Open Access

OBM Neurobiology

LIDSEN Publishing Inc.

Original Research

Computerized Assessment of Cognitive Development in Neurotypical and Neurodivergent Children

Igor Val Danilov [1, *], Sandra Mihailova [2], Araksia Svajyan [3]

1. Academic Center for Coherent Intelligence, Latvia; E-Mail: igor_val.danilov@acci.center
2. Riga Stradins University, Riga, Latvia; E-Mail: sandra.mihailova@rsu.lv
3. Republican Pedagogical-Psychological Center of MoESCS of RA, Yerevan, Armenia; E-Mail: svajyanaraqsya41@aspu.am

* **Correspondence:** Igor Val Danilov; E-Mail: igor_val.danilov@acci.center

Academic Editor: Fabrizio Stasolla

Special Issue: New Technologies of Assessment and Interventions for Neurodevelopmental Diseases

OBM Neurobiology
2022, volume 6, issue 3
doi:10.21926/obm.neurobiol.2203137

Received: July 05, 2022
Accepted: September 21, 2022
Published: September 28, 2022

Abstract

This study aims to observe the differences in the shared intentionality magnitude in mother-child dyads with neurotypical (NT) children and neurodivergent (ND) children aged 3-6 years. The quality of shared intentionality in infancy is associated with cognitive development. Our results showed that ND children scored six times higher (on average) in quiz-test than NT children. Children with difficulties in interaction (ND children) are more likely to use shared intentionality in conversation than NT children. We believe that this knowledge can contribute to developing computerized assessment methods which can diagnose developmental disabilities in such children.

Keywords

Shared intentionality; computerized assessment; cognitive delay; coherent intelligence; statistical learning mechanisms

1. Introduction

The assessment of cognitive development, especially in preschool-aged children, is one of the contemporary challenges in recent times. According to Zablotsky et al. [1], developmental disabilities were found in about 17% of 88,530 children, aged 3–17 years during a study from 2009–2017. Moreover, they reported 9.04% of children with attention-deficit/hyperactivity disorder (ADHD), 7.74% with learning disabilities (LD), 1.10% with intellectual disability (ID), and 1.74% of children with autism spectrum disorders (ASD). Under the umbrella of developmental disabilities, many disorders are often comorbid with each other. For example, 20% to 40% of children with ADHD have dyslexia [2, 3], and children with ASD are also at increased risk of having dyslexia [3, 4]. Children with dyscalculia [3, 5] and dysgraphia [3, 6] are more likely to have dyslexia than those without dyscalculia [3]. Subsequently, about 95% of the total children with developmental disabilities are associated with ADHD and LD, while 82% of children with developmental disabilities suffer from either ADHD or LD or both.

ADHD is a debilitating mental health disorder most frequently diagnosed during school years and is characterized by persistent symptoms of inattention and/or impulsivity and hyperactivity [7-9]. Early preventative approaches are less common for ADHD than other disorders [7, 10]. According to the most recent edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-5TM), the age of symptom onset was increased from 7 to 12 years [11]. Various diagnostic tools are used for identifying ADHD: MRI, EEG, questionnaires, motion data, performance tests, etc. [12]. However, parents play a central role in recognizing such behavioral problems early in their children by their perception, awareness, and acceptance of the disease and prompt decision to accompany the child to a specialist [9, 13].

LD is a term used by both the educational and legal systems. In medicine, a specific learning disorder (SLD) diagnosis refers to an impediment in the ability to learn or use certain academic skills [14]. An accurate diagnosis of SLD requires the detection of persistent difficulties in listening, thinking, speaking, writing, spelling, arithmetic, or mathematical reasoning skills [14]. Various types of learning disorders like dyslexia, dysgraphia, and dyscalculia are diagnosed in early school-aged children [3, 14-16]. A diagnosis is made through a combination of observations, interviews, family history, and school reports [17]. In order to be diagnosed with SLD, the difficulties in developing the above-mentioned skills should persist for at least six months in a child, despite targeted assistance [17].

Henceforth, early prediction of developmental disabilities in preschool children is an urgent issue as it provides efficient intervention in their growing years [3, 15, 18-23]; otherwise, these diseases impact lifelong health and well-being [21]. However, we can diagnose a children's developmental delay by verbal-perceptual expertise of their skills only at school. Diagnosing ADHD and LD in children requires both the high professionalism of the specialist along with the parent's perception and awareness of the disease for calling a specialist. If the disease assessment could be simpler and the results understandable and convincing to parents, parents could identify the disease early and understand the need to report it to a specialist.

A recent study has proposed a new assessment paradigm, other than the assessment of verbal-perceptual skills, to diagnose cognitive delay at an earlier stage. According to Danilov and Mihailova, this new approach could be based directly on the evaluation of caregiver-child interactions [24]. To the best of our knowledge, the social environment is a key factor in cognitive development. Vygotsky [25] stated that a child's cognition develops in the social environment through internalizing external relations and actions fixed in the meanings of these actions and relations. Interactions with other people enable the internalization of cognitive processes first achieved in the social context [25]. Recent evidence suggests that a deficit in basic communication and social interaction skills can indicate a developmental delay in children [18, 26-29]. Specifically, ADHD is caused by many factors, including environmental and behavioral factors [21]. According to Grigorenko et al. [22], environmental factors are strong predictors of SLDs. Although the etiology of developmental disabilities is multifaceted (genetic, neurobiological, perceptual, and cognitive factors, etc.), the social interaction deficit is a key factor in most developmental disabilities.

It is suggested that children acquire knowledge at the sensorimotor stage of development up to 8–9 months, as stated by Piaget, through protoconversations with their mothers [30, 31] and shared intentionality [32]. Recent research [33] showed the ability of young children aged 18, 28, 31, and 33 months, indwelling with their mothers, to display the bond between unfamiliar sounds (numbers in an unfamiliar language) and the appropriate items without any sensory clues. Their performance rose from 33% to 125% higher than random results by chance. Moreover, we suggest that the quality of shared intentionality remains unaffected in older children and adults since mothers can also share their intentionality of similar quality with the child. Furthermore, literary insights showed coordinated neuronal activity in subjects during meaningful social interactions [34, 35]. However, increased neuronal activities [36, 37] and improvement in learning skills were observed [33, 38-42] in the absence of sensory cues (without communication) between the subjects. Another study [43] showed 32% increased performance in 13 dyad experiments conducted on 58 mothers and 68 children, aged 8-10 years, who were asked to solve unintelligible tasks without sensory clues, although familiar to the mothers. A recent theoretical analysis [44] discussed this non-perceptual interaction modality at the onset of cognition from perspectives of communication theory, embodied dynamics, and genetics which inferred that shared intentionality complements a set of interaction modalities. However, a lack of shared intentionality in infancy can lead to cognitive delay [44]. We suggest that an assessment of the shared intentionality magnitude can show cognitive development trajectory. Easy assessment of social interaction and presentation of accurate results can make parents aware of the disease at an early stage and understand the need to go to a specialist. The current study attempts to observe the differences in the shared intentionality magnitude in mother-child dyads with neurotypical (NT) children and neurodivergent (ND) children aged 3-6 years.

2. Materials and Methods

2.1 Method

For testing protoconversation in 3- to 6-year-olds, we modeled the mother-newborn biological system, in which the child-caregiver interactions happen without sensory cues as occurring in newborns. During the experiments, the children were asked to categorize several unknown phenomena. We asked them unfamiliar questions that could not be solved independently without clues and excluded all casual associations. We received their answers to a 10-task quiz designed on the same principle. The study registered the deviation of the intellectual testing results by comparing the children's correct answers (events) with the probability of random choices. Due to unfamiliar and unintelligible tasks, children were not able to solve the problems rationally. Therefore, if they did not get any clues (without shared intentionality), their results corresponded to the results of a random choice. Equation (1) of the R-effect coefficient presented the experimental data in a universal, relative format. The R-effect shows a relative child's score; the resultant score is a compilation of several events (correct answers), depending on the probability score X(e), relying on the probability of random choice in a specific case. This coefficient is positive when the total number of events exceeds the number of chances. The R-effect coefficient denotes a child's result deviation from the random choice value X(e); the higher its positive value, the stronger the mother-child interaction and higher coherent intelligence.

$$R = \frac{1}{n}\sum_{n=0}^{n}\frac{\left(X(o) - X(e)\right)}{X(e)} \tag{1}$$

We applied probability theory to assess children's performance. The tasks were unfamiliar and unintelligible to children. During the experiments, the dyads were not provided with an evaluation of the children's results. Moreover, children did not know the correct answers and could not learn the symbols' meanings of these tasks during the test execution. After each task (question-and-answers), the subjects did not know whether the given answer was correct or not. Due to feedback lack in solving problems, any rational solution in problem-solving was excluded. Therefore, even though the subjects could apply different strategies in problem-solving, these tasks were independent trials. In this case, each probability of the event's occurrence was not affected by the occurrence of the other events. The probability of occurrence of an event in a single trial of the experiment is p, the probability that the event occurs exactly *k* times out of *n* independent trials is equal to:

$$P(k) = C^k p^k q^{n-k} \tag{2}$$

The Bernoulli equation (2) shows the probability of a number of events (correct answers) made in independent trials, where: *C* – number of combinations *n* by *k*; *p* – the probability in each task; n – independent trials (tasks), the probability of each is *p* (0 < *p* < 1); *k* – events, how many tasks the child answers correctly; *q = 1 - p*.

The R-effect is calculated depending on the trial number completed by each child. According to the Bernoulli equation (2), the number of events (the random success choices set) yields a higher probability (*p* = 0,28) to the set of 2 events in 10 independent trials appearing in a bigger number of subjects (Table 1). A set of 3 events bears a probability of *p* = 0,25. These 2 event sets (2 and 3) yield a close probability, significantly exceeding others for all 10 trials. Therefore, the mean value of scores of the two most significant sets, 2 and 5, is applied to the value of X(e) while calculating the data for ten trials. For subjects who completed 9 and 8 trial sets, the mean value of these most significant sets was 2.

Table 1 The probability of the different sets of events from 0 to 6 due to the Bernoulli equation (2).

Trails/Events	0	1	2	3	4	5	6
p(e) in 10 trials	0.06	0.19	0.28	0.25	0.14	0.06	0.016
p(e) in 9 trials	0.07	0.22	0.30	0.23	0.11	0.04	0.009
p(e) in 8 trials	0.10	0.26	0.31	0.21	0.08	0.02	0.004

2.2 Subjects

Nineteen mother-children dyads participated in the study. Although the results of the two dyads were rejected due to procedural errors, the other two children manifested attention deficit during the quiz; their results were rejected for answering only the four and five questions of the quiz instead of the demanded ten answers. Therefore, the outcomes of nine NT and six ND children were presented.

2.3 Stimuli

The mobile phone software showed ten unfamiliar tasks having four possible responses to all the subjects. Unfamiliar tasks were provided, numbering from 1 to 6, represented in different bicolor circles. Each of these six different bicolor circles is related to a specific number from 1 to 6 (Figure 1). Furthermore, the subjects did not know the relevance of the specific bicolor circle to a certain number during the test.

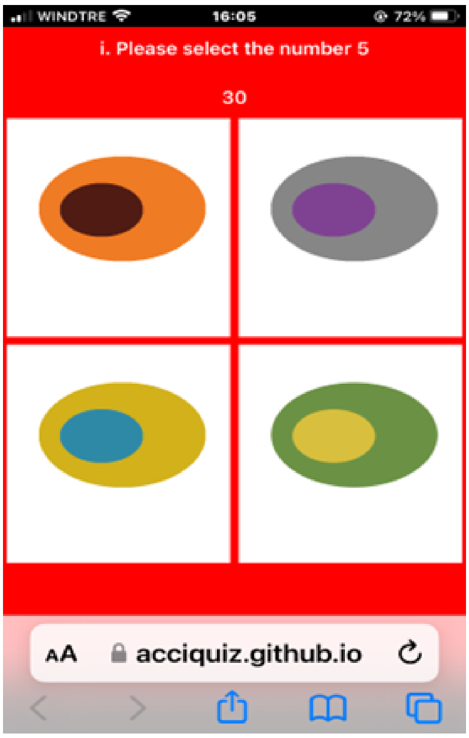

Figure 1 The task with four possible responses.

While the mothers and the children examined the questions on their smartphones (the mothers responded mentally without providing clues to the children), only the children independently responded to items by choosing options on the screen. The software showed the quiz items and collected the input from the children. Simultaneously, the smartphone produced an electromagnetic field in the visible range of the spectrum. The human-computer system software stimulated interpersonal dynamics by rhythmic changes in the light (wavelengths of 700 and 400 nm alternately with 80 bpm) [24]. In this manner, the software stimulated shared intentionality in the study's bioengineering system (Figure 2).

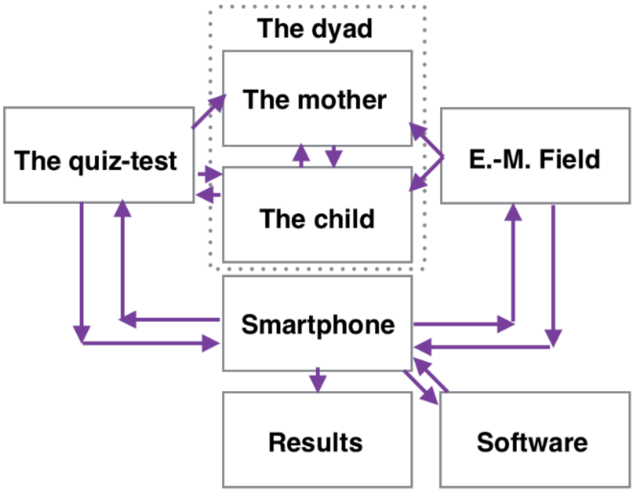

Figure 2 The scheme of the bioengineering system of the experiment.

2.4 Procedure

Before the initiation of the quiz, Republican Pedagogical-Psychological Center (RPPC) specialists explained the research goal and procedure to the parents who signed the multiple consent forms. The quiz was scheduled as per the convenience of the child and was conducted when the child was not tired, hungry, or agitated.

Ten minutes before the scheduled quiz, RPPC specialists carried out a short interview with the mother to clarify her role in the task (without her child). The most important quiz rules were watching the screen, following the instructions, and not telling the child about correct answers.

For children >3 years, a surprise gift was presented.

At the beginning of the scheduled quiz, RPPC specialists explained all the rules of the quiz to the dyads and told the story about a Wizard and his garden with colored figures in the trees.

At the beginning of each task, the RPPC specialist told the mother: "Mamma, please read the instructions at the top of the screen silently." After observing each question for 3–5 s, the RPPC specialist asked the mother: "Mamma, please ask your baby to choose one of the circles corresponding to the number "X" (from 1 to 5). Mamma and baby, I kindly ask you both to look at the screen carefully during the whole test. After the child's response, while expecting the end of each task, the RPPC specialist repeated: "Please look at the screen carefully, the new task is coming soon" as well as "Baby, please do not respond very fast on the next task to help the Wizard to find colors for his numbers. If you follow my instructions and achieve the best results, you will receive a gift when the game ends."

When completing the quiz tasks, the RPPC specialist refrained from evaluating the child's results from the current task and providing any verbal or non-verbal reaction to the child's actions and task responses.

3. Results

The results are presented in Table 2.

Table 2 The test results of Neurotypical vs. Neurodivergent children.

	ID	Sex, age	Diagnosis	Scores: Correct/Incorrect	*X(e)*	*X(o)*	*R-effect*	*R-effect* NT	*R-effect* ND
1	91971	girl, 4	NT	3/6 (9)	2	3	0,5	0,5	
2	74971	girl, 3	ND	4/5 (9)	2	4	1		1
3	59971	boy, 3	ND	3/7 (10)	2,5	3	0,2		0,2
4	50614	boy, 5	ND	5/5 (9)	2	5	1,5		1,5
5	96614	boy, 5	ND	2/7 (9)	2	2	0		0
6	75614	girl, 6	NT	3/7 (10)	2,5	3	0,2	0,2	
7	30971	girl, 5	NT	2/8 (10)	2,5	2	-0,2	-0,2	
8	26971	girl, 5	NT	3/6 (9)	2	3	0,5	0,5	
9	23554	girl, 5	NT	3/5 (8)	2	3	0,5	0,5	
10	72124	boy, 5	ND	3/6 (9)	2	3	0,5		0,5
11	81187	girl, 4	NT	2/7 (9)	2	2	0	0	
12	97614	boy, 4	ND	3/6 (9)	2	3	0,5		0,5
13	41681	boy, 3	NT	3/6 (9)	2	3	0,5	0,5	
14	12207	boy, 5	NT	1/9 (10)	2,5	1	-0,6	-0,6	
15	63681	boy, 3	NT	1/9 (10)	2,5	1	-0,6	-0,6	
Total			NT – 9 ND – 6		**32,5**	**41**	**4,5**	**0,8**	**3,7**

Notes: The numbers are children's ID; NT – Neurotypical children; ND – Neurodivergent children; *X(e)* – expected scores, i.e., the number of events with the highest probability of occurring, calculated by the Bernoulli equation (2); *X(o)* – observed scores.

4. Discussion

This section discusses the method for assessing shared intentionality. Firstly, this discussion encompasses the reasoning of methodological components. Secondly, as method validity and reliability are crucial for providing quantitative measurements, we have discussed method validity and reliability to satisfy the dependability in cognitive development assessments.

4.1 Methodological Components

4.1.1 Objective

The assessment objective is shared intentionality. Since this is an implicit variable, the study identifies its indicator–the manifested variable of shared intentionality that could be precisely assessed. When young children are asked to solve unintelligible tasks (to categorize the unknown symbols), they do not know the responses and cannot solve these problems independently. Hence, they need help from caregivers, who know the correct answers. This research procedure stimulated insight or intuition in children; however, for children, it was the only possible way to answer all questions correctly. During the study, children were asked to guess the answers intuitively in the presence of caregivers. It was expected that the dyad's intentionality would be shared under this condition since the children could only intuit the correct options, which were known to the caregivers. From this perspective, the indicator of shared intentionality was the child's intuition or the response to the request to intuit the correct answers during the quiz. Therefore, the assessment objective was to evaluate the child's intuition by answering the unintelligible problems and indwelling with the caregiver.

4.1.2 Data Collection Process

Stimuli were unintelligible and unfamiliar symbols. Children were asked to guess answers intuitively, and the data collection process was completed by registering the children's answers to the test items. Since all their answers were unfamiliar and pseudo-random, this was one of the reasons why probabilistic theory tools could fit the data analyses. Just before the quiz, the children were instructed to guess the correct answer for each task, following the "like/dislike" feelings, and were asked to make decisions based on their intuition or knowledge from sudden insights. The supervisor suggested that children should not adhere to any strategy while answering the quiz, and the data was recorded for further processing if the children answered 70% of the questions and did not follow any rational strategy, i.e., if decisions made by the child were pseudo-random. The deviation of the result from random choice showed the magnitude of the shared intentionality effect.

4.1.3 Method

The literature analysis shows that the period of the appearance of intentionality in infants depends more on social interaction features rather than the child's age [24]. Confronting the "observational" and "experimental" research methods reveal different outcomes–a similar task shows different performances. Danilov and Mihailova [24] argued that the "observational" research design differed from the "experimental" design by two variables: emotional stimulation and child-caregiver interaction without sensory cues that enabled children to respond accurately to the test by using shared intentionality. Hence, the social environment and social interaction deficit are potential factors in cognitive development and a majority of developmental disabilities, respectively. The core idea of the method for assessing children's cognition relies on estimating the social interaction magnitude between the mother and child.

Quality must be preserved to some extent throughout its life if appearing at birth. Therefore, we suggest that shared intentionality should accompany other interaction modalities during various life processes. The bioengineering system (human-computer system) re-created the "experimental" mother-newborn model to induce this interaction modality in more mature organisms. For this reason, the human-computer system formed interpersonal dynamics in the dyad by stimulating their interactional synchrony and emotional contagion.

4.2 Validity and Reliability

Rigorous research designs require reliable and valid psychometrically sound measurement tools for maintaining the integrity of study findings [45]. When study variables are abstract, it is not easy to measure quantitatively, which requires close attention to construct validity [45, 46]. Construct validity is the degree to which an instrument measures the construct about to be measured [45, 47]. Various ways exist to evaluate an instrument's construct validity, including contrasted groups [45] and methods–verification of a statistical method's validity by confronting results with estimation from another valid method. While statistical methods are widely applied in psychological research, the within-subject research design with two conditions seems more valid. This data collection mode is based on confronting the "primed" and "unprimed" conditions–where caregivers knew correct responses only in the "primed" condition. The current study repeated a recent research design [33, 38, 43]. While we evaluated results by comparison with the random choice, two of the above-noted research studies also verified the performance under within-subjects design, comparing the difference between the correct responses in the two conditions for caregivers: the "primed block" and "unprimed block" of items. The obtained data in both designs are consistent with the hypothesis and relevant to each other. Comparing the outcomes of two designs reveals the data correspondence that enables the usage of both designs for assessing intuition. Even though the within-subjects research design with two conditions seems more valid, the following arguments explain the reason for applying the research design based on a comparison with a random choice to assess young children.

Very young children have shorter attention spans. Focused attention proves effective if the situation involves the intake and processing of information or the completion of some goal-directed activity [48, 49]. The chosen studies contained unintelligible tasks in the form of ten quiz items without any feedback. However, recent evidence reveals that task difficulties affect performance [50-52], limit feedback, and reduce the incidence of trial-and-error problem-solving strategies [53, 54]. Scores in low-stakes tests correlate with motivation [55] whereas complex problems reduce motivation and attention during problem-solving, thereby decreasing performance. A longitudinal study on 2-2.5-year-old children's attention spans reported the timing of focused attention during free play. In a comparison of two research conditions of 5- and 10-min free play periods, no significant difference was observed in the number of focused attention episodes (about 12 episodes for the entire period in both conditions) and the mean duration per episode (5.36 and 6.1 s), respectively. The young children performed in the same duration of focused attention in both the 5-minute and 10-minute free play periods, thus, suggesting that 5 min sessions were aptly suitable for testing 3-year-old children since the extended testing time length can suppress the performance. Although the above claims are correct, the method with the double research conditions (within-subjects design) decreases the quantity of the quiz items from 10 to 5 due to limited time length, thereby challenging its validity. Therefore, recent studies have applied the research design based on a comparison with a random choice to assess young children.

Another argument supports this method's validity. Probabilistic models are increasingly used across the cognitive and neuroscience fields [56]. It is suggested that the children rely on statistical learning mechanisms at the onset of cognitive development [57, 58] and acquire initial social skills by keeping track of the statistical information available in the environment [59]. If this is correct, cognition develops due to statistical and probabilistic patterns in the initial stages. It is also possible that the tools of the probabilistic theory are appropriate for the phenomenon being measured; they are relevant to statistical learning mechanisms. Hence, this method for estimating the magnitude of shared intentionality in dyads is valid.

The above-noted validity verification modality is closely linked to an assessment of the method's reliability. According to DeVon et al. [45], unlike retest reliability, the alternative form’s reliability corresponds to scores from two tests, each with different modes to evaluate the same concepts. The verification of a statistical method's validity contributes to its equivalence reliability.

5. Limitations

5.1.1 Limitation 1: Caregiver-child Biological System is a Dynamical System

Reliability describes how far a method will produce similar results, assuming nothing else has changed [60] and presenting all aspects of coherence, stability, equivalence, and homogeneity [61, 62]. However, in psychology, the true score can never be known because no measure is considered perfect [45], assuming nothing else has changed [60]. Stability reliability is tested when the study’s attributes are not expected to change [45]. Test-retest reliability is relevant for those variables that are not expected to change over time. However, shared intentionality is not one of them. Many endogenous and exogenous factors impact the dynamic caregiver-child biological system and require shared intentionality assessments for collecting dynamic data inputs. Recent studies have noted that shared intentionality is not a constant feature in all interpersonal dynamics [24]. Furthermore, these five factors challenge the interaction ability: social entrainment, motivation, emotional arousal, intellectual stimuli, and interactional synchrony [24]. Apart from the quiz results, this dynamical data should also contain information about the crucial factors defining the current psychophysiological states of the biological system. Based on this, a dynamical system should be developed for collecting timely inputs and reproducing reliable results. This limitation of our study suggests that any association of observed outcomes with factors of shared intentionality is undone until an understanding relating all factors to this modality of social interaction becomes clear.

5.1.2 Limitation 2: Small Sample Size

The following limitation suggests that dyads cannot strengthen a shared intentionality magnitude to the same extent in routine life since endogenous and exogenous factors continuously vary, depending on social and biological rhythms. Furthermore, this modality of social interaction emerges almost randomly and accomplishes the child's success in keeping track of statistical information available in the environment. This is a probabilistic mechanism of statistical learning and needs more empirical data for the statistical power of the data analysis.

5.1.3 Limitation 3: Exotic Concept Constitutes a New Paradigm for Assessing Cognition

In contrast to the verbal-perceptual method of assessing cognitive development in children (dominant in contemporary pediatrics), the article proposes a new paradigm for assessing cognition development, based on data obtained from the non-verbal and non-perceptual methods. Even though the current study, along with recent evidence, shows a shared intentionality effect, we do not know the nature of its appearance. Additionally, the magnitude of the effect in a certain case is not predictable, even after the appearance of effects in this case.

This empirical evidence requires the establishment of a precise theoretical foundation. According to Danilov and Mihailova [63], shared intentionality is an outcome of evolutionary development that facilitates the ability to select only one shared cue for the entire group. This type of interaction modality is the elementary and archetypical modality that appears before communicating via sensory cues. Shared intentionality facilitates the training of newborns and ensures efficient cooperation among all group members without any communication. A hypothesis proposed protein molecules an agents for engaging neurons of different organisms in cooperative reactions to shared stimuli. However, only one hypothesis of neuronal coherence agent for shared intentionality [63] cannot constitute a hypothesis' competition that might facilitate knowledge development on the topic. This limitation challenges the current method, mainly based on assessing shared intentionality. Since any research design needs a well-developed theoretical approach to the studied object, further studies should develop hypotheses of neurobiological processes occurring during social interactions.

6. Future Research Perspectives

This section discusses the limitations of the contemporary approach to assessing developmental disabilities for revealing improved perspectives, different from the verbal-perceptual assessing paradigm. Perspectives pertaining to this approach for assessing developmental delay in children are also discussed.

6.1 Limitations of Verbal-perceptual Assessing Paradigm

Assessing individual differences has been one of the challenges faced by science since the beginning of the 19th century. After Binet et al., the verbal-perceptual psychological testing paradigm was widely developed and distributed and was also applied to screening cognitive development in young children. The diagnosis of developmental disabilities in children uses the factors in the verbal-perceptual paradigm as the main tools: observation, interviews, family history, and school reports. It is widely accepted that cognitive ability can be gauged from verbal expressions and behavior of the subjects due to sensing and perception skills. The following limitations encourage researchers to find other possibilities in the assessment of cognitive development different from the usual verbal-perceptual paradigm.

6.1.1 Limitation 1

In recent decades, several studies have been undertaken to develop new methods for diagnosing SLD by observing early signs in the initial growth phase. For instance, early signs of mathematical learning difficulties can be detected by assessing difficulties in numeracy [64, 65], subitizing [66-68], etc. Sometimes, speech processing skills both phonologically and morphosyntactically may show early signs of future reading and writing difficulties even in 30-month-old children: in perception or duration, in the prosody and phonotactics of word production attempts and word structures, as well as in the complexity of morphosyntactic features of expressions [23].

These new verbal methods should be studied well for sufficient application in pediatrics. However, it can be suggested that the verbal-perceptual assessment of developmental delay in many preschool children is questionable. Although there is no specific period for the manifestation of behavior markers or their "early signs" in a child; a window of opportunity can be utilized for cognitive reforms [69]. Again, detecting early signs of developmental disabilities in children requires both the high professionalism of the specialist as well as a parent's perception and awareness of the disease, in reporting to a specialist. Subsequently, parents play the key role here and should be aware of the disease in its early stages and understand the need for medical intervention.

6.1.2 Limitation 2

The development of verbal-perceptual methods for detecting earlier signs of learning disabilities in children, such as numeracy checking skills, is limited by the flexible borders of developmental periods. Incongruence between dynamics of personal development and universal ranges of markers' application yields an extent of uncertainty in developmental diagnosis [69]. However, these screening tools can prematurely detect only the most visible or severe difficult cases in LD. A verbal-perceptual inspection (through observations, interviews, and learning exercise reports) of children's reading, writing, and mathematical skills helps in deriving significant cognitive findings in school (not before).

6.2 Perspectives of Non-verbal and Non-perceptual Assessing Paradigm

Developmental disabilities in children can significantly affect many areas of life, including work, daily activities, social and family relationships, as well as psychological and physical well-being. The unbiased computerized assessment method for evaluating social interaction magnitude in dyads could help in rapid screening of early signs of delay, thus, complementing other diagnostic tools. Combined with the verbal-perceptual assessment tool (e.g., parents' interview), this knowledge about the social environment may provide early detection of developmental delay in children, even in online mode. Additionally, this method could yield a more effortless, unbiased procedure for parents and can become an additional control for improving the effectiveness of verbal-perceptual screening methods.

Another advantage is the socio-cultural tolerance of this approach. Indeed, this new method can develop great perspectives for diagnosing children in a multi-cultural environment (e.g., bilingual families, migrants, etc.) and in conditions where parents cannot fully explain behavior markers because of social, cultural, and linguistic differences.

Consequently, parents can correct a child's developmental delay by improving the exogenous factor of the social environment on time. The parents can also improve the child's social skills by assessing the previous social interactions and their outcomes if social interaction would be easily assessed and their outcome would be cogently presented. The unbiased assessment of social interaction power in caregiver-child dyads may contribute to understanding social environment problems for its timely improvement because his method's assessment outcome shows the quality of the social environment by assessing social interaction magnitude.

A few research directions for developing knowledge on this topic can be suggested. First, the discussion of the current study shows that a caregiver-child biological system is a dynamical system. It continuously evolves and changes shared intentionality magnitude due to exogenous and endogenous factors. The application of the dynamical assessment system of children's cognition abilities could do the needful. This human-computer dynamical assessment system collects information about crucial psychophysiological factors for defining the current biological system's states and provides reliable assessment results in collecting inputs in time and space. Therefore, further research should encompass the following components of the dynamical assessment system: (i) the methodological components, including factor analysis of shared intentionality magnitude; (ii) an algorithm for monitoring a dynamic biological system, clarifying the efforts of this human-computer dynamical assessment system in processing dynamic data that refer to the causality between the time of change in input value and the time denoting the steady-state value given by the system; (iii) metrological component, research should elaborate standardized assessment units for developing metrological components that determine the efficacy of these assessment units and provide a norm for universal correlation of all assessment results in practice. Secondly, future research should discuss elements for providing quantitative measurement to satisfy dependability in the cognitive development assessment, and it needs more empirical data for the statistical power of the data analysis. Thirdly, further theoretical research should develop hypotheses on neurobiological processes occurring during social interactions. These theoretical grounds allow us to precisely tune our research designs for developing a dynamical assessment system of children's cognition.

7. Conclusions

The neurodivergent children achieved an R-effect of 3.7 in contrast with an R-effect of 0.8 obtained by neurotypical children with average values for neurodivergent and neurotypical children of 0.62 and 0.09, respectively. Our results showed that children with difficult interactions apply shared intentionality more in conversations than neurotypical children. Future research can improve our understanding of the relevance of all factors for the shared intentionality magnitude if more empirical data are obtained for the statistical power of the data analysis. This knowledge could develop a hypothesis on neurobiological processes occurring during social interaction that could initiate further research on shared intentionality. We believe that the current study encourages further research for developing the assessment method of diagnosing children's cognition at an earlier age based on estimated shared intentionality. Additionally, future research on this new method can develop great perspectives for diagnosing children in a multi-cultural environment where parents cannot explain behavior markers due to social, cultural, and linguistic differences. This unbiased computerized assessment tool for evaluating social interaction magnitude in dyads could become a part of rapid screening of early signs of delay, thereby complementing other diagnostic tools.

Acknowledgments

Many thanks to Ambra Donega and RPPC specialists Haykanush Dilanyan and Yana Karapetyan that have technically supported this work.

Author Contributions

Igor Val Danilov conceived and designed the experiments. Sandra Mihailova and Araksia Svajyan reviewed the research design and gave valuable remarks. Igor Val Danilov formulated the hypothesis and wrote the first draft of the manuscript. Igor Val Danilov, Sandra Mihailova and Araksia Svajyan improved the text over several iterations.

Funding

No fundings.

Competing Interests

The authors have declared that no competing interests exist.

References

1. Zablotsky B, Black LI, Maenner MJ, Schieve LA, Danielson ML, Bitsko RH, et al. Prevalence and trends of developmental disabilities among children in the United States: 2009–2017. Pediatrics. 2019; 144: e20190811.
2. Germanò E, Gagliano A, Curatolo P. Comorbidity of ADHD and dyslexia. Dev Neuropsychol. 2010; 35: 475-493.
3. Sanfilippo J, Ness M, Petscher Y, Rappaport L, Zuckerman B, Gaab N. Reintroducing dyslexia: Early identification and implications for pediatric practice. Pediatrics. 2020; 146: e20193046.
4. Åsberg J, Kopp S, Berg-Kelly K, Gillberg C. Reading comprehension, word decoding and spelling in girls with autism spectrum disorders (ASD) or attention-deficit/hyperactivity disorder (AD/HD): Performance and predictors. Int J Lang Commun Disord. 2010; 45: 61-71.
5. Moll K, Landerl K, Snowling MJ, Schulte-Körne G. Understanding comorbidity of learning disorders: Task-dependent estimates of prevalence. J Child Psychol Psychiatry. 2019; 60: 286-294.
6. Döhla D, Heim S. Developmental dyslexia and dysgraphia: What can we learn from the one about the other? Front Psychol. 2016; 6: 2045.
7. Sonuga-Barke EJ, Koerting J, Smith E, McCann DC, Thompson M. Early detection and intervention for attention-deficit/hyperactivity disorder. Expert Rev Neurother. 2011; 11: 557-563.

8. Swanson JM, Sergeant JA, Taylor E, Sonuga-Barke EJ, Jensen PS, Cantwell DP. Attention-deficit hyperactivity disorder and hyperkinetic disorder. Lancet. 1998; 351: 429-433.
9. Rocco I, Corso B, Bonati M, Minicuci N. Time of onset and/or diagnosis of ADHD in European children: A systematic review. BMC Psychiatry. 2021; 21: 575.
10. Shaw DS, Dishion TJ, Supplee L, Gardner F, Arnds K. Randomized trial of a family-centered approach to the prevention of early conduct problems: 2-year effects of the family check-up in early childhood. J Consult Clin Psychol. 2006; 74: 1-9.
11. Leahy LG. Diagnosis and treatment of ADHD in children vs adults: What nurses should know. Arch Psychiatr Nurs. 2018; 32: 890-895.
12. Loh HW, Ooi CP, Barua PD, Palmer EE, Molinari F, Acharya U. Automated detection of ADHD: Current trends and future perspective. Comput Biol Med. 2022; 146: 105525.
13. Zwaanswijk M, Verhaak PF, Bensing JM, van der Ende J, Verhulst FC. Help seeking for emotional and behavioural problems in children and adolescents: A review of recent literature. Eur Child Adolesc Psychiatry. 2003; 12: 153-161.
14. American Psychiatric Association. Diagnostic and statistical manual of mental disorders, fifth edition (DSM-5). Washington: American Psychiatric Association Publishing; 2013.
15. Young AR, Beitchman JH. Specific learning disorder. In: Gabbard's treatments of psychiatric disorders. 5th ed. Washington: American Psychiatric Publishing; 2014. pp. 77-92.
16. Kulkarni M, Kalantre S, Upadhye S, Karande S, Ahuja S. Approach to learning disability. Indian J Pediatr. 2001; 68: 539-546.
17. Frolov L, Schaepper MA. What is specific learning disorder [Internet]? Washington: American Psychiatric Association; 2021. Available from: https://www.psychiatry.org/patients-families/specific-learning-disorder/what-is-specific-learning-disorder.
18. Pierce K, Gazestani VH, Bacon E, Barnes CC, Cha D, Nalabolu S, et al. Evaluation of the diagnostic stability of the early autism spectrum disorder phenotype in the general population starting at 12 months. JAMA Pediatr. 2019; 173: 578-587.
19. Hyman SL, Levy SE, Myers SM, Kuo DZ, Apkon S, Davidson LF, et al. Identification, evaluation, and management of children with autism spectrum disorder. Pediatrics. 2020; 145: e20193447.
20. McCarty P, Frye RE. Early detection and diagnosis of autism spectrum disorder: Why is it so difficult? Semin Pediatr Neurol. 2020; 35: 100831.
21. Wei Y. An Overview of predicting the prevalence of ADHD. In: 2022 3rd International Conference on Mental Health, Education and Human Development (MHEHD 2022). Zhengzhou: Atlantis Press; 2022. pp. 188-193.
22. Grigorenko EL, Compton DL, Fuchs LS, Wagner RK, Willcutt EG, Fletcher JM. Understanding, educating, and supporting children with specific learning disabilities: 50 years of science and practice. Am Psychol. 2020; 75: 37-51.
23. Richardson U, Kulju P, Nieminen L, Torvelainen P. Early signs of dyslexia from the speech and language processing of children. Int J Speech Lang Pathol. 2009; 11: 366-380.
24. Val Danilov I, Mihailova S. A new perspective on assessing cognition in children through estimating shared intentionality. J Intell. 2022; 10: 21.
25. Vygotskii LS. Myshlenie i rech (Russian). Moscow: Natsional'noe Obrazovanie; 2016.
26. Gresham FM, MacMillan DL. Social competence and affective characteristics of students with mild disabilities. Rev Educ Res. 1997; 67: 377-415.

27. Cullinan D. Students with emotional and behavioral disorders: An introduction for teachers and other helping professionals. Upper Saddle River: Merrill/Prentice Hall; 2002.
28. Margot P, Ozonoff S. Autism and pervasive developmental disorders. Cambridge: Cambridge University Press; 2007. pp. 69-128.
29. Rojas-Torres LP, Alonso-Esteban Y, Alcantud-Marín F. Early intervention with parents of children with autism spectrum disorders: A review of programs. Children. 2020; 7: 294.
30. Yingling JM. "Does that mean 'no'?": Negotiating proto-conversation in infant-caregiver pairs. Res Lang Soc Interact. 1990; 24: 71-108.
31. Trevarthen C. The concept and foundations of infant intersubjectivity. In: Intersubjective communication and emotion in early ontogeny. Cambridge: University Press; 1998. pp. 15-46.
32. Tomasello M. Becoming human. In: Becoming human. Cambridge: Harvard University Press; 2019.
33. Val Danilov I, Mihailova S, Reznikoff I. Frontiers in cognition for education: Coherent intelligence in e-learning for beginners aged 1 to 3 years. Proceedings of the 20th Int'l Conf on e-Learning, e-Business, Enterprise Information Systems, and e-Government, along with CSCE congress 2021; 2021 July 26th-29th; Las Vegas, NV, USA. Washington: American Council on Science and Education. Available from: https://www.american-cse.org/static/CSCE21%20book%20abstracts.pdf.
34. Oldham S, Murawski C, Fornito A, Youssef G, Yücel M, Lorenzetti V. The anticipation and outcome phases of reward and loss processing: A neuroimaging meta-analysis of the monetary incentive delay task. Hum Brain Mapp. 2018; 39: 3398-3418.
35. Valencia AL, Froese T. What binds us? Inter-brain neural synchronization and its implications for theories of human consciousness. Neurosci Conscious. 2020; 2020: niaa010.
36. Fishburn FA, Murty VP, Hlutkowsky CO, MacGillivray CE, Bemis LM, Murphy ME, et al. Putting our heads together: Interpersonal neural synchronization as a biological mechanism for shared intentionality. Soc Cogn Affect Neurosci. 2018; 13: 841-849.
37. Painter DR, Kim JJ, Renton AI, Mattingley JB. Joint control of visually guided actions involves concordant increases in behavioural and neural coupling. Commun Biol. 2021; 4: 816.
38. Val Danilov I, Mihailova S, Perepjolkina V. Unconscious social interaction, coherent intelligence in learning. Proceedings of the 12th annual conference ICERI; 2019 November 11th-13th; Seville, Spain. Valencia: International Academy of Technology, Education and Development. pp. 11-13.
39. Val Danilov I, Mihailova S. Emotions in e-learning: The review promotes advanced curriculum by studying social interaction. Proceedings of the 6th International Conference on Lifelong Education and Leadership for ALL; 2020 Jul 13th-16th; Sakarya, Turkey. Available from: https://hal.archives-ouvertes.fr/hal-02902339/.
40. Val Danilov I, Mihailova S. Knowledge sharing in social interaction: Towards the problem of primary data entry.Proceedings of the 11th Eurasian Conference on Language & Social Sciences; 2021 February 2nd; Gjakova, Kosovo. Available from: https://hal.archives-ouvertes.fr/hal-03176562.
41. Val Danilov I, Mihailova S. New findings in education: Primary data entry in shaping intentionality and cognition. Proceedings of the Thirteenth International Conference on Advanced Cognitive Technologies, and Applications, Cognitive 2021; 2021 April 18th; Porto, Portugal. Available from: https://hal.archives-ouvertes.fr/hal-03207125.

42. Val Danilov I, Mihailova S, Reznikoff I. Shared intentionality in advanced problem based learning: Deep levels of thinking in coherent intelligence. Proceedings of the 17th Int'l Conf on Frontiers in Education: Computer Science and Computer Engineering, along with CSCE congress (2021); 2021 July 26th-29th; Las Vegas, NV, USA. Washington: American Council on Science and Education. Available from: https://www.american-cse.org/static/CSCE21%20book%20abstracts.pdf.
43. Val Danilov I, Mihailova S. Intentionality VS chaos: Brain connectivity through emotions and cooperation levels beyond sensory modalities. Proceedings of the Thirteenth International Conference on Advanced Cognitive Technologies, and Applications (COGNITIVE 2021); 2021 April 18th; Porto, Portugal. Wilmington: International Academy, Research, and Industry Association. Available from: https://hal.archives-ouvertes.fr/hal-03207154.
44. Val Danilov I. Smartphone in detecting developmental disability in infancy: A theoretical approach to shared intentionality for assessment tool of cognitive decline and e-learning. In: Science and Information Conference. Cham: Springer; 2022. pp. 305-315.
45. DeVon HA, Block ME, Moyle-Wright P, Ernst DM, Hayden SJ, Lazzara DJ, et al. A psychometric toolbox for testing validity and reliability. J Nurs Scholarsh. 2007; 39: 155-164.
46. Hulley SB, Cummings SR, Browner WS, Grady D, Hearst N, Newman TB. Designing clinical research: An epidemiologic approach. In: Designing clinical research: An epidemiologic approach. Philadelphia: Lippincott Williams & Wilkins; 2001. p. 336.
47. Cronbach LJ, Meehl PE. Construct validity in psychological tests. Psychol Bull. 1955; 52: 281-302.
48. Pribram KH, McGuinness D. Arousal, activation, and effort in the control of attention. Psycholl Rev. 1975; 82: 116-149.
49. Ruff HA, Lawson KR. Development of sustained, focused attention in young children during free play. Dev Psychol. 1990; 26: 85-93.
50. Huber VL. Effects of task difficulty, goal setting, and strategy on performance of a heuristic task. J Appl Psychol. 1985; 70: 492-504.
51. Wood RE, Mento AJ, Locke EA. Task complexity as a moderator of goal effects: A meta-analysis. J Appl Psychol. 1987; 72: 416-425.
52. Gellatly IR, Meyer JP. The effects of goal difficulty on physiological arousal, cognition, and task performance. J Appl Psychol. 1992; 77: 694.
53. Salmoni AW, Schmidt RA, Walter CB. Knowledge of results and motor learning: A review and critical reappraisal. Psychol Bull. 1984; 95: 355-386.
54. Cope P, Simmons M. Some effects of limited feedback on performance and problem-solving strategy in a Logo microworld. J Educ Psychol. 1994; 86: 368.
55. Duckworth AL, Quinn PD, Lynam DR, Loeber R, Stouthamer-Loeber M. Role of test motivation in intelligence testing. Proc Natl Acad Sci U S A. 2011; 108: 7716-7720.
56. Chater N, Tenenbaum JB, Yuille A. Probabilistic models of cognition: Conceptual foundations. Trends Cogn Sci. 2006; 10: 287-291.
57. Saffran JR, Aslin RN, Newport EL. Statistical learning by 8-month-old infants. Science. 1996; 274: 1926-1928.
58. Saffran JR. Statistical learning as a window into developmental disabilities. J Neurodev Disord. 2018; 10: 35.
59. Saffran JR, Kirkham NZ. Infant statistical learning. Annu Rev Psychol. 2018; 69: 181-203.

60. Roberts P, Priest H. Reliability and validity in research. Nurs Stand. 2006; 20: 41-46.
61. Terwee CB, Bot SD, de Boer MR, van der Windt DA, Knol DL, Dekker J, et al. Quality criteria were proposed for measurement properties of health status questionnaires. J Clin Epidemiol. 2007; 60: 34-42.
62. Souza AC, Alexandre NM, Guirardello ED. Psychometric properties in instruments evaluation of reliability and validity. Epidemiol Serv Saude. 2017; 26: 649-659.
63. Val Danilov I, Mihailova S. Neuronal coherence agent for shared intentionality: A hypothesis of neurobiological processes occurring during social interaction. OBM Neurobiol. 2021; 5: 113. doi:10.21926/obm.neurobiol.2104113.
64. Jordan NC, Glutting J, Ramineni C. The importance of number sense to mathematics achievement in first and third grades. Learn Individ Differ. 2010; 20: 82-88.
65. Karagiannakis G, Baccaglini-Frank A, Papadatos Y. Mathematical learning difficulties subtypes classification. Front Hum Neurosci. 2014; 8: 57.
66. Val Danilov I, Mihailova S. A case study on the development of math competence in an eight-year-old child with dyscalculia: Shared intentionality in human-computer interaction for online treatment via subitizing. OBM Neurobiol. 2022; 6: 122. doi:10.21926/obm.neurobiol.2202122.
67. Gray SA, Reeve RA. Preschoolers' dot enumeration abilities are markers of their arithmetic competence. PLoS One. 2014; 9: e94428.
68. Reeve R, Reynolds F, Humberstone J, Butterworth B. Stability and change in markers of core numerical competencies. J Exp Psychol Gen. 2012; 141: 649-666.
69. Volkmar FR, Langford Booth L, McPartland JC, Wiesner LA. Clinical evaluation in multidisciplinary settings. In: Handbook of autism and pervasive developmental disorders: Assessment, interventions, and policy. New York: John Wiley & Sons, Inc.; 2014. pp. 661-672.