Auditory Processing in Children with Specific Language Impairments: Are there Deficits in Frequency Discrimination, Temporal Auditory Processing or General Auditory Processing?

Andreas Nickisch Claudia Massinger

Department of Phoniatrie and Pädaudiologie, Kinderzentrum München gGmbH, and Institute of Social Pediatrics, Ludwig Maximilian University Munich, Munich, Germany

Abstract

Background/Aims: Specific language impairment (SLI) is believed to be associated with nonverbal auditory (NVA) deficits. It remains unclear, however, whether children with SLI show deficits in auditory time processing, time processing in general, frequency discrimination (FD), or NVA processing in general. Patients and Methods: Twenty-seven children (aged 8–11) with SLI and 27 control children (CG), matched for age and gender, were retrospectively compared with regard to their performance on five NVA skills in terms of just noticeable differences (JND) and time order judgments (TOJ). JND was used for FD, intensity discrimination, and gap detection, while TOJ was used for FD and clicks. Results: Children with SLI performed significantly worse than the CG only on the FD tasks (JND and TOJ). The other nonverbal tasks showed no significant intergroup differences. Additionally, moderate associations were found between the FD tasks and phonological skills, as well as between FD tasks and language scores. Conclusion: Children with SLI appear to have restricted FD skills compared to controls, but there was no evidence for a common NVA deficit or reduced temporal auditory abilities.

Specific language impairment (SLI) describes a condition of markedly delayed language acquisition with normal nonverbal cognitive skills. Although peripheral hearing is unaffected, reduced nonverbal auditory (NVA) processing has often been described in children with SLI. Such a diagnosis may include specific impairments in auditory temporal processing, general deficits in temporal processing, or problems in specific auditory functions such as frequency discrimination (FD).

A deficit in NVA temporal processing may reduce the efficiency of discrimination and identification of spectrally complex sounds that change rapidly over time. Therefore, the perception of speech sounds may be distorted, resulting in unstable and reduced neural representations of phonemes during language development, which interfere with both the comprehension and the production of speech [1]. This hypothesis was supported by certain studies using the Rapid Auditory Test [e.g., 2,
changing transient information
dicate a more general impairment in processing rapidly
tends that deficits in auditory temporal processing in-

The skills correlations between FD scores and phonological/speech
researchers have identified significant moderate to strong
severity of language impairment were observed
pared to NDCs, no correlations between test scores and
dren with SLI scored poorly on speed-related tasks com-

– examination of only one or two different aspects of
too broad an age range, between 10 or 12 and 20 years

The contradictory findings of NVA processing tasks
in children with SLI do not clearly support or undermine
any one of the described hypotheses, and further, this
contradiction might be explained by:

– insufficient study population size, with no more than
17 participants in any SLI group [2, 6–8, 14–17, 20]
while only a few study populations included 25 par-
ticipants or more [3, 4];

– too broad an age range, between 10 or 12 and 20 years
[14–16];

– examination of only one or two different aspects of
NVA abilities [4, 6, 14, 18]. Only a few authors have
investigated three or more different aspects in chil-
dren with SLI as compared to NDC subjects. Two
studies [10, 20] featured SLI groups (n = 10 and 11) that
were not large enough to generalize the results. Corr-
iveau et al. [21] found poorer scores in 21 children
with SLI compared to NDC subjects in discrimination
of amplitude envelope rise time, detecting rise time of
two ramps in a tone, and differentiating tone dura-
tions, but not in tests that involved tone intensity or a
time order judgment (TOJ) task with two different

Furthermore, to date, there have been no comprehen-
sive reports of behavioral NVA findings in German-
speaking children with SLI that assess the described find-
ings in languages other than English.

Therefore, the purpose of our study was to compare
systematically different NVA abilities (FD, gap detec-
tion, tone intensity) with different task qualities (TOJ
and just noticeable differences, JND) in a larger group of
German-speaking children (aged 8–11) with SLI and
age- and gender-matched NDCs. If children with SLI
have specific NVA deficits in FD, we would expect dif-
fences between children with SLI and the NDC only in
the FD-related tasks. Associations between these tests
and phonological skills as well as language abilities would
be anticipated, indicating their importance for language
development.

Participants

All children in the SLI group were assessed in our Pho-
niatrics-Pedaudiology Department between 2003 and
2006. All children aged 8;0–11;0 years diagnosed with SLI
and with fully documented medical records were retro-
spectively selected from our database. The NDCs were
recruited from an elementary school (grades 3 and 4) and
had no history of speech disorders, dyslexia, or hearing
impairments. The control participants were matched for
age and gender to the children with SLI. Both the SLI
group and the control group (CG) consisted of 16 boys
and 11 girls.

All children (SLI and CG) demonstrated normal re-
sults in tympanometry and pure-tone audiometry
(thresholds of 15 dB and better between 500 and 8,000
Hz). All children with SLI had a performance or nonver-al IQ (Hamburg Wechsler Intelligence Scale for Chil-
dren-III or Kaufman-ABC) of at least 85 (mean 97.3, SD
7.6; normally distributed as confirmed by the Kolmogo-
rov-Smirnov Test). The children did not show any neuro-
logical abnormalities, oral structure problems, or autistic
disorders in ENT, neuropediatric, and psychological ex-
aminations.

All children (SLI and CG) underwent standardized
testing of language skills using two subtests of the ‘Hei-
delberger Sprachentwicklungstest’ (Heidelberger Speech
Development Test, HSDT) [22]. The HSDT determines the state of development of linguistic abilities in German-speaking children and consists of 13 subtests. The following two subtests (Guttmann’s lambda between 0.80 and 0.86 [22]) were applied: the Comprehension of Grammatical Structure Forms (CGS), which aims to examine the ability to understand subject-object differentiations in verbal instructions by acting them out, and the Imitation of Grammatical Structure Forms (IGS), which assesses the accurate repetition of longer sentences.

All tests were administered by experienced language therapists. For all children in the SLI group, the diagnosis of SLI was made during a spontaneous dialogue and was additionally confirmed if at least two of five selected HSDT subtests yielded values more than 1.0 SD below the mean of the reference population. Our standard clinical diagnostic procedure for children with SLI involves five subtests: IGS, CGS, and another three HSDT subtests (Correction of Semantically Inconsistent Sentences, Word Finding, and Sentence Construction).

One-way ANOVA (table 1) did not show any group differences in age [T(52) = 0.085, p = 0.69]. As expected, there were between-group differences for both language scores [expressive: T(52) = 8.30, p < 0.001; receptive: T(52) = 7.01, p < 0.001], with children in the SLI group exhibiting markedly lower mean expressive and receptive quotients (table 1).

### Outcome Measures

NVA abilities were examined using the PsychoAcoustical TestSYstem (PATSY; Pilot, Blankenfelde, Germany), which contains the following five subtests: JND for Tone Intensity (I-JND), JND for Tone Frequency (F-JND), JND for Gaps in Noise (G-JND), Monaural TOJ with two fixed-frequency tones and varying interstimulus intervals (F-TOJ), and Binaural TOJ (B-TOJ) with the present-

<table>
<thead>
<tr>
<th>Measure</th>
<th>Means (95% CI) SLI group (n = 27)</th>
<th>Means (95% CI) CG (n = 27)</th>
<th>Comparison (t test) t (52) p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, years</td>
<td>9.6 (9.4–9.9)</td>
<td>9.7 (9.3–9.9)</td>
<td>0.085 0.69</td>
</tr>
<tr>
<td>IGS</td>
<td>13.6 (11.4–15.8)</td>
<td>23.1 (22.4–23.8)</td>
<td>8.30 &lt;0.001</td>
</tr>
<tr>
<td>CGS</td>
<td>12.2 (11.2–13.2)</td>
<td>15.8 (15.4–16.2)</td>
<td>7.01 &lt;0.001</td>
</tr>
</tbody>
</table>

Means are shown together with 95% confidence intervals (CI) in parentheses as well as t and p values for t tests.

To investigate phonological skills, we applied the Heidelberger Lautdifferenzierungstest (Heidelberger Test of Phoneme Differentiation, HTPD [24]), a widely used test for German-speaking elementary school children (Cronbach’s alpha = 0.89–0.95 [21]). Two of the three subtests contained 25 word pairs that included real words and

Auditory Processing in Children with SLI
nonsense words. The word pairs were either comprised of two identical words (e.g., Dreck – Dreck) or a minimal pair (e.g., Drachen – krachen); the task was to verbally indicate whether the word pair was ‘equal’ or ‘different’ (phoneme differentiation subtest) and repeat the word pair (phoneme identification subtest). In the third subtest (phoneme analysis), the children had to analyze and specify the first two phonemes of 12 single words with a consonant-consonant-vowel combination at the beginning of each word.

The raw scores from the three HTPD subtests were combined to give a total ‘phonological score’, and the raw scores of the two HSDT subtests were summed to give a net ‘language score’.

Descriptive statistics were generated using the software package SPSS for Windows 15.0. For three of the five NVA tests and the language score, the Kolmogorov-Smirnov test resulted in p values < 0.1 (G-JND: p < 0.001, F-TOJ: p = 0.004, B-TOJ; p = 0.001, and language score p = 0.024), suggesting that the data were not normally distributed, whereas a normal distribution could be assumed for I-JND (p = 0.620), F-JND (p = 0.135), and the phonological score (p = 0.497). Therefore, all group comparisons were analyzed using the Mann-Whitney U test (two-tailed). Spearman’s correlations were analyzed between the five NVA variables and the net phonological and language scores. Following the recommendation to report individual scores rather than just group means [25], we calculated how many individuals showed results below the interquartile range of the CG in the NVA tasks and performed the χ²-test.

### Results

Descriptive statistics for the five NVA tasks of SLI children and the CG are listed in table 2: significant, large group differences were found regarding F-JND (24 vs. 126 Hz, respectively) and F-TOJ (26 vs. 400 ms, respectively). In contrast, no differences were seen regarding I-JND, G-JND, and B-TOJ. Furthermore, the number of individuals with test results below the interquartile range of the CG in the NVA tasks and performed the χ²-test.

### Table 2. Comparison of children with SLI to the control children for NVA skills: I-JND, F-JND, and G-JND, F-TOJ and B-TOJ

<table>
<thead>
<tr>
<th>Measure</th>
<th>Median, IR, n &gt; IR</th>
<th>CG (n = 27)</th>
<th>Comparison (Mann-Whitney U test)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I-JND</td>
<td>3 dB (2–6 dB); 8/27</td>
<td>4 dB (2–5 dB); 6/27</td>
<td>U p (two-tailed) r (effect size)</td>
</tr>
<tr>
<td>F-JND</td>
<td>126 Hz (85–155 Hz); 21/27</td>
<td>24 Hz (7–79 Hz); 6/27</td>
<td>347.0 0.76 –0.04</td>
</tr>
<tr>
<td>G-JND</td>
<td>5 ms (3–36 ms); 10/27</td>
<td>5 ms (3–8 ms); 6/27</td>
<td>133.5 &lt;0.001 –0.54</td>
</tr>
<tr>
<td>F-TOJ</td>
<td>400 ms (69–731 ms); 19/27</td>
<td>26 ms (24–101 ms); 6/27</td>
<td>355.5 0.88 –0.02</td>
</tr>
<tr>
<td>B-TOJ</td>
<td>91 ms (51–281 ms); 10/27</td>
<td>78 ms (30–112 ms); 6/27</td>
<td>146.5 &lt;0.001 –0.50</td>
</tr>
</tbody>
</table>

Medians are given for raw scores, with interquartile ranges (IR) in parentheses as well as U and p values for Mann-Whitney U tests, and the number of individuals showing test results poorer than the IR of the control group (n > IR).

<table>
<thead>
<tr>
<th>Measure</th>
<th>Raw scores (n = 54 children)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>phonological score</td>
</tr>
<tr>
<td></td>
<td>rho p</td>
</tr>
<tr>
<td>I-JND</td>
<td>–0.172 0.213</td>
</tr>
<tr>
<td>F-JND</td>
<td>–0.393 0.003*</td>
</tr>
<tr>
<td>G-JND</td>
<td>–0.077 0.581</td>
</tr>
<tr>
<td>F-TOJ</td>
<td>–0.556 &lt;0.001*</td>
</tr>
<tr>
<td>B-TOJ</td>
<td>–0.257 0.066</td>
</tr>
</tbody>
</table>

Nonverbal auditory tests: I-JND, F-JND, and G-JND, F-TOJ and B-TOJ. Significance after Bonferroni’s correction: * p < 0.005 (uncorrected alpha threshold was 0.05).
Spearman's correlation coefficients were computed to examine associations between the NVA tests and both phonological abilities and language skills (table 3). Significant (moderate) associations were found only in F-JND and F-TOJ, both for phonological skills and the language score. After Bonferroni's correction, all recorded correlations remained significant. The remaining NVA tests did not show any significant associations with phonological or language skills. Furthermore, no correlations were identified between the five NVA scores and nonverbal IQ (p > 0.23 for all). Only F-JND exhibited strong correlations with F-TOJ (r = 0.65, p < 0.001), although the other NVA tasks did not exhibit any significant correlations with each other.

Discussion

Our results clearly show that children with SLI may not be expected to have general deficits in NVA abilities because only two of the five NVA tasks showed significant group differences, with poorer scores for children with SLI. Furthermore, for SLI children, there was no evidence of restrictions in temporal auditory processing, as suggested Tallal [2] and Tallal et al. [3], because the children with SLI in our tests showed significant deficits only in the F-TOJ task and not in the other two tests of time-processing abilities (G-JND and B-TOJ). In fact, children with SLI achieved poorer results only in the two FD tasks (JND and TOJ), indicating the presence of specific deficits in FD. These results are consistent with previous findings of FD deficits in people with SLI [5, 15, 16, 26]. In contrast to these studies, some authors observed restricted FD abilities only under time processing demands in children with SLI [e.g., 2], but not in FD tasks using fixed-frequency tones without time processing demands. However, a slight FD deficit may not influence the results of FD tasks with fixed-frequency tones (e.g., 100 vs. 305 Hz [2]), but it could become more apparent by adding a time-processing task or by determining the threshold frequency difference as in our FD tasks for both conditions. Taking these aspects into account, findings with fixed-frequency tones [e.g., 2, 4] are not necessarily contradictory to our results. Furthermore, Tallal's [2] findings might not necessarily have been caused by time processing problems in children with SLI, but could have been induced by slight FD deficits in children with SLI. Poor performance in FD may reflect spectral rather than temporal processing of auditory signals, particularly speech signals [16]. Impaired spectral processing abilities may be associated with problems in distinguishing similar-sounding phonemes that differ primarily in terms of frequency transitions, regardless of their intensity or presentation rate. Instabilities of phoneme discrimination and phoneme identification might interfere with encoding and producing speech, which would ultimately lead to expressive and receptive language disorders [5]. In our study, we were able to replicate constraints of FD in German-speaking children with SLI. Therefore, we confirmed that lower FD scores in children with SLI are detectable in a language other than English.

The strength of our data lies in the examination of not only one or two NVA tasks in 8- to 11-year-old children with SLI and their age-matched controls, but rather five different NVA tests, including JND tasks (FD, intensity discrimination, gap detection) and TOJ tasks (fixed-frequency tones or clicks). Applying these five different NVA test modalities results in a more substantial overview of NVA skills in children with SLI compared to previous studies.

There are, however, some limitations to our study that must be taken into account when interpreting our data. Although our group size is relatively large compared to other studies, even a group size of 27 is unlikely to include the full distribution of the various SLI subtypes, which results in a limited generalizability of the reported findings and their interpretations. Furthermore, although we examined nonverbal intellectual skills in the SLI group, we did not test this in the CG. However, our CG showed normally distributed standard scores of digit span (Kolmogorov-Smirnov’s p = 0.45) that were within the normal range (mean = 48.2, SD = 10.2). Additionally, all children with SLI showed nonverbal IQ scores of 85 or better with normally distributed IQ values (Kolmogorov-Smirnov’s p = 0.782) and a mean IQ of 97.3, which we believe is similar to that of the general population. Furthermore, for the SLI group, we detected no associations between the IQ scores and any NVA task; thus, we do not believe that there were any fundamental effects of nonverbal IQ on our auditory processing results. Although the differences in FD that were identified between children with SLI and the CG appear to provide an important contribution to our understanding of deficits in children with SLI, only a fraction of our children with SLI showed poor FD abilities, with only moderate associations between these tasks and language skills. Therefore, these NVA abilities cannot be assumed to be factors that uniquely cause SLI.

Auditory Processing in Children with SLI
Further research must thus be conducted to assess the incidence of reduced FD in children with normal language development. Children with SLI and normal FD skills should be differentially examined in their language skills to determine differences in language profiles between these children with SLI and those with restricted FD skills. This research would clarify the importance of FD measures in working with SLI patients.

References