



Beyond group comparisons: Profiling sentence comprehension in Spanish-speaking children with hearing loss and with typical hearing

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Running headline: Sentence comprehension profiles in CHL

Title: Beyond group comparisons: Profiling sentence comprehension in Spanish-speaking children with hearing loss and with typical hearing

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Abstract: This study investigates comprehension of spoken sentences with varying morphosyntactic complexity in Spanish-speaking children with prelingual hearing loss (CHL) and children with typical hearing (CTH) matched on auditory experience. We compare comprehension abilities between the groups and explore the development of comprehension strategies by analyzing theoretically defined comprehension profiles across sentence types. Participants with three to 11 years of auditory experience completed a tablet-based sentence-picture matching task. CHL predominantly relied on an agent-first strategy, showing accurate comprehension of simple subject-verb-object sentences and subject relatives, but persistent difficulties with object topicalization, passives, and object relatives. CTH showed progress along the age range examined, with older children usually achieving comprehension of all structures except object relatives. Data-driven *k*-means clustering supported the theoretical profiles. These findings highlight distinct comprehension strategies and developmental trajectories in later childhood, demonstrating persistent morphosyntactic challenges in CHL and providing a framework for interpreting individual differences in sentence processing.

Abstract in Spanish: Este estudio investiga la comprensión oral de oraciones con distinta complejidad morfosintáctica en niños con hipoacusia prelocutiva (NH) y niños con desarrollo típico (NDT) hablantes de español, emparejados según su experiencia auditiva. Comparamos las habilidades de comprensión entre ambos grupos y exploramos el desarrollo de estrategias de comprensión a partir del análisis del rendimiento en distintos tipos de oraciones. Participantes con entre tres y 11 años de experiencia auditiva realizaron una tarea de emparejamiento oración-imagen en tableta. Los NH siguieron mayormente la estrategia de agente primero, con un buen desempeño en oraciones simples sujeto-verbo-objeto y relativas de sujeto, pero dificultades persistentes con la topicalización de objeto, las pasivas y las relativas de objeto. Los NDT mostraron progreso a lo largo del rango etario, de modo que los niños mayores generalmente alcanzaron la comprensión de todas las estructuras excepto las relativas de objeto. Un análisis de agrupamiento *k*-medias respaldó los perfiles teóricos. Estos resultados señalan estrategias de comprensión y trayectorias de desarrollo diferenciadas en la niñez tardía, evidencian desafíos morfosintácticos persistentes en los NH y ofrecen un marco para interpretar las diferencias individuales en el procesamiento de oraciones.

Introduction

Hearing loss affects approximately 34 million children worldwide (World Health Organization, 2024), with a prevalence ranging between 0.5% and over 2% depending on the region (Sheffield & Smith, 2019). Early-onset hearing loss can significantly impact oral language acquisition, which is the modality of communication in most families where children with hearing loss are born (Mitchell & Karchmer, 2004). Although hearing devices such as cochlear implants and hearing aids enable access to sound, the process of detection, diagnosis, device fitting, and habilitation often causes delays in exposure to spoken language. Moreover, hearing devices have inherent limitations: speech perception in noise remains challenging for hearing aid users (Walker, Sapp, et al., 2019), and cochlear implants provide reduced frequency resolution (Negm et al., 2024), which can affect the ability to segregate and attend to target speech in complex auditory environments (Reiss, 2020).

A wealth of research has shown that many children with prelingual hearing loss (CHL) experience language difficulties (Boons et al., 2013; Geers et al., 2009; Tomblin et al., 2015; Walker, Redfern, et al., 2019), in some cases despite early intervention (Wie et al., 2020) and persisting at least into adolescence (Delage & Tuller, 2007; Kronenberger & Pisoni, 2019). Sentence comprehension, in particular, often lags behind that of children with typical hearing (CTH), sometimes even compared to younger CTH. While their comprehension of simple sentences is usually preserved (Friedmann et al., 2008; Friedmann & Szterman, 2006; Norbury et al., 2002; Ruigendijk & Friedmann, 2017; Taboh et al., 2024), CHL often show poor comprehension of structures with non-canonical word order, such as object topicalization (Friedmann et al., 2008; Friedmann & Szterman, 2006; Fujiyoshi et al., 2012; Ruigendijk & Friedmann, 2017) and *wh*-questions (DeLuca et al., 2023; Friedmann & Haddad-Hanna, 2014; Friedmann & Szterman, 2011; Moita & Lobo, 2022; Ruigendijk & Friedmann, 2017; Schouwenaars et al., 2019), as well as structures with embedding, for instance, relative clauses (da Silva Braga, 2012; Friedmann et al., 2010; Friedmann & Haddad-Hanna, 2014; Friedmann & Szterman, 2006; Moita & Lobo, 2022; Ruigendijk & Friedmann, 2017; Volpato, 2020). These structures cannot be accurately interpreted using simple heuristic strategies. Instead, successful comprehension instead requires integrating syntactic cues (e.g., word order, morphological case marking) with lexico-semantic information to determine “who did what to whom,” making them especially demanding. For instance, a heuristic strategy could rely on assigning thematic roles based on linear order (e.g., an agent-first bias, where the first noun phrase is assumed to be the agent, Abbot-Smith et al., 2017; Gertner & Fisher, 2012). Indeed, if applied systematically, the agent-first bias would lead to good comprehension of structures

where the agent is in first position, but reversed interpretation of non-canonical sentences, resulting in below-chance performance rather than random guessing.

Interestingly, while evidence is generally consistent regarding difficulties with the aforementioned structures, research on passive sentences —though limited— is inconsistent: some studies report good comprehension (Norbury et al., 2002; Ruigendijk & Friedmann, 2017), whereas others find marked difficulties (Fujiyoshi et al., 2012; Moita & Lobo, 2022). It is possible that, in some languages, the greater salience of morphosyntactic cues in passive sentences (i.e., the auxiliary and the agent *by*-phrase) could help in overriding an agent-first bias, as has been suggested by Ruigendijk & Friedmann (2017).

Although difficulties with some non-canonical structures have been consistently reported in German, Hebrew, Italian, Arabic, and other languages, research on sentence comprehension in Spanish-speaking CHL remains scarce, as evidenced by a recent systematic review (to be disclosed after the peer-review process). Spanish offers an interesting testing ground because it allows relatively flexible word order, making it possible to examine whether CHL rely more heavily on heuristics or successfully integrate syntactic cues when interpreting sentences. Taboh et al. (2024) showed that Spanish-speaking CHL lagged behind CTH matched on hearing experience in their comprehension of active sentences with object topicalization. However, comprehension of other complex structures in Spanish has not yet been assessed in this population.

Research comparing CHL and CTH at the group level provides valuable insights, but such comparisons often mask substantial interindividual variability. For instance, Ruigendijk & Friedmann (2017) found that a group of CHL comprehended object relatives at chance level, with four out of 19 participants performing significantly above chance level and the other 15 at or below chance. While individual differences are also observed in typical language acquisition (Kidd & Donnelly, 2020), they are often greater in CHL, due to multiple factors, including degree and onset of hearing loss, type and timing of device fitting, duration of device use, therapy frequency, parental hearing status, and communication mode at home and school (Gillis, 2018; Tomblin et al., 2015). More broadly, prior studies show that while CHL as a group often perform worse than CTH, some individuals achieve near-ceiling performance or perform similarly to age-matched CTH even in challenging structures (Friedmann et al., 2010; Ruigendijk & Friedmann, 2017; Schouwenaars et al., 2019; Szterman & Friedmann, 2015).

Moreover, even when analyses of individual performance are included, they might not be sufficiently fine-grained. For example, sometimes studies report the proportion of children

performing above chance in each structure but do not distinguish between those who perform at or below chance (e.g., Ruigendijk & Friedmann, 2017; Volpato & Adani, 2009), even though they reflect very different underlying processes: performance at chance may reflect guessing, whereas below-chance patterns are compatible with systematic misinterpretations driven by strategies such as the agent-first bias. These findings underscore the importance of conducting detailed analyses at the individual level to uncover distinct patterns of sentence comprehension.

A growing body of studies has examined profiles of language performance in CHL, focusing on different domains. For example, looking at broad linguistic skills, Duchesne et al. (2009) identified four profiles in cochlear implant users based on receptive and expressive vocabulary and grammar, ranging from performance within normal limits across all domains to generalized delays. Other studies have focused more specifically on sentence comprehension and production, classifying children into subgroups according to their performance across different syntactic structures (Szterman & Friedmann, 2014, 2015; Wimmer et al., 2017). These studies often distinguish between children with selective deficits —e.g., difficulties restricted to structures with *Wh*-movement— and those with more generalized syntactic impairments. Importantly, they use comprehension profiles not only to characterize variability in performance, but also to draw inferences about the underlying processing mechanisms, shedding light on which aspects of syntactic processing pose the greatest challenges. Together, this body of work shows that CHL cannot be treated as a homogeneous group and highlights the need to move beyond group-level comparisons to analyze patterns of performance and comprehension strategies.

Recent work with other populations has applied clustering techniques to classify participants into data-driven profiles (Hamann & Abed Ibrahim, 2017; Manenti et al., 2024; Vogelzang & Torregrossa, 2024). For instance, Vogelzang & Torregrossa (2024) used *k*-means clustering to identify distinct reference production profiles in bilingual children. Similarly, clustering techniques have also been used to uncover reading strategies and ambiguity resolution mechanisms in adults (von der Malsburg & Vasishth, 2013). These findings support the use of clustering algorithms, such as *k*-means clustering, not only as a data-driven method for profile identification but also as a support tool for theory-driven classifications.

In light of this previous work, the present study addresses three main goals. First, we investigate sentence comprehension in Spanish-speaking CHL and CTH across a range of syntactic structures that vary in complexity and canonicity, comparing comprehension abilities

between the two groups. Second, we explore the development of comprehension strategies during childhood by examining whether children can be grouped according to their performance across different syntactic structures, thereby identifying comprehension profiles. Finally, we assess the distribution of these comprehension profiles across CHL and CTH and support our findings by comparing theoretically defined profiles with data-driven clusters obtained through *k*-means analyses.

Based on results from previous studies in other languages and on the limited research available in Spanish, we hypothesized that Spanish-speaking CHL's sentence comprehension would vary across morphosyntactic structures: comprehension would be preserved for simple active sentences with canonical word order but impaired for more complex structures. We further hypothesized that, at the group level, CHL would show greater difficulty with morphosyntactically complex sentences compared to CTH, and that this difference would increase as structures diverge further from the simple canonical active structure. For instance, within relative clauses, we expected object relatives to pose greater challenges than subject relatives, given that in the former the object of the relative clause precedes the verb, whereas in Spanish its unmarked position is postverbal. Moreover, we hypothesized that these comprehension difficulties would persist until older ages in CHL compared to CTH.

Method

Participants

This study included 71 CHL (aged 5;5 [years;months] to 14;7, $M = 9;9$, $SD = 2;2$, 30 female) and 71 CTH (aged 3;4 to 11;4, $M = 6;9$, $SD = 2;3$, 30 female). All participants were native Spanish speakers from Argentina. The CHL had not acquired any other language before receiving their hearing devices. All CHL had bilateral prelingual hearing loss, used cochlear implants and/or hearing aids, had been exposed exclusively or almost exclusively to spoken language (Spanish) – with little to no exposure to sign language – and communicated orally at home and at school. They had received their hearing devices between ages 0;7 and 5;5 ($M = 2;11$, $SD = 1;3$), and at the time of the study, their hearing age (i.e., the time with adequate access to sound, measured from the fitting of at least one effective device) ranged from 3;1 to 11;10 ($M = 6;9$, $SD = 2;3$). Forty-five children (63.4%) had bilateral cochlear implants, 12 (16.9%) used bilateral hearing aids (air or bone conduction), 11 (15.5%) had one cochlear implant and one hearing aid, and three (4.2%) had only one cochlear implant. Forty-three

children (60.6%) had profound hearing loss, 15 (21.1%) had severe hearing loss, eight (11.3%) had moderately severe hearing loss, and five (7%) had moderate hearing loss. Additional information on the clinical characteristics of this group is provided in Table S1 in Supplementary materials, available online at https://osf.io/g5c7s/overview?view_only=de83160b61a24be6a0ca89707a5f9c2a.

Each child from the CHL group was matched with a child from the CTH group of the same gender and hearing age (measured in months), which, for CTH, corresponds to their chronological age. The decision to match participants based on hearing age rather than chronological age stems from the fact that, in CHL, these two measures can differ substantially. Consequently, matching by chronological age would mean comparing CHL with peers who have had much longer exposure to language, which is useful for assessing whether CHL's language development is delayed relative to age expectations. However, this approach is less informative when the aim is to assess their linguistic skills more precisely. Instead, hearing age provides a more appropriate basis for comparison (Taboh et al., 2022), as it allows CHL to be matched with CTH who have had equivalent exposure to language, without penalizing them for the period during which they lacked access to it. When possible, matching was also done based on the mother's educational level as a proxy for socioeconomic status, measured in years of formal education. The CTH were randomly selected based on age and gender from a larger group recruited to examine the developmental trajectory of the sentence structures assessed in this study. A Wilcoxon signed-rank test confirmed that there were no statistically significant differences in auditory age between the two groups, $V = 1201$, $p = .661$, $r = .057$. However, significant differences were found in maternal educational level, which was significantly higher in the CTH group, $V = 410$, $p < .001$, $r = .607$. The demographic information of each participant is available in Table S2 in Supplementary materials.

Fourteen additional CHL were tested but were not included in the final sample for one of the following reasons: unilateral hearing loss ($n = 2$), exposure to another language (including sign language) at home ($n = 2$), long-term problems with their hearing device or device malfunction at the time of testing ($n = 2$), auditory age below three years ($n = 7$), or failure to complete the assessment ($n = 1$).

Participants were recruited through schools in the Buenos Aires Metropolitan Area. For CHL, these were special schools dedicated to the oral education of infants and children with hearing loss. These schools work with small groups and provide personalized instruction, as well as individual speech therapy and language intervention sessions, aiming to prepare CHL

for integration into mainstream schools alongside hearing peers. They also offer support sessions for CHL who have already transitioned to mainstream schools. Our sample included seven children who were mainstreamed and attended the special schools only for support sessions, while the other 64 were enrolled only in special schools and had not yet transitioned to mainstream education. CTH attended a private mainstream school in Buenos Aires.

Inclusion criteria required the absence of other developmental disorders unrelated to hearing loss in the CHL group and the absence of a history of neurological conditions, developmental disorders, learning disabilities, or language disorders in the CTH group.

The study followed the ethical principles established in the Declaration of Helsinki and Argentina's Personal Data Protection Law (No. 25326). It was approved by the Ethics Committee of the Facultad de Filosofía y Letras at Universidad de Buenos Aires (protocol number 017). Written informed consent was obtained from the parents/guardians of the children, and oral assent was obtained from the children.

Materials and Procedure

A sentence-picture matching task, similar to the one used by Friedmann & Szterman (2006), was designed to assess the comprehension of sentences with five syntactic structures: simple active sentences with canonical subject-verb-object word order (SVO), active sentences with non-canonical object-verb-subject order (OVS), passive voice sentences (PASS), and sentences with subject and object relative clauses (SR and OR, respectively) – see examples (1-5).

- (1) Active sentence with canonical word order (SVO):

La abuela besa a la princesa.

The grandmother kiss-3SG ACC the princess

'The grandmother kisses the princess.'

- (2) Active sentence with non-canonical word order (OVS):

A la abuela la besa la princesa.

ACC the grandmother CL.FEM kiss-3SG the princess

'The princess kisses the grandmother.'

- (3) Passive sentence (PASS):

La abuela es besada por la princesa.

the grandmother AUX kiss-PTCP by the princess

‘The grandmother is kissed by the princess.’

(4) Sentence with subject relative clause (SR):

La abuela que besa a la princesa vive lejos.

the grandmother REL kiss-3SG ACC the princess live-3SG far

‘The grandmother who kisses the princess lives far away.’

(5) Sentence with object relative clause (OR):

La abuela a la que besa la princesa vive lejos.

the grandmother ACC REL kiss-3SG the princess live-3SG far

‘The grandmother whom the princess kisses lives far away.’

Thirty transitive verbs and sixty nouns denoting animals, people, and professions were selected. These nouns were paired to form 30 noun pairs, and each verb was combined with two noun pairs, resulting in 60 different events (each verb was used twice with different nouns). For each event, five sentences were created, one for each syntactic structure, all in the present tense. A total of 300 sentences were generated and distributed across five lists using a Latin square design, ensuring that each list contained 12 sentences of each syntactic structure. For each of the 60 events, two pictures were created: one in which the first noun was the agent of the action and the second was the patient, and another in which the roles were reversed (see Figure 1). Appendix S1 in Supplemental materials provides all pictures along with the verb and noun combinations used to create the auditory stimuli.



Figure 1. An example for a picture pair used in the experiment. These pictures were presented along with one of the auditory stimuli in examples (1-5). The participant had to choose the picture that corresponded to the sentence they heard.

The sentence-picture matching task had a game-like format and was implemented digitally on a tablet. An animated character explained the game with simple examples, followed by a practice phase consisting of four trials and then a test phase comprising 60 trials. In each trial, the two illustrations of an event were displayed on the screen, and a recorded sentence was played. The participant had to tap the illustration that matched the sentence. During the practice phase, participants received visual feedback indicating whether their response was correct or not, whereas in the test phase, no feedback was provided. In both phases, if the participant did not respond within four seconds, they were prompted to listen again and the sentence was repeated. If there was still no response within four seconds, an attention prompt appeared to encourage a response. Finally, failure to respond within an additional four seconds prompted the task to advance to the next trial. During the test phase, motivational messages were displayed at intervals, and a break was provided every 20 trials. The duration of each break varied across participants, who resumed the task by tapping a button to continue. A demonstration video of the task is available at [to be disclosed after the peer-review process].

The location of the correct illustration (left or right) was counterbalanced across lists, as well as across the five syntactic structures within each list. The lists were administered so that each was presented to participants an equal amount of times. Stimuli presentation order was randomized. Participants' picture selection was recorded and accuracy subsequently calculated.

Two complementary tasks assessing abilities related to sentence comprehension were also included: the digit span subtest from the Spanish adaptation of the CELF-IV language assessment battery (Semel et al., 2003) was administered to all participants to obtain measures of short-term and working memory, and the Spanish adaptation of the Peabody Picture Vocabulary Test (Dunn et al., 1986) was administered to the CHL. Each participant's performance in these tasks is reported in Table S2 in Supplementary materials.

All tasks were administered by the first author. Testing was conducted individually in a quiet and familiar space within each child's educational institution. Each child was evaluated in two sessions of 15-20 minutes: one for the sentence comprehension task and another for the complementary tasks. After each session, children received stickers as a token of appreciation, even if they chose not to complete some tasks.

Analysis

Accuracy

The focus of the study was to assess the comprehension of structures with different morphosyntactic complexity. To this end, we conducted three analyses to comparing the comprehension of SVO sentences, as the baseline structure, with OVS, PASS, and sentences with relative clauses, respectively. This last analysis also included a comparison between the two types of relative clauses— SR and OR.

For each comparison, generalized linear mixed-effects models with a binomial function were used to analyze the probability of matching the sentence with the correct image as a function of group (CHL/CTH), syntactic structure, hearing age, and the interaction between group and structure. Maternal education level and children's chronological age were included as control variables. Random effects were included to capture variability between subjects and items, with random intercepts and random slopes for the Structure variable by subject, and random intercepts by item. The dependent variable was coded as 1 if the answer provided was correct and 0 if it was incorrect or if there was no response. For the binary explanatory variables—i.e., group and structure in the analyses of non-canonical active sentences and passives—orthogonal contrast coding was used: CTH and SVO were coded as 1, whereas CHL and OVS or PASS were coded as -1. For the analysis of relative clauses, a Helmert contrast was used to compare SVO sentences against relative clauses as a whole on one hand, and SR against OR on the other. The variables of hearing age and chronological age were measured in months and z-scored ($M = 0$, $SD = 1$) for analysis. These analyses were conducted using R software (v4.5.1; R Core Team, 2024) and R-Studio (v2025.05.1; Posit team, 2025) with the lme4 package (Bates et al., 2015) and the lmerTest package (Kuznetsova et al., 2017) to obtain p -values. The data file and script for analyses and figures are provided in Supplementary materials, available at https://osf.io/g5c7s/overview?view_only=de83160b61a24be6a0ca89707a5f9c2a.

Comprehension strategy profiles

Based on prior findings on individual variability in CHL performance, an analysis was conducted in order to explore potential comprehension strategies and identify different performance profiles among participants, considering comprehension across all five sentence structures (SVO, OVS, PASS, SR, and OR). For each participant and structure, accuracy was compared against chance level (50%) using a binomial test, following Ruigendijk & Friedmann

(2017). With 12 observations per structure, this test yielded significantly above-chance performance with 10 correct responses (83.3%) or more, and significantly below chance performance with two correct responses (16.7%) or less. Based on these thresholds, participants were classified into hypothesized profiles according to their individual pattern of comprehension across the five structures, following previous studies using a similar approach (Szterman & Friedmann, 2014, 2015).

To complement our theoretically defined comprehension profiles, we applied a *k*-means clustering algorithm to the individual accuracy scores across the five sentence structures, treating accuracy as a five-dimensional vector. *K*-means (MacQueen, 1967) is a simple unsupervised clustering method that partitions observations into a predefined number of clusters based on the patterns in the data itself. Importantly, this procedure does not take participants' group membership (CHL or CTH) into account; instead, it classifies them solely according to their performance. This approach allows us to examine whether systematic patterns of comprehension—reflecting underlying strategies—emerge naturally from the data, providing evidence for the profiles defined *a priori*. The number of clusters was set to $k = 7$, matching the number of hypothesized profiles. Clustering was performed in R (v4.4.2; R Core Team, 2024) and R-Studio (v2025.05.1; Posit team, 2025) using the `kmeans()` function. We then compared the resulting clusters with the theoretically defined profiles, examining both the correspondence between classification schemes and the distribution of participants across profiles and clusters.

Results

Accuracy

An examination of overall comprehension levels –considering all structures together– reveals a clear difference between the CTH and CHL groups, as shown in panel A in Figure 2. While at early hearing ages participants from both groups exhibit similar overall comprehension, around five years of hearing age the groups begin to diverge, and this difference becomes more pronounced across the hearing age range examined. This divergence arises because comprehension levels increase substantially with hearing age in the CTH group, whereas the performance of CHL remains relatively stable around 40-50%. However, the CHL group's overall performance around chance level is actually the result of markedly different comprehension patterns across structures, as can be seen in panel B in Figure 2. Both groups

demonstrated good comprehension of SVO and SR sentences, with accuracy rates around 80% and significantly above chance. For the remaining structures, the CHL group showed comprehension levels significantly below chance for OVS, PASS, and OR sentences. In contrast, in the CTH group, only OR sentences were comprehended significantly below chance, whereas for OVS and PASS sentences comprehension levels did not reach those observed for SVO and SR but were still significantly above chance.

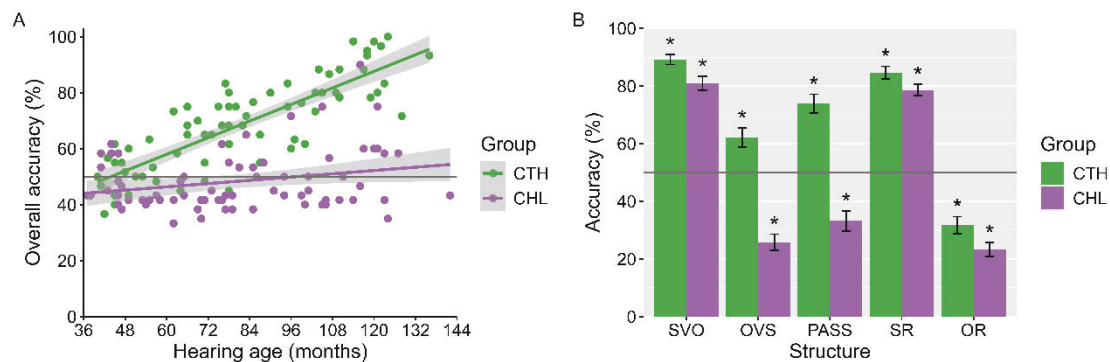


Figure 2. Individual overall accuracy as a function of hearing age for children with typical hearing (CTH) and children with hearing loss (CHL) (panel A) and accuracy in each structure by group (panel B). The gray line indicates chance level (50%). In panel A, shading indicates the 95% confidence interval around each regression line. In panel B, error bars represent the standard error of the mean and asterisks mark performance significantly different from chance. SVO = simple active sentences with canonical word order, OVS = active sentences with non-canonical order, PASS = passive sentences, SR = subject relative clauses, OR = object relative clauses.

Statistical analysis of accuracy revealed significant effects of both group and structure across all comparisons (see Table 1). In the SVO versus OVS comparison, the CTH ($M = 75.7\%$, $SE = 2.2$) were more likely to match the sentence to the correct image than the CHL ($M = 53.4\%$, $SE = 1.4$; $\beta = 0.919$, $SE = 0.163$, $z = 5.624$, $p < .001$). Accuracy was higher for SVO sentences ($M = 85.1\%$, $SE = 1.5$) than for OVS sentences ($M = 44\%$, $SE = 2.6$; $\beta = 1.279$, $SE = 0.098$, $z = 13.062$, $p < .001$). Additionally, there was a positive effect of hearing age on the probability of responding correctly, meaning that greater hearing age was associated with higher accuracy ($\beta = 0.440$, $SE = 0.201$, $z = 2.191$, $p = .028$). A significant interaction between group and structure was also found ($\beta = -0.340$, $SE = 0.094$, $z = -3.625$, $p < .001$). Post-hoc multiple comparisons revealed significantly higher comprehension levels for the CTH group compared to the CHL group for both SVO sentences (CTH: $M = 89.2\%$, $SE = 1.7$; CHL: $M = 81\%$,

$SE = 2.4; p = .010$) and OVS sentences (CTH: $M = 62.2\%$, $SE = 3.3$; CHL: $M = 25.8\%$, $SE = 2.8$; $p < .001$), though the difference was larger for OVS sentences.

Similarly, in the SVO versus PASS comparison, the CTH group ($M = 81.6\%$, $SE = 2.2$) outperformed the CHL group ($M = 57.1\%$, $SE = 2.1$; $\beta = 1.072$, $SE = 0.191$, $z = 5.622$, $p < .001$). SVO sentences were better comprehended than PASS sentences ($M = 53.6\%$, $SE = 2.9$; $\beta = 0.998$, $SE = 0.096$, $z = 10.410$, $p < .001$), and hearing age positively predicted accuracy ($\beta = 0.611$, $SE = 0.231$, $z = 2.645$, $p = .008$). The interaction between group and structure was again significant ($\beta = -0.421$, $SE = 0.092$, $z = -4.604$, $p < .001$), with post-hoc tests confirming higher comprehension for CTH than CHL for both SVO (CTH: $M = 89.2\%$, $SE = 1.7$; CHL: $M = 81\%$, $SE = 2.4$; $p = .009$) and PASS (CTH: $M = 73.9\%$, $SE = 3.2$; CHL: $M = 33.2\%$, $SE = 3.5$; $p < .001$), with a larger group difference for PASS sentences.

Finally, in the comparison of SVO and relative clauses, significant effects of group and structure were also observed. CTH ($M = 73.7\%$, $SE = 1.8$) were more likely to respond correctly than CHL ($M = 66\%$, $SE = 1.8$; $\beta = 0.545$, $SE = 0.104$, $z = 5.228$, $p < .001$). SVO sentences were better comprehended than relative clauses (SR and OR combined; $M = 54.6\%$, $SE = 1$; $\beta = 1.334$, $SE = 0.102$, $z = 13.055$, $p < .001$). Within relative clauses, a significant effect of type of relative clause emerged: SR yielded higher accuracy ($M = 81.6\%$, $SE = 1.5$) than OR ($M = 27.5\%$, $SE = 1.9$; $\beta = 1.538$, $SE = 0.097$, $z = 15.930$, $p < .001$). The interaction between group and structure was not significant. Unlike in the other comparisons, hearing age did not significantly predict accuracy, whereas chronological age had a positive effect ($\beta = 0.490$, $SE = 0.156$, $z = 3.149$, $p = .002$).

Table 1. Fixed effects from models predicting the probability of matching the correct picture for three sentence comparisons: SVO vs. OVS (left), passive (center), and subject and object relative clauses (right).

Term	SVO vs OVS				SVO vs Passives				SVO vs Relatives			
	β	SE	z	p	β	SE	z	p	β	SE	z	p
(Intercept)	0.982	0.091	10.799	< .001	1.361	0.107	12.690	< .001	0.949	0.065	14.622	< .001
Group	0.919	0.163	5.624	< .001	1.072	0.191	5.622	< .001	0.545	0.104	5.228	< .001
Structure	1.279	0.098	13.062	< .001	0.998	0.096	10.410	< .001	1.334	0.102	13.055	< .001
Type of relative clause: subject vs object relative									1.538	0.097	15.930	< .001
Hearing age (months)	0.440	0.201	2.191	.028	0.611	0.231	2.645	.008	0.112	0.130	0.866	.387
Maternal education (years)	0.068	0.089	0.766	.444	0.145	0.106	1.364	.172	0.098	0.057	1.726	.084
Chronological age (months)	0.383	0.243	1.577	.115	0.451	0.280	1.610	.107	0.490	0.156	3.149	.002
Group x Structure	-0.340	0.094	-3.625	< .001	-0.421	0.092	-4.604	< .001	0.100	0.092	1.079	.280
Group x Type of relative clause									-0.013	0.094	-0.139	.890

Note. SVO = active sentences with canonical subject-verb-object order. OVS = active sentences with non-canonical object-verb-subject order. β : Coefficient. SE = Standard error. z = z-value. p = p-value. Statistically significant effects are colored.

To further explore how comprehension develops with hearing experience, we divided the sample into quartiles based on hearing age, which represents the duration of adequate exposure to sound. CHL-CTH pairs were ordered by the CHL's hearing age and split into subgroups of 17 or 18 pairs, resulting in quartiles with hearing age ranges of 3;1–4;7, 4;9–6;5, 6;6–8;9, and 8;9–11;10, respectively (see Table S3 in Supplementary materials for more information). Figure 3 presents the mean accuracy for each structure in the CTH and CHL within each hearing age quartile. Each bar in the figure represents the average performance of participants within a given quartile. Performance that differed significantly from chance (after Bonferroni correction for multiple comparisons) is indicated with asterisks above the bars. This visualization complements the overall analyses by showing how comprehension of SVO, OVS, PASS, and subject and object relative clause structures develops with increasing hearing age in each group. The formal analyses by quartile are reported in Tables S4-S6 in Supplementary materials.

From an early hearing age, both CTH and CHL showed good comprehension of SVO and SR sentences, with accuracy consistently above chance across quartiles, except for the first CHL quartile with SVO, where performance approached 70% but did not reach statistical significance after correcting for multiple comparisons. Accuracy for these two structures increased progressively across quartiles. In contrast, OVS and PASS sentences were initially challenging for the youngest CTH, with performance at chance in the first quartile. PASS comprehension improved by the second quartile and approached SVO and SR levels by the fourth quartile, whereas difficulties with OVS persisted longer, with chance-level performance through the third quartile, and accuracy exceeding 90% in the fourth quartile. CHL, however, showed no clear improvement with age: OVS comprehension remained below chance in the first, second, and fourth quartiles and at chance in the third, while PASS comprehension was below chance in the first two quartiles and at chance in the latter two. Finally, OR posed substantial difficulties for both groups in all quartiles, with accuracy below chance except for the CTH in the eldest quartile, where it reached chance level.

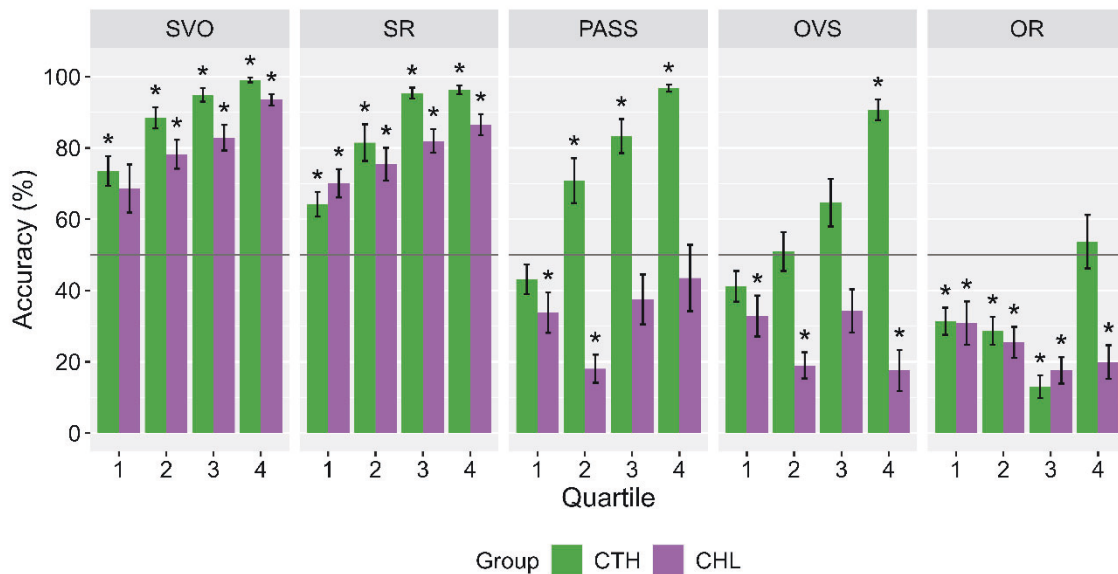


Figure 3. Average accuracy for simple active sentences with canonical word order (SVO), subject relative clauses (SR), active sentences with non-canonical order (OVS), passive sentences (PASS), and object relative clauses (OR), for children with typical hearing (CTH) and children with hearing loss (CHL) in each hearing age quartile. Error bars represent the standard error of the mean. The gray line indicates chance level (50%). Asterisks mark performance significantly different from chance after Bonferroni correction ($p < .0125$).

Comprehension strategy profiles

For CHL, a clear pattern emerged at the group level, with comprehension above chance for SVO and SR, and below chance for OVS, PASS, and OR sentences, as can be seen in Figure 2 (panel B). This pattern is consistent with the agent-first bias. Importantly, this not only suggests that CHL had difficulties with sentences where the agent was not in first position, but also that, for these sentences, they were not randomly choosing one picture or the other, but rather systematically reversing the thematic roles. However, individual overall accuracy ranged from around 30 to 90% (Figure 2, panel A), indicating that performance at the group level masked substantial variability. Moreover, the inspection of accuracy by hearing age quartiles showed that not all quartiles had comprehension patterns compatible with the agent-first bias (Figure 3). Specifically, the two older quartiles performed at chance with PASS sentences, suggesting that some children may have been able to comprehend these.

In light of this variability, and with the aim of uncovering the individual comprehension strategies behind the group-level patterns, we hypothesized the following profiles, ordered from most to least linguistic competence:

- **No difficulties:** accuracy significantly above chance in all structures.
- **Difficulties only with OR:** accuracy above chance for all structures except OR, where performance was at or below chance. This pattern suggests difficulties only when non-canonical word order and embedding occur together, but not when these sources of complexity appear separately.
- **Agent-first strategy + salience:** accuracy above chance for SVO, SR, and PASS, but below chance for OVS and OR. This profile suggests reliance on a linear heuristic assigning the agent role to the first noun phrase, unless salient morphology provides cues for thematic role assignment, as is the case in PASS.
- **Agent-first strategy:** accuracy above chance for SVO and SR, but below chance for OVS, PASS, and OR, indicating reliance on a linear heuristic without benefit from morphological salience.
- **Difficulties with non-canonical order and embedding:** accuracy above chance only for SVO, with chance-level or below-chance performance for all other structures, reflecting difficulties with both non-canonical order and embedding, even when they occur separately.
- **At-chance performance:** comprehension at chance for all structures, suggesting the absence of a predominant comprehension strategy.

This classification was based on stringent criteria for determining significant differences from chance (i.e., the binomial test required accuracy of 83.3% or higher for performance above chance, and 16.7% or lower for performance below chance). As a consequence, some of these profiles required quite extreme performance (i.e., very high or very low). Participants with comprehension patterns that did not match any of the profiles defined above were classified as “Other”. This additional category also captured participants whose patterns resembled one of the profiles but did not meet its thresholds.

Among CHL, the most frequent comprehension profile corresponded to the use of an agent-first strategy, with a little over one-fifth of the participants ($n = 15$) falling into this category (see panel A in Figure 4 for the distribution of participants from each group across profiles). In contrast, only one child with typical hearing showed this pattern. For the CTH group, the most common profile was the one reflecting selective difficulties with OR

sentences, which included just over one-fifth of the participants ($n = 16$), while only two CHL were classified in this profile.

Both groups included a subset of children who understood only SVO sentences above chance and others who did not perform above chance in any structure; the proportion of participants in these two profiles was higher in the CHL group than in the CTH group (only SVO above chance: 5 CTH, 7 CHL; all at chance: 7 CTH, 13 CHL). A small number of CTH ($n = 6$) showed comprehension above chance for all sentence structures, including OR sentences, a pattern not observed in any child with hearing loss. Moreover, only one child with typical hearing and two CHL were classified in the agent-first strategy + salience profile. Finally, approximately half of the participants in both groups (35 CTH, 30 CHL) exhibited comprehension patterns that did not match any of the theoretically defined profiles.

Notably, within the CTH group, profiles indicating broader difficulties were present at early hearing ages, whereas children in the higher half of the age range developed strategies that allowed them to comprehend all structures except OR. At even higher hearing ages, some were also able to comprehend OR. Thus, the distribution of profiles in this group was heavily age-dependent (see panel B in Figure 4 for the distribution of profiles as a function of group and hearing age). In contrast, in the CHL group, profiles reflecting widespread difficulties were present not only at early hearing ages but also later. Additionally, although most CHL in the second half of the age range were able to comprehend SR sentences, they predominantly adopted the agent-first strategy, and even children with higher hearing ages did not seem to outgrow it. Finally, this group showed remarkable variability among children with similar hearing ages. For instance, children with a hearing age of around 120 months were classified into four different profiles.

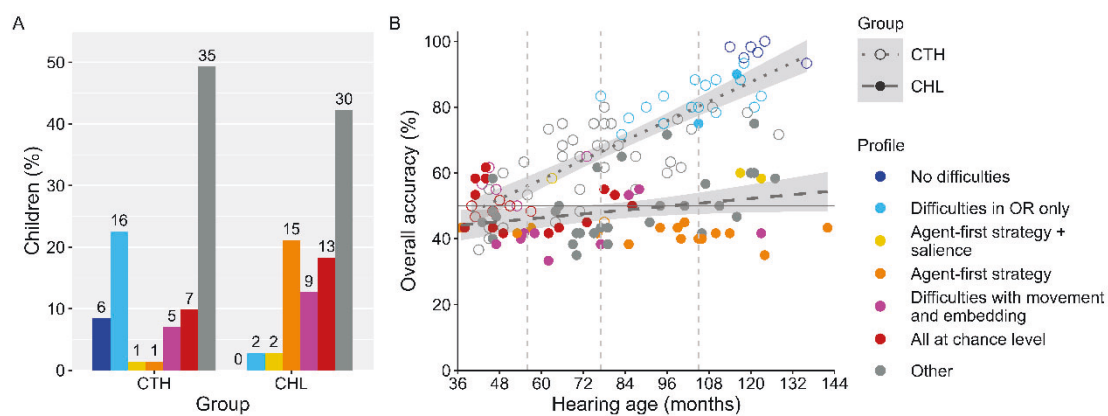


Figure 4. Classification of children with typical hearing (CTH) and children with hearing loss (CHL) into theoretical comprehension profiles. Colors denote the assigned profile. Panel A shows the percentage of children in each profile (numbers above bars indicate raw counts). Panel B shows the distribution as a function of hearing age. Each point represents one child, the gray line indicates chance level (50%), shading represents the 95% confidence interval around each regression line, and vertical dashed lines indicate the divisions into hearing age quartiles. OR = object relatives.

These theoretically defined profiles can also be visualized by plotting accuracy in each structure. In Figure 5, points and solid thick lines show the mean accuracy, while solid thin lines indicate the score ranges for each syntactic structure of the children classified into each theoretical profile. Structures are sorted in increasing complexity, which results in sigmoid-shaped profiles. Furthermore, each profile assumes one more low-performance structure than the previous one. If the emergence of the profiles was ordered by age, it would mean that children learn structures progressively, one at a time –SVO first, then SR, PASS, OVS, and lastly OR–, although longitudinal data is needed to further support this claim.

To further support the distinction among these *a priori* profiles, we compared them with the empirical clusters obtained through *k*-means clustering. As mentioned, this clustering algorithm is blind to linguistic theory and participant information, and classifies children based solely on their performance. In Figure 5, dashed lines show mean accuracy and score ranges for each syntactic structure of children classified into each cluster. Each data-driven cluster was matched to a theoretical profile based on mean accuracy in each structure. Both classifications are displayed superimposed to facilitate visual comparison, allowing us to evaluate the extent to which the accuracy patterns predicted by our theoretical profiles correspond to the empirical groupings.

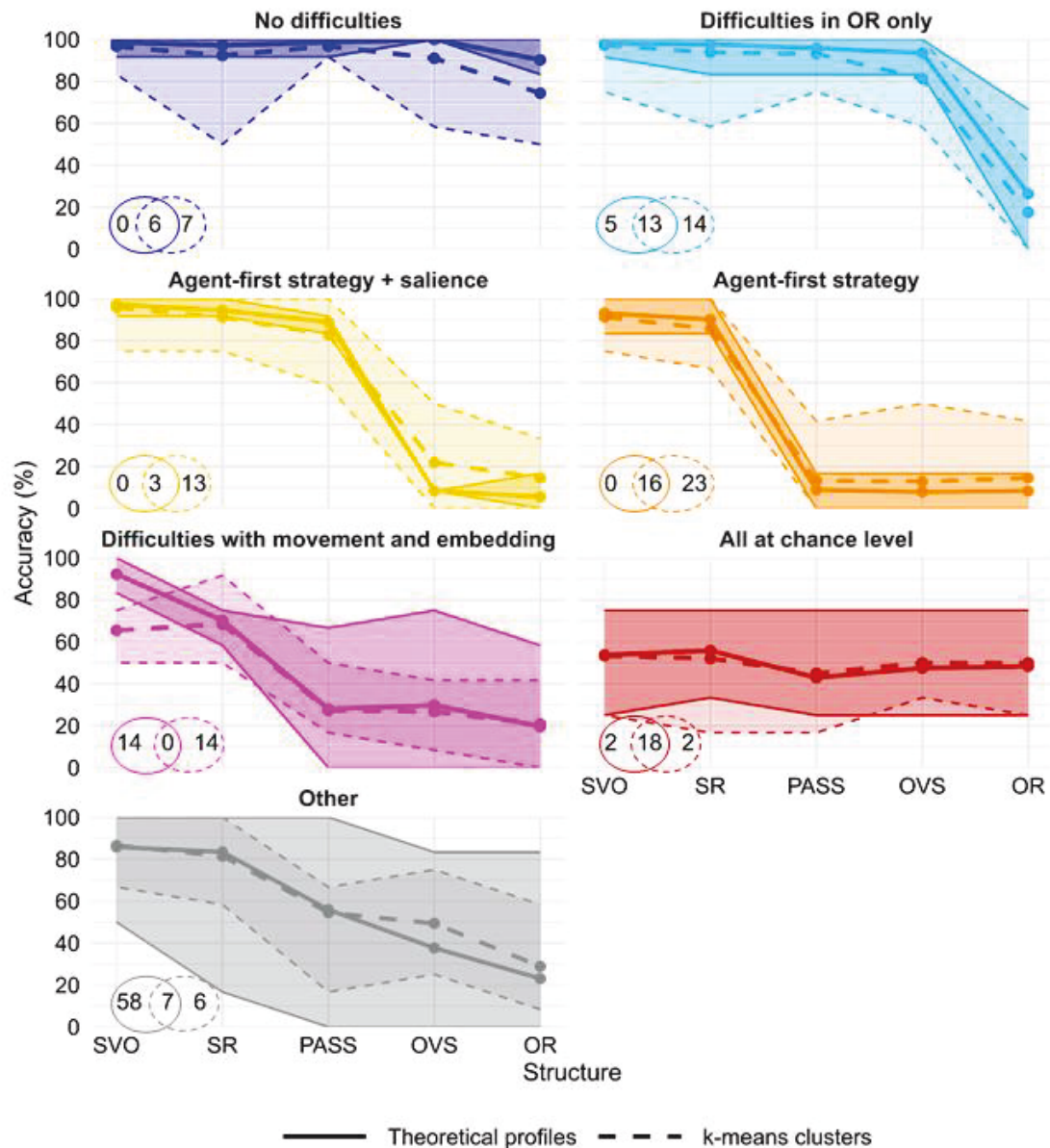


Figure 5. Mean accuracy and score ranges for each syntactic structure within each theoretical profile and data-driven cluster, with both classifications overlaid to facilitate visual comparison. The lower-left corner of each panel indicates the number of participants classified into each profile by the theoretical classification alone (left), into each cluster by *k*-means alone (right), and by both classifications (center). SVO = simple active sentences with canonical word order. SR = subject relative clauses. OVS = active sentences with non-canonical order. PASS = passive sentences. OR = object relative clauses.

Visual inspection of Figure 5 shows that the mean accuracy of the matched *k*-means clusters closely matches that of the theoretical profiles across all syntactic structures. However, the empirical clusters generally display wider score ranges, reflecting greater

variability among participants than is captured by the theoretical profiles. Overall, of the participants we were able to classify into a clearly distinguishable profile, 72.7% (56 out of 77) were assigned to the same profile/cluster by both classifications.

Participants categorized as “Other” by the theoretical classification did not meet the criteria set by the binomial test. However, *k*-means clustering showed that many of them clustered near the clearly defined theoretical profiles. For example, the “agent-first strategy” cluster included 39 children, compared to 16 in the equivalent theoretical profile; the “difficulties in OR only” cluster included 27 children, compared to 17; the “agent-first strategy + salience” cluster included 16 children, compared to 3; and the “no difficulties” cluster included 13 children, compared to 6. Importantly, the clustering results highlighted distinct comprehension patterns across groups: the larger proportion of children in the “agent-first strategy” cluster corresponded mainly to CHL, whereas the larger proportion in the “no difficulties” cluster corresponded mostly to CTH and the increase in the “difficulties in OR only” cluster was exclusive to CTH (see Figure S1 in Supplementary materials for the distribution of participants from each group across clusters).

This comparison also suggests that *k*-means provides a less stringent classification than the theoretical approach, as fewer participants fell into the “Other” category. In other words, the clustering analysis groups children into broader categories with wider score ranges, while the theoretical profiles require more extreme performance to be met. We then explored whether convergence between the two approaches is higher under less demanding criteria. We recalculated the theoretical profiles using more relaxed thresholds for determining performance above and below chance, based on raw percentages rather than statistical significance: 75-25% (9-3/12 correct) and 66.7-33.3% (8-5/12 correct). When applying these thresholds, more children could be classified into clearly defined profiles, and the percentage assigned to the same profile/cluster increased substantially, reaching 84.5% (71 out of 84) and 88.2% (82 out of 93), respectively (excluding the “Other” category).

Discussion

In the present study, we examined sentence comprehension in Spanish-speaking CHL and CTH, ranging in hearing age from 3;1 to 11;10. Using a sentence-picture matching task, we assessed comprehension of five different sentence structures varying in syntactic complexity and word order, including simple active sentences with canonical and non-canonical word

order, passives, and relative clauses. Our aim was to characterize patterns of comprehension in CHL, compare them to CTH, and investigate individual profiles of performance across different sentence structures.

Overall, CHL showed relatively good comprehension of the SVO sentences –the baseline structure– with accuracy above 81% at the group level and performance increasing across hearing age quartiles, from 68.6% accuracy in the youngest quartile to 93.5% in the oldest. However, CHL still performed significantly below CTH. While most previous studies on CHL report ceiling or near-ceiling comprehension of these structures (Friedmann et al., 2008, 2016; Friedmann & Haddad-Hanna, 2014; Friedmann & Szterman, 2006; Fujiyoshi et al., 2012; Norbury et al., 2002; Ruigendijk & Friedmann, 2017; Szterman & Friedmann, 2015), some have found differences relative to CTH (Delcenserie et al., 2021; Fortunato, 2015). It is important to note that these studies typically compared groups matched by chronological age, thus differing in hearing age. Matching by hearing age, as done here, avoids penalizing CHL for delayed exposure to language and allows for a more precise assessment of linguistic development (Taboh et al., 2022). The finding that CHL underperformed relative to CTH of the same hearing age suggests that differences reported in prior studies may not solely reflect differences in cumulative language exposure.

When considering OVS sentences, CHL comprehension was markedly lower than that of CTH, similarly to previous studies in other languages (Friedmann et al., 2008; Friedmann & Szterman, 2006; Ruigendijk & Friedmann, 2017). All hearing age quartiles of CHL performed below the first quartile of CTH, indicating persistent difficulty. Nevertheless, CTH showed modest performance on this structure (41.2–64.6% in the first three quartiles), suggesting that it is typically acquired later in development. Previous studies in Spanish and other languages similarly report relatively late typical acquisition of OVS sentences (Biran & Ruigendijk, 2015; Dittmar et al., 2008; Muñoz et al., 2014; Schipke et al., 2012).

Passive sentences also posed significant challenges for CHL, who performed below CTH and below chance in the younger quartiles. Although a slight increase in performance was observed in older hearing age quartiles, CHL did not surpass chance level. This contrasts with some prior studies in other languages reporting comparable comprehension between CHL and CTH of the same chronological age (Norbury et al., 2002; Ruigendijk & Friedmann, 2017), although differences in matching criteria and population heterogeneity obscure comparisons.

Regarding relative clauses, SR were well understood by both groups (CHL = 78.6%, CTH = 84.6%), with comprehension levels similar to those of SVO sentences. These results are

aligned with those of previous studies in other languages that also found preserved comprehension of these structures, although accuracy levels were often higher than in our study, above 90% (Friedmann et al., 2008; Friedmann & Costa, 2011; Friedmann & Haddad-Hanna, 2014; Friedmann & Szterman, 2006; Ruigendijk & Friedmann, 2017).

In contrast to SR, OR were challenging, with low comprehension levels in both groups, (similar to OVS in CHL, lower than OVS in CTH), and below-chance performance in all hearing age quartiles, except for the oldest CTH quartile, which was at chance. CHL's difficulties with OR compared to younger CTH have been consistently reported in other languages (da Silva Braga, 2012; Friedmann et al., 2010; Friedmann & Haddad-Hanna, 2014; Friedmann & Szterman, 2006), indicating considerable and persistent difficulties. Regarding typical development, these findings also align with previous evidence of performance below 50% in various groups of Spanish-speaking children aged 4-11 (Llompert & Dąbrowska, 2024; Presotto & Torregrossa, 2024; Zamora et al., 2023), indicating late acquisition in this language.

Considering all five syntactic structures, two distinct patterns emerged for the two groups of children. CTH performed above chance on all structures except OR, and showed clear differences between quartiles, with accuracy on PASS and OVS sentences increasing from chance level to above 90%. In contrast, CHL exceeded chance level only on the structures with the agent in first position (SVO and SR) and scored below chance on the others (OVS, PASS, and OR). This pattern was largely consistent across quartiles, with minimal differences between them. Beyond indicating difficulties with sentences with non-canonical order in CHL, the pattern suggests that these children often reversed thematic roles, possibly following an agent-first bias. However, the group-level results may conceal substantial individual variability, with some children comprehending non-canonical sentences well and others very poorly. To investigate whether comprehension strategies varied among children, we analyzed individual performance in each structure and classified children into theoretically defined comprehension profiles.

Analyses of individual comprehension profiles showed that, in general, the different theoretical profiles were present in both groups of children, though with markedly different frequency. CHL predominantly relied on an agent-first strategy, assigning the agent role to the first noun phrase. This resulted in accurate comprehension of SVO and SR sentences but consistent reversed interpretation of OVS, PASS, and OR. This profile was predominant across the range of hearing age, indicating persistent difficulties in the integration of morphosyntactic cues (e.g., case marking and passive morphology). Nevertheless, a small subset of CHL

achieved performance comparable to CTH of the same hearing age, even on complex structures, highlighting the need to investigate sources of individual differences.

In contrast to CHL, the predominant profile among CTH indicated good comprehension across all structures except OR, which are very complex because they involve embedding and non-canonical word order. Very few CTH exhibited an agent-first strategy profile, though such a profile may be more characteristic of children younger than those included in our study (i.e., under age 3;4).

A substantial proportion of children in both groups did not fit the proposed profiles, suggesting variability in comprehension strategies. However, it is important to note that the theoretical profile classification relied on very stringent criteria: performance above or below chance was defined using the binomial test (83.3% accuracy or higher for above chance; 16.7% or lower for below chance). Participants who did not meet these thresholds were classified as “Other.” Using less conservative thresholds (75-25% and 66.7-33.3%) resulted in a larger number of children captured by clearly defined profiles, suggesting that some children in the “Other” category displayed comprehension patterns similar to the theoretical profiles but did not meet the extreme performance criteria.

Correspondence between the theoretical profiles and data-driven *k*-means clusters further supports the robustness of our classification approach. *K*-means clustering, which is blind to theoretical assumptions and participant information, resulted in clusters that closely mirrored the theoretical profiles. When considering participants in clearly distinguishable theoretical profiles, a high proportion of participants were classified similarly by both approaches. Notably, very few participants classified as “Other” by the theoretical approach were not captured by any of the clusters corresponding to clearly defined profiles, indicating that *k*-means provides a less stringent classification resulting in broader score ranges. Moreover, the clustering analysis highlighted group-specific patterns even more clearly: the predominance of the “agent-first strategy” cluster in CHL and of the “difficulties in OR only” and “no difficulties” clusters in CTH was more pronounced than in the theoretical classification. Finally, the percentage of children assigned to the same profile/cluster increased substantially when theoretical profiles were recalculated using less demanding thresholds.

These results show that the *k*-means clusters largely reflect the comprehension patterns predicted by the theoretical profiles, while also capturing additional variability, particularly among participants in the “Other” category. This provides converging evidence that the profiles represent meaningful differences in sentence comprehension strategies

among children with and without hearing loss, and sets the stage for interpreting group differences and developmental trends.

The findings of the current study should be considered in light of some limitations. First, because it is a cross-sectional study, results of performance across the hearing age range should be considered with caution. Longitudinal studies are necessary to examine the progression of sentence comprehension as hearing age increases and shed light on developmental trajectories. Moreover, studies covering a wider range of hearing age could explore whether morphosyntactic integration emerges later in CHL. Second, the sample primarily included CHL attending special schools, limiting generalizability. Future research should explore whether CHL in mainstream education exhibit similar performance and profile distributions. Finally, studies with larger, more representative samples would also allow examining how audiological, cognitive, and demographic factors contribute to comprehension outcomes.

Despite these limitations, our findings have several implications for the study of language acquisition. First, they broaden our understanding of oral language development in CHL, contributing novel evidence from Spanish. They also provide new insights into typical development of sentence comprehension in Spanish, an area where evidence is also scarce. From a practical perspective, these results suggest that education and speech-language therapy professionals working with CHL should be aware that case-marking is acquired relatively late in Spanish, even by children with typical hearing. Moreover, interventions targeting CHL should consider that many children appear to rely on heuristic strategies when interpreting sentences, rather than fully analyzing morphosyntactic cues. Therefore, language support programs might benefit from combining explicit instruction on challenging structures, such as OR, OVS, and PASS, with activities that encourage children to process sentences more analytically, moving beyond heuristic-based comprehension. Furthermore, assessing comprehension profiles at the individual level, as illustrated here, may guide more personalized intervention strategies, identifying children who could benefit from more intensive support.

In sum, this study provides a novel examination of sentence comprehension in Spanish-speaking CHL, revealing both group-level differences and marked individual variability. By highlighting the role of syntactic complexity and identifying specific comprehension profiles, our findings inform theoretical models of language acquisition and offer actionable insights for

educational and clinical practice. Together, they highlight the importance of tailoring support to the diverse linguistic needs of CHL.

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