DIAGNOSTIC POTENTIAL OF THE SOFTWARE-HARDWARE COMPLEX FOR ANALYSIS OF SELF-IDENTIFICATION PHENOMENON IN EARLY CHILDHOOD

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The relevance of the study provided results from the need to search for the objectifying methods to assess self-identification phenomenon in early childhood. The study aimed to evaluate the diagnostic potential of the software-hardware complex for analysis of self-identification phenomenon in young children. The sample consisted of 136 subjects of early age (12–36 months): 57 boys and 79 girls. Assessment methods: functional neuropsychological tests for evaluation of facial and optical-spatial gnosis; test 22 — mirror image series of the Bayley-III cognitive scale; self-recognition mirror test; the developed software-hardware complex for analysis of self-identification phenomenon in early childhood (SHC). The study conducted has shown that self-identification emerges at the age of 18 months, which has been also confirmed by the earlier research. However, the response to one's own reflection in the mirror as one sign of self-identification manifests itself in children at an earlier age and in some children turns out to be shaped by the age of 12 months, which is suggested by the facts of successful test execution in the group aged 12–17 months and low specificity of the method for self-identification. Thus, high SHC specificity for self-identification in early childhood is reported based on the findings.

Keywords: early age, self-identification, software-hardware complex

Author contribution: the authors contributed to the study equally.

Compliance with ethical standards: the study was approved by the Ethics Committee of the Pirogov Russian National Research Medical University (protocol No. 240 dated 20 May 2024); the informed consent was submitted by all study participants.

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Received: 28.03.2025 **Accepted:** 14.04.2025 **Published online:** 25.04.2025

DOI: 10.24075/brsmu.2025.021

ДИАГНОСТИЧЕСКИЙ ПОТЕНЦИАЛ ПРОГРАММНО-АППАРАТНОГО КОМПЛЕКСА АНАЛИЗА ФЕНОМЕНА САМОИДЕНТИФИКАЦИИ ДЕТЕЙ РАННЕГО ВОЗРАСТА

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Актуальность предлагаемого исследования обусловлена необходимостью поиска объективизирующих методов оценки феномена самоидентификации детей раннего возраста. Целью исследования было оценить диагностический потенциал программно-аппаратного комплекса анализа феномена самоидентификации детей раннего возраста. Объем выборки составил 136 испытуемых раннего возраста (12–36 месяцев) — 57 мальчиков и 79 девочек. Методы исследования: функциональные нейропсихологические пробы оценки лицевого и оптико-пространственного гнозиса; проба 22 — Mirror image series когнитивной шкалы Bayley-III; Self-recognition mirror test; разработанный программно-аппаратный комплекс анализа феномена самоидентификации детей раннего возраста (ПАК). В результате проведенного исследования установлено, что самоидентификация появляется в возрасте 18 месяцев, что также подтверждено ранее проведенными исследованиями. Однако реакция на свое отражение в зеркале как одно из проявлений самоидентификации наблюдается у детей в более раннем возрасте и к 12 месяцам оказывается уже сформированной у части детей, на что указывают наличие успешных выполнений пробы в группе 12–17 месяцев и низкая специфичность методики для самоидентификации. Таким образом, на основании полученных результатов исследования зафиксирована высокая специфичность к самоидентификации детей раннего возраста ПАК.

Ключевые слова: ранний возраст, самоидентификация, программно-аппаратный комплекс

Вклад авторов: вклад авторов в исследование равнозначный

Соблюдение этических стандартов: исследование одобрено этическим комитетом РНИМУ имени Н. И. Пирогова (протокол № 240 от 20 мая 2024 г.); все участники подписали добровольное информированное согласие на обследование.

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Статья получена: 28.03.2025 **Статья принята к печати:** 14.04.2025 **Опубликована онлайн:** 25.04.2025

DOI: 10.24075/vrgmu.2025.021

In today's psychological science there is a problem of measurability and accuracy of measurement of the early-onset complex mental phenomena. Currently, mental development in early childhood is assessed by observation and scaling methods, which are characterized by high degree of subjectivity. The following equipment is used to assess self-identification at older ages: various types of speech therapy mirrors, during working with which it is necessary not only to find parts of the face, but also to correctly execute actions of the articulatory system; the Sondsorry technique, according to which it is necessary to accurately reproduce movements after listening to music; the Timocco complex, which is used to control movements of the character through one's own movements (through the camera).

In the last decade (2014–2023), the artificial intelligence and machine learning technologies have gained tremendous development. The range of tasks that can be solved with the help of those is growing every year. The current level of the artificial intelligence technology development makes it possible to use hardware solutions for working on challenging diagnostic issues [1].

B. Amsterdam, who published his experiment involving the use of the self-recognition mirror test, modification of the mark test (designed for primate experiments by Gordon G. Gallup in 1970 [2]) aimed at determining human self-identification, in infants in 1972, was a pioneer in studies of human self-identification. The author found that children started to identify their reflection in the mirror as representation of their body at the age of 1.5–2 years [3]. Multiple subsequent studies aimed to develop the problem of self-identification in early childhood were associated with the following names: A. Aron, B. Fraley [4], B. I. Bertenthal, K. W. Fischer [5], D. Bischof-Köhler [6], T. Broesch [7], S. Duval, R. A. Wicklund [8], K. Guise [9], J. Kärtner [10], J. P. Keenan [11], M. Lewis [12], K. Musholt [13], P. Rochat [14], S. Savanah [15].

In 1977, it was shown that the mentally retarded individuals not always successfully passed the self-recognition mirror test [16]. Later a number of scientists [17–19] studied self-identification in various disorders, such as schizotypal personality disorder, Alzheimer's disease, Down syndrome, autism, schizophrenia, and split-brain syndrome.

In 1999–2001, a number of studies were conducted aimed at identifying neuropsychological correlates of human self-identification suggesting that in humans self-identification was localized in the right hemisphere [20]. In 1999 [21] and 2005 [22], it was shown that patients with local brain damage in the right prefrontal cortex were unable to identify their reflection in the mirror as their own, while recognition of faces of other people was preserved, even when using the mirror. One of the leading researches disclosing the current view of the self-identification brain substrate structure are van S. J. Veiuw and S. A. Chance, who used fMRI to reveal the structure of the cerebral cortex activation associated with self-identification in 2014. Based on the experimental results they concluded that the most important were prefrontal cortex and the temporoparietal tracts [23].

Thus, the historical and prospective analysis of the methods to assess the self-identification phenomenon has shown that the mark test and its modification, the self-recognition mirror test, are used to identify neurocognitive self-identification markers in animals and humans, including in clinical trials. The conditions of conducting the test vary depending on the task; globally, these can be divided into three types: experiment without any additional intervention (used to assess humans, who are familiar with the mirror); experiment involving spontaneous learning how to interact with the mirror (used for all animal species); experiment involving controlled learning how to interact with the mirror (used for the majority of animals, except some primate species).

Willingness to interact with their reflection, i.e. to examine it, smile at it, play with it, represents one of the factors of self-identification development in early childhood. Such a positive response to their reflection is reported in both children, who do not yet have self-identification due to age, and children, who have already developed self-identification [24, 25].

The concept by Johannes L. Brandl, according to which neurocognitive self-identification markers are defined as neurocognitive functions that ensure the child's self-identification, represents methodological substantiation of the study reported [26]. On the one hand, self-recognition in the mirror is implemented based on the knowledge, what one's face looks like; on the other hand, it is implemented based on integration of proprioceptive and exteroceptive sensations with visual information. This makes is possible to match a visible reflection to one's movements and define oneself as a source of these movements. The cerebral cortex activation in the zones responsible for facial gnosis that takes place during execution of self-identification tasks also confirms an important role of recognizing one's own face in the mirror in the development of self-identification [23]. Thus, the following are considered as neurocognitive self-identification markers: positive response to the reflection; proprioceptive and exteroceptive gnosis; visual gnosis (facial, simultaneous, optical-spatial).

Conceptually, our reasoning is based on the mental ontogenesis concept. In accordance with the ontogenetic patterns, the self-identification process initiation begins with the emergence of the revival complex being an innovation of infancy (at the age of 2.5–3 months) and characterized by the emergence of vocalization, motor activity, and smile upon seeing a primary caregiver (mother or father). Later, at the age of 7–8 months, differentiation of other people's faces occurs within the "friend or foe" boundaries. The infant begins to differentiate his/her face from the face of another person by the age of 18 months (Fig. 1).

The development of the software-hardware complex (SHC) will make it possible to objectify the procedure for assessment of mental development in early childhood (age 1–3 years), as well as to shape the system of measurable criteria.

The study aimed to evaluate the diagnostic potential of the software-hardware complex for analysis of self-identification phenomenon in early childhood.

METHODS

The total sample size was 136 individuals (57 (42%) boys and 79 (58%) girls); the average age was 25.35 ± 10.38 months. The sample was formed based on the selected inclusion and exclusion criteria. Inclusion criteria: age 1–3 years; female and male sex; age-appropriate neurotypical cognitive development. Exclusion criteria: age under 1 year or over 3 years; noncompliance with the cognitive development age norms; decompensated severe somatic disorder; hearing and vision impairment.

Three study groups were formed based on the age periods critical for self-identification [3]: toddlers aged 12–17 months, toddlers aged 18–23 months, and toddlers over the age of 24 months.

The study was conducted at the Veltischev Research Clinical Institute of Pediatrics and Pediatric Surgery (Pirogov Russian National Research Medical University), Russian Children's Clinical Hospital (branch of the Pirogov Russian National Research Medical University), and Roshal Children's Clinical Center. Examination time per subject was 20–35 min.

The study was conducted in two phases. The goal of the first phase was to assess facial gnosis in early childhood using functional neuropsychological tests. The child was positioned in front of the experimenter (most often on mother's knees). The experimenter attracted the child's attention, introduced him/herself and invited the child to play; after that he/she asked: “Show me where your nose (or other part of the face) is”. The same procedure was used during the second test, but the child was asked to point at parts of the face of his/her primary caregiver. To perform the third test, the experimenter asked the primary caregiver to show images of relatives (mother, father, grandmother, grandfather, brother/sister) and ask the child,

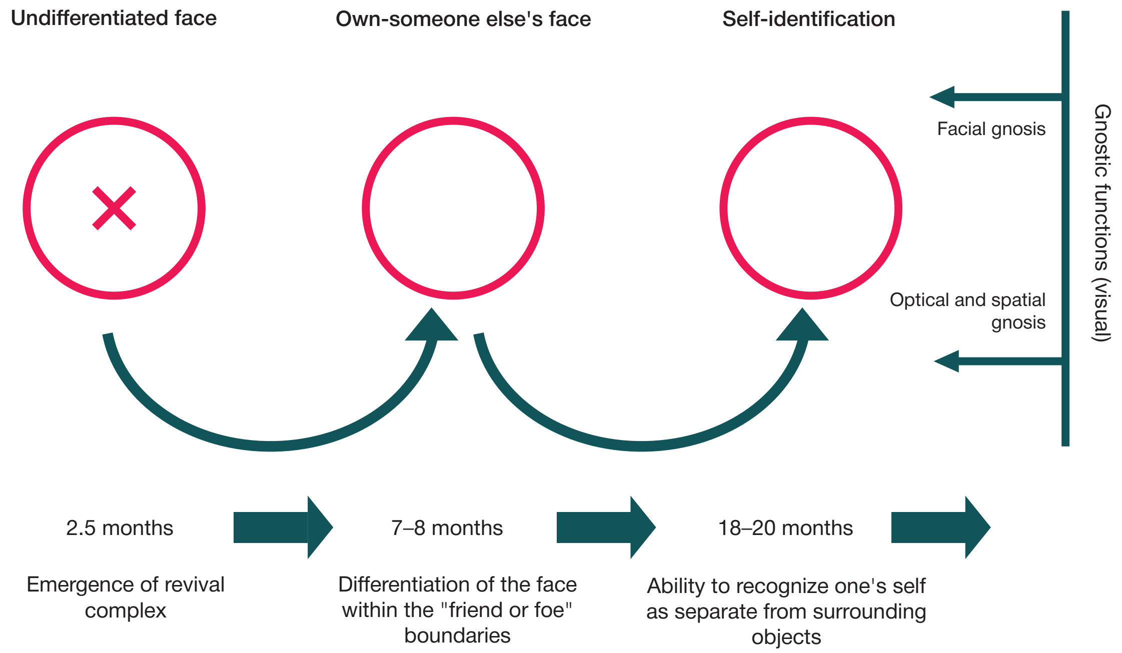

Fig. 1. Scheme of conceptual reasoning of ontogenesis of the self-identification phenomenon in early childhood

who was pictured. Facial gnosis was assessed based on the tempo, accuracy, and differentiation using the scale by Zh.M. Glozman: correct indication of the own face parts by the subject in accordance with the verbal instruction; correct indication of the other person's parts by the subject in accordance with the verbal instruction; recognition of the relative's face from a photograph.

The goal of the second phase was to assess self-identification in early childhood using the following: test 22 — mirror image series of the Bayley-III cognitive scale [27]; self-recognition mirror test (SMT) [3]; software-hardware complex (SHC) developed for analysis of self-identification phenomenon in early childhood [28].

The Bayley-III test procedure is as follows: the subject is shown a mirror sized 15 × 21 cm at a distance of 20–25 cm from the face, and the child's response to his/her reflection is assessed. Positive assessment is reported when the child is interested in the reflection, examines it and responds cheerfully.

The self-recognition mirror test procedure is as follows: the legal representative marks the subject's nose with bright cosmetics, and then the subject's behavior upon presentation of the mirror is recorded. The test is considered to be passed when the subject tries to touch or wipe the mark off his/her face, as well as when he/she uses a personal pronoun or says his/her name when asked "Who is this?" while pointing to the mirror. The test duration is 10 min, every 2 min 30 s the experimenter asks the legal representative to attract the subject's attention to the mirror, saying: "Look! Look! Look! Who is it?"

The procedure of testing using the SHC developed is as follows: the subject is positioned in front of the screen and video camera at a distance of 40–60 cm without any additional instructions. An image acquired using a video camera is displayed on the screen, with the marks drawn on the faces (Fig. 2).

If the child is distracted, one should draw his/her attention to the screen with the words: "Look!" If the subject does not respond to the mark within 20 s, the size of the mark is changed, and then, upon reaching the maximum size, its color is changed. If there is some response to the mark or all color

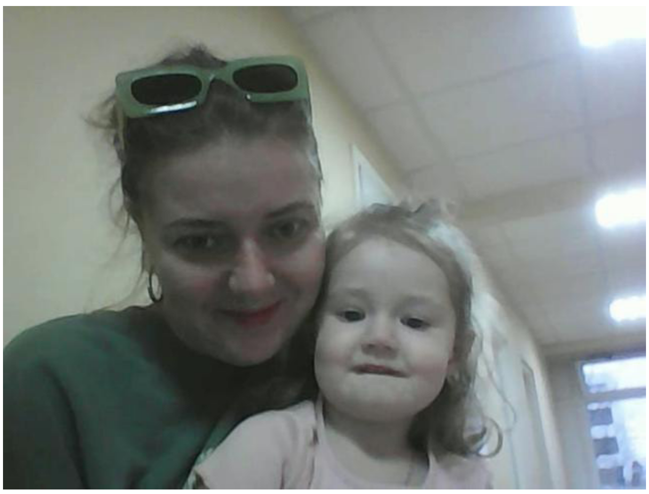

Image acquired using a video camera during assessment (35 months)

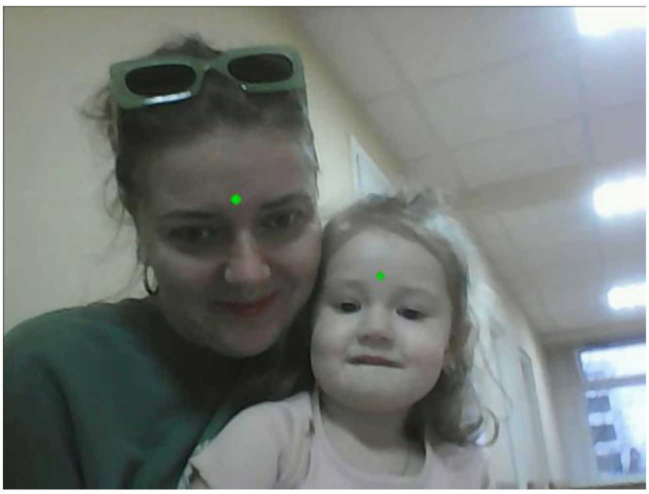

Image displayed on the screen during assessment (35 months)

Fig. 2. Example image acquired using the SHC

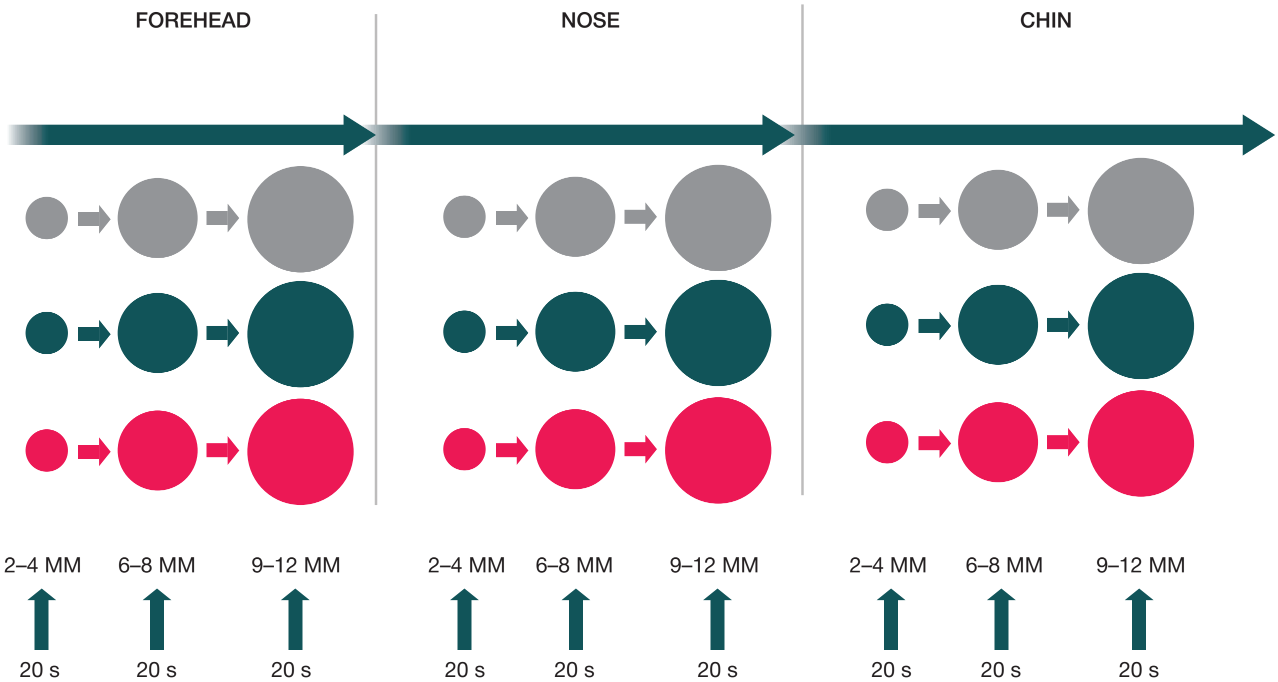

Fig. 3. Scheme of presenting the marks during the procedure of self-identification phenomenon assessment in early childhood using SHC

and size options presented, the position of the mark is changed to the next one. The marks are presented in the following order: green (first 2–4 mm, then 6–8 mm, and then 9–12 mm); blue (also as the size increases); red, as the size increases as well. The marks are presented sequentially in the following order of positioning: forehead, nose, chin (Fig. 3).

The diagnostic potential of the software and hardware computer vision technology for analysis of self-identification phenomenon in early childhood was assessed based on the sensitivity and specificity criteria. Sensitivity of the software and hardware technology characterizes accuracy of the diagnostic method, with which the program correctly determines the presence of the studied phenomenon and determines tolerance for type I errors (share of positive results defined as positive by the diagnostic method in the entire pool of the results obtained). Specificity characterizes accuracy of the diagnostic method when recording the studied trait (tolerance for type II errors) and shows the share of negative results determined as negative by the diagnostic method (in the entire pool of the results obtained).

Processing and interpretation of the acquired empirical study results

Quantitative data processing was performed using the descriptive and correlation statistics (Spearman's rank correlation), as well as using factor analysis with varimax rotation ($p < 0.05$).

RESULTS

Assessment of the results of performing functional neuropsychological tests for the diagnosis of facial and optical-spatial gnosis has shown, that children under the age of 18 months demonstrate low tempo, accuracy, and differentiation in all the tests proposed.

The age-specific features allowing one to trace the process of developing complex visual gnosis types in early childhood

Table 1. Results of correlation analysis of the mirror image series, SMT, and SHC tests in different age groups performed using Spearman's rank correlation

Indicators compared	Age groups (months)			
	12–17	18–23	24+	Total
SMT and SHC with the mark on the forehead	–	0.43	0.43	0.52**
SMT and SHC with the mark on the nose	–	0.68*	0.43	0.59**
SMT and SHC with the mark on the chin	–	0.68*	0.50*	0.66**
SMT and SHC	–	0.68*	0.50*	0.66**
SMT and Bayley-III	–	0.62	0.68**	0.64**
SHC with the mark on the forehead and SHC with the mark on the nose	–	0.62	0.58**	0.63**
SHC with the mark on the forehead and SHC with the mark on the chin	–	0.62	0.82**	0.79**
SHC with the mark on the nose and SHC with the mark on the chin	–	1**	0.82**	0.89**
Bayley-III and SHC with the mark on the forehead	–	0.25	0.27	0.33*
Bayley-III and SHC with the mark on the nose	–	0.41	0.27	0.38*
Bayley-III and SHC with the mark on the chin	–	0.41	0.33	0.42**
Bayley-III and SHC	–	0.41	0.33	0.42**

Note: * — $p < 0.05$; ** — $p < 0.01$.

Table 2. Results of factor analysis of facial gnosis and self-identification in early childhood

Variable		Factor 1	Factor 2	Factor 3
Indication of the own face part in accordance with the verbal instruction	Tempo	0.89	0.33	0.24
	Accuracy	0.91	0.25	0.23
	Differentiation	0.91	0.25	0.23
Indication of the other person’s face part in accordance with the verbal instruction	Tempo	0.82	0.19	0.46
	Accuracy	0.82	0.17	0.48
	Differentiation	0.81	0.2	0.44
Recognition of the relative’s photograph	Tempo	0.57	0.1	0.82
	Accuracy	0.57	0.1	0.82
	Differentiation	0.57	0.1	0.82
Bayley-III		0.17	0.34	0.83
Self-recognition mirror test		0.41	0.64	0.28
SHC with the mark on the face		0.13	0.84	0.09
SHC with the mark on the nose		0.16	0.89	0.11
SHC with the mark on the chin		0.19	0.95	0.12
SHC		0.19	0.95	0.12

have been identified based on the results obtained. The following sequence of phases have been determined: at the age of 16 months, the process of recognizing parts of another person's face is shaped (in accordance with the verbal instruction), which is associated with the rapid development of the nominative function of speech; then, by 18 months, optical-spatial gnosis is developed, specifically recognition of the spatially related parts of the face in a picture with the schematic view. Furthermore, within 16–18 months recognition of the parts of one’s own face in accordance with the verbal instruction is developed. At the age of 18–22 months, arrangement of the details of the schematic face representation within the boundaries of face oval relative to each other becomes possible (ontogenetically accessible). This, in turn, provides the basis for recognition of faces of close and familiar people, and then for differentiation of faces of strangers (or unfamiliar people) in both real world and pictures (schematic or realistic). As for the tempo, accuracy, and differentiation criteria in terms of ontogenesis, the tempo characteristics are shaped first, than differentiation, and after that the accuracy characteristics.

The analysis of self-identification in early childhood was conducted by the following methods: self-recognition mirror test; test 22, mirror image series of the Bayley-III cognitive scale; SHC. The use of the specified instruments implies qualitative assessment of the results based on the execution criterion (identified — not identified). As a result, it has been found that the percentage of successful execution of all self-identification tests increases with age: children become able to successfully pass the self-recognition mirror test and SHC since the age of 18 months.

Then we performed assessment of the proposed SHC external validity, which consisted of two phases. In the first phase, we performed assessment based on the sensitivity and specificity criteria. The results of the self-recognition mirror test were determined as benchmark positive and negative values, while test 22, mirror image series of the Bayley-III cognitive scale, and SHC were determined as assessment methods to be compared. High SHC specificity is reported for the task of analyzing self-identification phenomenon in early childhood with the sensitivity increasing from the test with the mark on the forehead (45.45%) to the test with the mark on the nose (54.55%) and from the test with the mark on the nose to the test with the mark on the chin (63.64%). In general, the maximum SHC sensitivity is reported for the age group 18–23 months, but the test with the mark on the forehead shows the highest sensitivity in the older group (24+ months). It is impossible to assess SHC sensitivity in the group under the age of 18 months due to the lack of the facts of successful SMT execution by children of this age.

In the second phase, we assessed consistency of the results of analyzing self-identification in early childhood obtained using the SMT, SHC, and mirror image series methods. Table 1 provides the results of pairwise correlation analysis of the above methods performed using Spearman’s rank correlation. When performing analysis of the SHC results, each test (with the mark on different parts of the face) was assessed separately, along with the indicator of passing of at least one of three tests during assessment of the subject.

The age group 18–23 months has shown a significant correlation between the SMT and SHC tests with the marks on the nose and chin, as well as with the indicator of successful execution of at least one test ($p < 0.05$). Furthermore, the results of the SHC tests with the marks on the nose and chin are fully consistent ($p < 0.01$). In the group over the age of 24 months, significant correlations of the SMT results with the SHC test with the mark on the chin and the indicator of successful execution of at least one test are observed ($p < 0.05$). Moreover, there are significant correlations between all SHC tests and between SMT and the Bayley-III score ($p < 0.01$). The analysis of the entire sample has revealed significant correlations of all the studied parameters. The highest correlation coefficients are reported for the correlations between SMT and the SHC test with the mark on the chin, indicator of successful execution of at least one test and the Bayley-III score, as well as for correlations between SHC tests.

To assess neurocognitive self-identification markers in early childhood, the factor analysis with varimax rotation was performed based on the results of assessing facial and optical and spatial gnosis, as well as self-identification scores obtained using the mirror image series, SMT, and SHC. Criteria were selected based on the Kaiser's criterion; to reduce the number of intersecting factors in the tested variables, we used orthogonal decomposition with varimax rotation. The fact of the variable belonging to the factor was determined based on the weight value ≥ 0.4. The factor analysis results are provided in Table 2.

We distinguished three factors based on the factor analysis of the indicators of facial and optical-spatial gnosis and the methods to assess self-identification in early childhood. Factor 1: indication of one's own face part in accordance with the verbal instruction — 0.9 (the mean of the assessment criteria); indication of the other person's face part in accordance with the verbal instruction — 0.817 (the mean of the assessment criteria); recognition of the relative's photograph — 0.56 (the mean of the assessment criteria); self-recognition mirror test — 0.41. Factor 2: indicator of successful execution of at least one SHC test — 0.95; SHC tests: with the mark on the face — 0.82; with the mark on the nose — 0.89; with the mark on the chin — 0.95; self-recognition mirror test: 0.64. Factor 3: Bayley-III scale test — 0.83; recognition of the relative from the photograph — 0.8 (the mean of the assessment criteria); indication of the other person's face part in accordance with the verbal instruction — 0.46 (the mean of the assessment criteria). Based on the factors distinguished we can conclude that the self-recognition mirror test results are more strongly correlated to the SHC results, than to the Bayley-III scale test and facial gnosis assessment test results.

Consistency of variables within the factors was tested using the Cronbach's alpha; high consistency coefficients were reported: factor 1 — $\alpha = 0.97$; factor 2 — $\alpha = 0.93$; factor 3 — $\alpha = 0.97$.

DISCUSSION

Self-identification emerges at the age of 18 months, which is confirmed by the earlier reported research [3] and the results of our study, in which no cases of successful self-identification test execution have been revealed in the group aged 12–17 months. At the same time, the response to one's own reflection in the mirror registered using the mirror image series emerges in children at an earlier age and in some children turns out to be developed by the age of 12 months, which is suggested by the facts of successful test execution in the group aged 12–17 months and low method specificity for self-identification. Given the tandem with high sensitivity and the presence of significant correlations based on the external validity assessment results (obtained using the Bayley-III scale test and self-recognition mirror test) reported for the group over the age of 24 months and the entire sample, it can be concluded that interest in one's own reflection, examination of the reflection, and positive response represent a neurocognitive marker of self-identification in early childhood.

CONCLUSIONS

The software-hardware complex for analysis of self-identification phenomenon in early childhood shows high specificity for self-identification in young children, while the method sensitivity is not so high. We assume that sensitivity is affected by the mark characteristics and realism. The data obtained show the increase in sensitivity and correlation with the self-recognition mirror test from the first test presented to the last one, along with significant correlations between two last SHC tests in all age groups, which can result from the sequence effect. The factor analysis showed that the self-recognition mirror test belonged to two factors: factor of predominant association with facial gnosis; factor of predominant association with SHC. Furthermore, the self-recognition mirror test results turned out to be most important for the second factor, which confirmed the relationship between the SHC and self-recognition mirror test results. The fact that the self-recognition mirror test results belong to the first factor confirms the importance of facial gnosis for self-identification in early childhood. Accordingly, assessment of the influence of changing the color, shape of the mark, computer algorithms for positioning the mark relative to the subject's face and the use of realistic images as a mark on the SHC sensitivity and assessment of the influence of the sequence and position of the mark on the subject's face on the test execution success are considered as the potential of further research involving the use of the SHC developed.

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