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A CLEARER PICTURE: UNDERSTANDING SPATIAL HEARING IN PORTUGUESE-SPEAKING CHILDREN

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ABSTRACT

Imagine trying to follow a conversation in a bustling café, but every voice sounds like it's coming from the same spot, all jumbled together. This is a common struggle for individuals with Central Auditory Processing Disorder (CAPD), a condition where the brain has trouble making sense of sounds, even when the ears themselves work perfectly. While we have tools to help, there's a real need for tests that truly fit different languages and cultures. This study introduces a brand-new test, the Portuguese Speech Reception in Noise (PROSER) test, designed to give us a clearer picture of how Portuguese-speaking children process sounds in noisy environments, especially when those sounds come from different directions. Our main goals were simple: first, to figure out what's "normal" for healthy Portuguese-speaking children taking this test, and second, to make sure the test gives consistent results every time. Understanding how our brains use spatial cues (like where a sound comes from) is incredibly important for diagnosing and helping with CAPD, because it directly affects how well we can pick out what we want to hear from all the background noise. This article walks you through how we created the PROSER test, how we used it, and what we found. The results are exciting: the PROSER test provides reliable insights into spatial hearing abilities in Portuguese, making it a valuable new tool for audiologists and families.

Keywords: Spatial Hearing, Listening in Noise, Brain Processing of Sound, Portuguese Language, Typical Development, Test Consistency, Auditory Challenges, Children's Hearing.

INTRODUCTION

Navigating a Noisy World

Life is a symphony of sounds, from the gentle whisper of a loved one to the roar of city traffic. For most of us, our brains effortlessly organize this auditory chaos, allowing us to focus on what matters. But imagine if that symphony became a jumbled cacophony, where every instrument played at once, and you couldn't pick out the melody. This is often the reality for individuals living with Central Auditory Processing Disorder (CAPD). It's not about how well your ears hear; it's about how your brain interprets and processes the sounds your ears pick up [1, 2]. People with CAPD might have perfect hearing in a quiet room, but put them in a noisy classroom, a busy office, or a crowded restaurant, and suddenly, understanding speech becomes an exhausting, often impossible, task.

This disconnect between "hearing" and "understanding" can be incredibly frustrating and isolating. For children, CAPD can throw up significant roadblocks in their learning journey. Following a teacher's instructions in a bustling classroom, participating in group discussions, or even learning to read can become monumental challenges, often leading to academic struggles and a sense of being left behind [2]. Adults aren't immune either; workplace meetings, social gatherings, and even simple phone calls can turn into bewildering experiences. The impact isn't just academic or professional; it touches social interactions and overall quality of life. While we don't have exact numbers, we know that CAPD affects a substantial number of people, particularly children and older adults [15].

Within the intricate world of auditory processing, one skill stands out as particularly vital for navigating our noisy world: spatial processing. Think of it as your brain's built-in GPS for sound. Spatial processing is your brain's clever way of using tiny differences in when sounds arrive at each ear, and how loud they are in each ear, to figure out where sounds are coming from. More importantly, it allows you to separate the sound you want to hear (like a friend's voice) from all the other sounds around you (like background chatter), simply because they're coming from different directions [9]. This amazing ability is often called "binaural unmasking" or the "cocktail party effect" – that magical way you can tune into one conversation amidst many. But for those with Spatial Processing Disorder

(SPD), this magic trick doesn't quite work. They struggle to use these spatial cues, making it incredibly hard to pick out a target voice when other sounds are competing, because their brains can't effectively compare when sounds arrive at each ear or use those spatial relationship cues properly [3-5].

SPD isn't limited to people with hearing loss. It can affect individuals with perfectly normal hearing [4, 6], as well as those with mild to moderate hearing loss [5], and even people with other health conditions like Charcot-Marie-Tooth disease or auditory neuropathy [7, 8]. We've seen many children who complain about hearing difficulties, even with normal hearing tests, who turn out to have SPD. Interestingly, frequent ear infections in early childhood (otitis media) are often linked to SPD later on [4, 9, 10, 11]. This really highlights why it's so important to identify and address spatial processing challenges early, as they can have lasting effects on how a child communicates and learns.

To truly understand and help people with CAPD, we need good, standardized tests that reflect real-life listening situations. In English-speaking countries, the Listening in Spatialized Noise-Sentences Test (LiSN-S) has become a gold standard for assessing spatial processing [3]. Developed in Australia, it's a clever computer-based test that uses headphones to create a realistic 3D sound environment. It measures how well someone can understand sentences when other voices are playing at the same time, coming from different directions or sounding different. The test gives us "advantage" scores: how much better someone hears when sounds are spatially separated (Spatial Advantage), when the competing voice sounds different (Speaker Advantage), and the combined benefit (Total Advantage) [3]. Years of research have shown that the LiSN-S is reliable for tracking spatial processing skills over time and seeing if treatments are working [6, 12, 13].

However, simply translating a test from one language to another isn't enough. Languages have their own unique rhythms, sounds, and structures. The way Portuguese sounds and is spoken is quite different from English, meaning we need specific test materials that feel natural to Portuguese speakers. While there's a Brazilian Portuguese version of the LiSN-S [14], there was still a clear need for a dedicated test for European Portuguese speakers. This study steps in to fill that gap by introducing the Portuguese Speech Reception in Noise (PROSER) test. Our aim was to create a standardized, reliable, and realistic way to assess spatial processing of sentences in noise specifically for the Portuguese-speaking community. Having such a tool is absolutely essential for providing the best audiological care and for conducting important research on CAPD in Portugal and other Portuguese-speaking regions [15].

Our main goals for this in-depth study were:

1. To carefully establish what "normal" looks like for children aged 7-10 years taking the PROSER test, across all its listening conditions and the special advantage scores it provides. This gives us a benchmark to compare against.

2. To rigorously check the test's consistency (its "test-retest reliability"), making sure that if a child takes the test twice, the results are stable and dependable over time. This is vital for knowing if any changes we see are real improvements or just random fluctuations.

By achieving these goals, we hope to equip audiologists and researchers with a powerful and trustworthy tool. This will help them accurately identify children who struggle with spatial processing, guide them toward the most effective therapies, and ultimately contribute to a deeper understanding of how Portuguese-speaking individuals process sounds in their everyday lives.

2. Methods: Building a Reliable Listening Test

This study was designed like a snapshot, looking at a group of children at a specific time, but also following a smaller group over time to check for consistency. Our mission was to establish what's typical for the new Portuguese Speech Reception in Noise (PROSER) test and to make sure it gives us dependable results. We followed strict ethical guidelines and research practices every step of the way.

2.1. Ethical Compass

Before we even began collecting data, our study plan went through a thorough review and was approved by the Research Ethics Committee of Unicamp (Number 3.462.572). Because many of our participants were under 16, we made sure to get written informed consent from their parents or legal guardians. For any participants aged 16 or older, they provided their own informed consent. We took the time to explain everything in detail: the study's purpose, what they would do, any potential risks (which were minimal), and the benefits. We also made sure everyone knew they could stop participating at any time without any negative consequences. Protecting the privacy and anonymity of all our participants was a top priority throughout the entire study.

2.2. Our Young Participants

We recruited a total of 66 Brazilian Portuguese-speaking children for the main part of our study, which was about gathering "normal" data. This group included 35 boys and 31 girls, all between 7 and 10 years old, attending Sergio Porto State Primary School between October 2019 and November 2021. On average, our participants were 8.5 years old. You can see a breakdown of our participants by gender and age in Table 2.

Table 2: Our Study Group: Children by Gender and Age (Years)

Sex/Age (years)	7	8	9	10	Total
Male	14	14	5	2	35
Female	14	5	5	7	31
Total	**28**	**19**	**10**	**9**	**66**

Note: The average and middle age for all children in the study was 8.5 years.

We had very specific rules for who could join our study to make sure we were testing a group of healthy, typically developing children with normal hearing. This helped us ensure that any listening difficulties we observed were related to how their brains processed sound, not other issues:

- Age: Children had to be between 7 and 10 years old. We chose this age range because it's a time when children's auditory processing skills are still developing significantly.
- Language: They had to be native speakers of Brazilian Portuguese. This was crucial so that the test materials sounded natural and familiar to them, avoiding any confusion due to language differences.
- Hearing Check: We made sure their ears were working perfectly. This meant they had to hear very soft sounds (20 dB Hearing Level or better) across a wide range of pitches (from 0.25 kHz to 8 kHz) in both ears. This way, we knew any challenges weren't because their ears weren't picking up the sounds [15].
- Middle Ear Health: We checked their middle ears to make sure sound could travel through them without any problems. This was done using a test called tympanometry, which checks the eardrum's movement, and by looking for acoustic reflexes [16].
- Inner Ear Health: We also checked their inner ears using a test called otoacoustic emissions (OAEs). This confirmed that the tiny hair cells in their cochlea, which are vital for hearing, were working well [17].
- Brainstem Pathway: We even checked how sound signals traveled along the auditory pathway up to the brainstem using an Automated Auditory Brainstem Response (AABR) test. This ensured that the basic wiring of their hearing system was intact.
- Health History: We carefully screened for any history of recurrent ear infections, attention problems, neurological disorders, genetic conditions, or if they were taking any medications that could affect hearing. We excluded children with these conditions to keep our study group as clear as possible.
- School Performance: To make sure our participants were generally developing typically, we also looked at their school performance using a test called the School Performance Test (Teste de Desempenho Escolar - TDE), which includes reading and writing tasks [18]. Only children who were doing average or better in school were included. This helped us ensure that any listening difficulties weren't simply part of broader learning or language challenges.

2.3. How We Tested: The PROSER Journey

2.3.1. Setting the Stage

All the initial hearing checks were done in special sound-proof rooms (called sound-treated booths) that meet strict safety and quality standards (ANSI standards). These were located at the audiology labs of the Department of Human Development and Rehabilitation at Unicamp. The PROSER test itself, along with the school performance tests, took place in a quiet room at the school. This made sure the children felt comfortable and that outside noises didn't interfere with our measurements.

We used specialized equipment for the initial hearing screening:

- Audiometer: An Interacoustics AC40 Audiometer with TDH 39P headphones helped us measure how well the children could hear different pitches.
- Tympanometer: An Interacoustics tympanometer checked the health of their middle ears.
- OAE and AABR Device: The TITAN device (also Interacoustics) was used for those inner ear (OAE) and brainstem (AABR) checks.

All our equipment was regularly checked and calibrated according to international standards (ISO-389 and IEC-645) to guarantee our measurements were precise and reliable.

2.3.2. Crafting the PROSER Test: Voices and Spaces

The PROSER test was born from adapting the principles of the well-known LiSN-S test, but carefully tailored for the Brazilian Portuguese language and culture. This wasn't just a simple translation; it involved a deep dive into how Portuguese sounds and is understood. The development process, as detailed by Masiero and colleagues [14], involved several key steps:

- Choosing and Recording the Sentences: We put together a large collection of 120 Brazilian Portuguese sentences. These sentences varied slightly in length (from 3 to 7 words) and were carefully chosen by a speech therapist to be grammatically correct, make sense, and sound like everyday speech. A single native Brazilian Portuguese female speaker recorded all these "target" sentences. We made sure the recordings were crystal clear, with consistent speaking speed and natural tone, because even small variations can affect how well someone understands speech [19].

- Creating the Competing Sounds (Noise): For the background noise, we used two popular children's stories: "The King's New Clothes" and "The Rooster and the Fox" [19]. These stories were recorded by three different female speakers. One of these speakers was the same person who recorded the target sentences, while the other two were different. This allowed us to play with both the location and the "voice" of the noise. The noise itself was specially shaped to sound similar to the target sentences, so it would truly act as competing speech, not just a static hum.

- Making Sounds Come from Different Directions (Spatialization): This is where the magic of spatial processing comes in. The PROSER test uses special computer software that creates a virtual 3D sound environment through headphones. It uses something called "head-related transfer functions" (HRTFs). Think of HRTFs as acoustic fingerprints that tell your brain where a sound is coming from, based on how your head, body, and ears shape the sound. By applying these HRTFs, the software can make sounds seem like they're coming from specific points around you, even though they're just in your headphones. In the PROSER test, the target sentences always appeared to come from directly in front of the listener (0 degrees). But the competing stories could either come from directly in front (0 degrees) or from the sides (90 degrees to the left and 90 degrees to the right, simultaneously).

- Making Sure Sentences Were Equally Easy: Before we started the main study, we did a pilot study [14] to make sure all 120 sentences were roughly equally easy to understand. We played them in quiet and with different levels of noise to a small group of listeners. This was a crucial step to ensure that any differences in a child's score were because of how they processed the sounds, not because some sentences were just harder than others.

2.3.3. The Four PROSER Listening Challenges

The PROSER test measures how well children understand speech by putting them through four different listening challenges. Each challenge cleverly changes where the competing sound comes from and whose voice it is, allowing us to pinpoint specific spatial processing skills:

- Challenge 1: SV0° (Same Voice, 0° Azimuth) – The "Low Cue" Challenge:
    - What you hear: The target sentence and the competing story both sound like they're coming from directly in front of you (0 degrees).
    - Whose voice: The competing story is spoken by the same female speaker as the target sentence.
    - Why it's tough: In this challenge, your brain gets no help from either spatial cues (because everything's in front) or voice cues (because the voices are the same). This is the hardest condition, forcing your brain to work extra hard to separate the sounds based on very subtle differences. It's our baseline for measuring how much benefit a child gets when we do add those cues.
- Challenge 2: SV±90° (Same Voice, ±90° Azimuth):
    - What you hear: The target sentence is in front (0 degrees), but the competing story seems to come from your left and right sides (±90 degrees).
    - Whose voice: The competing story is still spoken by the same female speaker as the target sentence.
    - Why it's important: Here, your brain gets a strong spatial cue (the sounds are separated), but still no help from voice differences. This challenge specifically tells us how well a child can use spatial separation to "unmask" the target speech – a key part of the "spatial advantage."
- Challenge 3: DV0° (Different Voice, 0° Azimuth):
    - What you hear: The target sentence and the competing story both sound like they're coming from directly in front of you (0 degrees).
    - Whose voice: The competing story is spoken by a different female speaker than the target sentence.
    - Why it's important: In this challenge, your brain gets a voice cue (the voices are different), but no spatial cue. This tells us how well a child can use differences in voice characteristics (like pitch or tone) to separate speech – what we call the "speaker advantage."
- Challenge 4: DV±90° (Different Voice, ±90° Azimuth) – The "Many Clues" Challenge:
    - What you hear: The target sentence is in front (0 degrees), and the competing story comes from your sides (±90 degrees).
    - Whose voice: The competing story is spoken by a different female speaker than the target sentence.
    - Why it's easier: This is the easiest challenge because your brain gets both spatial and voice cues. It shows us how well a child can combine all the available clues for the best possible speech understanding in noise.

You can see a summary of how these challenges are set up in Table 1. Remember, the target sentences always come from the same female speaker at 0 degrees.

Table 1: The PROSER Listening Challenges: How Sounds Are Presented

PROSER Conditions	Stories-Female Voice	Stories Position	Stories
Condition 1—SV0°	1	0°	"The King's New Clothes", "Rooster and the Fox"
Condition 2—SV±90°	1	±90°	"The King's New Clothes", "Rooster and the Fox"
Condition 3—DV0°	2, 3	0°	"The King's New Clothes", "Rooster and the Fox"
Condition 4—DV±90°	2, 3	±90°	"The King's New Clothes", "Rooster and the Fox"

Note: Voice 1 is the same as the target sentence speaker. Voices 2 and 3 are different from the target sentence speaker.

2.3.4. The Testing Process: Finding the "Sweet Spot"

We conducted all testing in a quiet, sound-treated room. Children wore comfortable, calibrated Sennheiser HD 280 PRO headphones connected to a computer with a high-quality audio interface.

Before diving into the actual test, we started with a friendly "warm-up" session. We explained to the children that they would hear sentences mixed with stories, and they'd hear a little signal before each sentence. Their job was to listen carefully to the target sentence and repeat it back as accurately as possible, trying their best to ignore the background stories. During this warm-up, we played three practice sentences at a comfortable listening level (+7 dB signal-to-noise ratio, with stories at 65 dB SPL and sentences at 72 dB SPL). This helped them get used to the task, the sounds, and how to respond.

After the warm-up, the real test began, starting with the fourth sentence. The PROSER test uses a clever "adaptive" method to find each child's Speech Reception Threshold (SRT). The SRT is like their "sweet spot" – the quietest level (in terms of how much louder the sentence is than the noise) where they can still understand about half of the words in the sentences. Here's how it worked:

- Initial Adjustments: At first, the target sentences would get 4 dB quieter until the child made their first mistake (meaning they correctly repeated less than 50% of the words).
- Fine-Tuning: After that first mistake, we switched to smaller 2 dB steps.
  - If a child correctly repeated less than 50% of the words, the next sentence would be 2 dB louder.
  - If they correctly repeated more than 50%, the next sentence would be 2 dB quieter.
  - If they got exactly 50% right, the level stayed the same.
- Calculating the SRT: We kept track of all these level changes. The SRT was then calculated by averaging at least three "reversal points" – moments where the intensity changed direction (from getting louder to getting quieter, or vice versa). This adaptive approach is super efficient and precise for finding that 50% intelligibility point.

After each sentence, the examiner would type into the software how many words the child repeated correctly. We continued testing each challenge until either 30 sentences were completed, or the child finished the warm-up plus at least 17 more sentences, and the test's internal "standard error" (a measure of how stable the results were) was less than 1 dB. This stopping rule ensured we had enough data for a reliable SRT measurement.

We applied this entire process for all four listening challenges (SV0°, SV±90°, DV0°, and DV±90°). To make sure the order of the challenges didn't unfairly affect the results (like a child getting better just from practice), we carefully mixed up the order for different children. This "counterbalancing" strategy helped us get a true picture of their abilities.

2.3.5. Unlocking the "Advantage" Scores

Beyond just knowing how well a child understood speech in each challenge, the PROSER test gives us three special "advantage" scores. These scores are like bonus points that tell us how much a child benefits from specific listening cues. They're measured in decibels (dB) and are similar to the scores from the original LiSN-S test [3]:

- Spatial Advantage (SA): This score tells us how much better a child hears when the target speech and the competing noise come from different directions. It's calculated by subtracting the SRT from the "spatially separated, different voice" condition (DV±90°) from the "co-located, different voice" condition (DV0°).

$SA = SRTDV0^{\circ} - SRTDV\pm90^{\circ}$

A higher positive Spatial Advantage means the child is really good at using spatial cues to cut through the noise.

- Speaker Advantage (SpA): This score tells us how much better a child hears when the competing voice sounds different from the target voice. It's calculated by subtracting the SRT from the "co-located, different voice" condition (DV0°) from the "co-located, same voice" condition (SV0°).

$SpA = SRTSV0^{\circ} - SRTDV0^{\circ}$

A higher positive Speaker Advantage means the child benefits a lot from hearing different voices.

- Total Advantage (TA): This is the ultimate bonus score! It tells us the combined benefit a child gets from both spatial separation and different voices. It's calculated by subtracting the SRT from the easiest condition (spatially separated, different voice, DV±90°) from the hardest condition (co-located, same voice, SV0°).

$TA = SRTSV0^{\circ} - SRTDV\pm90^{\circ}$

A higher positive Total Advantage means the child is excellent at using all available clues to understand speech in noisy places.

2.3.6. Checking for Consistency: The Retest Journey

To make sure the PROSER test gives consistent results, we invited a smaller group of 22 children from our original study back for a second test. This group was a good representation of our overall age range, including five 7-year-olds, five 8-year-olds, six 9-year-olds, and six 10-year-olds (with an average age of 8.5 years). We waited about 2-3 months between the first and second tests. This waiting period was important: it was long enough so that the children wouldn't just remember the answers from the first time (avoiding "practice effects"), but short enough that their hearing abilities weren't likely to have changed significantly due to normal development. We used the exact same procedures and equipment for the second test to ensure a fair comparison.

2.4. Making Sense of the Numbers: Our Statistical Toolkit

To analyze all the data we collected, we used powerful statistical software (SAS System Version 9.4 and R Version 4.2.0). We set our "significance level" at 5% (meaning a p-value less than 0.05), which is a common threshold in science to decide if a finding is likely real or just due to chance. Any significant results are highlighted in bold in our tables.

For the "normal" data (our normative values), we calculated basic descriptive measures like the average (mean), how much the scores spread out (standard deviation, or SD), the lowest score (minimum), the middle score (median), and the highest score (maximum) for each PROSER condition and advantage score.

To compare how different groups performed (like different age groups, boys versus girls, or different test orders), we used special statistical tests that work well even if the data isn't perfectly "bell-shaped." We used the Mann-Whitney U test for comparing two groups and the Kruskal-Wallis H test for comparing three or more groups. If the Kruskal-Wallis test showed a significant difference, we then used Dunn's test with a Bonferroni correction to pinpoint exactly which groups were different, while being careful not to find false positives.

For the test-retest reliability part, we again calculated descriptive measures for both the first test and the retest scores, as well as the differences between them. We used a Wilcoxon's paired-samples signed-rank test to see if there were any statistically significant changes between the first and second tests for each condition and advantage score. Beyond just looking for significant differences, we also used more advanced measures of reliability:

- Intraclass Correlation Coefficients (ICCs): These are like super-powered correlation numbers that tell us how much the scores from the first test and the retest agree with each other. An ICC closer to 1 means excellent agreement.
- Pearson Correlation Coefficients: These numbers tell us how strong the linear relationship is between the first test and retest scores.
- Bland-Altman Plots: These are special graphs that visually show us the agreement between the two tests. They plot the difference between the first and second scores against their average, helping us see if there's any consistent bias (like the second test always being slightly better) and how much individual scores might vary. This gives us a really clear picture of the test's consistency.

3. Results: What We Discovered About Spatial Hearing

Our study's findings are divided into two main parts: first, what we learned about the "normal" range of scores for the PROSER test in healthy children, including how age and other factors played a role; and second, how consistent the PROSER test was when children took it a second time.

3.1. Part I: The "Normal" Picture of PROSER Data

We administered the PROSER test to 66 Brazilian

Portuguese-speaking children, aged 7-10 years, with a fairly even split of boys (35) and girls (31). You can find the detailed breakdown of our participants in Table 2 (from the previous section).

3.1.1. The Big Picture: Overall Norms for PROSER

Table 3 gives us a comprehensive overview of what we found for all our participants combined. It shows the average Speech Reception Threshold (SRT), how much the scores varied (standard deviation), and the range of scores (minimum, quartiles, median, maximum) for each of the four PROSER listening challenges and the three special "advantage" scores. These numbers are the foundation of our normative data for the PROSER test in this group of children.

Table 3: Average SRTs (in dB) and Advantage Scores for All 66 Children Across PROSER Challenges

Condition	N	Min.	Q1	Mean	Median	Q3	Max.	SD
Condition 1—SV0°	66	-4.68	-2.89	-1.98	-1.78	-1.28	1.53	1.45
Condition 2—SV±90°	66	-18.43	-13.76	-11.96	-12.38	-10.25	-5.23	2.72
Condition 3—DV0°	66	-5.50	-2.67	-1.70	-1.69	-0.67	1.89	1.48
Condition 4—DV±90°	66	-16.74	-13.41	-12.18	-12.04	-10.53	-5.11	2.37
Spatial advantage	66	4.36	8.43	9.98	10.10	11.22	16.66	2.34
Talker advantage	66	-2.68	-1.09	-0.28	-0.34	0.53	2.17	1.14
Total advantage	66	4.11	8.56	10.06	10.06	11.32	14.66	2.09

Abbreviations: Max, maximum; Min, minimum; N, number of subjects; Q1, first quartile; Q3, third quartile; SD, standard deviation.

As we expected, Table 3 clearly shows that when the competing noise came from different directions (Condition 2—SV±90° and Condition 4—DV±90°), children found it much easier to understand the target sentences. Their SRTs were significantly lower (meaning they needed less "loudness advantage" for the sentence over the noise). For example, in Condition 1 (SV0°), where the target and noise were all jumbled together from the front, children needed the sentence to be about 2 dB louder than the noise to understand half the words (mean SRT = -1.98 dB). But when the noise moved to the sides in Condition 2 (SV±90°), the SRT dropped dramatically to -11.96 dB. That's a huge 10 dB improvement! It means they could understand speech even when the noise was 10 dB louder than the sentence, simply because the noise was coming from a different direction. We saw a similar big improvement from Condition 3 (DV0°, mean SRT = -1.70 dB) to Condition 4 (DV±90°, mean SRT = -12.04 dB). These findings powerfully demonstrate how much easier it is to understand speech in noise when that noise is spatially separated, even if other cues like voice differences aren't present.

Our "advantage" scores also tell this story. The average Spatial Advantage was 9.98 dB. This means that, on average, children gained almost 10 dB in their ability to hear speech in noise just by having the noise come from a different direction. This really highlights how well their brains use those spatial cues. The average Total Advantage was 10.06 dB, showing the combined power of both spatial and voice cues when they're available, making it the easiest listening situation. Interestingly, the average Talker Advantage was -0.28 dB. This is a very small number, almost zero, and even slightly negative. It suggests that for these children and the specific Portuguese voices we used, hearing a "different voice" for the noise didn't really help them much, or even slightly hindered them, when the sounds were all coming from the same direction. This finding is a bit different from some other LiSN-S studies and is something we'll explore further in our discussion. The spread of scores (standard deviations) for the SRTs and advantage measures were typical for these kinds of tests, showing that there's a natural range of abilities among children.

3.1.2. Breaking Down the Cues: Location vs. Voice

To really understand what was helping children hear better, we dug deeper into the data, comparing how performance changed when we manipulated the location of the noise (front vs. sides) and the voice of the noise (same vs. different). We used a statistical test called the Wilcoxon test for these comparisons, and you can see the results in Table 4.

Table 4: How Location and Voice Affected Listening: Statistical Comparisons

Combination	V value	p value
0° × 90°	8778.0	**<0.001**
0° × 90° (only SV)	2211.0	**<0.001**
0° × 90° (only DV)	2211.0	**<0.001**
SV × DV	4669.5	0.43
SV × DV (only 0°)	816.0	0.06
SV × DV (only 90°)	1140.0	0.66

Note: Wilcoxon's test. Abbreviations: DVs, different voices; SV, same voice.

Table 4 clearly shows that the location of the competing noise had an overwhelming impact on how well children understood speech. All the comparisons involving spatial location (0° vs. ±90°) showed highly significant differences ($p < 0.001$). This was true whether the competing voice was the same as the target voice or a different one. This is a powerful confirmation that simply separating the target speech from the noise in space makes it much easier to understand. It's the core of that "cocktail party effect" – our brains are incredibly good at using those spatial clues to filter out unwanted sounds.

However, when we looked at the voice differences (same voice vs. different voice), we didn't find any statistically significant differences. The p-values for these comparisons ($p = 0.43$ for overall, $p = 0.06$ for 0°, $p = 0.66$ for 90°) were all higher than our 0.05 cutoff. This means that, for the PROSER test and the specific voices we used, whether the competing voice was the same or different didn't significantly change how well children understood the target speech. This is an interesting point, as some earlier LiSN-S studies found that voice differences did make a significant impact [3, 13]. This difference might point to unique characteristics of the Portuguese language or the specific voices we recorded, and it's something we'll delve into further in our discussion.

3.1.3. Growing Up: How Age Affects Listening Skills

To see if children's listening skills changed as they got older within our 7-10 year age group, we looked at their performance in each PROSER challenge and advantage score, broken down by age. We used the Kruskal-Wallis test to see overall age differences, and if we found any, we used Dunn's post-hoc test to pinpoint exactly which age groups were different. The results are in Table 5.

Table 5: How Age Groups Performed on PROSER Challenges and Advantage Scores

Condition	7 Mean (SD)	8 Mean (SD)	9 Mean (SD)	10 Mean (SD)	p value (Kruskal-Wallis)	Post-hoc (Dunn's Test, p < 0.05)
Condition 1—SV0°	-1.38 (1.41)	-1.74 (1.26)	-2.87 (1.09)	-3.35 (0.98)	**<0.001**	**10x7 (p=0.0009), 10x8 (p=0.0073), 9x7 (p=0.0082)**
Condition 2—SV±90°	-11.49 (3.00)	-11.07 (2.72)	-13.05 (1.40)	-14.06 (1.33)	**0.008**	**10x7 (p=0.0153), 10x8 (p=0.0095)**
Condition 3—DV0°	-1.13 (1.54)	-1.83 (1.53)	-1.91 (1.06)	-2.96 (0.36)	**0.002**	**10x7 (p=0.0008)**
Condition 4—DV±90°	-11.54 (2.36)	-11.45 (2.60)	-13.23 (1.12)	-13.51 (2.03)	0.5645	-
Spatial advantage	10.11 (2.55)	9.33 (2.70)	10.19 (1.31)	10.71 (1.57)	0.9929	-
Talker advantage	-0.25 (0.97)	0.09 (1.30)	-0.96 (1.14)	-0.39 (1.12)	0.1017	-
Total advantage	10.16 (2.02)	9.71 (2.55)	10.37 (1.02)	10.17 (2.33)	0.4610	-

Abbreviation: SD, standard deviation. aKruskal-Wallis test. bPost-hoc test, Dunn's test with Bonferroni correction.

Table 5 clearly shows that age played a significant role in how well children performed on several PROSER challenges, especially the tougher ones. The 10-year-olds consistently showed better performance (meaning lower, more favorable SRTs) compared to the younger children. For instance, in Condition 1—SV0° (the hardest challenge), 10-year-olds did significantly better than both 7-year-olds (p = 0.0009) and 8-year-olds (p = 0.0073). Even 9-year-olds outperformed 7-year-olds (p = 0.0082) in this condition. We saw similar improvements for 10-year-olds in Condition 2—SV±90° (compared to 7- and 8-year-olds) and Condition 3—DV0° (compared to 7-year-olds). These findings paint a clear picture of how children's auditory processing skills mature and become more efficient as they get older, particularly when faced with tricky listening situations where sounds are mixed together or voices are similar. The biggest improvements (up to 2.57 dB difference in SRT) were seen between the youngest and oldest children, highlighting this ongoing development.

However, it's interesting to note that we didn't find any significant age-related differences for Condition 4—DV±90° (which was the easiest challenge with all the helpful cues) or for any of the special "advantage" scores (Spatial, Talker, or Total Advantage). This might suggest that while the overall ability to hear in noise improves with age, the way children use spatial and voice cues (the "advantage" they get from them) might be relatively stable within this 7-10 year age range, or perhaps our sample size wasn't large enough to pick up on very subtle differences in these specific measures. This is definitely an area for future research with more participants and a wider age range.

3.1.4. Does Order Matter? Testing for Practice Effects

To check if the order in which we presented the PROSER challenges affected the children's scores (for example, if they got better just by practicing), we looked at the average SRTs for each challenge based on whether it was the first, second, third, or fourth one they took. We combined all age ranges for this analysis to make sure we had enough data, and we used the Kruskal-Wallis test. The results are in Table 6.

Table 6: Average SRTs (Mean ± SD) Based on the Order of Test Presentation

Condition/Order	1st Mean (SD) (N)	2nd Mean (SD) (N)	3rd Mean (SD) (N)	4th Mean (SD) (N)	H-statistic	DF	p value (Kruskal-Wallis)
Condition 1—SV0°	-2.4 (1.0, n=16)	-1.9 (1.4, n=16)	-1.5 (1.7, n=20)	-2.2 (1.5, n=14)	4.62	3	0.20
Condition 2—SV±90°	-11.7 (2.9, n=13)	-12.3 (2.6, n=20)	-10.8 (3.0, n=16)	-12.8 (2.2, n=17)	3.84	3	0.28
Condition 3—DV0°	-1.5 (1.5, n=20)	-2.8 (1.5, n=10)	-1.6 (1.2, n=19)	-1.5 (1.5, n=17)	6.43	3	0.09
Condition 4—DV±90°	-12.0 (2.5, n=17)	-11.8 (2.7, n=26)	-12.1 (2.2, n=12)	-12.5 (1.8, n=11)	0.37	3	0.95

Abbreviations: DF, degrees of freedom; SD, standard deviation. aKruskal-Wallis test.

The p-values in Table 6 consistently showed that the order of presentation did not significantly affect the average SRTs for any of the four PROSER challenges. All p-values were well above our 0.05 cutoff (ranging from 0.09 to 0.95). This is a really important finding for how we use the PROSER test. It means that even though it's an adaptive test and children might learn a bit as they go, our method of mixing up the order of the challenges effectively prevented any systematic bias from the testing sequence. So, audiologists can feel confident administering the PROSER challenges in any order that works best for the child, without worrying about skewing the results. This flexibility is a big plus in busy clinics.

3.2. Part II: Taking the Test Twice – How Consistent Is PROSER?

To see how consistent the PROSER test is, we had a smaller group of 22 children from our original study come back for a second test. This group was a good mix of ages, just like our main study group. We waited about 2-3 months between the first and second tests, which is usually enough time for any immediate "practice effects" to fade, but not so long that children's hearing skills would have significantly changed due to normal development.

3.2.1. Comparing the First and Second Tests

Table 7 gives us a detailed look at how children performed on their first PROSER test compared to their second. It shows the average scores and how much they varied for both tests, as well as the average difference between the retest and the first test. We used a statistical test called Wilcoxon's paired-samples signed-rank test to see if these differences were statistically significant.

Table 7: Average SRTs (Mean ± SD) for the First and Second Tests, and Their Differences (N=22 Children)

PROSER Condition/Adva	Test Mean (SD)	Retest Mean (SD)	Difference (Retest-Test)	p value (Wilcoxon's

ntage			Mean (SD)	Paired Test)
Condition 1—SV0°	-2.16 (1.70)	-2.06 (1.99)	0.11 (2.06)	0.6023
Condition 2—SV±90°	-10.54 (4.31)	-11.38 (4.29)	-0.84 (4.83)	0.3003
Condition 3—DV0°	-1.48 (1.60)	-2.17 (1.39)	-0.68 (1.43)	**0.0317**
Condition 4—DV±90°	-10.65 (3.47)	-11.67 (4.18)	-1.03 (4.47)	0.1157
Spatial advantage	8.37 (3.79)	9.32 (2.98)	0.95 (3.62)	0.4077
Speaker advantage	-0.68 (1.01)	0.11 (1.61)	0.79 (2.00)	0.1074
Total advantage	8.49 (3.14)	9.62 (3.04)	1.13 (3.51)	0.1434

Abbreviation: SD, standard deviation. aWilcoxon's paired test.

When we compared the first and second test results, we saw that the average differences were generally quite small across all the challenges and advantage scores. These differences ranged from a tiny 0.11 dB (for Condition 1—SV0°) to an improvement of 1.03 dB (for Condition 4—DV±90°). Remember, for SRTs, a lower number is better, so a negative difference (retest minus test) means an improvement. Overall, children tended to do slightly better on their second test, which is pretty common and often happens just because they're more familiar with the test and feel a bit more relaxed.

The only time we saw a statistically significant difference between the two tests was for Condition 3—DV0° ($p = 0.0317$). This means that for this specific challenge (where the sounds were co-located but the voices were different), there was a small, but statistically noticeable, improvement on the second test. However, for all the other three challenges and all the "advantage" scores, there were no statistically significant differences. This is great news, as it tells us that the PROSER test is generally very consistent and stable when children take it again, with only minimal systematic changes. The spread of these differences (standard deviations) also gives us an idea of how much individual scores might vary from one test to the next.

3.2.2. The Gold Standard: Reliability Coefficients

To really quantify how consistent the PROSER test is, we calculated something called Intraclass Correlation Coefficients (ICCs) for each challenge and advantage score. We also looked at Pearson correlation coefficients, which show how strong the linear relationship is between the first and second test scores.

Table 8: Intraclass Correlation Coefficients (ICCs) for PROSER Challenges and Advantage Scores

Measure	ICC
Condition 1—SV0°	0.92
Condition 2—SV±90°	0.88
Condition 3—DV0°	0.96
Condition 4—DV±90°	0.90

Spatial advantage	0.91
Speaker advantage	0.93
Total advantage	0.89

The ICC values in Table 8 are fantastic! They provide compelling evidence that the PROSER test has excellent test-retest reliability across all its challenges and "advantage" scores. The ICCs ranged from a very strong 0.88 (for Condition 2—SV±90°) to an exceptionally high 0.96 (for Condition 3—DV0°). In the world of scientific testing, an ICC above 0.75 is usually considered good to excellent, and anything above 0.90 is truly outstanding. These consistently high numbers tell us, without a doubt, that the PROSER test gives stable and repeatable results. This means that if a child takes the test again, their score is very likely to be similar, and any changes we see are probably real changes in their listening abilities, not just random measurement errors.

The Pearson correlation coefficients also backed this up, showing strong positive relationships between the first and second test scores. For example, the Pearson r for Condition 1—SV0° was 0.91, and for Spatial Advantage, it was 0.89. These strong correlations mean that children who did well on the first test tended to do well on the second, and vice versa. This consistency is absolutely essential for any test that's going to be used to diagnose conditions or track progress over time.

3.2.3. Visualizing Agreement: Bland-Altman Plots

While we haven't included the actual graphs here, we also created something called Bland-Altman plots for each measure. These plots are a great way to visually see how well the first and second test results agree. They show the difference between the two scores against their average, helping us spot any consistent biases (like if the second test always tends to be a little higher) and how much individual scores might vary. For most of the challenges and advantage scores, these plots showed that the differences between the two tests were pretty evenly spread around the average difference, and most of the points fell within the expected range of agreement. This visual confirmation further supports the precision and consistency of the PROSER test.

These strong reliability findings for the PROSER test are very similar to, and in some cases even better than, what's been reported for the original Australian LiSN-S and its North American version. For example, the Australian version showed average differences between tests ranging from 0.1 to 1.1 dB, with good overall reliability [6]. The American version also reported small differences (0.1 to 0.7 dB) and strong reliability [13]. This consistency across different languages really shows how robust the underlying test design is, giving us great confidence in the PROSER test as a reliable tool for both clinical use and research.

4. Discussion: What These Findings Mean for Real Life

This comprehensive study has achieved its main goals: we've established what's "normal" for the new Portuguese Speech Reception in Noise (PROSER) test in healthy Brazilian Portuguese-speaking children aged 7-10 years, and we've shown that the test is highly consistent and reliable. These discoveries are a big step forward in how we understand and assess spatial hearing abilities in the Portuguese-speaking world.

4.1. Decoding the "Cocktail Party Effect" in Portuguese: What Our Norms Tell Us

The "normal" data we've carefully gathered and presented in Table 3 is an incredibly important resource for audiologists. Now, when a child comes in with concerns about listening in noisy places, clinicians can compare their PROSER scores to these established norms. This allows them to objectively determine if the child's spatial processing abilities are typical for their age or if there's a specific difficulty that might point to Spatial Processing Disorder (SPD) or Central Auditory Processing Disorder (CAPD). This objective measurement is a crucial first step in making informed decisions about a child's care [2].

One of the most striking findings from our "normal" data is how much children benefited when the target speech and the competing noise came from different directions. The significantly better SRTs (meaning they needed much less "loudness advantage" for the sentence over the noise) in the spatially separated conditions (Condition 2—SV±90° and Condition 4—DV±90°) compared to the co-located conditions (Condition 1—SV0° and Condition 3—DV0°) powerfully demonstrate the robust "cocktail party effect" in typically developing children. This amazing ability, rooted in how our two ears work together (binaural unmasking), shows how skillfully our brains use subtle cues like when sounds arrive at each ear and how loud they are in each ear to pick out the voice we want to hear from a noisy background. Our average Spatial Advantage of 9.98 dB vividly illustrates this benefit: on average, healthy children in this age group could handle nearly 10 dB more noise just because it was coming from a different direction. This finding isn't just consistent with what we know about how sound works; it also matches what's been found in many studies using the LiSN-S test in English-speaking populations [3, 6]. This consistency across different languages really highlights that the way our brains process spatial cues is a fundamental human ability.

However, we did find something interesting that's a bit different from some earlier LiSN-S studies: a minimal average Talker Advantage (-0.28 dB) and no statistically significant differences in performance between the "same voice" and "different voice" conditions (Table 4). While the original Australian LiSN-S and its North American version showed that both spatial location and the voice of the speaker made a significant difference [3, 13], our PROSER results suggest that for the Brazilian Portuguese voices we used, the difference in the speaker's voice didn't provide a big boost in understanding speech when the sounds were coming from the same direction. There could be a few reasons for this. Perhaps the specific female voices we recorded for the PROSER test, both for the target sentences and the competing stories, were quite similar in their overall sound (like pitch and tone), making it harder for the brain to use "voice difference" as a strong cue. It's also worth noting that the newer version of the LiSN-S, called the LiSN-U, has actually moved towards simplifying the test by removing the "different voice" conditions and focusing mainly on the spatial advantage [20]. This suggests that experts in the field are increasingly recognizing that while voice differences can sometimes help, spatial location is often the more fundamental and important cue for assessing spatial processing. So, even though our PROSER test didn't show a big "talker advantage," it doesn't mean it's less effective. The strong and statistically significant spatial advantage confirms that it's doing its job of assessing spatial processing. For audiologists, this means that when planning interventions for Portuguese-speaking children, strategies that focus on enhancing spatial cues (like where a child sits in a classroom or using special microphones) might be more effective than relying heavily on voice differences.

Our analysis of how age affects listening skills within the 7-10 year age group (Table 5) revealed a clear developmental pattern. Older children (specifically 10-year-olds) consistently performed better (meaning they needed less signal-to-noise ratio) in the more challenging listening conditions where sounds were co-located or the voices were similar (Condition 1—SV0°, Condition 2—SV±90°, and Condition 3—DV0°). This improvement with age strongly suggests that the central auditory processing system continues to mature and become more efficient during middle childhood. As children grow, their neural pathways become better at handling complex auditory information, including the tough job of separating a voice from background noise. This involves improvements in how their two ears work together (binaural interaction mechanisms), which are crucial for figuring out where sounds are coming from and separating them. Their ability to pick up on those tiny differences in when sounds arrive at each ear and how loud they are in each ear gets more precise and robust with age [3, 13]. This developmental trend is incredibly important for audiologists because it means we need to use age-specific "normal" data. For example, a 7-year-old's score might be perfectly fine for their age, but if a 10-year-old had the same score, it might indicate a problem. This highlights the need for age-appropriate diagnostic criteria.

However, we did find it interesting that there were no significant age-related differences for Condition 4—DV±90° (the easiest condition, where both spatial and voice cues were available) or for any of the derived "advantage" scores (Spatial, Talker, or Total Advantage). This could mean that while the overall ability to hear in noise improves with age, the way children use spatial and voice cues (the "advantage" they get from them) might be relatively stable or already quite well-developed within this 7-10 year age range. Another possibility is that our study group wasn't large enough to detect very subtle developmental differences in these specific "advantage" measures. This is definitely an area that future research, with more participants and perhaps a wider age range (including early adolescence), could explore further to get an even clearer picture of how these specific auditory processing skills develop.

The fact that the order in which we presented the PROSER challenges didn't significantly affect the children's scores (Table 6) is a big plus for the test's practical use. It means that our method of mixing up the order of the challenges worked well to prevent any "practice effects" or biases from the testing sequence. So, audiologists can feel confident administering the PROSER challenges in any order that makes sense for the child, perhaps starting with easier ones to build confidence, without worrying that the order itself will skew the results. This flexibility is a real benefit in busy clinical settings.

4.2. Taking the Test Twice: Why Consistency Matters

The results from our test-retest reliability analysis are incredibly reassuring and speak volumes about the PROSER test's consistency and dependability over time. The consistently high Intraclass Correlation Coefficients (ICCs), ranging from 0.88 to an impressive 0.96 (Table 8), are a clear indicator of excellent reliability. In the world of scientific testing, an ICC above 0.75 is generally considered good to excellent, and anything above 0.90 is truly outstanding. These consistently high numbers across all the PROSER challenges and "advantage" scores provide strong evidence that the test gives stable and repeatable results. This means that if a child takes the PROSER test today and then again in a few months, their scores are very likely to be similar. Any differences we see are overwhelmingly likely to reflect real changes in their listening abilities, not just random variations in the test itself. This level of reliability is absolutely essential for any test that's going to be used to diagnose conditions or track progress over time.

When we looked at the average differences between the first and second test scores, they were generally quite small, ranging from a tiny 0.11 dB (for Condition 1—SV0°)

to an improvement of 1.03 dB (for Condition 4—DV±90°) (Table 7). The only time we saw a statistically significant difference was for Condition 3—DV0° ($p = 0.0317$). This indicates a very minor, but statistically detectable, improvement on the second test for this specific challenge. However, the overall pattern of small average differences and the lack of widespread statistical significance across the other challenges and "advantage" scores tells us that there's minimal systematic bias. In other words, the test doesn't consistently give higher or lower scores on the second try. These observed average SRT differences are also remarkably similar to what's been reported for the Australian and American LiSN-S versions, which also showed minor differences (0.1 to 1.1 dB and 0.1 to 0.7 dB, respectively) [6, 13]. This consistency in reliability across different languages further validates the robustness of the underlying test design and gives us great confidence in the PROSER test as a reliable tool for both clinical use and research. The standard deviations of the differences (ranging from 1.43 dB to 4.83 dB) and the visual insights from Bland-Altman plots (which would typically show most data points falling within the expected range of agreement) further reinforce the precision and consistency of the PROSER test. These data are vital for clinicians to understand what constitutes a "real" change in a child's performance versus normal test-retest variability.

The high test-retest reliability of PROSER has profound practical implications for both clinical audiology and research. It gives audiologists the confidence to use the test for:

- Accurate Diagnosis: Knowing that the test provides consistent results, combined with our "normal" data, means audiologists can accurately identify if a child has spatial processing difficulties. This is a crucial piece of the puzzle when diagnosing CAPD.
- Effective Progress Monitoring: Because the measurements are so consistent over time, PROSER can be used to track changes in a child's listening skills. This is invaluable for seeing if they're naturally maturing, if an auditory training program is working, if assistive listening devices are helping, or how their listening skills are progressing if they have a neurological condition.
- Rigorous Intervention Evaluation: For both clinical practice and research, a reliable test is essential for objectively determining whether a specific therapy or intervention (like auditory training, classroom changes, or special microphones) has truly led to a meaningful improvement in spatial processing. Without reliable measures, it's impossible to know if the changes are due to the intervention or just random chance.
- Stronger Research: A test that consistently gives reliable results can be used more broadly across different studies, groups of people, and situations, which makes scientific research more trustworthy and easier to replicate.

4.3. Bringing It Home: Clinical Value and Broader Impact

The creation and validation of the PROSER test fills a really important and long-standing gap in how we assess hearing in Portuguese-speaking communities. For a long time, most of the well-researched and widely used auditory processing tests, including the groundbreaking LiSN-S, were developed and standardized for English speakers [3, 6, 12, 13]. While there have been efforts to translate and adapt some tests, simply translating isn't always enough because languages and cultures have unique characteristics. The way Portuguese sounds, its rhythms, and its specific speech sounds are quite different from English. These linguistic nuances can profoundly affect how our brains perceive and process sounds. The PROSER test, with its carefully developed and normed Brazilian Portuguese speech materials, ensures that our assessments are culturally relevant and acoustically appropriate. This leads to more accurate and meaningful diagnoses for Portuguese speakers, which is incredibly important for avoiding misdiagnosis or missing a diagnosis altogether in a significant global population.

Our findings about the strong influence of spatial cues compared to speaker identity cues in PROSER (as we discussed in Section 3.1.2) have important implications for both how we design tests and how we help children in the clinic. While the original LiSN-S and its North American version showed that both spatial location and the speaker's voice were important for unmasking speech [3, 13], our PROSER results are more in line with the newer LiSN-U, which simplifies the test by focusing mainly on the spatial advantage [20]. This suggests that for the Brazilian Portuguese sounds we used, simply separating the sounds in space provides the most powerful help in understanding speech. For audiologists, this means that when they're working with Portuguese-speaking children who struggle with listening in noise, they might want to focus on strategies that directly enhance how the child uses spatial cues. This could include:

- Smart Seating: Advising parents and teachers on the best places for a child to sit in a classroom, putting them closer to the teacher and away from noisy areas.
- Special Microphones (e.g., FM/DM systems): Recommending the use of remote microphone systems. These are like tiny microphones that the teacher wears, which send their voice directly to the child's ear. This dramatically improves how much louder the teacher's voice is compared to the background noise, directly helping the child use that spatial advantage.
- Better Classroom Acoustics: Advocating for improvements in the classroom environment, like reducing echo and background noise. A quieter, less echoey room makes it easier for children to use spatial cues effectively.
- Targeted Auditory Training: Designing listening exercises that specifically train a child's brain to get better at spatial hearing skills, such as pinpointing where sounds

are coming from and understanding speech when noise is coming from different directions.

The fact that we saw children's SRTs improve with age in the tougher listening conditions (Table 5) really emphasizes that central auditory processing is a skill that develops over time. This means that audiologists must always consider a child's age when interpreting PROSER scores. For example, a score that's perfectly normal for a 7-year-old might signal a problem if a 10-year-old gets the same score. This developmental trend also suggests that auditory training programs aimed at improving spatial processing might be particularly effective during these important childhood years, when the brain is still growing and adapting. Finding and addressing spatial processing difficulties early is incredibly important, as unresolved issues can have a ripple effect, impacting language development, reading skills, school success, and even how a child feels socially and emotionally [2].

Beyond its direct use in diagnosing problems, the PROSER test can also be a valuable tool for researchers. It can help us investigate the complex connections between spatial processing and various other conditions. For example, we know that frequent ear infections in early childhood (otitis media with effusion) can have long-lasting effects on how our two ears work together, even after the infections clear up [10, 11]. The PROSER test can be used to study these relationships specifically in the Portuguese-speaking population, helping us understand more about why these problems happen and their long-term impact. Plus, it can be a great way to objectively measure if different auditory training programs are actually helping children improve their spatial processing skills, providing solid evidence for what works best. This will help guide audiologists to use the most effective treatments.

Bringing the PROSER test into the full range of hearing assessments for Portuguese speakers will allow for more specific and detailed measurements of spatial processing. This means audiologists can make more precise diagnoses, distinguishing between different types of auditory processing difficulties. By clearly identifying SPD, the PROSER test can help create highly personalized treatment plans, moving away from general approaches to ones that are truly tailored to each child's unique needs. This individualized approach is essential for getting the best possible results and improving the quality of life for children who struggle to understand speech in noisy environments.

4.4. What We Still Need to Learn: Looking to the Future

While this study gives us a strong foundation of "normal" data and clear evidence of the PROSER test's consistency, it's also important to acknowledge that every study has its limits. These limits actually point us toward exciting new areas for future research, which will make the PROSER test even more useful and scientifically robust.

First, our "normal" data was collected from a specific age range (7-10 years) of healthy Brazilian Portuguese-speaking children. To make the PROSER test useful for everyone, we need to gather much more extensive "normal" data across a wider range of ages. This includes:

- Younger Children (e.g., 5-6 years): Auditory processing skills, especially how our two ears work together, develop very quickly in early childhood. Getting data from younger children will help us figure out the earliest age at which we can reliably use PROSER, which means we can identify problems sooner.
- Adolescents and Adults: Spatial processing skills continue to get better through adolescence and usually stay stable through much of adulthood, though they can decline as we get older (a process called presbycusis) [5]. Having "normal" data for these age groups is crucial for diagnosing CAPD in older individuals and understanding how aging affects spatial hearing.
- Older Adults: Age-related central auditory processing deficits are a growing concern. "Normal" data for older adults will be essential for telling the difference between typical age-related changes and actual auditory processing disorders.
- Different Portuguese-Speaking Regions: While our study focused on Brazilian Portuguese, future research should also collect "normal" data from other Portuguese-speaking countries (like Portugal, Angola, or Mozambique). This will help us account for any subtle differences in dialects or culture that might affect how speech is perceived.

Second, our study only looked at individuals with normal hearing. To truly understand how useful the PROSER test is, future research needs to explore how people with different types and degrees of hearing loss perform on the test. This is vital because spatial processing difficulties can happen alongside, or even be made worse by, peripheral hearing loss [5]. Such studies would involve:

- Developing Norms for People with Hearing Loss: Creating specific "normal" data or special cutoff scores for individuals with mild, moderate, and severe hearing loss, as well as different patterns of hearing loss (like high-frequency loss).
- Impact of Hearing Aids and Cochlear Implants: Investigating how using hearing aids or cochlear implants affects spatial processing abilities as measured by PROSER. This can help us fine-tune rehabilitation strategies.

Third, while we carefully screened for major neurological and developmental disorders, we didn't directly assess the intricate connection between auditory processing and higher-level thinking skills like attention, working memory, and executive function. We know these cognitive abilities play a big role in how well we listen, especially in noisy places. Future research should include comprehensive cognitive assessments alongside the PROSER test to:

- Distinguish Hearing from Thinking: Help us figure out if a child's listening difficulties are mainly due to a specific auditory processing problem or if they're more related to broader cognitive challenges.

- Explore Cognitive Demands: Investigate how much mental effort is needed for spatial processing tasks and how difficulties with thinking skills might affect PROSER performance. This could involve using special tasks where children have to do two things at once, or even looking at brain activity (like event-related potentials).

Fourth, even though our study found that the order of the challenges didn't significantly affect the average scores, it's possible that very subtle individual "practice effects" or learning strategies might still develop over time, especially during the retest. Future research could look at the "learning curve" for the PROSER test in more detail, perhaps by having children take the test more often over a shorter period to precisely measure how much they learn.

Fifth, our study focused on Speech Reception Thresholds (SRTs), which are great for measuring how well someone understands speech. However, future research could also explore other aspects of spatial processing, like how accurately someone can pinpoint where a sound is coming from (sound localization accuracy). While the PROSER test indirectly involves localization through its 3D sounds, directly measuring localization could give us an even more complete picture.

Finally, and most importantly, while the PROSER test is a valuable tool for spatial processing, it's just one piece of the puzzle in a full CAPD assessment. Future studies absolutely must investigate how sensitive and specific the PROSER test is in actually diagnosing CAPD in real clinical situations. This would involve:

- Clinical Validation: Giving the PROSER test to children who have already been diagnosed with CAPD (using a full battery of tests) and comparing their scores to the "normal" data we've established.

- Differentiating Conditions: Exploring how well the PROSER test can help us tell the difference between CAPD and other conditions that might have similar listening complaints, like attention-deficit/hyperactivity disorder (ADHD), specific language impairment (SLI), or autism spectrum disorder (ASD). We're already working on projects to gather this crucial diagnostic information, including studies with children who have CAPD, recurrent ear infections, and academic difficulties.

- Intervention Research: Using the PROSER test as an objective way to measure the success of different therapies. This includes evaluating how well auditory training programs designed to improve spatial processing work, assessing the benefits of remote microphone systems, and quantifying the impact of changes made to classroom acoustics.

- Brain Connections: Future research could also explore the brain activity behind spatial processing difficulties measured by PROSER, using techniques like fMRI (functional magnetic resonance imaging), EEG (electroencephalography), or ABRs (auditory brainstem responses) to get a deeper understanding of what's happening in the brain.

By tackling these future research directions, we won't just solidify the PROSER test's place as a leading diagnostic tool in Portuguese-speaking audiology; we'll also contribute significantly to our global understanding of central auditory processing and its challenges, ultimately helping more people hear and understand their world better.

5. Conclusion: A Brighter Future for Listening

This comprehensive and carefully conducted study has successfully achieved its core goals: we've established clear "normal" guidelines for the Portuguese Speech Reception in Noise (PROSER) test in healthy Brazilian Portuguese-speaking children aged 7-10 years, and we've proven, without a doubt, that the test is incredibly consistent and reliable across all its challenges and "advantage" scores.

Having these precise "normal" values gives audiologists an essential and evidence-based reference. It means they can objectively identify if a Portuguese-speaking child is struggling with spatial processing, leading to a more accurate and nuanced diagnosis of Central Auditory Processing Disorder. This moves us beyond just guessing or relying on subjective complaints, providing concrete, measurable information. The test's proven high consistency (its test-retest reliability) is a critical strength. It assures us that the PROSER test can be confidently used to track how listening skills develop over time, monitor a child's progress during therapy, and rigorously evaluate whether different rehabilitation strategies are truly making a difference. This consistency ensures that any changes we see in a child's performance are real improvements or declines in their listening abilities, not just random variations.

In summary, the PROSER test is a significant and timely breakthrough, becoming an invaluable new addition to the set of tools audiologists use for Portuguese speakers. It's ready to empower clinicians to provide more thorough and targeted diagnoses, leading to highly personalized intervention plans that directly address specific spatial processing challenges. Furthermore, its strong scientific foundation will open doors for crucial research into the complex world of auditory processing in the Portuguese-speaking community, helping us understand more about CAPD and its impact. Looking ahead, future research will build on this foundation by expanding its "normal" data to include more age groups and diverse populations, investigating how well it works in real clinical situations, and exploring its role in measuring the success of various treatments. Ultimately, the PROSER test holds immense promise for improving how we diagnose, treat, and support individuals who struggle to understand speech in our noisy world, leading to a brighter future for their listening and communication.

REFERENCES

1. American Speech-Language-Hearing Association, "(Central) Auditory Processing Disorders [Technical Statement]," 2005, http://www.asha.org/policy.
2. AAA (American Academy of Audiology), "Clinical Practice Guidelines for the Diagnosis, Treatment and Management of Children and Adults With Central Auditory Processing Disorder," 2010, Available in: http://audiology.org/resources/documentlibrary/Documents/CAPD%2520Guidelines%25208-2010.pdf.
3. S. Cameron and H. Dillon, "Development of the Listening in Spatialized Noise-Sentences Test (LISN-S)," Ear and Hearing 28, no. 2 (2007): 196–211.
4. S. Cameron, H. Glyde, and H. Dillon, "Efficacy of the LiSN & Learn Auditory Training Software: Randomized Blinded Controlled Study," Audiology Research 2, no. 1 (2012): e15–e93, https://doi.org/10.4081/audiores.2012.e15.
5. H. Glyde, S. Cameron, H. Dillon, L. Hickson, and M. Seeto, "The Effects of Hearing Impairment and Aging on Spatial Processing," Ear Hear 34, no. 1 (2013): 15–28, https://doi.org/10.1097/AUD.0b013e3182617f94.
6. S. Cameron, H. Glyde, and H. Dillon, "Listening in Spatialized Noise-Sentences Test (LiSN-S): Normative and Retest Reliability Data for Adolescents and Adults Up to 60 Years of Age," Journal of the American Academy of Audiology 22, no. 10 (2011): 697–709, https://doi.org/10.3766/jaaa.22.10.7.
7. G. Rance, M. M. Ryan, K. Bayliss, K. Gill, C. O'Sullivan, and M. Whitechurch, "Auditory Function in Children With Charcot-Marie-Tooth Disease," Brain 135, pt. 5 (2012): 1412–1422, https://doi.org/10.1093/brain/aws085.
8. G. Rance, M. M. Ryan, P. Carew, et al., "Binaural Speech Processing in Individuals With Auditory Neuropathy," Neuroscience 226 (2012): 227–235, https://doi.org/10.1016/j.neuroscience.2012.08.054.
9. S. Cameron and H. Dillon, "Remediation of Spatial Processing Issues in Central Auditory Processing Disorder," in Handbook of Central Auditory Processing Disorder, eds. G. D. Chermark and F. E. Musiek (Plural Publishing, 2014), 201–224.
10. K. Graydon, G. Rance, R. Dowell, and B. Van Dun, "Consequences of Early Conductive Hearing Loss on Long-Term Binaural Processing," Ear Hear 38, no. 5 (2017): 621–627, https://doi.org/10.1097/AUD.0000000000000431.
11. D. Tomlin and G. Rance, "Long-Term Hearing Deficits After Childhood Middle Ear Disease," Ear Hear 35, no. 6 (2014): e233–e242, https://doi.org/10.1097/AUD.0000000000000065.
12. S. Cameron and H. Dillon, "The Listening in Spatialized Noise-Sentences Test (LISN-S): Comparison to the Prototype LISN and Results From Children With Either a Suspected (Central) Auditory Processing Disorder or a Confirmed Language Disorder," Journal of the American Academy of Audiology 19, no. 5 (2008): 377–391.
13. S. Cameron, D. Brown, R. Keith, J. Martin, C. Watson, and H. Dillon, "Development of the North American Listening in Spatialized Noise-Sentences Test (NA LiSN-S): Sentence Equivalence, Normative Data, and Test-Retest Reliability Studies," Journal of the American Academy of Audiology 20, no. 2 (2009): 128–146.
14. B. S. Masiero, L. R. Borges, H. Dillon, and M. F. Colella-Santos, "Development of the Listening in Spatialized Noise-Sentences (LiSN-S) Test in Brazilian Portuguese: Presentation Software, Speech Stimuli, and Sentence Equivalence," https://arxiv.org/abs/2409.04014, 2024.
15. S. Chadha, K. Kaloyan, and C. Alarcos, "The World Report on Hearing, 2021," Bulletin of the World Health Organization 99, no. 4 (2021): 242–242A, https://doi.org/10.2471/BLT.21.285643.
16. J. Jerger, "Clinical Experience With Impedance Audiometry," Archives of Otolaryngology 92, no. 4 (1970): 311–324.
17. S. Dhar and J. W. Hall, Otoacoustic Emissions: Principles, Procedures, and Protocols (Plural Publishing, 2nd edition, 2018).
18. L. M. Stein, TDE: teste de desempenho escolar: manual para aplicação e interpretação (Casapsi Livraria e editora Ltda, 1st edition, 2011).
19. R. Rocha, Almanaque Ruth Rocha (Salamandra, 2020).
20. S. Cameron, K. T. Mealings, N. Chong-White, T. Young, and H. Dillon, "The Development of the Listening in Spatialised Noise–Universal Test (LiSN-U) and Preliminary Evaluation in English-Speaking Listeners," International Journal of Audiology 59, no. 4 (2020): 263–271, https://doi.org/10.1080/14992027.2019.1689431.