Speech production in child language development

Janaina Weissheimer, Natália Mota

https://doi.org/10.1590/SciELOPreprints.14998

Submitted on: 2026-01-30
Posted on: 2026-02-03 (version 1)
(YYYY-MM-DD)

Type of submission: Critical Perspective

SPEECH PRODUCTION IN CHILD LANGUAGE DEVELOPMENT

PRODUÇÃO ORAL NO DESENVOLVIMENTO DA LINGUAGEM INFANTIL

Janaina Weissheimer
Departamento de Línguas Estrangeiras Modernas (DLLEM), Universidade Federal do Rio Grande do Norte (UFRN)
https://orcid.org/0000-0002-6318-4906
janaina.weissheimer@ufrn.br

Natália Bezerra Mota
Instituto de Psiquiatria (IPUB), Universidade Federal do Rio de Janeiro (UFRJ)
https://orcid.org/0000-0003-2802-2001
natalia.mota@ipub.ufrj.br

Abstract

Mapping the neural and psycholinguistic processes that underlie speech production and development is crucial to understanding how children learn and use language. In this article, we briefly review theories of child speech production and development. We then present a school-based ecological technique to assess children's naturalistic speech production, which uses graph theory as a model to understand speech connectedness and recurrence patterns. We discuss data provided by a series of studies using graph analysis, which evidence the power of this technique in predicting children's reading and linguistic skills by assessing their speech production early on. In general, results from these studies show that larger long-range connectedness and fewer short-range recurrences in children's speech production were predictive of reading performance and linguistic skills in both typically developing and neurodiverse children. Findings from studies like these may inform accommodations and interventions that address delays and disorders in language development, ranging from early speech development to reading acquisition and developmental language disorders. In a broader sense, the relevance of these investigations lies in the possibility of grounding intervention programs, translational research and public educational policies.

Keywords: Speech Production. Child Language Development. Speech Graphs Analysis.

Resumo

Mapear os processos neurais e psicolinguísticos subjacentes à produção e ao desenvolvimento da fala é crucial para compreender como as crianças aprendem e usam a linguagem. Neste artigo, revisamos brevemente teorias da produção e do desenvolvimento da fala infantil. Em seguida, apresentamos uma técnica ecológica aplicada no ambiente escolar para avaliar a produção natural da fala em crianças, utilizando a teoria dos grafos como modelo para compreender a conectividade e os padrões de recorrência da fala. Discutimos dados fornecidos por uma série de estudos que utilizam análise de grafos, os quais evidenciam o poder dessa técnica na predição das habilidades de leitura e linguísticas das crianças, por meio da avaliação precoce de sua produção da fala. De modo geral, os resultados desses estudos mostram que uma maior conectividade e um menor número de recorrências curtas na produção da fala das crianças foram preditivos do desempenho em leitura e das habilidades linguísticas, tanto em crianças com desenvolvimento típico quanto em crianças neurodivergentes. As descobertas de estudos como esses podem fundamentar adaptações e intervenções que abordem atrasos e distúrbios no desenvolvimento da linguagem, desde o desenvolvimento inicial da fala até a aquisição da leitura e os transtornos do desenvolvimento da linguagem. Em um sentido mais amplo, a relevância dessas investigações reside na possibilidade de embasar programas de intervenção, pesquisa translacional e políticas públicas de educação.

Palavras-chave: Produção Oral. Desenvolvimento da Linguagem Infantil. Análise de Grafos da Fala.

Lay Summary

In this article, we focus on child speech production and development. We present a school-based ecological technique to investigate how children tell stories, which use graph analysis to understand speech repetition patterns. We discuss data provided by a series of studies using graph analysis, which show that it can predict children's reading and linguistic skills. In general, children who produce more connected narratives, with fewer repetitions, become better readers and develop better linguistic skills later on. Studies like the ones reported here are important for grounding intervention programs, translational research and public educational policies.

1. Child speech production and development

Acquiring oral language is a natural process for humans, and our brains are previously set to learn linguistic cues (Dehaene, 2009). Unless children have particular forms of genetic defect, such as Specific Language Impairment, they are likely to achieve a high degree of skill understanding and producing language.

From the final stages of pregnancy to the end of our lives, evolution has allowed us to acquire oral language without any kind of formal instruction. Humans have been capable of communicating with each other since the first hominids, even if communication happened, in the beginning, in a simplistic manner. Nonetheless, with evolution, it has been possible to systematize the sounds, and humans developed the ability to think symbolically. Despite the debate whether language is an innate faculty of the human cognitive system or a byproduct of human evolution and its interaction with the environment, it is known that language is used to communicate thoughts and, to do so, everyone must acquire it (Traxler, 2024).

Despite the variability of the input they receive, babies can develop oral language only with the input they receive from their parents, without any formal instruction, and this starts very early, when they are still in the womb. The fetus' auditory system can perceive environmental input in the third trimester of pregnancy. Thus, a third-trimester fetus has a functioning perceptual system that can already process auditory stimuli that are present in the environment. Specifically, the fetus is exposed to auditory stimuli that provide the basic outline for the prosodic features of the fetus' native language. Because the mother's voice is generated in and propagated through the mother's body, it is, on average, the loudest thing the fetus is exposed to. Prosodic characteristics of speech (like accent, for example) are available to the fetus and can help the child identify important components of the speech signal. As soon as a fetus learns something about the prosody of their native language, they will gain substantial benefits when it comes to learning their first language (Traxler, 2024).

From birth on, phonemes constitute the building blocks of words in the baby's new language. Thus, one basic task that the infant must solve is to figure out how the inventory of speech sounds is organized. Once again, prosody plays a big role. Infants make use of prosodic features to identify boundaries between words in fluent speech. In addition, infants notice patterns in complex stimuli and use those patterns to analyze speech stimuli and identify important subcomponents, including words. They can use several strategies to segment and understand the functioning of the language and how it is organized. First, they need to identify the spoken sounds, noticing what the possible phonemes of the specific language are that the given context will allow them to learn.

But how do we know how babies process language before they can speak? Among many possible ways to investigate the language acquisition phenomenon in babies, researchers have developed a technique that measures the applied pressure on pacifiers that babies use during the experiment while different conditions are being tested. Therefore, scientists can observe what babies are paying attention to when acquiring language (Traxler, 2024). A pioneer study employing this technique was conducted by Eimas et al. (1971), who aimed on the perception of newborns about phonemes. A specific sound was played and then replaced with another phoneme (for example, /ba/ was replaced by /pa/). The results showed that newborn babies can already distinguish between the two sounds, allowing them to assimilate possible phonemes in the language being acquired.

In addition to differentiating between phonemes, children need to identify how sounds (phonemes) are organized in words as well. According to Traxler (2024), this ability appears at around 6 months of age. One of the strategies they possibly use is prosody, since this linguistic feature of speech can assist in understanding the beginning and ending of probable words. The baby would be able to understand which sound is the limit of a word according to the intonation and emphasis (stressed syllable) that adults make. Later on, children also make use of phonological information in the target language, identifying the patterns of occurrence of phonemes and estimating the possibility of certain syllabic sound occurring in the language being acquired (Traxler, 2024). Once phoneme and word notions are acquired, children begin to learn the meaning of words (lexicon) and, finally, the way in which they are organized within a sentence (syntax).

Understanding the neural processes that underlie behavior and developmental trajectories of spoken language in infancy is crucial to a range of psycholinguistic hypotheses for how children learn other linguistic skills later on, such as reading. Nonetheless, although the biological bases of language acquisition are essential, and to some extent determinant, one cannot underestimate or neglect the role of experience in this process.

2. The impact of experience on early speech development

The role of the environment is essential in language development. Infants learn about their first language by listening to people talk. When we talk to infants, the way we speak changes radically: the pitch of our voice increases, we speak in shorter sentences, we speak more clearly and distinctly, and we vary our pitch and our loudness much more than we do when we speak to adults. This collection of speech properties goes by the name infant-directed speech, child-directed speech, or motherese. Research on infant-directed speech indicates that, although it may not be necessary for children to learn their first language, it helps them master some aspects of speech comprehension and word learning (Traxler, 2024).

Parents, and the socioeconomic context they belong to, have a great deal of influence on the course of a child's language development. This influence is translated into the size of the baby's vocabulary and the speed with which the baby can process incoming speech, for example. Further, these two abilities are in a symbiotic relationship, which have long-term, cumulative effects; that is, the more words the child knows, the faster they can recognize familiar words; the faster they can recognize familiar words, the more resources they have left over to pay attention to and learn from other parts of the speech signal. Research has mapped this virtual cycle, children who are faster at recognizing familiar words at 6 months old have bigger vocabulary at 24 months old than children who are slower at recognizing familiar words at 6 months old (Traxler, 2024). In other words, differences between fast and slow processors can be explained largely as a kind of practice effect and are impacted by socioeconomic differences.

Socioeconomic disparities are associated with differences in cognitive development and disparities in brain structure, more prominently in regions supporting language, reading, executive functions and spatial skills (Noble et al., 2015). Differences in processing efficiency between different infants can also be attributed in part to how much adults talk to them, and there are vast differences between and within different socioeconomic groups in the amount of speech that gets directed toward infants (Noble et al., 2015). Maternal education also appears to matter a great deal. Independent of socioeconomic status, mothers with more formal education speak more to their children than mothers with less formal education.

As we have seen so far, there is wide consensus about the interplay between nature and nurture when it comes to child language development. In this sense, research in the field must consider both the neurobiological underpinnings and the effects of experience when investigating child speech.

3. Neuroimaging techniques: potential and limitations

Until recently, investigations of the neurobiology of early language development had been hindered by the lack of age-appropriate neuroimaging techniques. This has changed rapidly due to technological advances such as fNIRS (functional near infrared spectroscopy). These non-invasive tools have allowed a deeper understanding of how the developing brain deals with language. Recently, the establishment of neuroimaging methodological protocols for infant experimental studies has consolidated research pathways, leading to a more robust understanding of this line of research. That means that neural pathways and trajectories have been identified that demonstrate a reliable association with different dimensions of language development. Understanding this relationship, grounded on the neurobiology of early language production and comprehension, has the potential to yield new models of developmental trajectories.

However, neuroimaging techniques are still not widely accessible or affordable, especially in the case of scientists doing research in WILD countries[1] like Brazil. The alternative generally involves integrating advances in neuroimaging (e.g., fNIRS, fMRI, ERPs) and more ecological study designs, consisting of behavioral techniques and translational perspectives to address fundamental questions on early language acquisition and developmental trajectories.

4. Alternative approaches: Graph-based Analysis of Child Narrative Speech

The investigation of oral abilities in children is relevant in many ways, since it can simultaneously provide information about features of their linguistic development as well as their level of competence at the discourse level in naturalistic contexts. Oral narrative skills in kindergarten have been associated with later-acquired reading outcomes (e.g., Catts et al., 2006). In addition, research findings also show that young children's oral narrative skills predict their social and behavioral competence, corroborating the fundamental role of oral narrative abilities to literacy development and overall academic performance (Huang et al., 2022).

Among non-semantic network approaches, speech graphs offer a novel technique that focuses on structural patterns and recurrence rather than focusing on meaning or grammar. In this approach, words are represented as nodes and their sequential connections as edges, creating a network-like map of how a story unfolds (Mota et al., 2023). The resulting speech graph yields two unique metrics: Largest Strongly Connected Component (LSC) and Repeated Edges (RE). These are non-language specific, and provide a complementary lens for examining connectedness, with the potential to reveal subtle disruptions in narrative organization that are characteristic of speech in early child development.

---

[1] The acronym WILD - Worldwide, *In situ*, Local, Diverse - (Alves *et al.*, 2022), has been used to contrast research done in Latin America to that done in WEIRD - Western, Educated, Industrialized, Rich and Democratic – countries, such as the USA.

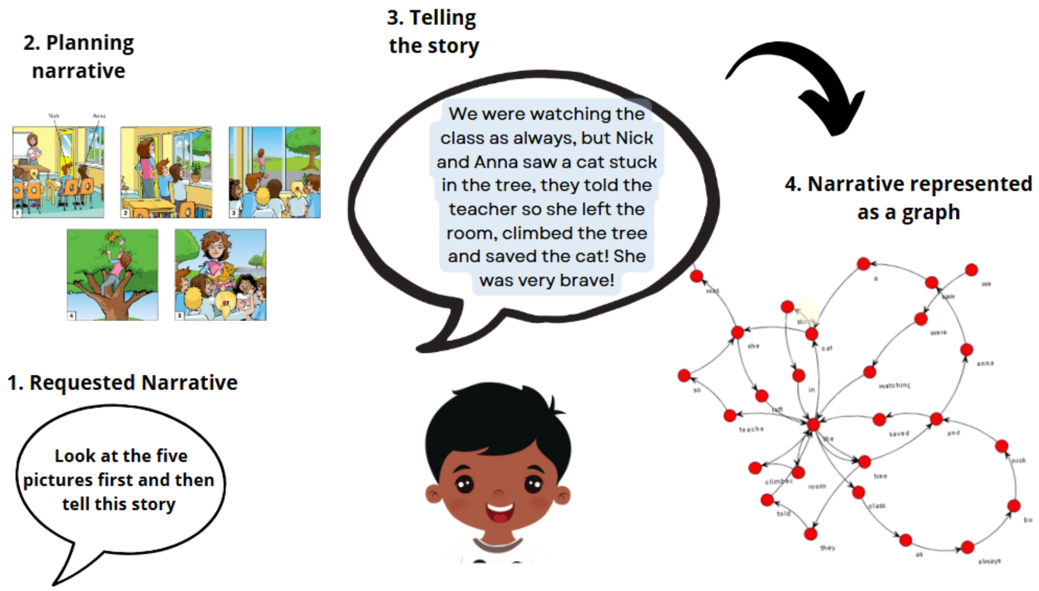

***Figure 1*. Example of an oral narrative protocol**
Source: the authors

Narratives are particularly useful for speech graph analysis because, unlike casual conversation, they place greater cognitive demands on the speaker. Narrative production requires the mental organization of ideas before verbal expression, making it a complex and revealing context for examining how thoughts are connected over time (McGregor, 1997). In such a context, speech graph analysis can differentiate between short-range recurrence, or repeated associations between the same pair of words (e.g., "*a boy, a boy*"), and long-range connectedness, which refers to the number of nodes within a connected component. For example, in the sequence "*The **boy** with the cap on his head is the **boy** I spoke to yesterday*" words are indirectly connected through multiple associations, providing a measure of global connectedness (Mota et al., 2016).

While most linguistic metrics provide a holistic analysis of cohesion by capturing complexity across the whole narrative, speech graph analysis offers an alternative by quantifying structural organization and recurrence patterns within speech, providing insights independent of meaning or grammatical form. Taken together, speech graph features provide a promising approach to studying narrative structure, demonstrating how connectedness can be measured in stories.

In children, the increase in language complexity is generally associated with a more complex mental organization informing cognitive development. Based on the idea that children's narrative skills reveal how they organize their thoughts, a graph-theoretical-based approach - in which each node represents a word, and each directed edge represents the temporal order of consecutive words - is quite informative in naturalistic settings in different contexts.

Previous studies applying speech graph analyses have reported that the oral narrative structure changes from a short to a long-range recurrence pattern as soon as a child starts to read, increasing connectedness. In Mota et al. (2016), narratives from seventy-six second-grade children (ages from 6 to 8 years old) were collected in the middle of the school year, together with the intelligence quotient (IQ), theory of mind (ToM), as well as reading and math scores acquired from a national assessment four months later. The results reveal that the Largest Strongly Connected Component (LSC) predicted the national reading exam performance five months later. Furthermore, the results reveal that the association with reading performance was independent of IQ and ToM performances. In a subsequent study with the same participants in the third grade, Mota et al. (2019) reported that exclusively verbal short-term memory was associated with connectedness measures (LSC). In addition, the correlation between short-term memory and reading fluency was significant only in the second grade, pointing to a specific dynamics associated with the reading acquisition process. More recently, Malcorra et al. (2024) conducted a longitudinal study with 253 children (first and second graders), which corroborated the results in Mota et al. (2016), showing that speech connectedness predicted performance in phonological awareness, reading comprehension, and word reading accuracy 3–4 months prior to full literacy.

In the case of children with developmental language disorder (DLD), Perez et al. (2025) showed that the analysis of children's narratives with speech graphs may provide a language-independent complement to standardized tools for identifying speech-level disruptions in atypical populations. The study examined longitudinal changes in oral narrative retelling among children with and without DLD and combined speech graphs analysis, semantics and morphosyntax scores over one year to differentiate typically developing (TD) and DLD groups. Forty-two children (21 TD, 21 DLD) matched on age, gender and IQ completed a set of Semantics and Morphosyntax tests and narrative retelling tasks at two time points. Composite scores for semantics and morphosyntax were analyzed alongside speech graph measures of long-range (uninterrupted utterances) and short-range (repetitions) connectedness. Results show that typically developing children achieved higher semantic and morphosyntactic composite scores than peers with DLD, and showed greater linguistic gains across time. Higher composite scores predicted greater long-range connectedness, reflecting stronger narrative cohesion. Children with DLD produced narratives with significantly lower long-range and higher short-range connectedness, indicating fragmented speech organization.

Taken together, the studies reviewed here evidence the power of the speech graphs technique in predicting children's linguistic skills, in clinical and non-clinical samples, by assessing their speech production early on.

5. Conclusion: The future of speech graphs investigations

Speech graphs provide a safe and scalable way to evaluate educational policies, since the stories may be recorded and transcribed automatically using an AI-based algorithm. Each narrative is represented computationally by a word recurrence graph, which is analyzed to determine academic development. In a typical school environment, graph attributes indicate academic development, according to Mota et al (2016; 2019). Therefore, this protocol can be a valuable, language-independent tool for education professionals. As a monitoring tool, researchers (and also teachers) can plot information on the narrative structure obtained through graphs on a normative curve representing the evolution of oral narrative complexity throughout the school years. With this curve, they can evaluate the development of the user's communication skills compared to their peers in the same or different school years, providing a global perspective of their ability to generate narratives.

Speech graph models may also inform accommodations and interventions that address delays and disorders in language development, ranging from early speech development to reading acquisition. Thus, investigations into the neurobiology of language development, considering aspects that are increasingly focusing on translational research, highlight the relevance this field for practitioners as well as interdisciplinary and novice researchers.

The studies reviewed in the article point to a feasible, low-cost, and inclusive assessment based on storytelling (as it does not require the child to be able to read), enabling the screening and tracking of cognitive development related to reading acquisition on a large scale. For Latin American countries such as Brazil, scalable solutions could be crucial to planning public educational policies based on data. Public and policy domains may benefit from more translational studies such as the ones reported here, which aim to be illustrative of the field, rather than exhaustive.

Future studies could examine the relationship between language connectedness and various cognitive and linguistic attributes in a more diverse sample, including families of different socioeconomic status and educational levels, and examine whether it would be possible to replicate the results in a more heterogeneous sample.

In addition, future studies could evaluate other measures based not only on transcriptions but also on acoustic signals and facial expressions, which could help us understand communication in depth, as well as the role of a child's temperament, considering that the ability to speak may be challenging for shy children.

In conclusion, there are many benefits of a special issue on neurobiology of early language development. In a broader sense, the relevance of this publication lies within the need for further understanding of the neurocognitive processes that ground language development and the optimization of language investigation and intervention programs. In that sense, we hope that the present article has offered a humble contribution to important discussions in the field.

Acknowledgments

The authors thank all the parents, educational professionals and children for their generous participation in the studies.

ADDITIONAL INFORMATION

Conflict of Interest

NBM works at Motrix, a Technology startup.

Declaração de Disponibilidade de Dados de Pesquisa

Data sharing is not applicable to this article, as no new data were created or analyzed in this study.

Funding Sources

JW receives a grant as productivity researcher at the National Council of Technological and Scientific Development - CNPq (n.308917/2022-7).

Contribuição de Autoria

JW was responsible for Conceptualization, Writing – Original Draft, and Writing – Review and Editing. NBM was responsible for Conceptualization, Writing – Original Draft, and Writing – Review and Editing.

References

ALVES, Marcus Vinícius; EKUNI, Roberta; HERMIDA, Maria Julia; VALLE-LISBOA, Juan (ed.). *Cognitive sciences and education in non-WEIRD populations*: a Latin American perspective. Springer Nature, 2022.

CATTS, Hugh W.; ADLOF, Suzanne M.; WEISMER, Susan Ellis. Language deficits in poor comprehenders: A case for the simple view of reading, 93 Journal of Speech, Language and Hearing Research, 49(2), 278, 2006.

DEHAENE, Stanislas. Reading in the brain: The science and evolution of a human invention. Viking, 2009.

EIMAS Peter D.; SIQUELAND Einar R.; JUSCZYK Peter; VIGORITO James. Speech perception in infants. Science. 1971 Jan 22;171(3968):303-6. doi: 10.1126/science.171.3968.303. PMID: 5538846.

HUANG, Becky H.; BEDORE, Lisa M.; RAMÍREZ, Rica; WICHA, Nicole. Contributions of oral narrative skills to English reading in Spanish-English Latino/a dual language learners. Journal of Speech, Language, and Hearing Research, 65(2), 653–671, 2022.

MCGREGOR, Karla. K. The nature of word-finding errors of preschoolers with and without word-finding deficits. *Journal of Speech, Language, and Hearing Research*, 708 40(6), 1232–1244. 1997. https://doi.org/10.1044/jslhr.4006.1232

MALCORRA, Bárbara; RIBEIRO, Marina; JENSEN, L. *et al.* Speech connectedness predicts reading performance three months in advance: a longitudinal experiment. *npj Sci. Learn.* **9**, 35, 2024. https://doi.org/10.1038/s41539-024-00248-4

MOTA, Natália Bezerra et al. Speech as a Graph: Developmental Perspectives on the Organization of Spoken Language. Biol. *Psychiatry.* 8, 985–993, 2023.

Mota, Natália Bezerra; Callipo, Renata; Leite, Lígia; Torres, Ana Raquel; Weissheimer, Janaina; Bunge, Silvia; Copelli, Mauro; Ribeiro, Sidarta. Verbal short-term memory underlies typical development of thought organization measured as speech connectedness. *Mind, Brain and Education*, 14(1), 51–60, 2019. https://doi.org/10.1111/mbe.12208

MOTA, Natália Bezerra et al. The maturation of speech structure in psychosis is resistant to formal education. *npj Schizophrenia* v. 4, 25, 2018.

MOTA, Natália Bezerra et al. A naturalistic assessment of the organization of children's memories predicts cognitive functioning and reading ability. *Mind Brain Educ*. 10, 184–195, 2016.

MOTA, Natália Bezerra, COPELLI, Mauro; RIBEIRO, Sidarta. Thought disorder measured as random speech structure classifies negative symptoms and schizophrenia diagnosis 6 months in advance. *npj Schizophrenia* 3, 18, 2017.

NOBLE, Kimberly, HOUSTON, Suzanne, BRITO, Natalie *et al.* Family income, parental education and brain structure in children and adolescents. *Nat Neurosci* **18**, 773–778, 2015. https://doi.org/10.1038/nn.3983

PEREZ, Reinaldo Cabrera; WEISSHEIMER, Janaina; BEDORE, Lisa; PEÑA, Elizabeth. Longitudinal Speech Graph Analysis of Narrative Retelling in Bilingual Spanish-English Children with and without Developmental Language Disorder. *SSRN Electronic Journal*, v. 1, p. 1, 2025.

TRAXLER, Matthew J. *Introduction to Psycholinguisitics*. West Sussex: Blackwell Publishing, 2ed., 2012.