two children there are 3 and two have 4 low scores and one child has 5 low scores. Low rates of information processing speed (E-5 profiles, A-3 profiles) as well as three profiles combining short-term and low working memory rates are more common.

Eighteen different cognitive ability profiles were found in control group, the most common was without cognitive difficulties – 13 children or 39% of the sample, 8 children (23%) have only one low cognitive ability, 9 children (26%) have 2 low scores, 2 children (5.8%) have 3 low cognitive abilities and one child has 4 low cognitive abilities.

Looking at cognitive ability profiles for all three groups, it can be observed that apart from the profile without cognitive impairment, which is the most common in all groups, no other profile recur in all groups. The ADHD and control group have 6 common profiles and the ADHD and the ADHD and Epilepsy group have 3 common profiles.

Discussion

ADHD is the most commonly diagnosed mental health disorder in children and adolescents (Willcutt, 2012). The clinical profile for children with ADHD has some overlap with epilepsy (Wang et al., 2020) which makes it even more critical to spot the differences when making the diagnoses. Given the gradual shift in psychology towards a more online-based approach, developing new methods to assess cognition and other psychological functions is crutial.

Thus, the aim of this study was to explore the differences in cognitive abilities among children groups diagnosed with ADHD, epilepsy and ADHD compared to the control group sample. The study found no differences when comparing the three groups when controlling for age thus confirming the initial hypothesis that variance in cognitive abilities between clinical groups would be non-existent or very small. Age was found to be an important predictor of cognitive function across ADHD/epilepsy group and control group.

Previous studies have shown that children with ADHD (Nigg et al., 2005; Willcutt et al., 2005) and epilepsy (Yuan, Li & Zhong, 2015) present overall lower cognitive abilities that together make a pattern specific to ADHD and epilepsy diagnosis. Such cognitive patterns should also be observed via psychological assessment across the clinical subgroups. This study also explored the cognitive ability profiles of the current sample that showed rather varied cognitive apabilities among children. It was rare that more than a few

of them had the same cognitive ability difficulties or even remotely similar ones. Moreover, even control group had shown drawbacks in few cognitive abilities indicating that profiles of cognition in children should not be generalized. Authors of this study suggest that heterogeneity of cognitive abilities that can been seen in analysis of children profiles accounts for the findings of no statisticaly significant differences in cognitive abilities among groups. Further research into these profiles, their correlation with age and other variables should be conducted as it would shed a new light into diagnosis and treatment of ADHD. Clinical profile heterogeneity signifies that ADHD is rather a complex disorder with potential link to core neuropsychological impairments (Luo et al. 2019). Individualistic approach in ADHD / epilepsy psychological assessment, specifically when conducting further research is necessary (Rosales et al., 2015; Karalunas, & Nigg, 2020).

Limitations and future research directions

The small number of participants, especially in clinical samples prevents generalizing the results to the clinical population as a whole. While response from people was rather big, attracting clinical samples was found to be an issue. Since participation was on a voluntary basis, this may not have been enough motivation in itself for parents whose kids were diagnosed with ADHD to enroll in the study.

Covid-19 pandemic safety measures that were enforced during the process of conducting the testing played a huge role in how to conduct data collection. Since the initial plan of conducting the testing offline was no longer possible, an alternative was found in online testing. To ensure the same experimental procedure, carefully designed guidelines were created to guide parents through the process of the experiment and, although thorough and as clear as possible, these guidelines could never substitute a real researcher conducting an testing. This could have been one of the biggest implications as the process was almost entirely in the hands of parents and their offsprings.

One of the biggest strengths of this study is collaboration with Children's Clinical University Hospital and therefore involvement of participants with epilepsy and ADHD. The most important contribution of the study was the development of cognitive profiles (Skara, 2022), which clearly shows the heterogeneity of symptoms in clinical and neurotypical children samples.

While remote assessment comes with a lot of obstacles and drawbacks, it can be argued that it provides a much safer and familiar environment for children to do the testing.

Conclusions

Findings show that there were no statistically significant differences among groups in cognitive abilities when controlling for age. It was observed that the results among participants within each group were rather varied thus leading to assume that the cognitive abilities were found to be heterogeneous. This lends to a growing number of literature suggesting a shift to a more individualistic approach in clinical assessment for ADHD and epilepsy. To observe more meaningful findings, the research should be conducted in a larger sample size.

References

Alloway, T. P., Gathercole, S. E., Willis, C., & Adams, A.-M. (2004). A structural analysis of working memory and related cognitive skills in young children. *Journal of Experimental Child Psychology*, *87*(2), 85–106. https://doi.org/10.1016/j.jecp.2003.10.002

American Psychiatric Association. (2013). Diagnostic and statistical manual of mental disorders (5th ed.). https://doi.org/10.1176/appi.books.9780890425596

Beblo, T., Macek, C., Brinkers, I., Hartje, W., & Klaver, P. (2004). A new approach in clinical neuropsychology to the assessment of spatial working memory: The block suppression test. *Journal of Clinical and Experimental Neuropsychology, 26*(1), 105–114.

Bergwerff, C. E., Luman, M., Weeda, W. D., & Oosterlaan, J. (2019). Neurocognitive Profiles in Children With ADHD and Their Predictive Value for Functional Outcomes. *Journal of Attention Disorders*, *23*(13), 1567–1577. https://doi.org/10.1177/1087054716688533

Bromfield, E. B., Cavazos, J. E., Sirven, J. I.,& editors. (2006). An Introduction to Epilepsy [Internet]. *Chapter 4, Epilepsy Surgery*. West Hartford (CT): American Epilepsy Society. Retrieved December 27, 2020, from https://www.ncbi.nlm.nih.gov/books/NBK2514/.

Conners, C. K., Sitarenios, G., Parker, J. D., & Epstein, J. N. (1998). The revised Conners' Parent Rating Scale (CPRS-R): Factor structure, reliability, and criterion validity. *Journal of Abnormal Child Psychology, 26*(4), 257–268. https://doi.org/10.1023/a:1022602400621

Fair, D. A., Bathula, D., Nikolas, M. A., & Nigg, J. T. (2012). Distinct neuropsychological subgroups in typically developing youth inform heterogeneity in children with ADHD. *Proceedings of the National Academy of Sciences*, *109*(17), 6769–6774. https://doi.org/10.1073/pnas.1115365109

Costa Dias, T. G., Iyer, S. P., Carpenter, S. D., Cary, R. P., Wilson, V. B., Mitchell, S. H., Nigg, J. T., & Fair, D. A. (2015). Characterizing heterogeneity in children with and without ADHD based on reward system connectivity. *Developmental Cognitive Neuroscience, 11*, 155–174.

Diamond, A. (2002). Normal development of prefrontal cortex from birth to young adulthood: Cognitive functions, anatomy, and biochemistry. In *Principles of frontal lobe function* (pp. 466–503). Oxford University Press.

Eldreth, D. A., Patterson, M. D., Porcelli, A. J., Biswal, B. B., Rebbechi, D., & Rypma, B. (2006). Evidence for multiple manipulation processes in prefrontal cortex. *Brain Research, 1123*(1), 145–156. https://doi.org/10.1016/j.brainres.2006.07.129

Fair, D. A., Bathula, D., Nikolas, M. A., & Nigg, J. T. (2012). Distinct neuropsychological subgroups in typically developing youth inform heterogeneity in children with ADHD. *Proceedings of the National Academy of Sciences, 109*(17), 6769–6774.

Fried, E. I., & Nesse, R. M. (2015). Depression is not a consistent syndrome: An investigation of unique symptom patterns in the STAR*D study. *Journal of Affective Disorders*, *172*, 96–102. https://doi.org/10.1016/j.jad.2014.10.010

Friedman, N., & Miyake, A. (2016). Unity and Diversity of Executive Functions: Individual Differences as a Window on Cognitive Structure. Cortex, 86.

Gathercole, S. E., Pickering, S. J., Ambridge, B., & Wearing, H. (2004). The Structure of Working Memory From 4 to 15 Years of Age. *Developmental Psychology, 40*(2), 177–190. https://doi.org/10.1037/0012-1649.40.2.177

Jarrold, C., & Towse, J. N. (2006). Individual differences in working memory. *Neuroscience, 139*(1), 39–50. https://doi.org/10.1016/j.neuroscience.2005.07.002

Karalunas, S. L., Geurts, H. M., Konrad, K., Bender, S., & Nigg, J. T. (2014). Annual research review: Reaction time variability in ADHD and autism spectrum disorders: measurement and mechanisms of a proposed trans-diagnostic phenotype. *Journal of Child Psychology and Psychiatry, and Allied Disciplines, 55*(6), 685–710. https://doi.org/10.1111/jcpp.12217

Karalunas, S. L., & Nigg, J. T. (2020). Heterogeneity and Subtyping in Attention-Deficit/Hyperactivity Disorder—Considerations for Emerging Research Using Person-Centered Computational Approaches. *Biological Psychiatry*, *88*(1), 103–110. https://doi.org/10.1016/j.biopsych.2019.11.002

Karalunas, S. L., Geurts, H. M., Konrad, K., Bender, S., & Nigg, J. T. (2014). Annual research review: Reaction time variability in ADHD and autism spectrum disorders: Measurement and mechanisms of a proposed trans-diagnostic ... – PubMed—NCBI.

Kofler, M. J., Soto, E. F., Fosco, W. D., Irwin, L. N., Wells, E. L., & Sarver, D. E. (2019). Working memory and information processing in ADHD: Evidence for directionality of effects. *Neuropsychology*. http://search.ebscohost.com/login.aspx?direct=true&db=pdh&AN=2019-60760-001&site=ehost-live

Luo, Y., Weibman, D., Halperin, J. M., & Li, X. (2019). A Review of Heterogeneity in Attention Deficit/Hyperactivity Disorder (ADHD). *Frontiers in Human Neuroscience, 13*, 42. https://doi.org/10.3389/fnhum.2019.00042

Magnus, W., Nazir, S., Anilkumar, A. C., & Shaban, K. (2021). Attention Deficit Hyperactivity Disorder. *StatPearls Publishing*.

Motamedi, G., & Meador, K. (2003). Epilepsy and cogniton. *Epilepsy & behavior: E&B, 4*(2), 25–38. https://doi.org/10.1016/j.yebeh.2003.07.004.

Nigg, J. T., & Casey, B. J. (2005). An integrative theory of attention-deficit/hyperactivity disorder based on the cognitive and affective neurosciences. *Development and Psychopathology*, *17*(3), 785–806. https://doi.org/10.1017/S0954579405050376

Nigg, J. T., Stavro, G., Ettenhofer, M., Hambrick, D. Z., Miller, T., & Henderson, J. M. (2005). Executive functions and ADHD in adults: Evidence for selective effects on ADHD symptom domains. *Journal of Abnormal Psychology*, *114*(4), 706–717. https://doi.org/10.1037/0021-843X.114.3.706

Reitan, R. M. (1959). Manual for Administration of Neuropsychological Test Batteries for Adults and Children. Neuropsychology Laboratory, Indiana University medical Center.

Rosales, A., Vitoratou, S., Banaschewski, T., Asherson, P., Buitelaar, J., Oades, R. D., Rothenberger, A., Steinhausen, H.-C., Faraone, S. V., & Chen, W. (2015). Are all the 18 DSM-IV and DSM-5 criteria equally useful for diagnosing ADHD and predicting comorbid conduct problems? *European Child & Adolescent Psychiatry, 24*(11), 1325–1337. https://doi.org/10.1007/s00787-015-0683-7

Rubia, K. (2013). Functional neuroimaging across development: a review. *Eur. Child Adolesc. Psychiatry, 22*, 719–731. doi: 10.1007/s00787-012-0291-8

Shneker, B. F., & Fountain, N. B. (2003). Assessment of acute morbidity and mortality in nonconvulsive status epilepticus. *Neurology, 61*(8), 1066–1073. https://doi.org/10.1212/01.wnl.0000082653.40257.0b

Skara, D. (2022). Heterogeneity of executive, attentional functions and information processing speed abilities in children with and without ADHD. Unpublished master's thesis, University of Latvia, Riga.

Smith, A. (1968). The Symbol-Digit Modalities Test: A Neuropsychologic Test of Learning and Other Cerebral Disorders. In *Learning Disorders*, Special Child Publications, Seattle, 83–91.

Song, Y. (2015). Cognitive Function in Attention Deficit Hyperactivity Disorder. In Jill M. Norvilitis (Ed.), *ADHD – New Directions in Diagnosis and Treatment*. IntechOpen. https://doi.org/10.5772/60785

Song, Y., & Hakoda, Y. (2012). The interference of local over global information processing in children with attention deficit hyperactivity disorder of the inattentive type. *Brain & Development, 34*(4), 308–317. https://doi.org/10.1016/j.braindev.2011.07.010

Sonuga-Barke, E. J. S., Sergeant, J. A., Nigg, J., & Willcutt, E. (2008). Executive dysfunction and delay aversion in attention deficit hyperactivity disorder: Nosologic and diagnostic implications. *Child and Adolescent Psychiatric Clinics of North America, 17*(2), 367–384, ix. https://doi.org/10.1016/j.chc.2007.11.008

Strauss, E., Sherman, E., & Spreen, O. (2006). *Compendium of Neuropsychological Tests: Administration, Norms, and Commentary* (Third Edition). Oxford University Press.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. Journal of *Experimental Psychology, 18*(6), 643–662.

Terman, L. M. (1916). *The measurement of intelligence* (pp. xiii, 374). Houghton, Mifflin and Company. https://doi.org/10.1037/10014-000

Vanags, E., Ekmanis, J. (2018). Affect arousal and valence recognition from EDA asymmetry and HRV measurements during computerised cognitive ability testing, The 4th international conference of the European Society for Cognitive and Affective Neuroscience (ESCAN), Neherlands.

Wang, M., Zhao, Q., Kang, H., & Zhu, S. (2020). Attention deficit hyperactivity disorder (ADHD) in children with epilepsy. *Irish Journal of Medical Science, 189*(1), 305–313. https://doi.org/10.1007/s11845-019-02042-3

van Rijckevorsel, K. (2006). Cognitive problems related to epilepsy syndromes, especially malignant epilepsies. *Seizure, 15*(4), 227–234.

Willcutt, E. G. (2012). The prevalence of DSM-IV attention-deficit/hyperactivity disorder: A meta-analytic review. *Neurotherapeutics: The Journal of the American Society for Experimental NeuroTherapeutics, 9*(3), 490–499. https://doi.org/10.1007/s13311-012-0135-8

Willcutt, E. G., Doyle, A. E., Nigg, J. T., Faraone, S. V., & Pennington, B. F. (2005). Validity of the executive function theory of attention-deficit/hyperactivity disorder: A meta-analytic review. *Biological Psychiatry, 57*(11), 1336–1346.

Zeeuw, P. de, Weusten, J., Dijk, S. van, Belle, J. van, & Durston, S. (2012). Deficits in Cognitive Control, Timing and Reward Sensitivity Appear to be Dissociable in ADHD. *PLOS ONE, 7*(12), e51416. https://doi.org/10.1371/journal.pone.0051416

Yuan, Q., Li, F, & Zhong, H. (2015). Early diagnosis, treatment and prognosis of epilepsy with continuous spikes and waves during slow sleep. *International journal of clinical and experimental medicine, 8*(3), 4052–4058