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Repercussions of gestational exposure to toxoplasmosis on language and learning: a comparative analysis in non-monozygotic triplets

Abstract

Background: Gestational toxoplasmosis may lead to neurological and developmental repercussions capable of affecting language development and learning abilities during childhood.

Objective: To comparatively analyze language development and early academic indicators in non-monozygotic triplets with gestational exposure to toxoplasmosis, including one child with confirmed congenital infection.

Methods: Observational descriptive comparative study conducted with three non-monozygotic triplets aged 7 years (84 months), exposed to gestational toxoplasmosis and inserted in the same family and educational context. Assessments included the Oral and Written Dictation Test proposed by Capovilla and Seabra, Piagetian operational tasks and the School Performance Test, in addition to qualitative language analysis. The study is part of a multidisciplinary project approved by the Research Ethics Committee (CAAE 79727424.0.0000.0096).

Results: Child A, diagnosed with confirmed congenital toxoplasmosis, showed greater difficulties in verbal comprehension, auditory sequential processing, language tasks and early arithmetic skills, obtaining 27/40 correct responses. Child B, exposed to gestational toxoplasmosis without confirmed congenital infection, achieved intermediate performance (34/40). Child C, also exposed to gestational toxoplasmosis without confirmed congenital infection, demonstrated preserved language and academic abilities, obtaining 40/40 correct responses.

Conclusion: Different cognitive, linguistic and academic outcomes were identified among children exposed to gestational toxoplasmosis despite similar environmental conditions. The findings reinforce the importance of longitudinal monitoring of language and learning abilities in exposed children, even in the absence of confirmed congenital disease.

Keywords: prenatal exposure delayed effects, child development, literacy, academic performance, cognition, toxoplasmosis, congenital

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Introduction

Congenital toxoplasmosis remains an important public health concern, particularly in middle-income countries, due to the potential neurological, ophthalmological, and neurodevelopmental consequences resulting from the vertical transmission of *Toxoplasma gondii*.[1–3] Maternal infection and fetal involvement during pregnancy exhibit heterogeneous clinical patterns, varying according to the gestational age at infection, parasite burden, timing of treatment initiation, and maternal-fetal immunological factors.[2–4] Although the classical manifestations of congenital toxoplasmosis include chorioretinitis, hydrocephalus, and intracranial calcifications, contemporary studies have demonstrated that more subtle alterations, particularly those related to auditory processing, executive functions, language, and learning, may persist even in children who show no apparent severe neurological manifestations at birth.[4–6]

The international literature has progressively expanded the discussion regarding the long-term neurocognitive consequences of gestational exposure to *T. gondii*, particularly with respect to cortical maturation, language development, and early academic performance.[1,5,7] Deficits in working memory, sequential auditory processing, perceptual discrimination, and semantic-pragmatic integration have been described in children with a history of congenital infection, suggesting that the effects of toxoplasmosis may extend beyond the classical sensory impairments and affect functional domains directly associated with formal schooling.[4,8] Nevertheless, longitudinal research investigating linguistic and cognitive abilities in children exposed during pregnancy remains limited, especially in Latin American and Brazilian settings.[7]

Language development and early academic learning depend on the integration of cognitive, perceptual, and executive functions, with language playing a fundamental role in communication and the organization of thought. Skills such as working memory, attention, auditory perception, and semantic processing directly contribute to language comprehension and academic achievement, particularly in reading, writing, and mathematical reasoning. According to Piaget,[3] language development occurs alongside the evolution of cognitive structures, involving a progressive capacity for symbolization and logical organization. Therefore, subtle neurodevelopmental alterations, including those resulting from gestational infectious conditions, may manifest early as academic difficulties and impairments in formal learning, even in the absence of classical neurological deficits.

Furthermore, an important gap remains in understanding the potential differences between children with confirmed congenital infection and those who were merely exposed to maternal infection

during pregnancy without diagnostic confirmation of the disease. This distinction is particularly relevant, as recent evidence suggests that intrauterine exposure to inflammatory, immunological, and infectious processes may itself influence neurodevelopmental trajectories, even when fetal infection is not clinically established.[1,5,9] In this context, studies involving siblings exposed to the same family, social, and educational environment represent a valuable methodological approach, as they help minimize potentially confounding environmental factors and allow a more accurate assessment of outcomes associated with gestational exposure.

Within this framework, investigating early markers of linguistic and cognitive alterations in children exposed to toxoplasmosis during pregnancy is particularly relevant, especially given the limited number of studies addressing the long-term functional consequences of intrauterine exposure to *Toxoplasma gondii*.[5,7] A better understanding of these manifestations may contribute to the development of early screening strategies, multidisciplinary follow-up programs, and individualized educational interventions aimed at minimizing adverse effects on child development and the formal learning process.

Therefore, the present study aimed to comparatively analyze language indicators and early academic performance in non-monozygotic triplets exposed to gestational toxoplasmosis, seeking to identify potential outcomes associated with both congenital infection and intrauterine exposure to *Toxoplasma gondii*.

Methods

This was a descriptive observational study with a comparative design and a mixed qualitative–quantitative approach, conducted through the assessment of three non-monozygotic seven-year-old triplet siblings exposed to gestational toxoplasmosis. The children shared the same family, social, and educational environment, attending the same school, enrolled in the same grade, and taught by the same classroom teacher. This condition was considered methodologically relevant for minimizing potential environmental confounding factors related to learning processes and cognitive development.

The present study represents an analytical component of a multidisciplinary research project linked to a master's degree program, aimed at investigating the effects of gestational exposure to *Toxoplasma gondii* on language, cognition, and school learning. The project was approved by the Research Ethics Committee under protocol CAAE 79727424.0.0000.0096 and was conducted in full accordance with the ethical principles established by Resolution No. 466/2012 of the Brazilian National Health Council. The children's legal guardians provided written informed consent authorizing the assessments and the use of data for scientific purposes.

Assessments were conducted individually in a quiet and organized environment with minimal distracting stimuli to preserve sustained attention and optimize cognitive performance during testing. Considering the participants' age and the potential influence of cognitive fatigue on linguistic and operational tasks, evaluations were performed on separate days for each child, ensuring adequate physical and mental rest at the time of data collection. In addition, scheduled play-based breaks were incorporated throughout the assessment sessions, using brief age-appropriate recreational activities to reduce attentional overload, minimize situational anxiety, and promote engagement in the proposed tasks.

All assessments were conducted individually and lasted approximately 45 to 60 minutes. Instructions were delivered in a standardized manner to all participants, and task instructions were repeated whenever comprehension difficulties were observed, following the same procedure for each child.

Interviews were also conducted with the children's caregivers to obtain clinical, gestational, educational, and neurodevelopmental information, including maternal toxoplasmosis during pregnancy, medical follow-up, clinical manifestations, treatment history, and family perceptions regarding academic and communicative performance.

The investigation included a language assessment composed of standardized instruments and qualitative clinical observation. Among the instruments used, the Oral and Written Dictation Test proposed by Capovilla and Seabra[10] was administered to evaluate phonological processing, auditory decoding, phonemic discrimination, spelling under dictation, and grapheme-phoneme correspondence. The test allows the identification of alterations related to phonological awareness, verbal auditory memory, and linguistic processing involved in literacy development.

Piagetian operational tasks based on the genetic epistemology of Jean Piaget[11,12] were also administered, including conservation, classification, and seriation tasks. These assessments were intended to investigate logical-operational thinking, cognitive organization, quantity concepts, categorization, and logical sequencing abilities. The tasks provided indicators of cognitive developmental stage and symbolic reasoning skills expected for the children's age group.

To assess early academic performance, the School Performance Test (TDE)[13] was used, with emphasis on basic arithmetic skills, number recognition, numeral writing, and the resolution of elementary mathematical operations. The instrument was employed to evaluate core academic competencies associated with formal learning.

In addition to the standardized instruments, a qualitative analysis of receptive and expressive language was conducted. This analysis considered comprehension of simple and sequential verbal commands, retention of auditory information, semantic organization, communicative pragmatics, overall interpretation of linguistic stimuli, and interactional behavior during the assessment process. Aspects related to visual discrimination, sustained attention, cognitive flexibility, and problem-solving strategies were also observed.

Clinical observations were recorded using individualized descriptive protocols, allowing comparative analysis among the participants. Subsequently, quantitative and qualitative data were organized and analyzed descriptively and interpretatively, taking into account the clinical, cognitive, and linguistic characteristics of each child, as well as the heterogeneity of outcomes associated with gestational exposure to toxoplasmosis.

Results

Three seven-year-old children (84 months, 10 days), non-monozygotic triplets, were evaluated. All participants shared the same family, social, and educational environment. They attended the same school, were enrolled in the same grade level, and were taught by the same classroom teacher at the time of data collection.

Among the participants, child A had a previous diagnosis of congenital toxoplasmosis, associated with ocular involvement and a history of treatment during the first year of life. Children B and C had a history of gestational exposure to toxoplasmosis but no confirmed diagnosis of congenital infection.

Piagetian operational tasks based on genetic epistemology were administered to all three participants, including activities related to

conservation of quantity, conservation of mass, classification, class inclusion, seriation, and logical-sequential organization. During the assessments, substantial variability in linguistic, academic, and cognitive performance was observed among the triplets, both in comparison with one another and with developmental expectations for their age group.

Child A demonstrated the greatest overall difficulty during the assessments. In the oral dictation and picture recognition tasks, the child correctly identified 27 of the 40 stimuli presented, corresponding to an accuracy rate of 67.5%. Child A showed uncertainty when responding to phonologically similar stimuli, frequently required repetition of instructions, and demonstrated slower task execution. Throughout the assessment, the child experienced difficulty maintaining engagement in tasks for extended periods, requiring frequent breaks, verbal mediation, and repeated redirection of attention.

In tasks involving sequential verbal comprehension, child A tended to retain predominantly the last piece of information presented, particularly when instructions involved multiple steps. In situations requiring the integration of receptive language, immediate auditory memory, and practical responses, a greater number of execution errors were observed.

During the Piagetian operational tasks, child A demonstrated difficulty maintaining continuous logical reasoning and completing activities without interruptions. In conservation tasks, fluctuations were observed in the understanding of quantity constancy when perceptual characteristics were altered. In classification and class inclusion activities, the child showed difficulty establishing consistent grouping criteria. In seriation tasks, increased verbal support was required to organize the proposed sequences.

Child B demonstrated intermediate performance among the siblings. In the oral dictation and picture recognition tasks, the child correctly identified 34 of the 40 stimuli presented, corresponding to an accuracy rate of 85%. During testing, child B exhibited functional communication and an adequate overall understanding of the proposed activities, although occasional episodes of distraction and attentional fluctuation were observed throughout the tasks.

At times, occasional repetition of phrases, expressions, or gestures previously presented by the examiner was noted, as well as mild difficulties in discriminating visually similar stimuli. Nevertheless, the child successfully completed most of the proposed activities.

In the Piagetian operational tasks, child B demonstrated partially satisfactory performance. Adequate understanding was observed in some conservation and classification tasks, however, fluctuations emerged in activities requiring greater logical-sequential organization and prolonged attentional maintenance. In seriation tasks, the child completed the proposed sequences only partially and required redirection on some occasions.

Child C demonstrated the most consistent overall performance among the participants. In the oral dictation and picture recognition tasks, the child correctly identified all 40 presented stimuli, corresponding to 100% accuracy. Child C demonstrated appropriate phonological discrimination, accurate recognition of verbal stimuli, and well-organized responses throughout all administered activities.

During the assessments, child C displayed attentive behavior, a high level of concentration, and consistent maintenance of sustained attention throughout the tasks. The child demonstrated adequate comprehension of both simple and sequential verbal commands, as well as good immediate auditory retention.

In the Piagetian operational tasks, child C demonstrated satisfactory performance across all proposed activities. Preserved understanding was observed in quantity and mass conservation tasks, along with appropriate classification skills based on logical criteria, satisfactory performance in class inclusion activities, and accurate organization of sequences in seriation tasks. The child also efficiently solved the problem situations presented during the assessments.

Overall, the triplets exhibited substantial variability in linguistic, academic, and cognitive performance despite sharing similar family and educational environments, as summarized in Table 1.

Table 1 Comparative analysis of language assessment results among the triplets

Assessed dimension	Child a (congenital toxoplasmosis)	Child b (gestational exposure)	Child c (gestational exposure)
Dictation/ pictures performance	67.5% correct answers (27/40)	85% correct answers (34/40)	100% correct answers (40/40)
Auditory processing	Difficulty with sequential commands; retention of the last piece of information	Adequate global comprehension; episodes of echolalia/repetition	Preserved comprehension of simple and sequential commands
Attentional profile	Marked instability; constant need for mediation	Attentional fluctuations and moments of distraction	Preserved sustained attention and concentration
Logical-operative structure	Unstable performance in conservation and classification tasks	Partial performance; difficulties in sequential organization	Satisfactory performance in all operative tasks

Source: The authors (2026).

Finally, child A, who had a diagnosis of congenital toxoplasmosis, exhibited a higher frequency of difficulties related to verbal comprehension, sequential auditory processing, sustained attention, and logical-sequential organization. Among the siblings who were only exposed to gestational toxoplasmosis, child B demonstrated intermediate performance, with attentional fluctuations and partial performance in some operational tasks, whereas child C showed overall performance consistent with age-related expectations across all assessed activities.

Considering the participants' age of seven years, children are expected to be in Piaget's concrete operational stage, demonstrating

satisfactory performance in tasks involving conservation, classification, class inclusion, and seriation. At this developmental stage, children are also expected to exhibit adequate comprehension of complex verbal instructions, sustained attention during structured activities, and progressive consolidation of reading, writing, and logical-mathematical reasoning skills. Therefore, the observed findings were interpreted in light of these expected developmental milestones.

Discussion

The present study aimed to comparatively analyze indicators of language, cognitive processing, and early academic performance in non-monozygotic triplets exposed to gestational toxoplasmosis, seeking to identify potential outcomes associated with both congenital infection and intrauterine exposure to *Toxoplasma gondii*. The findings revealed substantial heterogeneity among the participants despite their shared family, social, and educational environment, suggesting that the consequences of gestational exposure may manifest in a variable and multifactorial manner.

Considering the expected developmental milestones for typically developing seven-year-old children, satisfactory performance is generally anticipated in conservation, classification, and seriation tasks, along with adequate attention during structured activities and the progressive consolidation of literacy-related skills. Therefore, the findings observed in child A and, to a lesser extent, child B should be interpreted in light of these expected developmental benchmarks.

Child A, who had a confirmed diagnosis of congenital toxoplasmosis, demonstrated a higher frequency of difficulties related to sequential verbal comprehension, auditory processing, sustained attention, written language, and logical-sequential organization. These findings are consistent with the contemporary literature regarding the long-term neurofunctional consequences of congenital toxoplasmosis, particularly the subtle neurodevelopmental alterations that often remain undetected during the first years of life.[1,4,5]

Although the classical manifestations of congenital toxoplasmosis primarily emphasize ophthalmological and structural neurological impairments, recent studies have shown that deficits involving working memory, executive functions, sustained attention, and auditory processing may persist even in children without evident severe neurological abnormalities.[5,6,9] In this regard, the difficulties observed in retaining sequential verbal instructions and the recurrent need for repetition of commands may reflect impairments in verbal working memory and sequential auditory processing, functions that are strongly associated with formal learning and language acquisition.[14,15]

According to Baddeley,[15] working memory is an essential system for the temporary storage and manipulation of verbal information during complex cognitive activities, including language comprehension, reading, writing, and mathematical problem-solving. Deficits in this system frequently affect a child's ability to understand complex instructions, organize responses, and retain auditory information long enough for accurate task execution. This pattern was particularly evident in child A, who often retained only the last piece of verbally presented information, demonstrating a significant limitation in the sequential integration of auditory stimuli.

From the perspective of age-appropriate child development, seven-year-old children are generally expected to demonstrate satisfactory comprehension of complex verbal commands, adequate sustained attention during structured activities, and progressive consolidation of early literacy and logical-mathematical reasoning skills.[16,17] At this stage, greater stability in classification, conservation, and seriation tasks is also expected, consistent with Piaget's concrete operational stage.[11,12] Therefore, the fluctuations observed in the operational tasks and the difficulty completing activities without interruptions suggest performance below what would be expected for the chronological age of the child with congenital toxoplasmosis.

The Piagetian operational tasks provided relevant insights into differences in logical-operational thinking among the participants. While child C demonstrated consistent performance in conservation, classification, and seriation tasks, reflecting cognitive organization compatible with the concrete operational stage, child A exhibited instability in logical reasoning when faced with tasks requiring sequential organization, sustained attention, and abstraction. According to Piaget,[11] the consolidation of these abilities represents a fundamental milestone in cognitive development and is directly related to symbolization, categorization, and problem-solving capacities.

With regard to the oral dictation and picture recognition tasks proposed by Capovilla and Seabra,[10] marked differences were observed among the participants. child A achieved an accuracy rate of 67.5% (27/40), child B achieved 85% (34/40), and child C demonstrated perfect performance (40/40). Considering the participants' age and the expected literacy development at seven years of age, child C's performance was consistent with adequate consolidation of phonological skills, auditory discrimination, and lexical recognition expected during the early school years.[18]

Conversely, child A's lower performance suggests difficulties related to phonological processing, auditory discrimination, and grapheme-phoneme integration, all of which are considered fundamental for reading and writing development.[18,19] According to Capovilla and Seabra,[10] persistent difficulties in these competencies may directly affect formal academic learning, particularly in contexts requiring automatized phonological decoding, verbal comprehension, and linguistic organization. The observed difficulties in sequence recall, sustained attention, and overall interpretation of instructions also suggest a potential impact on literacy development and the acquisition of foundational academic skills.

Although child B did not have a confirmed diagnosis of congenital toxoplasmosis, the child demonstrated intermediate performance characterized by attentional fluctuations, distractibility, and partially satisfactory performance on operational tasks. Although these findings were mild and did not appear to significantly affect academic performance at the time of assessment, they warrant attention, as recent literature has discussed possible neuroinflammatory and neurodevelopmental consequences associated with intrauterine exposure to *T. gondii*, even in the absence of clinically established fetal infection.[5,9]

Another relevant aspect concerns the relative environmental homogeneity among the participants. The fact that all three siblings shared the same family environment, school, teacher, and sociocultural conditions partially reduces the influence of environmental factors on the observed differences, strengthening the hypothesis that biological and neurodevelopmental factors contributed to the discrepancies identified during the language and academic assessments.

From a pediatric and developmental perspective, the literature highlights that subtle language and learning difficulties often go unnoticed during the early school years, particularly when severe motor or neurological impairments are absent.[17,20] These children are frequently described as merely "distracted," "immature," or as having "difficulty concentrating," which may delay referral for specialized

evaluation and intervention.[20] In this context, the findings of the present study reinforce the importance of careful monitoring of linguistic and academic performance in children exposed to potentially neurotropic infectious conditions during pregnancy.

The comparison between children B and C deserves particular attention. Although both had a history of gestational exposure to toxoplasmosis, negative investigations for congenital infection, and shared the same family, educational, and sociocultural environment, relevant differences were observed in cognitive, attentional, and academic performance. While child C demonstrated overall performance consistent with age-expected developmental milestones, child B exhibited attentional fluctuations, distractibility, and partially satisfactory performance in some operational tasks.

These findings suggest that gestational exposure to *Toxoplasma gondii* alone does not appear sufficient to explain the variability observed among the participants. The literature indicates that neurocognitive development results from a complex interaction among biological, genetic, environmental, and maturational factors, which may influence individual developmental trajectories in different ways.[1,5,9] Therefore, differences in neurological maturation, individual genetic variability, and other developmental factors not investigated in this study may have contributed to the distinct profiles observed among the siblings.

Although child A had a confirmed diagnosis of congenital toxoplasmosis and demonstrated poorer performance than the siblings, a finding consistent with previously reported evidence regarding the neurofunctional consequences of congenital infection,[1,4,5] the discrepancy observed between children B and C raises additional questions regarding the factors involved in the heterogeneity of neurodevelopmental outcomes. In this sense, the principal contribution of the present study may lie in demonstrating that children equally exposed during gestation, living in a similar environment, and without confirmed congenital infection may nevertheless follow distinct developmental trajectories.

These findings reinforce the need for longitudinal follow-up of children exposed to gestational toxoplasmosis, even in the absence of confirmed congenital infection, as well as the importance of future studies incorporating detailed information regarding neuropsychomotor developmental milestones, school history, and clinical evolution throughout childhood to better understand the factors associated with the different developmental trajectories observed in this population.[5,9]

Additionally, the results were subsequently discussed with the children's legal guardians through individualized feedback sessions addressing linguistic performance, early academic skills, and the specific characteristics identified during the assessments. This process enabled families to communicate with the school regarding each child's particular needs, facilitating pedagogical adaptations and more individualized educational strategies.

Among the measures discussed were the divisions of verbal instructions into smaller steps, extended time for task completion, the use of visual supports for literacy instruction, and adjustments to teaching strategies aimed at optimizing the literacy process. Such approaches are particularly relevant for children who experience difficulties related to sequential auditory processing, verbal working memory, and sustained attention.[18,20]

This aspect further emphasizes the importance of early identification of subtle language and learning difficulties, enabling not only timely interdisciplinary follow-up but also educational interventions tailored to each child's specific needs. Pediatric and educational literature highlights that early school-based adaptations may significantly improve academic performance, strengthen educational autonomy, and help prevent secondary difficulties associated with school failure.[17,20]

Although this study has limitations inherent to its observational design and small sample size, it represents a particularly relevant comparative analysis due to the methodological uniqueness of evaluating non-monozygotic triplets raised within the same environmental context. This characteristic allowed a more refined observation of individual differences related to linguistic and cognitive development.

Furthermore, because the participants were non-monozygotic triplets, individual genetic differences may have contributed to the heterogeneity observed among them, making it impossible to attribute the findings exclusively to gestational exposure or congenital infection.

Another limitation relates to the inclusion of only one family. Although evaluating triplets within the same family, educational, and sociocultural context reduced the influence of potentially confounding environmental factors, the findings cannot be generalized to all children exposed to gestational toxoplasmosis. Future studies involving multiple families and larger samples are needed to confirm the patterns observed in the present investigation.

Conclusion

The findings of this study highlight the need for longitudinal follow-up of children exposed to gestational toxoplasmosis, including ongoing monitoring of language development, learning abilities, and academic performance throughout the school years. The observed variability among the triplets, despite their shared family, educational, and social environment, suggests that both congenital infection and intrauterine exposure to *Toxoplasma gondii* may be associated with distinct neurodevelopmental trajectories.

These results underscore the importance of expanding research on the long-term neurofunctional consequences of intrauterine exposure to *T. gondii*, particularly in Brazilian pediatric populations, which remain underrepresented in the current literature. Greater understanding of these outcomes may contribute to earlier identification of subtle developmental difficulties and support the implementation of targeted educational and multidisciplinary interventions aimed at improving long-term developmental and academic outcomes.[21–23]

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Author contribution

Andrea Maciel de Oliveira Rossoni supervised this work. Tony Tannous Tahan and Fabiana Vanessa Achy de Almeida contributed as co-supervisors.

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Conflicts of interest

The authors declare that there are no conflicts of interest.

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