Sonority's Effect as a Surface Cue on lexical Speech Perception in Children with Cochlear Implants vs Normal Hearing in the Greek Language (Pilot Study)

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Introduction

Sonority's role as a feature of speech segments has been of interest to study for some time (1).

Sonority (or vowel-likeness) is a scalar phonological/ phonetic aspect. Phonologically, it refers to the loudness or relative perceptual prominence of a particular segment compared to other sounds of the same length, stress, and pitch (2, 3). Phonetically, sonority is related to the degree of stricture (articulatory opening) of the vocal tract during the segment's production (4). The more open the vocal tract is, the more sonorous the segment; accordingly, vowels are considered to be the most sonorous sounds. Further, voiced sounds are considered to be more sonorous than voiceless sounds (4).

Sonorous sounds include vowels, glides, liquids (flaps, laterals), and nasals, while non sonorous sounds include obstruents (fricatives, affricates, and plosives) (4). Various scales have been proposed to quantify the degree of sonority of speech sounds. The ordering of speech sounds from the least to most sonorous is called sonority hierarchy. A detailed Sonority scale classifies phoneme classes from 0 (most sonorous) to 7 (least sonorous): 0– vowels, 1–glides, 2–liquids, 3–nasals, 4–voiced fricatives, 5–voiceless fricatives, 6–voiced stops, 7–voiceless stops (5, 6)

The syllable has two elements; the onset, which includes any consonants that precede the nuclear element (the vowel), and the Rhyme, which subsumes the nuclear element (the vowel) as well as any marginal elements (consonants) that might follow it known as coda (7). Languages typically impose quite severe restrictions on the ability of speech sounds to follow one another in phonological strings. This patterned phonotactic behaviour has been attributed to sonority, where more sonorous sounds prefer to occur next to less sonorous sounds. This is known as the Sonority Sequencing Principle (SSP), where the tendency for a sound to occur in a syllable coda vs. onset is directly proportional to how high vs. low it is in sonority respectively (8). Sonority is of importance for phonotactics, because it defines the shape of a well-formed syllable. Cross-linguistic studies have found that a maximum difference in sonority is preferred between the onset of a syllable and its nucleus, presumably to increase the perceptual salience of segments within the syllable. Such patterns are widely attested and strongly imposed in most languages (9).

Each syllable has a peak of sonority (which is usually a vowel) (10). In well-formed syllables, the consonants that are more sonorous are located closer to the peak and the less sonorous ones – further away from it. This principle has been reiterated by current linguists as Sonority Sequencing Generalisation (SSG) (4, 11). Syllable codas do not share this preference for a sharp change in sonority, with claims that there is a greater preference for codas that fall less sharply (1).

In syllables with an empty coda slot, which is the case in our study CV-CV, there is no fall at all in sonority level (1). It has been hypothesized that one reason for the tendency in many languages to have a less sharp fall in sonority at the coda position is to enable the initial segment of the following syllable or word to be lower in sonority than the final segment of the previous syllable or word (12).

The concept of sonority has been argued to explain syllable structure (1, 4, 13), phonotactic rules (8), the emergence of prosodic features (14), cross-linguistic variation (9), and diachronic changes (15).

Sonority is one of the factors predicting the sequence ordering mastered by young children (16, 17), the rate and type of errors observed in individuals with developmental or acquired language impairments (18-25), and aspects of speakers' implicit knowledge of phonological grammar as measured by perception and production tasks (26-28).

Study Rationale and Scope:

In children with a cochlear implant (CI) not all sound components are compromised; temporal processing can be as good or better than that of normal hearing (NH) listeners, (29, 30) , in contrary to the spectral cue transmission(31).

Sonority from an acoustic point may tend to rely more on intensity and temporal cues rather than on spectral cues. Therefore sonority may influence lexical processing by children with CI and their facility for tapping into phonological grammar during lexical access.

In this study we aim to investigate whether speech auditory perception capacity of children with CI in lexical processing is affected by the sonority values at word-level (auditory salience cues), or by the sonority constraints which represent language learning rules (SSP), relative to NH children, and NH adults.

Methodology:

A Pilot Case-Control study including three groups; Children with CI (CI_C), NH Children (NH_C) and NH adults (NH_A) was conducted. Three children with CI were tested

(5-11 years). They were implanted before or up to the age of 3 years and had a post-implant age of 2 years or greater (2-8 years), were monolingual and had no additional disabilities. A control group of NH children included six children of matched age (5-11 years) and sex. The control group of NH adults included four adults within age range 30-32 years.

The sonority experiment was built using E-prime 2.0 Professional. Stimuli included audios of 16 novel words that follow a CV-CV sequence. Since vowels are sonorous sounds, the manipulation of consonants to be sonorous (S) versus non-sonorous (N) phonemes resulted in four possible sonority conditions at a lexical level; SS-SS, SS-NS, NS-SS and NS-NS. In terms of auditory salience at word level SS-SS has the best salience followed by SS-NS and NS-SS, and finally NS-NS. In terms of SSP; NS-NS and NS-SS have the best SSP relative to SS-NS and SS-SS at a word level.

The initial and second syllable phonemic content was matched in frequency of occurrence for the first and second position in the Greek Language. Novel words did not contain words with the same place of articulation, and manner. Each novel word was randomly assigned to a funny object. Funny objects were obtained with author's permission from a previous study by (32). Fast mapping (33) procedure was used to familiarize the funny object with the specific target novel word. Then, each funny object was paired with another funny object and placed in a choice of two picture array format for the identification task. The position of the funny object was randomized but the novel word-funny object pairing was preserved. Both accuracy measures and reaction times were recorded through a touch screen.

The study has been approved by the Medical Ethical Committee of the UZ Leuven / KU Leuven, by the Medical Ethical Committee of AHEPA hospital/Thessaloniki and by the Special Committee of Research Ethics of UOM/Thessaloniki.

Results:

Table 1 shows that in terms of accuracy, words were identified accurately 100% by adults. Normally-hearing children had slightly lower mean overall accuracy rate than NH_A. Furthermore, children with CI showed slightly lower mean overall accuracy rate than both NH_C and NH_A. Accuracy measures in children appeared to depend on the sonority condition of word stimuli. The most accurate sonority condition for NH_C was NS-SS, where words in that condition were accurately identified 100%. The least accurate sonority condition for that group was SS-SS with a mean accuracy rate of 87.5 +/- 0.18%. For CI_C both NS-SS and SS-SS conditions were the most accurate conditions with a mean accuracy rate of 91.67 +/- 0.19%.

Table 2 shows that the overall mean reaction times (RTs) in milliseconds (ms) of accurate responses of CI_C group (2117+/- 2572ms) were relatively longer than NH_C (1067+/-2048ms) which in turn were longer than NH_A group (662+/-515ms). Reaction times varied according to the sonority conditions. For NH_A the shortest mean RT was for NS-NS condition (540+/- 293 ms) and the longest mean RT was for SS-NS condition (800+/- 541 ms). For NH_C the shortest mean RT was for SS-SS condition (702+/- 208 ms), which had the worst accuracy scores, and the longest mean RT was for SS-NS condition (1684+/- 1599). For CI_C group the shortest mean RT was for SS-SS condition (2011+/- 804 ms) and the longest mean RT was for NS-NS condition (4131+/- 2756 ms).

Discussion:

Normal hearing adults showed a ceiling effect when performing the task in terms of accuracy, where they identified correctly all the words regardless of the testing condition. However, the mean reaction times of the group varied with the sonority testing condition, where they performed quickest on the NS-NS condition, followed by the NS-SS and SS-SS condition, and the longest RT was on the SS-NS condition. This pattern of performance is suggestive that SSP is most salient cue in word lexical processing for NH_A.

Children scored less than 100% in some conditions and therefore a criteria using a combination of accuracy and RT measures is used to rank the performance on the different testing conditions. The upper weight is given to accuracy. If two conditions show the same accuracy then the RT of accurate responses is used to rank the performance.

Using this criteria, NH_C performed best on the NS-SS condition (100% accuracy), followed by the NS-NS which had the same accuracy mean score as SS-NS. However the mean RT for NS-NS was shorter (790+/- 328 ms) than that of SS-NS (1026+/- 786 ms) placing it as a better performance. Worst performance was on SS-SS condition with a mean accuracy score of 87.5+/-0.18. This pattern of performance is also suggestive that SSP is most salient cue in word lexical processing for NH_C.

For CI_C they performed best on the SS-SS and NS-SS condition regarding accuracy (91.67+/-0.17). However, SS-SS condition showed a shorter mean RT (2011+/- 804ms) than NS-SS (2133 +/- 1453 ms). Similarly SS-NS and NS-NS condition had the lowest accuracy (83.33+/-0.19). However, SS-NS condition showed a shorter mean RT (2062+/-501 ms) than NS-NS (4131+/- 2756 ms). So by combining accuracy and RT measures best performance was on SS-SS, followed by NS-SS, then SS-NS and finally NS-NS condition.This pattern of performance suggests that for CI_C, unlike for NH_A and NH_C, the overall sonority at the lexical level is the most salient cue in word lexical processing.

Follow up Study:

A point of concern during the analysis of the results was that the chance level was 79.16% at ($p< 0.05$). One out of the six NH_C and one out of the three CI_C in the pilot study scored below chance level. To overcome this a third picture was randomly introduced to the identification slide to act as a foil in a three array choice, instead of two for each of the 16 pairs. The chance level was calculated to be 52.75% at ($p< 0.05$). Five NH_C were tested using the new three picture array choice experiment. All children scored above chance level. Table 3 shows a comparison of performance of NH_C in the first pilot ((a choice of two picture array) versus the second pilot (a choice of three picture array) in terms of accuracy. Table 4 shows a comparison of performance of NH_C in the first pilot (a choice of two picture array) versus the second pilot (a choice of three picture array) in terms of RT. NH_C in the second pilot appeared to have relatively equal RT across the different tested conditions. Mean accuracy performance was best in NS-NS condition followed by NS-SS and SS-SS, and finally SS-NS. The order of performance in the second pilot of the NH_C resembled that of the NH_A in the first pilot in that SSP is the most salient cue in word lexical processing for NH_C.

A second point of concern was that the performance of different groups could be attributed to differences in Group RT rather than the sonority conditions. We recommend for future work to add a visual task as a control condition to ensure that potential signfiicant difference in the auditory conditions can be attributed to the hypotheses under test. Differences in performance on the audio-visual task in absence of differences in the visual task will allow for conclusions to be drawn upon the actual impact of the sonority conditions (audio).

Conclusion:

Children with CI appear to rely on different sonority cues than NH children and adults in the process of lexical processing. Children with CI may rely more on the overall sonority values at word-level which compose cues of auditory salience, while NH children and adults may rely on SSP, a language learning rule, in the process of lexical processing.

Tables:

Table 1: Average accuracy performance in % (+Sd) of test groups and according to sonority test conditions

Test Group	Accuracy in % +/- Sd				
	Overall	SSSS	SSNS	NSSS	NSNS
NH_A	100 +/-0	100+/-0	100+/-0	100+/-0	100 +/- 0
NH_C	94.8+/- 0.12	87.5+/- 0.18	95.83+/- 0.08	100 +/- 0	95.83+/- 0.08
CI_C	87.5 +/- 0.17	91.67+/- 0.17	83.33+/- 0.19	91.67+/- 0.19	83.33+/- 0.19

Table 2: Average reaction time in msec (+Sd) of accurate responses of the different test groups and according to sonority test conditions

Test Group	Reaction times in ms +/- Sd				
	Overall	SSSS	SSNS	NSSS	NSNS
NH_A	662+/- 515	625+/- 188	800+/- 541	683.13+/- 170	540+/- 293
NH_C	1067+/- 2048	702+/- 208	1684+/- 1599	1026+/- 786	790+/- 328
CI_C	2117+/- 2572	2011+/- 804	2062+/- 501	2133 +/- 1453	4131+/- 2756

Table 3: Average accuracy performance in % (+Sd) of normal hearing children and according to sonority test conditions in the first and second pilot study

Test Group	Accuracy in % +/- Sd				
	Overall	SSSS	SSNS	NSSS	NSNS
NH_C 1	94.8+/- 0.12	87.5+/- 0.18	95.83+/- 0.08	100 +/- 0	95.83+/- 0.08
NH_C 2	90+/- 0.15	90+/- 0.12	85+/- 0.22	90+/- 0.12	95+/-0.1

Table 4: Average reaction time in msec (+Sd) of accurate responses of the normal hearing children and according to sonority test conditions in the first and second pilot

Test Group	Reaction times in ms +/- Sd				
	Overall	SSSS	SSNS	NSSS	NSNS
NH_C 1	1067+/- 2048	702+/- 208	1684+/- 1599	1026+/- 786	790+/- 328
NH_C 2	859+/- 772	830 +/- 528	840+/- 559	847+/- 505	835+/- 408

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