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Executive Functions and Regulation of Activation Functions in 6–9 Year-Old Children: Confirmatory Factor Analysis of Neuropsychological Data¤

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ABSTRACT

Background. There are two groups of functions involved in almost any activity according to A. R. Luria. These groups are executive functions and regulation of activation functions. It is necessary to compare and contrast the state of these functions and their interrelations to understand general patterns of preschool and primary school children cognitive development. Neuropsychological diagnostics and computer testing are used to measure the state of executive functions and regulation of activation functions.

Objective. To construct and test models that establish a correlation between the results of neuropsychological diagnostics and various groups of cognitive functions associated with self-regulation of behavior and general regulation of mental activity.

Design. The subjects were 434 children aged 6–9 years (from older preschoolers to third graders). All the children were given a neuropsychological examination adapted for children 6–9 years old, and tests were performed using a computerized neuropsychological examination battery for children aged 6–9 years. The results of the examination were used to conduct a confirmatory factor analysis.

Results. A three factor model was proposed.One factor corresponds to executive functions and two factors are related to regulation of activation functions: the factor of hyperactivity and impulsiveness symptoms, and the factor of fatigue and sluggishness

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symptoms. The model's fit indices fit with the empirical data well. The combined use of traditional indicators and computerized neuropsychological examination improved the model quality.

Conclusion. The analysis made it possible to identify indicators that can reflect the state of individual groups of executive functions and of regulation of activation functions. Weakness of one of the identified components of regulation of activation can lead to a specific change in behavioral responses that show up in a neuropsychological examination. A more serious and extensive deficiency can be connected to attention deficit hyperactivity disorder or sluggish cognitive tempo syndrome.

***Keywords**:* Executive functions, regulation of activation, functional blocks of the brain, neuropsychological examination, younger schoolchildren, confirmatory factor analysis

Highlights:

- A structural analysis of the results of a neuropsychological examination was performed, which substantiates the selection of the integral state indices executive functions and regulation of activation.
- A list of the indicators of the state of these functions were proposed.
- The legitimacy of differentiating two integral indices of regulation of activation was shown: sluggish cognitive tempo and hyperactivity/impulsivity.
- The coherence of the methods of traditional and computerized neuropsychological techniques and the possibility of their combined use in a comprehensive assessment of cognitive functions were shown.

АННОТАЦИЯ

Актуальность. Работа посвящена проблеме измерения и соотношения двух важнейших групп функций, которые участвуют практически в любой деятельности – функций регуляции активности и управляющих функций. Исследование их структуры и возможностей оценки их состояния у детей дошкольного и младшего школьного возраста методами нейропсихологической диагностики и компьютеризированного тестирования важны как с точки зрения практики работы нейропсихолога, так и с точки зрения понимания общих закономерностей развития когнитивной сферы в этом возрасте.

Цель. Построение и проверка моделей, устанавливающих соотношение результатов нейропсихологической диагностики и различных групп когнитивных функций, связанных с произвольной регуляцией поведения и общей регуляцией психической активности.

Материалы и методы. В исследовании приняли участие дети в возрасте 6–9 лет (от старших дошкольников до третьеклассников), в общей сложности 434 человека. Все дети были обследованы с помощью нейропсихологического обследования, адаптированного для детей 6–9 лет, а также выполняли тесты из батареи компьютеризированного нейропсихологического обследования для детей 6–9 лет. Результаты обследования использовались для проведения конфирматорного факторного анализа.

Результаты. Предложена модель, включающая три фактора — один соответствует управляющим функциям и два относятся к регуляции активности — фактор проявлений гиперактивности и импульсивности и фактор проявлений утомляемости и замедленности. Оценки модели показали хорошее соответствие эмпирическим данным. Совместное использование показателей традиционного и компьютерного нейропсихологического обследования повысило качество модели.

Выводы. Проведенный анализ позволил выделить индикаторы, которые могут отражать состояние отдельных групп функций регуляции произвольной деятельности и регуляции активности. Слабость одного из выделенных компонентов регуляции активности может приводить к специфическому изменению поведенческих реакций, проявляющихся в нейропсихологическом обследовании, а при более серьёзном и обширном дефиците — к появлению синдрома дефицита внимания и гиперактивности или синдрома низкого когнитивного темпа.

Ключевые слова: Управляющие функции, регуляция активности, функциональные блоки мозга, нейропсихологическое обследование, младшие школьники, конфирматорный факторный анализ

Ключевые положения:

- Проведен структурный анализ соотношения результатов нейропсихологического обследования, обосновывающий выделение интегральных индексов состояния управляющие функции (executive functions) и функции регуляции активности (regulation of activation).
- Предложен состав показателей (индикаторов) состояния этих функций.
- Показана правомерность выделения двух интегральных показателей регуляции активности — Slow cognitive tempo и Hyperactivity/ impulsivity.
- Показана согласованность методов традиционных и компьютеризированных нейропсихологических методик и возможность их совместного использования при комплексной оценке когнитивных функций.

RESUMEN

Introducción. Hay dos grupos de funciones involucradas en casi cualquier actividad, según A. R. Luria. Estos grupos son funciones ejecutivas y funciones de regulación de activación. Es necesario comparar y contrastar el estado de estas funciones y sus interrelaciones para entender los patrones generales del desarrollo cognitivo en los niños de preescolar y primaria. Los diagnósticos neuropsicológicos y las pruebas informáticas se utilizan para evaluar el estado de las funciones ejecutivas y regulación de las funciones de activación.

Objetivo. Construir y probar los modelos que establezcan una correlación entre los resultados de diagnósticos neuropsicológicos y diversos grupos de funciones cognitivas asociadas a la autorregulación de la conducta y regulación general de la actividad mental.

Diseño. Los sujetos fueron 434 niños de 6 a 9 años (desde preescolares hasta el tercer grado). A todos los niños se les realizó un examen neuropsicológico adaptado para niños de 6 a 9 años con una batería de pruebas computerizadas. Los resultados de la evaluación se utilizaron para realizar un análisis factorial confirmatorio.

Resultados. Se propuso un modelo de tres factores. Un factor corresponde a las funciones ejecutivas y dos factores están relacionados con la regulación de funciones de activación: el factor de los síntomas de hiperactividad e impulsividad, y el factor de los síntomas de fatiga y lentitud. Los índices de ajuste del modelo corresponden bien a los datos empíricos. El uso combinado de indicadores tradicionales y examen neuropsicológico computarizado mejoró la calidad del modelo.

Conclusión. El análisis permitió identificar indicadores que puedan reflejar el estado de grupos individuales de funciones ejecutivas y de regulación de funciones de activación. La debilidad de uno de los componentes identificados de la regulación de activación puede llevar a un cambio específico en las respuestas conductuales que aparecen en un examen neuropsicológico. Una deficiencia más grave y extensa puede estar relacionada con el trastorno por déficit de atención con hiperactividad o el síndrome del ritmo cognitivo lento.

Palabras clave: Funciones ejecutivas, regulación de la activación, bloques funcionales del cerebro, exploración neuropsicológica, escolares menores, análisis factorial confirmatorio

Destacados:

- Se realizó el análisis estructural de los resultados de un examen neuropsicológico que fundamenta la distinción de los índices de estado integral, que son funciones ejecutivas y regulación de activación.
- Se propuso una lista de indicadores del estado de estas funciones.
- Se demostró la legitimidad de diferenciar dos índices integrales de regulación de la activación: tempo cognitivo lento e hiperactividad/impulsividad.
- Se mostró la coherencia de los métodos de técnicas neuropsicológicas tradicionales y computerizadas, y la posibilidad de su uso combinado en la evaluación integral de las funciones cognitivas.

RESUME

Origines. Il existe deux groupes de fonctions impliquées dans presque toutes les activités selon A. R. Luria. Ces groupes sont les fonctions exécutives et la régulation des fonctions d'activation. Il est nécessaire de comparer et d'opposer l'état de ces fonctions et leurs interrelations pour comprendre les schémas généraux du développement cognitif des enfants d'âge préscolaire et primaire. Les diagnostics neuropsychologiques et les tests informatiques sont utilisés pour mesurer l'état des fonctions exécutives et la régulation des fonctions d'activation.

Objectif. Construire et tester des modèles établissant une corrélation entre les résultats des diagnostics neuropsychologiques et divers groupes de fonctions cognitives associées à l'autorégulation du comportement et à la régulation générale de l'activité mentale.

Mise au point. L'étude a porté sur des enfants âgés de 6 à 9 ans (des enfants d'âge préscolaire aux élèves de troisième année). Tous les enfants ont subi un examen neuropsychologique adapté aux enfants de 6 à 9 ans et des tests ont été réalisés à l'aide d'une batterie d'examens neuropsychologiques informatisés pour les enfants de 6 à 9 ans. Les résultats de l'examen ont été utilisés pour effectuer une analyse factorielle confirmatoire.

Résultats. Un modèle est proposé qui comprend trois facteurs – un facteur correspond aux fonctions de contrôle et deux facteurs se rapportent à la régulation de l'activité - le facteur des manifestations d'hyperactivité et d'impulsivité et le facteur des manifestations de fatigue et de lenteur. Les estimations du modèle ont montré un bon accord avec les données empiriques. L'utilisation combinée d'indicateurs d'examen neuropsychologique traditionnel et informatique a amélioré la qualité du modèle.

Conclusion. Cette analyse a permis d'identifier des indicateurs pouvant refléter l'état de groupes individuels de fonctions régulation de l`activité arbitraire et de régulation de l'activité. La faiblesse de l'un des composants identifiés de la régulation de l'activité peut conduire à une modification spécifique des réponses comportementales qui se manifestent à l'examen neuropsychologique, et à une déficience plus grave et étendue, à l'apparition d'un trouble de déficit de l'attention et de l`hyperactivité ou d'un syndrome de ralentissement du rythme cognitif.

Mots-clés: Fonctions exécutives, régulation de l'activité, blocs fonctionnels du cerveau, examen neuropsychologique, jeunes écoliers, analyse factorielle confirmatoire

Points principaux:

- Une analyse structurelle de la corrélation entre les résultats d'un examen neuropsychologique a été réalisée, justifiant l'attribution d'indices intégraux de l'état des fonctions exécutives et de la régulation de l'activation.

- La liste d'indicateurs de l'état de ces fonctions est proposée.
- La légitimité de distinguer deux indicateurs intégraux de la régulation de l'activité a été démontrée : rythme cognitif lent (Slow cognitive tempo) et hyperactivité/impulsivité.
- La cohérence des méthodes des techniques neuropsychologiques traditionnelles et informatisées et la possibilité de leur utilisation conjointe dans une évaluation complète des fonctions cognitives est montrée.

Introduction

The study and diagnosis of cognitive functions in children of preschool and primary school age are actively discussed subjects in modern psychology, and two important questions raised are the assessment of individual components of the cognitive domain and how the results of diagnostic methods correspond with theoretical ideas about the structure and development of mental functions. Our work concerns measurement of the functions of regulation of activation (functional block I of the brain, according to A.R. Luriya) and executive functions (block III) (Khomskaya, 2005; Luriya, 1973). Both groups of functions affect all mental domains, and therefore their assessment is especially important, while also requiring specific methods to extract data about their state from various tasks.

Executive functions in Soviet and Russian neuropsychology are often called functions of programming, regulation, and control (Luriya, 1962, 1973). They provide for planning and programming of any activity; holding to a plan while performing activities; monitoring its implementation and results, etc. This group of functions affects all human activity, and the frontal lobes of the cerebral cortex are considered to be its substrate (Luriya, 1973; Maloney, Schmidt, Hanten, & Levin, 2020). In contemporary neuropsychology, work continues on the analysis of the internal psychological and brain structure of executive functions and the identification of subfunctions within the regulatory domain (Miyake & Friedman, 2012). In preschoolers and younger schoolchildren, the state of executive functions is a predictor of success in school and future work (Dias, Trevisan, León, Proust, & Seabra, 2017); there are many works on the development of executive functions in children and tests of their effectiveness (Bodrova, Leong, & Akhutina, 2011; Diamond, Barnett, Thomas, & Munro, 2007; Pylaeva & Akhutina, 1997, and others). Dysfunction of the regulatory domain is manifested in aspontaneity, inactivity, or field behavior, inability to form a program of action and to follow it (Khomskaya, 2005).

A second group, affecting all mental activity, comprises the functions of regulation of activation. Their substrate is considered to be the stem and subcortical sections of the brain: block I, according to A.R. Luriya. They modulate general and selective activation, that is, they maintain the optimal tone of the cortex, the level of wakefulness, and the functional states necessary to perform current activities (Danilova, 1992; Luriya, 1973). When the structures combined in block I are damaged, there is a depression of consciousness, a dynamic deficit of mental activity (low tempo, increased exhaustion, productivity fluctuations, difficulty concentrating), as well as modal non-specific memory impairments (Khomskaya, 2005; Lutkenhoff et al., 2020; Snider et al., 2019). In childhood, two symptom complexes are most often distinguished, with a disturbance of the dynamic aspect of activity: attention deficit hyperactivity disorder with its subtypes (ADHD; see, for example, Chhabildas, Pennington, & Willcutt, 2001), and sluggish cognitive tempo (SCT, see Carlson & Mann, 2002). At present, these symptom complexes are considered independent of each other (Becker et al., 2016), with an underlying complex, non-local brain pathology (Becker et al., 2016; De La Fuente, Xia, Branch, & Li, 2013). An assessment of these symptom complexes has been developed as part of a neuropsychological examination (Agris, Akhutina, Korneev, 2014; Akhutina, 2016).

In neuropsychological diagnostics, it is sometimes difficult to distinguish which of the described areas of dysfunction relate to what is observed in the child's behavior. For example, a slow tempo of task completion may be associated with both lack of energy and with difficulties in maintaining a program of action. An integral assessment of the state of functional blocks I and III reveals a close correlation between them (Akhutina et al., 2019), and therefore, the problem arises of how these areas should specifically be assessed (and the validity of assessing them separately).

In the use of integral indices, it is important to analyze how the individual parameters of the performance of neuropsychological procedures and tests correlate with each other, and whether they can, in different combinations, reflect the state of controlling and modulating activation functions. This question is also important because, in the Russian neuropsychological approach, using one procedure can contribute to assessing several mental domains at once, and analysis of the results from different techniques allows for cross-checking, clarifying and complementing the results obtained (Balashova & Kovyazina, 2017).

Our work aimed at testing the possibility of qualitative as well as statistically substantiated differentiation of the indicators in a comprehensive neuropsychological examination into factors that reflect the state of functional blocks I and III. Confirmatory factor analysis can be used for such verification. This method has been seldom used in neuropsychological trials, although it is quite common in the study of the structure of cognitive functions. There have been studies of the factor structure of executive functions, in which various components are distinguished: inhibition, updating, and shifting (Friedman & Miyake, 2017). An analogous approach is used in analysis of the structure of intelligence, with the children's version of the Wechsler test, which identifies four factors (Bodin, Pardini, Burns, & Stevens, 2009).

We surmise that, using this method, we will be able to show the legitimacy of distinguishing relatively independent groups of functions related to the brain's functional blocks I and III, based on a neuropsychological examination of children of older preschool and primary school age. Assuming the unity of mechanisms operating in the norm and in pathology (Vygotsky, 1936), as well as the actual data of the pathology, namely the presence of two relatively independent symptom complexes — ADHD and SCT — our hypothesis is that we will detect two relatively independent patterns of weakness in the functions of regulation of activation, behaviorally manifested in 1) hyperactivity and impulsivity, and 2) sluggishness and fatigue.

Methods

Participants

There were 434 children participating in the study, including 131 preschoolers (72 boys, 59 girls, mean age 6.46 ± 0.55), 88 first-graders (33 boys, 55 girls, mean age 7.63 ± 0.46), 150 second-graders (87 boys, 63 girls, mean age 8.65 ± 0.42) and 65 third-graders (39 boys, 26 girls, mean age 9.64 ± 0.35). The participants had no diagnosed neurological or developmental disorders.

Procedure

Traditional Neuropsychological Examination

Methods of neuropsychological examination of children aged 6–9 were used to diagnose the state of cognitive functions (Akhutina, 2016). The full examination includes 20 behavioral tests; in this study we use the following tests:

1. Go–No-Go test. Two series of tasks were presented: in the first, the child must tap twice in response to one tap, and once in response to two taps; in the second series, tap twice in response to one tap, and no taps in response to two taps. In this test the ability to follow instructions, and the number of mistakes were assessed.
2. Verbal associations (free and directed). In free associations, the children were asked to say any words they liked for one minute; in directed associations, they were first asked to say as many verbs as possible for one minute, and in the second minute, the names of different plants. This evaluated productivity (as number of produced words), the number of repetitions; the number of words that are inappropriate to the task; and the number of word combinations.
3. Counting. Preschoolers and first graders were asked to count from 1 to 10, from 10 to 1, from 3 to 7, and from 8 to 4. Second and third graders were asked to do reversed counting: from 20 down by 3's. The ability to do the counting test and the number of errors were assessed.
4. Odd One Out. The variant we used was taken from the methodology for assessing verbal-logical thinking by L.I. Peresleni, E.M. Mastyukova, and L.F. Chuprov (Peresleni, Mastyukova, & Chuprov, 1990). It assessed productivity; the character of the explanation: the number of categorical, specific situational, and inappropriate explanations or refusals.
5. Dynamic praxis. This used the classical version of Luriya's "fist–edge–palm" diagnostic program for the dominant hand. It evaluated mastery of a motor program, execution of the program, errors of serial organization.
6. Auditory-verbal memory (remembering two groups of three words each). The child was first asked to repeat two groups of three words each, and then to remember which words were in the first group, which were in the second. The trial evaluates the productivity of each attempt, as well as various types of errors, including inclusion in the answers of extraneous words that are not similar to the stimuli.

Observations made during the examination allowed us to determine the state of regulation of activation functions (block I), assessing signs of fatigability, slow tempo of activity, perseveration, impulsivity, and hyperactivity (Akhutina, 2016).

Computerized Procedures

In our work, we have also used computerized neuropsychological examination of children aged 6–9 (Korneev, Akhutina, Gusev, Kremlev, & Matveeva, 2018). The battery includes 10 tests, three of them were used in this study:

Dots test (Davidson, Amso, Anderson, & Diamond, 2006; Korneev et al., 2018). The test consists of three trials, each presenting 20 stimuli. In the first trial, stimuli (hearts) are presented on the computer monitor in a quasi-random order, either to the left or to the right of the fixation cross; the child's task is to press a button as quickly as possible on the side where the stimulus appeared. In the second trial, we assess the subject's ability to inhibit a "natural" response that is irrelevant to the task: another stimulus appears on the screen (a flower), and the subject's task is to press the button as quickly as possible from the side opposite to that where the stimulus appeared. In the third trial, we assess the child's ability to switch between two programs: two types of stimuli are presented on the screen in random order, and the subject's task is to press a key on the same side when a heart appears, and on the opposite side when a flower appears. The test assesses the average reaction time and productivity (number of correct answers).

Computerized version of the Schulte Tables test, as modified by F.D. Gorbov (Korneev et al., 2018). The test has five parts, each with a table of 20 cells, in which two rows of numbers from 1 to 10 are placed in a quasi-random order; one row is black numbers, the second is red ones. The subject has to search and point to the numbers in a certain order, using a touch screen. In the first part, the child has to point to the black numbers from 1 to 10; in the second, the red numbers from 1 to 10; in the third, the black numbers from 10 to 1; in the fourth, two parallel rows, showing red and black numbers in ascending order (1 black, 1 red, 2 black, 2 red, etc.); in the fifth, the red numbers from 10 to 1. This assesses the average time to search for a number (reaction time) and the number of errors, both for the trial overall and separately for the five samples.

Computerized version of the Corsi Cubes test (Korneev et al., 2018). Nine cubes are presented on the touch screen, which light up one by one. The task is to remember their position on the screen, and then reproduce the sequence of lighted cubes. The trial begins with a row of two cubes; when the child gives the correct answer, the length of the row increases. We assess the maximum length of a correctly reproduced sequence, the average time for the first answer, and the pauses between answers within the sequence.

Processing the Results

An expert neuropsychologist performed the primary processing of the neuropsychological examination results; the results of computerized testing were initially processed in the Praktika-MSU system. The results, summarized in a single database, were used in confirmatory factor analysis. Because part of the test performance is assessed on ordinal scales, we employed the method of weighted least squares with corrections for mean and variance (WLSMV), which is used in the analysis of this type of scale and is resistant to non-normal distribution of data. The calculations were performed in the R environment, version 4.0.55 using the lavaan package, version 0.6-8 (Rossel, 2012).

Results

We built several factor models, clarifying, first, the possible factor structure, and, second, the possibility of combined use of the results of the traditional and computerized examinations.

A two-factor model was built as the first step, using the indicators of the traditional neuropsychological examination. The first factor, corresponding to executive functions (the EF factor), comprised the following indicators: the total number of errors and the score for mastering the instructions for the second trial of the choice reaction; the productivity of the free and directed (verbal) associations, as well as the number of inappropriate responses in the directed associations (plants); ability to do the counting trial and the number of errors; productivity, total score, and the number of inappropriate answers in the "Odd One Out" trial; score for mastering instructions in dynamic praxis; number of non-relevant words in the auditory-speech memory trial. The second factor used five indicators for evaluating the functions of the first block of the brain: signs of fatigability, slow tempo of activity, perseveration, impulsivity, and hyperactivity. Since indicators of the EF factor that are related to the same trial may be the same, not only due to a common factor, but also since they pertain to the same task, we added additional correlations of the residuals of variables related to the same trial. This technique allows us to identify both the influence of the general "functional" factor and the trial factors (Korneev, Akhutina, & Voronova, 2016); therefore, additional connections were added within the indicators related to the Go–No-Go, Verbal Associations, Counting, and Odd One Out trials. The model also allowed for a correlation between the two factors. This model's fit indices were not very high: $\chi^2(110) = 504.259$, CFI = 0.900, TLI = 0.876, RMSEA = 0.091.

In the second model, instead of one factor reflecting the state of regulation of activation functions, two factors were introduced: the fatigue/sluggishness factor (FS factor) and the hyperactivity/impulsivity factor (HI factor). The first included fatigability, slow tempo of activity, and perseveration, while the second included impulsiveness and hyperactivity. The composition of the EF factor was not changed. The fit indices of this model were noticeably better: $\chi^2(108) = 310.545$, CFI = 0.948, TLI = 0.935, RMSEA = 0.066. At the same time, we obtained an insignificant loading of the EF factor on the number of errors in the Counting trial, so this variable was excluded; the model's fit indices remained practically unchanged ($\chi^2(94) = 267.760$, CFI = 0.950 TLI = 0.937, RMSEA = 0.065). The coefficients of this model are presented in Appendix, Table A1.

The following factor correlations were obtained: between EF and FS, the standardized coefficient was 0.660 (0.050, here and below in parentheses: standard error), between EF and HI, 0.252 (0.063), and between EF and HI, 0.366 (0.066). Also significant were the additional correlations of productivity in the free and directed association trials (0.489 (0.044)), in the Odd One Out trial the correlations of productivity with the total score (0.482 (0.042)) and the number of inappropriate responses (–0.372 (0.049)), and the total score with the number of inappropriate responses (–0.797 (0.016)).

Table 1

Coefficients of the model of the results of a comprehensive neuropsychological examination

Factor	Indicator	Estimation	Standard error	95% confidence interval
Executive functions	Understanding the instruction for the second trial in the Go–no-go task	0.570	0.056	[0.460; 0.679]
	Number of errors in Go – no-go task	0.585	0.019	[0.547; 0.622]
	Productivity in Verbal fluency task 1 (any words)	–0.546	0.026	[–0.597; –0.496]
	Productivity in Verbal fluency task 2 (any verbs)	–0.516	0.025	[–0.564; –0.467]
	Inappropriate responses in Verbal fluency task 3 (names of plants)	0.478	0.018	[0.442; 0.514]
	Ability to do Counting task	–0.583	0.034	[–0.649; –0.516]
	Productivity in Odd One Out task	–0.462	0.036	[–0.532; –0.392]
	Total score in Odd One Out task	0.349	0.024	[0.302; 0.396]
	Inappropriate responses in Odd One Out task	0.165	0.052	[0.063; 0.267]
	Understanding the instruction in 3 positions test (“Fist-Edge-Palm”)	0.478	0.019	[0.441; 0.515]
	Irrelevant words in Verbal Memory task	0.122	0.046	[0.032; 0.213]
	Productivity in 3rd subtest of the Dots task	–0.406	0.042	[–0.487; –0.325]
	Number of errors in 4th Schulte tables	0.214	0.050	[0.116; 0.312]
Slow cognitive tempo	Fatigability	0.724	0.039	[0.648; 0.800]
	Slow tempo	0.421	0.033	[0.356; 0.485]
	Tendency to perseveration	0.578	0.037	[0.505; 0.651]
	Reaction time in 1st Schulte table	1.147	0.118	[0.915; 1.379]
	Reaction time in 1st subtest of the Dots task	0.577	0.083	[0.414; 0.740]
	Mean pause duration in the Corsi Tapping block test	0.327	0.049	[0.231; 0.424]
Hyperactivity/ impulsivity	Impulsivity	0.827	0.052	[0.725; 0.93]
	Hyperactivity	0.839	0.053	[0.734; 0.944]
	Reaction time in 1st Schulte table	–0.921	0.124	[–1.164; –0.679]
	Reaction time in 1st subtest of the Dots task	–0.560	0.091	[–0.739; –0.382]
	Mean pause duration in the Corsi Tapping block test	–0.387	0.067	[–0.519; –0.255]

Note: all estimates are significantly different from zero ($p < 0.001$).

The next step was to include in the model not only the indicators of the traditional examination, but also those of the computerized methods. The results of the trials most related to programming and control functions were added to the EF factor: the productivity of the third part of the Dots test and the number of errors in the fourth Schulte table. Three indicators were added to both factors related to regulation of activation: the average reaction time in the first part of the Dots test, the average search time in the second Schulte table, and the average time between responses when reproducing the sequence in the Corsi Cubes test. The overall model fit indices improved as a result of this extension of the model: $\chi2(179) = 473.507$, CFI = 0.969, TLI = 0.964, RMSEA = 0.062. At the same time, it is important to note that the factor loadings for the indicators simultaneously included in the two factors have different signs for each of them. Full information about the coefficients is presented in Table 1.

The correlations between the factors were as follows: between EF and FS — 0.771 (with a standard error of 0.044), between EF and HI — 0.226 (0.061); the correlation between EF and HI increased and amounted to 0.726 (0.048). Additional correlations of error between measures within trials remained almost the same as in the previous model.

Discussion

The constructed models of the correlation of performance indicators for traditional and computerized neuropsychological examinations allowed us to discover some interesting facts about groups of executive functions and regulation of activation functions. The first model, which includes two undifferentiated factors of executive functions and regulation of acivation functions, received low quality scores, which indicates that such a general division of the two groups of functions is insufficient. In the second model of the two factors, further differentiation related to regulation activation functions led to a significant improvement in the assessed quality of the model. These factors may correspond, in our view, to various patterns of functional weakness of a single system associated with regulation of activation, which is consistent with previous results (Agris et al., 2014). One pattern combines signs of fatigability and sluggishness, and when pathological, in the form a symptom complex such as NKT (Becker, 2021; Becker et al., 2016), while the second combines signs of hyperactivity and impulsivity, which when pathological can manifest themselves in one of the subtypes of ADHD (Bush, 2010). Judging by our results, we should distinguish between these two differently directed (although not independent) components when assessing the state of block I. This differentiation seems important both for neuropsychological diagnostics and from the point of view of theoretical ideas about the structure of cognitive functions in children. This is consistent with studies that have separated the indicators for assessment of activation components between those related to hyperactivity and to sluggishness (Becker, 2021; McBurnett, Pfiffner, & Frick, 2001).

The introduction of computerized testing results into the three-factor model improved its validation, which indicates the coherence of the two groups of methods and provides a basis for combined use of traditional and computerized neuropsychological examinations. Previously, we analyzed the interrelation of the results of these two groups of methods at the level of correlations of individual parameters (Gusev, Kremlev, Korneev, Matveeva, & Akhutina, 2020). The results of the present work confirm the data on the coherence of these two methodological approaches to neuropsychological diagnostics. Studies on the interrelation of computerized and traditional neuropsychological methods have noted that at the level of correlation analysis, the agreement between them may be low (Cole, Arrieux, Ivins, Schwab, & Qashu, 2018; Smith, Need, Cirulli, Chiba-Falek, & Attix, 2017). According to our data, agreement at the level of structural factor models is quite high. Perhaps such a comprehensive approach to analyzing and describing data is more productive than assessing correlations.

An important illustration in this context is the multidirectional factor loadings of the same indicators for computerized trials included simultaneously in both factors associated with regulation of activation processes. This is logical: reaction time is lawfully associated positively and negatively with the factors of sluggishness and impulsivity/hyperactivity, respectively; that is, the inclusion of objective temporal indicators logically complements the assessments of a traditional neuropsychological examination. This result also indicates that assessed correlations of the coherence of different techniques may not be high due to ambiguous interrelations: individual differences may have different causes and may correlate differently with neuropsychological estimates. The construction of models can make it possible to identify and evaluate such heterogeneous relationships, not only in the case of estimating activation components.

It is worth discussing separately the correlations between factors obtained in the models. In the three-factor models, we obtained a rather high correlation of the executive functions factor with the fatigue/sluggishness factor (0.660 and 0.771 before and after the inclusion of computer techniques, respectively) and a low correlation with the hyperactivity/impulsivity factor (0.252 and 0.256). This is not entirely consistent with the results of other studies, in which executive functions show clear but weaker associations with sluggish cognitive tempo symptoms than with hyperactivity symptoms (Tamm, Brenner, Bamberger, & Becker, 2018). Possibly these differences are due to the fact that these studies use questionnaires for teachers and parents to assess functions, rather than direct behavioral assessment. On the other hand, a neuroimaging study showed that the severity of sluggish cognitive tempo symptoms correlates with lower functional connectivity of enlarged frontal lobes.(Camprodon-Rosanas et al., 2019), which is consistent with our high correlation. Overall, we believe that the relationship between the executive and activation groups of functions requires additional research and clarification.

The correlation between the two factors associated with regulation of activation increased markedly when the results of computerized methods were added (from 0.366 to 0.726). This increased correlation may be for technical reasons: confirmatory factor analysis works in such a way that adding the same indicators to different factors can increase the correlation between them, so this coefficient cannot be interpreted meaningfully from this model. It seems more reasonable to consider correlation in a model that includes the non-overlapping indicators of a traditional examination.

The small positive correlation between the two factors associated with regulation of activation seems quite sensible, since underlying them are the functional structures of the first block.

Conclusion

In our work, we confirmed the legitimacy of distinguishing separate groups of executive functions and funtions of regulation of activation. The empirical basis was children neuropsychological examination. We identified relatively independent factors associated with functional blocks I and III of the brain, and found performance indicators for traditional and computerized neuropsychological examination tasks, which may be viewed as indicators of the state of these functions. Within the framework of functions associated with block I of the brain, two separate areas are distinguished, each of which contributes to regulation of activation. Weakness of each of these components of regulation of activation can lead to a specific change in behavioral responses that show up in a neuropsychological examination (signs of hyperactivity, impulsivity or sluggishness, fatigability), and a more serious and extensive deficiency can be connected to ADHD and SCT syndromes. The results are important for the differentiation of children's individual characteristics, both in normative and non-normative development. Our analysis was carried out at the level of behavioral indicators; a separate question is the interrelation of the state of the groups of functions we have considered with the state of brain structures, which requires separate research.

Ethics Statement

The parents of all children who participated in the study gave informed consent for them to participate.

Author Contributions

Tatiana Akhutina, Ekaterina Matveeva and Aleksei Korneev designed and directed the project; Tatiana Akhutina developed the theoretical framework; Ekaterina Matveeva and Alexey Bukinich collected the data and performed the primary analysis and data preparation; Aleksei Korneev and Alexey Bukinich performed the statistical analysis; Aleksei Korneev, Alexey Bukinich and Ekaterina Matveeva drafted the manuscript and designed the figures; Tatiana Akhutina aided in interpreting the results and worked on the manuscript. All authors discussed the results and contributed to the final manuscript.

Conflict of Interest

The authors declare no conflict of interest.

References

Agris, A.R., Akhutina, T.V., & Korneev, A.A. (2014). Varianty defitsita funktsiĭ I bloka mozga u deteĭ s trudnostiami obucheniia (okonchanie) [Types of I brain block functions deficit in children with learning disabilities (conclusion). *Vestnik Moskovskogo universiteta. Seriya 14: Psikhologiya* [Moscow University Psychology Bulletin], *4*, 44–55. (In Russ.).

Akhutina, T.V. (2016). *Metody neiropsikhologicheskogo obsledovaniia deteĭ 6–9 let* [Methods of neuropsychological investigation of 6–9-year-old children]. Moscow: V. Sekachev. (In Russ.).

Akhutina, T.V., Korneev, A.A., Matveeva, E.Yu., Gusev, A.N., Kremlev, A.E., & Bukinich, A.M. (2019). Opyt razrabotki integral'nykh pokazatelei batarei komp'iuterizirovannoi neiropsikhologicheskoi diagnostiki [Developing integral indexes for a computerized neuropsychological test battery]. In E.V. Pechenkova & M.V. Falikman (Eds.), *Kognitivnaia nauka v Moskve: novye issledovaniia* [Cognitive science in Moscow: new investigations] (pp. 571–576). Moscow: OOO Buki Vedi, IPPiP. (In Russ.).

Balashova, E.Yu., & Kovyazina, M.S. (2017). *Neiropsikhologicheskaia diagnostika v voprosakh i otvetakh* [Neuropsychological diagnostics in questions and answers]. Moscow: Genezis. (In Russ.).

Becker, S.P. (2021). Systematic review: Assessment of sluggish cognitive tempo over the past decade. *Journal of the American Academy of Child & Adolescent Psychiatry*, *60*(6), 690–709. https://doi.org/10.1016/j.jaac.2020.10.016

Becker, S.P., Leopold, D.R., Burns, G.L., Jarrett, M.A., Langberg, J.M., Marshall, S.A., McBurnett, K., Waschbusch, D.A., & Willcutt, E.G. (2016). The internal, external, and diagnostic validity of sluggish cognitive tempo: A meta-analysis and critical review. *Journal of the American Academy of Child & Adolescent Psychiatry, 55* (3), 163–178. https://doi.org/10.1016/j.jaac.2015.12.006

Blair, C. (2017). Educating executive function. *Wiley Interdisciplinary Reviews: Cognitive Science*, *8*(1–2), e1403. https://doi.org/10.1002/wcs.1403

Bodin, D., Pardini, D.A., Burns, T.G., & Stevens, A.B. (2009). Higher order factor structure of the WISC-IV in a clinical neuropsychological sample. *Child Neuropsychology*, *15*(5), 417–424. https://doi.org/10.1080/09297040802603661

Bodrova, E., Leong, D.J., & Akhutina, T.V. (2011). When everything new is well-forgotten old: Vygotsky/Luria insights in the development of executive functions. *New Directions for Child and Adolescent Development*, *133,* 11–28. https://doi.org/10.1002/cd.301

Bush, G. (2010). Attention-deficit/hyperactivity disorder and attention networks. *Neuropsychopharmacology*, *1*(35), 278–300. https://doi.org/10.1038/npp.2009.120

Carlson, C. L., & Mann, M. (2002). Sluggish cognitive tempo predicts a different pattern of impairment in the attention deficit hyperactivity disorder, predominantly inattentive type. *Journal of Clinical Child and Adolescent Psychology*, *31*(1), 123-129.

Camprodon-Rosanas, E., Pujol, J., Martínez-Vilavella, G., Blanco-Hinojo, L., Medrano-Martorell, S., Batlle, S., Forns, J., Ribas-Fitó, N., Dolz, M. & Sunyer, J. (2019). Brain structure and function in school-aged children with sluggish cognitive tempo symptoms. *Journal of the American Academy of Child & Adolescent Psychiatry*, *2*(58), 256–266. https://doi.org/10.1016/j.jaac.2018.09.441

Chhabildas, N., Pennington, B.F., & Willcutt, E.G. (2001). A comparison of the neuropsychological profiles of the DSM-IV subtypes of ADHD. *Journal of Abnormal Child Psychology*, *29*(6), 529–540. https://doi.org/10.1023/A:1012281226028

Cole, W.R., Arrieux, J.P., Ivins, B.J., Schwab, K.A., & Qashu, F.M. (2018). A comparison of four computerized neurocognitive assessment tools to a traditional neuropsychological test battery in service members with and without mild traumatic brain injury. *Archives of Clinical Neuropsychology*, *33*(1), 102–119. https://doi.org/10.1093/arclin/acx036

Danilova, N.N. (1992). Psikhofiziologicheskaia diagnostika funktsional'nykh sostoiani [Psychophysiological diagnostics of functional states]. Moscow: MSU publ. (In Russ.).

Davidson, M.C., Amso, D., Anderson, L.C., & Diamond, A. (2006). Development of cognitive control and executive functions from 4 to 13 years: Evidence from manipulations of memory, inhibition, and task switching. *Neuropsychologia*, *44*(11), 2037–2078. https://doi.org/10.1016/j.neuropsychologia.2006.02.006

De La Fuente, A., Xia, S., Branch, C., & Li, X. (2013). A review of attention-deficit/hyperactivity disorder from the perspective of brain networks. *Frontiers in Human Neuroscience*, *7,* 192. https://doi.org/10.3389/fnhum.2013.00192

Diamond, A., Barnett, W. S., Thomas, J., & Munro, S. (2007). Preschool program improves cognitive control. *Science*, *318*(5855), 1387–1388. https://doi.org/10.1126/science.1151148

Dias, N.M., Trevisan, B.T., León, C.B.R., Prust, A.P., & Seabra, A.G. (2017). Can executive functions predict behavior in preschool children? *Psychology & Neuroscience*, *10*(4), 383–393. https://doi.org/10.1037/pne0000104

Friedman, N.P., & Miyake, A. (2017). Unity and diversity of executive functions: Individual differences as a window on cognitive structure. *Cortex, 86,* 186–204. https://doi.org/10.1016/j.cortex.2016.04.023

Gusev, A.N., Kremlev, A.E., Korneev, A.A., Matveeva, E.Yu., Akhutina, T.V. (2020). Otsenka chuvstvitel'nosti komp'iuternykh metodik neiropsikhologicheskoi diagnostiki mladshikh shkol'nikov [Computer neuropsychological tests for young schoolchildren's sensitivity assessment]. In *Psikhologiia obrazovaniia: obrazovatel'nyi potentsial razvitiia lichnosti: Materialy VI Vserossiiskoi nauchno-prakticheskoi konferentsii psikhologov obrazovaniia Sibiri s mezhdunarodnym uchastiem* [Educational psychology: Educational potential of personality development: materials of VI all-Russian scientific-practical psychological conference of Siberian psychologists with international participation] (pp. 192–199). Irkutsk: Irkutskii gosudarstvennyi universitet. (In Russ.).

Khomskaya, E.D. (2005). *Neiropsikhologiia* [Neuropsychology], 4th edition. Saint Petersburg: Piter. (In Russ.).

Korneev, A., Akhutina, T., Gusev, A., Kremlev, A., & Matveeva, E. (2018). Computerized neuropsychological assessment in 6–9 year-old children. *KnE Life Sciences*, *4*(8), 495–506. https://doi.org/10.18502/kls.v4i8.3307

Korneev, A.A., Akhutina, T.V., & Voronova, M.N. (2016). Otsenka soglasovannosti neiropsikhologicheskikh indeksov s pomoshch'iu konfirmatornogo faktornogo analiza [Neuropsychological indexes of consistency evaluation via confirmatory factor analysis]. In T.V. Akhutina (Ed.), *Metody neiropsikhologicheskogo obsledovaniia detei 6–9 let* [Methods of 6–9 years old children neuropsychological investigation] (pp. 224–239). Moscow: V. Sekachev. (In Russ.).

Luriya, A.R. (1969). *Vysshie korkovye funktsii cheloveka* [Higher mental functions] Moscow: MSU publ. (In Russ.).

Luriya, A.R. (1973). *Osnovy neiropsikhologii: uchebnoe posobie dlia universitetov* [Fundaments of neuropsychology: training manual for universities]. Moscow: MSU publ. (In Russ.).

Lutkenhoff, E.S., Wright, M.J., Shrestha, V., Real, C., McArthur, D.L., Buitrago-Blanco, M., Vespa, P.M., & Monti, M.M. (2020). The subcortical basis of outcome and cognitive impairment in TBI: A longitudinal cohort study. *Neurology, 95*(17), e2398–e2408. https://doi.org/10.1212/WNL.0000000000010825

Maloney, K.A., Schmidt, A.T., Hanten, G.R., & Levin, H.S. (2020). Executive dysfunction in children and adolescents with behavior disorders and traumatic brain injury. *Child Neuropsychology, 26*(1), 69–82. https://doi.org/10.1080/09297049.2019.1640868

McBurnett, K., Pfiffner, L.J., & Frick, P.J. (2001). Symptom properties as a function of ADHD type: An argument for continued study of sluggish cognitive tempo. *Journal of Abnormal Child Psychology, 29*(3), 207–213. https://doi.org/10.1023/A:1010377530749

Miyake, A., & Friedman, N.P. (2012). The nature and organization of individual differences in executive functions: Four general conclusions. *Current Directions in Psychological Science*, *21*(1), 8–14. https://doi.org/10.1177/0963721411429458

Peresleni, L.I., Mastyukova, E.M., & Chuprov, L.F. (1990). *Psikhodiagnosticheskii kompleks metodik dlia opredeleniia urovnia umstvennogo razvitiia mladshikh shkol'nikov (uchebno-metodicheskoe posobie)* [Psychological complex of methods for young schoolchildren's intellectual development level assessment (educational and methodical manual)]. Abakan: AGPI, 68. (In Russ.).

Pylaeva, N.M., & Akhutina, T.V. (1997). *Shkola vnimaniia: Metodika razvitiia i korrektsii vnimaniia u detei 5–7 let* [School of attention: Method for development and correction of attention for children 5–7 years old]. Moscow: INTOR. (In Russ.).

Rosseel, Y. (2012). Lavaan: An R package for structural equation modeling and more. Version 0.5–12 (BETA). *Journal of Statistical Software*, *48*(2), 1–36.

Smith, P.J., Need, A.C., Cirulli, E.T., Chiba-Falek, O., & Attix, D.K. (2013). A comparison of the Cambridge Automated Neuropsychological Test Battery (CANTAB) with "traditional" neuropsychological testing instruments. *Journal of Clinical and Experimental Neuropsychology, 35*(3), 319–328. https://doi.org/10.1080/13803395.2013.771618

Snider, S.B., Bodien, Y.G., Bianciardi, M., Brown, E.N., Wu, O., & Edlow, B.L. (2019). Disruption of the ascending arousal network in acute traumatic disorders of consciousness. *Neurology, 93*(13), e1281–e1287. https://doi.org/10.1212/WNL.0000000000008163

Tamm, L., Brenner, S.B., Bamberger, M.E., & Becker, S.P. (2018). Are sluggish cognitive tempo symptoms associated with executive functioning in preschoolers? *Child Neuropsychology*, *24*(1), 82–105. https://doi.org/10.1080/09297049.2016.1225707

Vygotsky, L.S. (1936). *Diagnostika razvitiia i pedologicheskaia klinika trudnogo detstva* [Developmental diagnostics and the Pedological Clinic for Difficult Children]. Moscow: Izdanie eksperimental'n. defektologicheskogo instituta im. M.S. Epshteina. (In Russ.).

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Appendix

Table A1

Estimations in the model of traditional (face-to-face) neuropsychological examination

Factor	Indicator	Estimation	Standard error	95% Confidence interval
Executive functions	Understanding the instruction for the second trial in Go – no-go task	0.553	0.071	[0.414; 0.691]
	Number of errors in Go – no-go task	0.544	0.040	[0.465; 0.622]
	Productivity in Verbal fluency task 1 (any words)	–0.508	0.047	[–0.601; –0.414]
	Productivity in Verbal fluency task 2 (any verbs)	–0.455	0.053	[–0.558; –0.352]
	Inadequate responses in Verbal fluency task 3 (names of plants)	0.534	0.041	[0.453; 0.615]
	Ability to do the Counting task	–0.552	0.041	[–0.632; –0.472]
	Productivity in Odd one out task	–0.428	0.042	[–0.51; –0.346]
	Total score in Odd one out task	0.350	0.043	[0.266; 0.433]
	Inadequate responses in Odd one out task	0.333	0.046	[0.243; 0.423]
	Understanding the instruction in 3 positions test (“Fist-Edge-Palm”)	0.204	0.052	[0.101; 0.306]
	Irrelevant words in Verbal Memory task	0.165	0.049	[0.069; 0.261]
Slow cognitive tempo	Fatigability	0.854	0.044	[0.768; 0.941]
	Slow tempo	0.510	0.042	[0.427; 0.592]
	Tendency to perseveration	0.724	0.047	[0.631; 0.816]
Hyper-activity/ impulsivity	Impulsivity	0.883	0.085	[0.717; 1.049]
	Hyperactivity	0.855	0.079	[0.699; 1.011]

Note: all estimates are significantly different from zero ($p < 0.001$).