Article

Not peer-reviewed version

The Link Between the Applied Visual Strategy when Copying the Rey-Osterrieth Complex Figure and the Language Abilities of Children with Specific Language Impairment

Ivana Milanović *, Milena Paštar, Saška Žunić, Maša Marisavljević, Mile Vuković, Vladimir Janjić, Milan Đorđić, Miško Subotić

Posted Date: 5 February 2025

doi: 10.20944/preprints202502.0338.v1

Keywords: specific language impairment; visual perception; visual organization; language abilities; Rey-Osterrieth complex figure

 doi:10.20944/preprints202502.0338.v1

Article

The Link Between the Applied Visual Strategy when Copying the Rey-Osterrieth Complex Figure and the Language Abilities of Children with Specific Language Impairment

Ivana Milanović [1,2,*], Milena Paštar [1,2], Saška Žunić [1,2], Maša Marisavljević [1,2], Mile Vuković [3], Vladimir Janjić [4,5], Milan Đorđić [4] and Miško Subotić [1]

[1] Cognitive Neuroscience Department, Research and Development Institute "Life Activities Advancement Institute", 11000 Belgrade, Serbia; m.pastar@add-for-life.com; s.fatic@add-for-life.com; m.marisavljevic@add-for-life.com; m.subotic@add-for-life.com

[2] Department of Speech, Language and Hearing Sciences, Institute for Experimental Phonetics and Speech Pathology "Đorđe Kostić", 11000 Belgrade, Serbia

[3] Faculty of Special Education and Rehabilitation, University of Belgrade, 11000 Belgrade, Serbia; mvukovic.dr@gmail.com

[4] Department of Communication Skills, Ethics and Psychology, Faculty of Medical Sciences, University of Kragujevac, 34000 Kragujevac, Serbia; vladadok@yahoo.com; mcpikac@gmail.com

[5] Department of Psychiatry, Faculty of Medical Sciences, University of Kragujevac, 34000 Kragujevac, Serbia

* Correspondence: i.milanovic@add-for-life.com; Tel.: +381 11 69 69 158

Abstract: Background/Objectives: Although specific language impairment (SLI) was thought to be a language impairment, recent studies suggest that it is also associated with domain-general and nonverbal deficits such as deficits in nonverbal working memory, visual short-term memory, executive functions, etc. This study aimed to examine if applied visual strategy when copying the Rey-Osterrieth complex figure (ROCF) correlates with language abilities in children with SLI. **Methods**: The sample consisted of 24 children diagnosed with SLI, divided into two groups based on the used strategy when copying ROCF. We used ROCF for the assessment of perceptual organization and planning, and Peabody Picture Vocabulary Test, Boston Naming Test, Token Test, Grammatical Judgment, The Children's Grammar, and Global Articulation Test for the language measurement. One-way ANOVA with the Brown-Forsythe Test was used for statistical analysis. **Results**: The results indicate that children who used a more mature strategy when copying ROCF achieved better results on tests used to assess grammar and articulation status. **Conclusions**: These results support the conclusion that there are neurocognitive mechanisms underlying both grammatical deficits and visuospatial deficits The obtained results suggest the importance of examining visual and visuospatial functions in children with SLI and the need for more comprehensive treatment of those children.

Keywords: specific language impairment; visual perception; visual organization; language abilities; Rey-Osterrieth complex figure

1. Introduction

Specific language impairment (SLI) is a neurodevelopmental disorder that affects understanding and/or producing language [1, 2], which is not due to intellectual disability, neurological impairments, hearing impairments [2-4], social deprivation, or impairments in reciprocal social interactions [5]. This condition manifests as deficits in syntax, morphology, semantics, and phonology [6]. Comprehension deficits manifest as deficits in comprehending syntactically complex questions [7], questions with greater length that have a greater number of elements, questions that require two

 doi:10.20944/preprints202502.0338.v1

consecutive actions [8], and object questions [9, 10]. SLI is also characterized by deficits in comprehension of structures with noncanonical word order [8, 11] and in comprehension of passive sentences [11].

The expressive language of children with SLI is characterized by short, agrammatical, and incomplete sentences [12]. Some authors [1, 13-15] argue that grammatical deficits are a hallmark of children with SLI. Studies have shown that children with SLI exhibit deficits in noun-verb agreement, marking finite verbs for tense and agreement [15], plural markers [15], and noun cases [16]. Agrammatical sentences are characterized by the absence or inadequate use of function words [16]. In addition to difficulties in constructing grammatical structures, children with SLI also struggle with grammatical judgment [15, 17].

Studies investigating the lexical abilities of children with SLI have shown that they experience challenges in lexical acquisition [18, 19], difficulties in acquiring word meanings [18, 20], and word definitions [18, 21, 22]. Moreover, they exhibit significantly smaller vocabulary sizes compared to typically developing children [18, 19, 23], as well as reduced use of nouns and verbs [24].

In terms of the phonetic-phonological level, children with SLI exhibit deficits in phonological perception [4], along with abnormalities in speech production such as mispronunciations, omissions, substitutions, or inversions of phonemes, significantly impairing others' ability to understand the speech of these children [23].

Although the term SLI implies that the essence of SLI is a language disorder, a growing body of studies has investigated the presence of non-linguistic factors [17, 25-29]. The findings of these studies indicate the heterogeneity of symptoms present in SLI, leading some authors to suggest the necessity of a different approach [27] concerning the definition, diagnostic criteria, and classification [29].

Despite the increasing need to expand current research and focus not just on linguistic but on non-linguistic aspects, findings from recent studies explaining language impairment from the perspective of non-linguistic functions are controversial in current speech and language research [25]. When it comes to investigations of non-linguistic functions, authors investigated: auditory abilities [30-32], visual abilities [15, 26, 33], cognitive functions [1, 3, 15, 26, 27, 29, 34], and motor abilities [19, 35].

When investigating a correlation between grammar abilities and visuospatial skills using tests from Luria's neuropsychological assessment battery and the Rey-Osterrieth Complex Figure Test, Kiselev [36] found a correlation between grammar comprehension and visuospatial abilities. Similar to these results are results from a study by Fahiem and Mohammed [29], who emphasized the association between SLI and non-verbal abilities. These authors found that the semantic-pragmatic and syntactic phonological types of SLI showed a significant deficit among visuospatial abilities and spatial working memory.

Studies examining working memory and its components have yielded contrary results. Some authors proposed that impairment of working memory subcomponents is restricted only to damage to the verbal central executive system, as children with SLI performed similarly to their typically developing peers on visuospatial tasks and tasks assessing the visuospatial central executive component of working memory [34, 37]. Contrary to previously mentioned studies, other authors have shown through their studies that impairment extends to the visuospatial component of working memory [28, 38, 39]. When Vugs et al. [40] examined the correlation between working memory components (verbal storage, visuospatial storage, verbal central executive factor, visuospatial central executive factor) and language abilities (receptive and expressive vocabulary, verbal comprehension, syntactic development), only the low correlation between visuospatial storage and expressive vocabulary was found. Conducting a meta-analysis, Vugs et al. [39] indicated that most studies demonstrate that children with SLI perform worse on visuospatial working memory tasks than their typically developing peers. Both verbal and visuospatial working memory deficits suggest a deficit in overall processing capacity, which manifests whenever tasks exceed processing capacities [41, 42].

Nickisch and von Kries [33] investigated auditory and visual short-term memory and its correlation with language abilities in children with SLI. The results indicated that children with SLI have impaired auditory and visual short-term memory. Children with receptive SLI showed significantly poorer performance on the visual short-term memory test (recall of symbol sequences)

 doi:10.20944/preprints202502.0338.v1

than the children with expressive SLI and the control group. Visual short-term memory was found to be one of the predictors of receptive language, suggesting that visual short-term memory, in addition to auditory, has an independent impact on receptive language. An alternative explanation could be the existence of a third factor necessary for understanding, which is also directly associated with auditory and visual short-term memory.

By examining the ability of children with SLI to recognize the grammaticality/ ungrammaticality of sentences, Weismer et al. [15] found that nonverbal working memory predicts morphosyntactic abilities regarding error sensitivity and reaction speed. The authors of this study suggest that individual differences in nonverbal working memory predict how accurately and/or quickly children detect morphosyntactic errors. Nonverbal working memory predicts detecting errors occurring later in the sentence for children without SLI. Contrary to that, nonverbal working memory is not a predictor of later errors but of errors occurring at the beginning of the sentence for children with SLI. Schaeffer [43] also highlights the association between nonverbal working memory and grammar in children with SLI.

One of the tests that is frequently used to assess visual abilities in children with SLI is the Rey-Osterrieth Complex Figure Test (ROCF). This neuropsychological test is designed to evaluate visual memory and visuospatial constructive abilities. Also, it provides significant qualitative information about the strategies employed during the copying and recall of complex figures and organizational approaches, since it consists of multiple components that can be perceived as gestalt or separate details. Hence, executive functions, particularly planning and organization, are also examined through this test [44].

Kiselev and Glozman [17] utilized the ROCF for assessing holistic abilities, alongside "Comprehension of grammatical structures'' from Luria's neuropsychological assessment batteries for comprehension of reversible passive sentences and comprehension of sentences with prepositions that indicate the spatial relations between objects in children with SLI. The results of their study indicated that children with grammar deficits use immature strategies when copying the ROCF. Given these results, the authors concluded that weakness in holistic synthesis can explain the problems in different abilities, including visuospatial abilities and grammar understanding [17]. On the other hand, authors who investigated visual abilities in children with ADHD [45] also noted the use of immature strategies in these children, which is expected for younger children. Additionally, children with ADHD reproduced the parts of the figure without organizing them as a whole, which these authors explain with the process of encoding information that can be affected by the executive deficit, which is typical of this diagnosis [45]. According to Akshoomoff et al. [26], using immature coping strategies in the ROCF suggests inefficient visuospatial processing, which may arise secondarily due to attention and planning deficits.

Considering the heterogeneity of results regarding non-linguistic abilities in children with SLI, it is necessary to expand research from linguistic abilities to non-linguistic functions and determine to what extent non-linguistic factors may influence the development of linguistic abilities [26]. This study aimed to determine whether the strategy employed during copying the Rey-Osterrieth Complex Figure (ROCF) correlates, and to what extent, with linguistic abilities in children with SLI.

2. Materials and Methods

2.1. Study Design and Participants

The research involved 26 children with SLI who were receiving speech therapy treatment at the Institute for Experimental Phonetics and Speech Pathology in Belgrade ,,Đorđe Kostić'', ages 6:01 to 8:11. The average age of the respondents was 86.17 months (SD = 12.92). All subjects included in the sample were diagnosed with SLI by a qualified specialist (speech-language therapist) by using tests to assess speech and language development. Inclusion criteria in the sample were a diagnosis of SLI, average or above average IQ, and age over six years. Exclusion criteria were below-average intellectual functioning, hearing and vision impairment, brain damage or other neurological diseases, the presence of motor disorders, and genetic anomalies. Subjects were divided into two groups based on their strategy when copying the ROCF. Among the respondents, 1 respondent (3.8%) used strategy I, 11 respondents (42.3%) used strategy II, 13 respondents (50%) used strategy IV, and 1 respondent

 doi:10.20944/preprints202502.0338.v1

(3.8%) used strategy VII. Since strategy I and strategy VII were used by only one respondent each, both respondents were excluded from further statistical analysis. Therefore, the final number of subjects was 24 children with SLI who were divided into two groups based on the strategy used on the ROCF: the first group consisted of children who copied ROCF using strategy II (first copying the details that are related to central rectangle or with some part of it, then finishing the rectangle and adding parts), while the second group consisted of children who used the IV strategy while copying the ROCF (arranging the details found in the drawing without an organized structure).

2.2. Measurements

2.2.1. Visuoperceptual Skills Assessment

Rey-Osterrieth Complex Figure – ROCF [46] was used to assess perceptual organization and planning. The subject is given a white piece of paper and ROCF, which does not resemble any known object, and 5-6 colored felt-tipped pens. The participant was instructed to copy a horizontally placed figure as precisely as possible and to reproduce it from memory after a certain time. For the purpose of this research, only the first part was used, i.e. direct figure copying. The subject is given the task of copying the given figure while the examiner monitors the execution of the task. Each time the subject completes one part of the figure, the examiner switches the pen and notes the order in which the subject uses the pens. The total score is obtained by summing points for each successfully drawn detail of the figure. There are 18 details that are scored with 0, ½, or 2 points according to their presence, accuracy, and placement. Also, the strategy used to copy the figure is noted. All strategies that can be used when copying ROCF are listed in Appendix A.

2.2.2. Speech-Language Assessment

The Peabody picture vocabulary test - PPVT-III-HR [47] was used to assess receptive vocabulary, such as knowledge of nouns, verbs, and adjectives. The test has a total of 204 tasks grouped into 17 strings with 12 words each. Black and white drawings are placed in front of the subject, i.e. four pictures, from which the subject must point out the picture representing a named object, action, or phenomenon. Examining is carried out until the subject makes eight mistakes within one string. The examination stops when he makes eight mistakes in one string for the first time, and a total score is formed. The raw score is obtained by summing the correct answers, while the standard score is obtained by converting the raw score, based on achievement and age.

The Boston Naming Test – BNT [48] was used to assess expressive vocabulary, i.e. object naming. The test consists of 60 black-and-white drawings of objects and assesses confrontational naming ability. Drawings are placed in front of the subject, who is asked to name them. Suppose the subject cannot name the object from the drawing. In that case, he can be given semantic support (explaining the term through its description/function; for example, the explanation ``What do we sleep on'' is used for the bed) or phonological support (given initial phoneme). All correct answers given by the subjects without support, with semantic and with phonological support are scored. For this research, only the answers the respondents gave without support were scored. By summing up the correct answers, a total score was obtained.

A shortened version of the Token Test [49] was used to assess auditory comprehension. The test consists of 39 verbal commands, which are divided into 6 subscales, ranked according to the degree of morphosyntactic complexity of the commands. Plastic tokens of different sizes (small and large), colors (white, red, green, blue, yellow), and shapes (circle and rectangle) are placed in front of the subject. The subject is then given verbal commands that require the subject to perform a specific activity with the tokens (eg., show them, touch them, pick them up, touch each other, put them on top of each other…). The tokens are placed according to the pre-existing rules in a fixed order. In 4 subscales, all 20 tokens are used, while in the other four subscales, only 10 tokens are used, i.e. only large tokens. Before the examination, it is determined whether the subject distinguishes the features of the visual material, i.e. whether he distinguishes shapes and colors. When it is determined that it differs, the respondent is given an example to understand how the order is executed. After manipulation of the tokens by the subject, the examiner returns them to the initial position.

 doi:10.20944/preprints202502.0338.v1

Achievement on each task is graded as correct or incorrect. By summing up the successfully completed tasks, the total score is obtained.

Grammatical Judgment is a test constructed by the author for research purposes. The test consists of 40 sentences, of which 20 are grammatical, and 20 are ungrammatical. The sentences are formulated in such a way that they are concise, so as not to burden the respondents' working memory. Agrammatic sentences are composed in such a way that the order of the words in the sentence is not by the grammar of the Serbian language, or they contain inadequate use of functional words (he came from his mother/the owl lives in the forest/ we will go the cinema), or inadequate morphological endings for the form. The subject reads a sentence and is asked to say whether the sentence is correct or not. Before testing, the test taker is given an example sentence to determine if they have understood the task. The respondent is given the example "The mouse eats ham_" (with omission of the morphological mark for case) and is asked if it is adequately said. After the respondent says the sentence adequately, the testing starts. Each sentence is scored as pass or fail. The total score is obtained by summing up the successful answers. The test is given in Appendix B.

The Children's Grammar [10, 50, 51] was used to assess the expressive component of grammar. The mentioned instrument evaluates the use of the plural, gender, case, verbal nouns, pronouns, adjectives, verb tenses, prepositions and adverbs, complex statements, interrogative sentences, and interrogative-negative sentences. Each of the mentioned tasks consists of visual material, where the examiner begins with pronouncing a particular sentence, which the child should complete by producing a particular grammatical form. If there is a need for it, the examiner provides the child with additional support in the form of an explanation of what is in the picture so that the child can adequately produce the required shape. All correct answers are scored; the score is obtained by adding up all successfully given answers. A detailed description of the instrument is given in the work of Bogavac et al. [51].

The Global Articulation Test – GAT [50-52] was used to assess articulatory status. The test consists of 30 bisyllabic words where the tested sounds are positioned in medial (vowels) and initial (consonants) word positions. To identify the type and degree of pathological pronunciation, the examiner-speech therapist relies on auditory assessment of acoustic characteristics of the uttered sounds, simultaneously observing the position of the child's speech organs during pronunciation. By summing correctly pronounced sounds, a score is obtained. A detailed description of the instrument is provided in the work by Rakonjac et al. [52].

2.2.3. Cognitive Assessment

Cognitive skills were tested using Weschler's Intelligence Scale for Children—Serbian version (REVISK; [53]). The verbal and nonverbal intelligence scores were assessed by an experienced child psychologist with experience in cognitive skills assessment.

2.3. Procedure

The research data were collected from February 2023 to September 2023 within the Institute for Experimental Phonetics and Pathology ,,Đorđe Kostić''. Subjects were tested in a quiet, plain room to eliminate most of the potential distractors. Only the participant and the examiner were present in the room. An experienced speech-language pathologist assessed visuo-perceptual and speech-language abilities, while an experienced psychologist assessed cognitive skills. Since six tests were applied, the testing was done over two days so as not to fatigue the participants. Before administering each test, the examiner provided examples to ensure that the subject understood what was being asked of him. When the examiner made sure that the subject understood the task, the research was started. If there was a need for it, the speech-language therapist additionally directed the child's attention before giving the order or made additional breaks until the child was focused on the task again.

The complete study protocol was in accordance with the Ethical Principles in Medical Research Involving Human Subjects, as established by the Declaration of Helsinki, and had been approved by the Ethics Committee of the Institute for Experimental Phonetics and Speech Pathology in Belgrade, Serbia (No S-23-01). The children's parents gave written informed consent for cognitive and speech-language assessment and participation in this study.

 doi:10.20944/preprints202502.0338.v1

2.4. Statistical Analysis

All data were analyzed using the SPSS 20.0 software package [IBM Corp., 2011]. The Total Score of all the applied tests was calculated. Then, the outliers were detected, and the scale's reliability was assessed. After that, descriptive statistics were conducted, the normality of the distribution was tested, and accordingly, we made a decision to use the parametric Chi-square test two groups comparison with normal distribution in terms of gender, and the One-Way ANOVA test with Brown-Forsythe test for 2+ groups' comparisons with normal distribution in terms of investigated dependent variables. We decided to use the One-Way ANOVA test with Brown-Forsythe because it is more robust and resistant to deviation from the normality of distribution and variances inequality. A p-value equal to or less than .05 was considered statistically significant.

3. Results

Since the results of the Shapiro-Wilk test showed that scores on some tests deviated significantly from normality, and the results of Levene's test of homogeneity showed violations of homogeneity of variance, we decided to use One-Way ANOVA with the Brown-Forsythe test to examine the differences between the two groups. The mentioned test is more robust and resistant to the absence of normal distribution and homogeneity of variance, therefore its application in this case is justified.

Results of One-Way ANOVA with the Brown-Forsythe test showed that there are no statistically significant differences between groups regarding age (F_{BF} (1, 22)=2.97, p =.10), verbal IQ (F_{BF} (1, 20.04)=1.93, p =.18) and nonverbal IQ (F_{BF} (1, 19.53)=.28, p =.60). Results of Chi-square showed that there was no statistically significant difference between groups regarding gender ($\chi 2$ (1) = 0.84, $r\varphi$ = .19, p = .36). Sample distribution regarding gender, age and intellectual status (IQv and IQm) is given in Table 1.

Table 1. Sample distribution regarding gender, age, and intellectual status (IQv and IQm).

	gender		age	IQm	IQv	total
	m	f				
Group I	10 (90.9%)	1 (9.1%)	90.91 (13.64)	103.55 (16.45)	89.73 (15.42)	11
Group II	10 (76.9%)	3 (23.1%)	82.15 (11.27)	100.23 (13.65)	81.46 (13.39)	13

Note: The age of the respondents is shown in months.

By summing the correct answers, the results of each test were obtained. The average score on the ROCF for the entire sample was M = 15.52 (SD = 8.30), while for the group I was M = 19.50 (SD = 9.32), and for the group II was M = 12.15 (SD = 5.74). The t-test results for independent samples showed a statistically significant difference between children with RD who used different strategies regarding ROCF scores. Those who used strategy II (M = 19.50, SD = 9.32) showed statistically significantly better results (t = 2.37, p = .03) than those who used strategy IV (M = 12.15, SD = 5.74). Average scores, measures of descriptive statistics for the ROCF, and applied speech-language tests are given in Table 2.

Table 2. Descriptive statistics of all applied tests.

		M	SD	Min	Max
ROCF	Group I	19.50	9.32	6	33
	Group II	12.15	5.74	6	23.5
PPVT-III-HR	Group I	85.18	22.65	43	110
	Group II	85.15	13.95	64	104
BNT	Group I	27.36	6.99	14	36

 doi:10.20944/preprints202502.0338.v1

	Group II	25.69	7.16	16	36
Token Test	Group I	105.91	33.22	28	135
	Group II	81.00	29.00	39	135
Grammatical Judgment	Group I	31.09	5.22	21	38
	Group II	25.31	7.81	11	37
The Children's Grammar	Group I	18.91	2.84	13	23
	Group II	14.92	5.60	6	25
GAT	Group I	27.18	2.14	23	30
	Group II	24.62	2.60	20	30

The results showed that there is a statistically significant difference between the two groups of children who used a different strategy when copying the ROCF on the Grammatical Judgment test ($F_{BF}(1, 20.99)=4.66$, p=.04), the Children's Grammar ($F_{BF}(1, 18.37)=5.04$, p=.04) and the GAT (F_{BF} (1, 21.99)=7.05, p=.01). On other tests (PPVT-III-HR, BNT, and Token test) no statistically significant difference was found between the two groups (p>.05).

4. Discussion

Our results showed that 11 children with SLI (45.8%) had used a conceptual strategy, starting by tracing the rectangle first and then adding associated details. Conversely, more children with SLI (54.2%) used a less mature strategy, namely a fragmented strategy characterized by drawing in fragments, part by part, related to the central rectangle. In other words, these children did not demonstrate an organized structure when copying the given figure. The fragmented strategy indicates a partial approach to the figure and an inability to integrate and connect parts into a whole [54], reflecting difficulties in processing the gestalt of complex visual information [44]. The inability to integrate parts into a whole and perceive gestalt is associated with immature and undeveloped executive functions, particularly planning, conceptual reasoning, and problem-solving abilities [44, 55]. Apart from the correlation between planning and the use of specific strategies, authors Larson, Gangopadhyay, Kaushanskaya, & Weismer [56] have found a link between planning abilities and language skills. They identified that children with SLI and poorer language abilities struggle more with planning [56]. Abdul Aziz and colleagues [57] have demonstrated that children with SLI follow a different and slower trajectory in the development of inner speech, which is crucial for planning and directing behavior, serving as a verbal mediator [58].

Although it is traditionally believed that children with SLI exhibit a similar developmental pattern of executive functions as typically developing children, given the fact that SLI is exclusively characterized by a language development disorder [1], there is a growing body of evidence suggesting the presence of non-linguistic deficits in children with SLI [59, 60]. For instance, Kiselev [36] suggests that children with SLI use less accurate, less mature, fragmented strategies and exhibit subtle deficits in processing configurational information. Based on this, an assumption has been proposed that children with SLI, especially those with grammatical SLI, have a deficit in a specific brain mechanism responsible for holistic synthesis, resulting in simultaneous deficits in both linguistic and non-linguistic domains [17].

In the work of Akshoomoff et al. [26], poorer performance was observed in children with SLI on the ROCF compared to typically developing peers matched by age, indicating less mature and less efficient approaches to visuospatial tasks or subtle deficits in visuospatial processing tasks. Our study results showed that children using a more mature strategy also had more drawn elements or a higher score on this test, consistent with findings from other authors [61, 62]. Some authors [27, 28, 39] confirm that children with SLI have deficits in executive functions, affecting both verbal and nonverbal components. Furthermore, studies examining memory have shown that children with SLI exhibit impaired verbal working memory [3] and impaired visuospatial working memory due to reduced visuospatial storage and inefficient verbal coding during visuospatial working memory tasks [28].

 doi:10.20944/preprints202502.0338.v1

When considering the impact of the applied copying strategy on language abilities, the results of our study showed a statistically significant difference between the groups examined in expressive and receptive components of grammar, as well as articulation status. In contrast, no statistically significant difference was found between groups regarding receptive and expressive vocabulary and comprehension. Children who used a more mature strategy achieved better results on all mentioned tests. The link between the chosen strategy and grammatical abilities finds its basis in Luria's theory regarding the influence of spatial perception on grammatical abilities. According to Luria, these abilities may share underlying mechanisms. Both abilities require: 1. the ability to segment the input into parts; 2. understanding that certain parts can be assembled together as components of a recognizable structure of a known type; 3. an understanding of the whole e in terms of the relationship between these parts [17]. In terms of ROCF, it means that the participant must perceive the parts and the whole of the presented figure. Similarly, in processing the grammar of spoken discourse, it is necessary to recognize each word and understand its relationship with other words to interpret and understand the sentence adequately. Understanding grammar and its correct usage requires simultaneous processing of words and morphemes received auditorily. Since children with SLI have difficulty in the simultaneous processing of auditorily presented information, it is considered that they cannot identify and understand constant changes in morphological and syntactic patterns, following all language rules along with the changes in the dynamic environment of conversation [6].

Furthermore, another potential explanation for such results is the inability to integrate audio-visual stimuli, which also contributes to language deficits in SLI. This explanation is consistent with the results of our study. Specifically, in the Grammatical Judgment and GAT, participants were required to understand and then successfully perform tasks based on visual inspection of the examiner and auditory presentation of stimuli (for Grammatical Judgment, determining if a sentence was grammatically correct, and for GAT, repeating a word with a target phoneme, while watching and listening to the examiner). Children with SLI who use less mature figure copying strategies may achieve lower scores on grammar tests and articulation tests because they cannot integrate what they hear and see, i.e., they cannot adequately process speech-language information. This difficulty is particularly observed when lip-reading, as they cannot process information appropriately and respond to it accordingly. Similar to our results are findings from other authors. For instance, Norrix, Plante, Vance, and Boliek [30] examined the McGurk task in children with SLI. In this task, children were audibly presented with the syllable /bi/ and visually presented with /gi/ to determine whether participants relied more on auditory or visual information. Using the McGurk task, these authors found that children with SLI relied less on visual information than their typically developing peers. They concluded that, in addition to deficits in auditory perception exhibited by these children, they also experience difficulties in audio-visual processing. Furthermore, results from the same study indicate that children with SLI exhibit poorer performance than the control group in detecting audio-visual asynchronies in human and synthetic speech. Additionally, Kaganovich, Schumaker, and Rovland [63] also reported that children with SLI are less sensitive to matching auditory words with visual articulations, suggesting difficulties in connecting what they hear (speech sounds) with what they see (visible movements of speech organs during articulation). Moreover, findings from a study conducted by Pons, Sanz-Torrent, Ferinu, Birules, & Andreu [64] to investigate whether children with SLI might show reduced attention to the talker's mouth showed that these children did not demonstrate a preference for mouths or eyes; their gaze was equally directed toward both, indicating a deficit in perceiving and integrating audio-visual cues in speech. In other words, these results indicate that as a group, children with SLI look less at mouths compared to typically developing peers [64]. These findings are consistent with those of Heikkila et al. [65], which found that 7-year-old children with SLI look significantly less at lips compared to their typical peers. Similarly, Meronen et al. [66] reported reduced reliance on lip-reading in noisy situations.

Although participants in the first group who used a more mature strategy showed higher scores on each individual test, the observed differences on vocabulary tests (PPVT-III-HR and BNT) and comprehension tests (Token test) were not statistically significantly better compared to the group of children with SLI who applied a less mature strategy. The nature of the tasks in the applied tests can

 doi:10.20944/preprints202502.0338.v1

explain these findings. The PPVT-III-HR test requires children to point out the requested term, i.e. "Show where the child is," using visually presented stimuli (pictures with minimal detail). The BNT requires children to name pictures and answer a basic question, "What is this?" Children found it more accessible, and deficits in audiovisual integration were less noticeable when presented with tasks involving visually presented stimuli or pictures. During the Token test, children looked at tokens placed in front of them and manipulated them. In contrast, tasks that required listening and observing the examiner (in tests assessing grammar and articulation status) more heavily challenged audiovisual integration. Therefore, it is possible that in tasks of that nature, visual strategies had a more significant impact on language abilities in grammar and articulation.

The obtained results indicate the significance of visual perception and organization abilities in developing language skills, highlighting that these abilities cannot be viewed separately from linguistic functions. As noted by some authors, speech perception is a multimodal process that requires the integration of auditory and visual inputs [67]. Studies using the McGurk effect have also shown that audiovisual perception and integration are present even in very young children and play a significant role in developing speech and language abilities [68, 69]. Audiovisual integration is also observed in older children and adults, and it plays an important role in understanding speech in everyday social situations. Although the study sample is small, the results can have practical implications and provide guidance for therapeutic work with children with SLI, as well as direction for future research. Examining auditory perception alongside visual perception would contribute to a better understanding of the phenomenology of SLI and the specifics of auditory and visual stimulus processing. This approach could foster a holistic view of this disorder.

5. Conclusions

In this study, the link between visual perception/organization and language abilities in children with SLI was investigated. Based on the results, the following conclusions can be drawn:

- Among children with SLI up to the age of 9, two strategies were identified during the copying of the Rey-Osterrieth Complex Figure: some employed a mature strategy using gestalt principles to integrate parts into a whole. In contrast, others used a fragmented strategy, copying parts of the figure without clear organization or integration into a whole.
- Children with SLI who used a less mature drawing strategy particularly exhibit deficits in processing linguistic information requiring simultaneous listening and observing of the examiner
- The results support the conclusion that there are neurocognitive mechanisms underlying both grammatical deficits and visuospatial deficits

The results indicate a link between visual strategy and performance on speech-language tests based on audiovisual perception. However, it remains an open question whether visual perception is the cause of poorer outcomes or if both are rooted in shared neurocognitive processes. Further research is necessary to answer this question. Also, these findings suggest that children with SLI are not a homogeneous group in terms of visual strategies. They support the existence of perceptual and visuospatial deficits in SLI, not just linguistic deficits, as previously believed. The presence of perceptual and visuospatial deficits and deficits in audiovisual integration in children with SLI would warrant a reconsideration of the definition, diagnostic criteria, and classification of SLI. Furthermore, the results of our study could be beneficial for guiding speech therapy, which should include intensive encouragement of visual-perceptual, visuospatial, and executive functions. This could lead to a more comprehensive understanding and assessment of SLI.

Author Contributions: Conceptualization, I.M., and M.S.; methodology, I.M., M.V., and M.S.; formal analysis, M.S., V.J., and M.Đ.; investigation, I.M., M.P., and S.Ž.; data curation, I.M., M.P., S.Ž., and M.M.; writing—original draft preparation, I.M., M.P., S.Ž., and M.M.; writing—review and editing, M.V., M.S., V.J., and M.Đ.; supervision, M.V., and M.S.; project administration, M.S. All authors have read and agreed to the published version of the manuscript.

Funding: This work was partially supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia. This project is realized in cooperation with the Faculty of Medical Sciences, University of Kragujevac, Serbia.

 doi:10.20944/preprints202502.0338.v1

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of the Institute for Experimental Phonetics and Speech Pathology in Belgrade, Serbia (No S-23-01).

Informed Consent Statement: In accordance with the Declaration of Helsinki, participants gave informed written consent to the use of the survey data.

Data Availability Statement: Data are contained within the article.

Conflicts of Interest: The authors report no competing interests to declare.

Abbreviations

SLI	Specific language impairment
ROCF	The Rey-Osterrieth complex figure
PPVT-III-HR	The Peabody picture vocabulary test
BNT	The Boston Naming Test
GAT	The Global Articulation Test

Appendix A - Strategies used when copying ROCF.

Strategy 1- excellent organization; a drawing started with a large rectangle, and other elements are then added to it;

Strategy 2 - conceptual strategy first copying the details that are related to central rectangle or with some part of it, then finishing the rectangle and adding parts;

Strategy 3 - part-configural organization; drawing the outer frame without highlighting the rectangles, then internal elements are drawn;

Strategy 4 - fragmented organization, arranging the details found in the drawing without an organized structure

Strategy 5 - random organization with copying individual parts of the figure without organizing the whole;

Strategy 6 - replacing the figure with another object;

Strategy 7 - unrecognizable; the subject may draw a substitution or an unrecognizable scrawl.

Appendix B - Grammatical Judgment Test

1. Pas grize mačka.

The dog bites *the cat*_. (incorrect case mark of noun cat)

2. On će da ide kod zubara.

He is going to go to the dentist. (grammatically correct sentence)

3. Slika je iznad kreveta.

The picture is above the bed. (grammatically correct sentence)

4. To je staklena vaza.

It's a glass vase. (grammatically correct sentence)

5. Luka i Aleksa čita knjigu.

Luke and Alexa (3.m.pl.) read (3.m.sg.) the book. (incorrect verb form regarding verb number)

6. Ja se zovem Marko.

I am Marco. (grammatically correct sentence)

7. On se kupa.

He is taking a bath. (grammatically correct sentence)

8. Ja neće supu.

I (1.sg.) doesn't want (3.sg.) a soup. (incorrect verb form regarding verb person)

9. Sofija i njena sestra idu u vrtić.

Sofia and her sister are going to kindergarten. (grammatically correct sentence)

10. Dečaka guraju devojčica.

The girl (3.sg) push (3. pl) the boy. (incorrect verb agreement)

11. Oblači ona se.

 doi:10.20944/preprints202502.0338.v1

Dressed she getting is. (incorrect word order)

12. Devojčica drži lutku.

The girl is hanging a doll. (grammatically correct sentence)

13. Dečak ne majku budi.

The boy doesn't mom wake up. (incorrect word order)

14. Dečaka gura devojčicu.

The boy (acc. sg.) pushes the girl (acc. sg.). (both of the subject and object are given in accusative case)

15. Mama ljulja bebi.

The mom rocks the baby (dat. sg.). (incorrect case mark – dative case instead of accusative case)

16. On neće da kupi olovku.

He won't buy a pen. (grammatically correct sentence)

17. Vidi, eno ga Sara!

Look, there he is, it's Sara! (incorrect pronoun)

18. Mama je bio na bazenu.

Mom (f.) was (m.) at the pool. (incorrect subject-verb agreement regarding gender)

19. On češlja svako jutro.

He _ combs his hair every morming. (omission of reflexive pronoun)

20. Marina će da ide kući.

Marina is going to go home. (grammatically correct sentence)

21. Lazar neće jede bananu.

Lazar is not going _ eat a banana. (omission of conjunction *to*)

22. Moj drug David i njen mama idu u prodavnicu.

My friend David and *her* mom are going to the store. (inadequate use of pronoun regarding gender)

23. Slona hrane deca.

The kids are feeding the elephant. (grammatically correct sentence)

24. Sneg pada juče.

It *is snowing* yesterday. (incorrect verb form regarding tense agreement)

25. Vuk je pojurio lisicu.

The wolf chased the fox. (grammatically correct sentence)

26. Kiša je padala pre dva dana.

It rained two days ago. (grammatically correct sentence)

27. On je došao mamom.

He came _ mom. (omission of preposition *with*)

28. Pčela živi u košnici.

A bee lives in a hive. (grammatically correct sentence)

29. Lopta je ispod sto.

The ball is under *the table*_. (incorrect case mark)

30. Ja sam se igrao sa sekom.

I was playing with my sister. (grammatically correct sentence)

31. Lekar ne prodaje cveće.

The doctor doesn't sell flowers. (grammatically correct sentence)

32. Sova živi šuma.

The owl lives _ the wood. (omission of preposition *in*)

33. Oni šetaju kroz šumu

They walk through the forest. (grammatically correct sentence)

34. To je plava sto.

It's a blue (f.sg.) desk (m.sg.). (incorrect noun-adjective agreement)

35. Mama gura kolica.

Mom pushes the stroller. (grammatically correct sentence)

36. Ema se obuva.

Ema is putting on her shoes. (grammatically correct sentence)

 doi:10.20944/preprints202502.0338.v1

37. Mi cemo idemo u bioskop.
We are going _ go to the cinema. (omission of conjunction *to*)
38. Moj brat je bio u zoološkom vrtu.
My brother was at the zoo. (grammatically correct sentence)
39. Ja se zove Petar.
I *is* Peter. (incorrect verb form regarding person form)
40. Ja hoću vodu.
I want a water. (grammatically correct sentence)

References

1. Conti-Ramsden, G., M.T. Ullman, and J.A. Lum, The relation between receptive grammar and procedural, declarative, and working memory in specific language impairment. Frontiers in Psychology, 2015. **6**: p. 1090.
2. Barman, A., et al., *Auditory processing in children with specific language impairment: a FFR based study.* Indian Journal of Otolaryngology and Head & Neck Surgery, 2022: p. 1-6.
3. Kapa, L.L. and E. Plante, *Executive function in SLI: Recent advances and future directions.* Current developmental disorders reports, 2015. **2**: p. 245-252.
4. Loucas, T., et al., Phonological processing in children with specific language impairment with and without reading difficulties. International Journal of Language & Communication Disorders, 2016. **51**(5): p. 581-588.
5. Vuković, M., B. Drljan, and I. Arsenić, *Pragmatske sposobnosti i socijalno funkcionisanje dece sa specifičnim jezičkim poremećajem.* Actual defectological practice international thematic collection of papers, 2015: p. 93-100.
6. Mukhopadhayay, P., L. Bhattacharya, and P. Roy, A Comparative Study on Deficits of Cognitive Processing Skills Among Children with Specific Reading Disorder and Specific Language Impairment. Asia Pacific Journal of Advanced Research, I, 2018: p. 331-339.
7. Leonard, L.B., et al., Sentence comprehension in specific language impairment: A task designed to distinguish between cognitive capacity and syntactic complexity. 2013.
8. Krstić, N., P. Vidović, and M. Vuković, *Razumevanje složenih iskaza kod dece sa razvojnim jezičkim poremećajem.* Specijalna edukacija i rehabilitacija, 2011. **10**(4): p. 633-651.
9. Friedmann, N. and R. Novogrodsky, Which questions are most difficult to understand?: The comprehension of Wh questions in three subtypes of SLI. Lingua, 2011. **121**(3): p. 367-382.
10. Škara, Z. and M. Vuković, Procena sposobnosti razumevanja jezika kod dece sa specifičnim jezičkim poremećajem i promenama elektroencefalografskih aktivnosti: preliminarno ispitivanje. Beogradska defektološka škola, 2017. **23**(1): p. 27-40.
11. Montgomery, J.W., et al., "Whatdunit?" Sentence comprehension abilities of children with SLI: Sensitivity to word order in canonical and noncanonical structures. Journal of Speech, Language, and Hearing Research, 2017. **60**(9): p. 2603-2618.
12. Auza, A., M.T. Harmon, and C. Murata, Retelling stories: Grammatical and lexical measures for identifying monolingual Spanish speaking children with specific language impairment (SLI). Journal of Communication Disorders, 2018. **71**: p. 52-60.
13. Rice, M.L., A unified model of specific and general language delay: Grammatical tense as a clinical marker of unexpected variation, in Language competence across populations. 2003, Psychology Press. p. 63-95.
14. Leonard, L.B., Children with specific language impairment. 2017: MIT press.
15. Ellis Weismer, S., et al., The role of nonverbal working memory in morphosyntactic processing by children with specific language impairment and autism spectrum disorders. Journal of Neurodevelopmental Disorders, 2017. **9**: p. 1-16.
16. Murao, A., et al., *Grammatical case-marking in Japanese children with SLI.* Clinical Linguistics & Phonetics, 2017. **31**(7-9): p. 711-723.
17. Kiselev, S.Y. and J.M. Glozman, *Holistic brain mechanism in preschool children with weakness in grammar understanding.* Procedia-Social and Behavioral Sciences, 2016. **233**: p. 83-87.
18. Mainela-Arnold, E., J.L. Evans, and J.A. Coady, Explaining lexical–semantic deficits in specific language impairment: The role of phonological similarity, phonological working memory, and lexical competition. 2010.
19. Vukovic, M. and V. Stojanovik, Characterising developmental language impairment in Serbian-speaking children: a preliminary investigation. Clinical linguistics & phonetics, 2011. **25**(3): p. 187-197.
20. Čabarkapa, N.D. and J. Srećković, *Struktura leksikona disfazične dece*. 2002: Zadužbina Andrejević.
21. Vuković, I., Korelacija socijalne zrelosti, jezičke razvijenosti i motornih sposobnosti kod dece sa razvojnom disfazijom. Magistarska teza, Beograd: Univerzitet u Beogradu, 2007.

 doi:10.20944/preprints202502.0338.v1

22. Dosi, I. and Z. Gavriilidou, The role of cognitive abilities in the development of definitions by children with and without Developmental Language Disorder. Journal of Psycholinguistic Research, 2020. **49**(5): p. 761-777.
23. Vuković, I. and M. Vuković, *Articulation-phonological deficit in children with developmental dysphasia.* Beogradska defektološka škola, 2009(2): p. 49-56.
24. Leonard, L.B., C. Miller, and E. Gerber, *Grammatical morphology and the lexicon in children with specific language impairment.* Journal of speech, language, and hearing research, 1999. **42**(3): p. 678-689.
25. Ullman, M.T. and E.I. Pierpont, Specific language impairment is not specific to language: The procedural deficit hypothesis. Cortex, 2005. **41**(3): p. 399-433.
26. Akshoomoff, N., J. Stiles, and B. Wulfeck, *Perceptual organization and visual immediate memory in children with specific language impairment.* Journal of the International Neuropsychological Society, 2006. **12**(4): p. 465-474.
27. Rodríguez, V.A., G.R. Santana, and S.H. Expósito, *Executive functions and language in children with different subtypes of specific language impairment.* Neurología (English Edition), 2017. **32**(6): p. 355-362.
28. Vugs, B., et al., Working memory performance and executive function behaviors in young children with SLI. Research in developmental disabilities, 2014. **35**(1): p. 62-74.
29. Fahiem, R.A. and H.O. Mohammed, *Panorama of the non-verbal cognitive abilities among children with SLI.* Egyptian Journal of Ear, Nose, Throat and Allied Sciences, 2020. **21**(3): p. 165-175.
30. Norrix, L.W., et al., Auditory-visual integration for speech by children with and without specific language impairment. 2007.
31. Richards, S. and U. Goswami, Auditory processing in specific language impairment (SLI): Relations with the perception of lexical and phrasal stress. Journal of Speech, Language, and Hearing Research, 2015. **58**(4): p. 1292-1305.
32. Moradi, S., et al., The efficacy of short-term gated audiovisual speech training for improving auditory sentence identification in noise in elderly hearing aid users. Frontiers in Psychology, 2017. **8**: p. 368.
33. Nickisch, A. and R. Von Kries, Short-term memory (STM) constraints in children with specific language impairment (SLI): are there differences between receptive and expressive SLI? 2009.
34. Archibald, L.M. and S.E. Gathercole, Short-term memory and working memory in specific language impairment, in Working memory and neurodevelopmental disorders. 2012, Psychology Press. p. 139-160.
35. Mati-Zissi, H. and M. Zafiropoulou, Visuomotor coordination and visuospatial working memory of children with specific reading disabilities: a study using the Rey-Osterrieth Complex Figure. Perceptual and Motor Skills, 2003. **97**(2): p. 543-546.
36. Kiselev, S., *Children with weakness in grammar understanding have weakness in visuospatial abilities.* European Journal of Public Health, 2020. **30**(Supplement_5): p. ckaa166. 1018.
37. Baird, G., et al., *Memory impairment in children with language impairment.* Developmental Medicine & Child Neurology, 2010. **52**(6): p. 535-540.
38. Henry, L.A., D.J. Messer, and G. Nash, *Executive functioning in children with specific language impairment.* Journal of child psychology and psychiatry, 2012. **53**(1): p. 37-45.
39. Vugs, B., et al., *Visuospatial working memory in SLI: A meta-analysis.* PDF hosted at the Radboud Repository of the Radboud University Nijmegen, 2017: p. 19.
40. Vugs, B., et al., Interactions between working memory and language in young children with specific language impairment (SLI). Child Neuropsychology, 2016. **22**(8): p. 955-978.
41. Montgomery, J.W., Examining the nature of lexical processing in children with specific language impairment: Temporal processing or processing capacity deficit? Applied Psycholinguistics, 2002. **23**(3): p. 447-470.
42. Marton, K., *Visuo-spatial processing and executive functions in children with specific language impairment.* International Journal of Language & Communication Disorders, 2008. **43**(2): p. 181-200.
43. Schaeffer, J., Linguistic and cognitive abilities in children with specific language impairment as compared to children with high-functioning autism. Language Acquisition, 2018. **25**(1): p. 5-23.
44. Kim, M.S., Y. Namgoong, and T. Youn, *Effect of organizational strategy on visual memory in patients with schizophrenia.* Psychiatry and clinical neurosciences, 2008. **62**(4): p. 427-434.
45. Rubiales, J., et al., *Organization strategies in the Rey-Osterrieth Complex Figure in children with ADHD.* European Journal of Investigation in Health, Psychology and Education, 2017. **7**(2): p. 99-110.
46. Rey, A. and P.A. Osterrieth, *Rey-Osterrieth complex figure copying test.* Psychological Assessment, 1941.
47. Dunn, L.M. and L.M. Dunn, *PPVT-III: Peabody picture vocabulary test*. 1997: American Guidance Service.
48. Kaplan, E., H. Goodglass, and S. Weintraub, *The Boston Naming Test. Lea & Febiger.* Philadelphia, PA, 1983.
49. Spellacy, F.J. and O. Spreen, *A short form of the Token Test.* Cortex, 1969. **5**(4): p. 390-397.
50. Kostić, Đ. and S. Vladisavljević, *Tests for speech and language assessment*. 1983, ZUNS.
51. Bogavac, I., et al., *The speech and language profile of a child with turner syndrome–a case study.* Clinical Linguistics & Phonetics, 2022. **36**(6): p. 565-578.
52. Biro, M., *REVISK priručnik (drugo izdanje).* Beograd: Društvo psihologa Srbije, 1998.
53. Stern, R.A., et al., The Boston qualitative scoring system for the Rey-Osterrieth complex figure: Description and interrater reliability. The Clinical Neuropsychologist, 1994. **8**(3): p. 309-322.

 doi:10.20944/preprints202502.0338.v1

54. Anderson, P., V. Anderson, and J. Garth, Assessment and development of organizational ability: The Rey complex figure organizational strategy score (RCF-OSS). The Clinical Neuropsychologist, 2001. **15**(1): p. 81-94.
55. Larson, C., et al., *The relationship between language and planning in children with language impairment.* Journal of Speech, Language, and Hearing Research, 2019. **62**(8): p. 2772-2784.
56. Abdul Aziz, S., J. Fletcher, and D.M. Bayliss, *Self-regulatory speech during planning and problem-solving in children with SLI and their typically developing peers.* International Journal of Language & Communication Disorders, 2017. **52**(3): p. 311-322.
57. Kapa, L.L., E. Plante, and K. Doubleday, *Applying an integrative framework of executive function to preschoolers with specific language impairment.* Journal of Speech, Language, and Hearing Research, 2017. **60**(8): p. 2170-2184.
58. Bishop, D.V., *What causes specific language impairment in children?* Current directions in psychological science, 2006. **15**(5): p. 217-221.
59. Montgomery, J.W., B.M. Magimairaj, and M.C. Finney, Working memory and specific language impairment: An update on the relation and perspectives on assessment and treatment. 2010.
60. Davies, S.R., et al., The ecological validity of the Rey–Osterrieth Complex Figure: Predicting everyday problems in children with neuropsychological disorders. Journal of Clinical and Experimental Neuropsychology, 2011. **33**(7): p. 820-831.
61. Resch, C., et al., Does strategy instruction on the Rey-Osterrieth Complex Figure task lead to transferred performance improvement on the Modified Taylor Complex Figure task? A randomized controlled trial in school-aged children. The Clinical Neuropsychologist, 2019. **33**(1): p. 108-123.
62. Kaganovich, N., J. Schumaker, and C. Rowland, Atypical audiovisual word processing in school-age children with a history of specific language impairment: an event-related potential study. Journal of Neurodevelopmental Disorders, 2016. **8**: p. 1-22.
63. Pons, F., et al., Children with SLI can exhibit reduced attention to a talker's mouth. Language Learning, 2018. **68**: p. 180-192.
64. Heikkilä, J., et al., The effect of audiovisual speech training on the phonological skills of children with specific language impairment (SLI). Child Language Teaching and Therapy, 2018. **34**(3): p. 269-287.
65. Meronen, A., et al., Audiovisual speech perception in children with developmental language disorder in degraded listening conditions. 2013.
66. Desjardins, R.N., J. Rogers, and J.F. Werker, *An exploration of why preschoolers perform differently than do adults in audiovisual speech perception tasks.* Journal of Experimental Child Psychology, 1997. **66**(1): p. 85-110.
67. Patterson, M.L. and J.F. Werker, *Matching phonetic information in lips and voice is robust in 4.5-month-old infants.* Infant Behavior and Development, 1999. **22**(2): p. 237-247.

1.