Sentence Final Hearing Aid Gain Requirements of Some Non-English Languages

Ajustements spécifiques de gain des appareils auditifs pour les finales de phrases de certaines langues autres que l'anglais

Marshall Chasin

Abstract

The speech intelligibility index (SII) has many uses for assessing aided gain from hearings aids. In an effort to extend the various hearing aid fitting formulae to non-English languages, some researchers have modified the SII. These changes result in a number of frequency response-related issues such as an increase in the low frequency region due to a language being tonal or morae based. Nevertheless, the SII provides no information for supra-segmental, morphological or syntactic properties of a language. Linguistic differences that would not show up on a measure of the SII are the subject of this study. Specifically, languages that possess a syntactic word order of subject-object-verb (SOV) have lower intensity sentence final levels than English. It was hypothesized that in these SOV languages more gain for soft-level (sentence final) inputs would be required than when listening to, or speaking English. One hundred and two bilingual hard of hearing subjects (71 female and 31 male) who spoke English as well as another language possessing a SOV word order and who were undergoing a routine clinical hearing aid evaluation were assessed. Each of the subjects was provided control over the NOAH hearing aid module and was instructed to adjust the amount of gain required for soft-level inputs while listening to .wav files of cold running speech in their non-English language, as well as while listening to a similar .wav file of English. Differences in the amount of gain desired for soft-level inputs for each of the 102 subjects was recorded at 1000 Hz. Clinical information was provided concerning how the amount of hearing aid gain for soft-level inputs can be changed as a function of language that inherently has less sentence final intensity than English. Results indicate that languages that possess a SOV word order requires about 3 dB more gain for soft-level inputs found in a sentence final position (verb) than for languages that possess a SVO word order such as English. This finding, based on a suprasegmental characteristic of speech, would not be seen on conventional measures of SII.

Abrégé

L'index d'intelligibilité de la parole (IIP) a de nombreux usages pour évaluer le gain d'appareils auditifs. Dans un effort d'appliquer les différentes formules d'ajustement des appareils auditifs à des langues autres que l'anglais, certains chercheurs ont modifié l'IIP. Ces changements aboutissent à un certain nombre de problèmes reliés à la réponse en fréquence comme une augmentation dans les basses fréquences due au fait qu'une langue soit basée sur les tons ou les morae. Quoi qu'il en soit, l'IIP ne donne aucune information pour les propriétés supra-segmentales, morphologiques ou syntaxiques d'une langue. Des différences linguistiques qui ne ressortiraient pas sur une mesure de l'IIP font l'objet de la présente étude. Plus précisément, les langues possédant un ordre syntactique de type sujet-objet-verbe (SOV) ont des niveaux de finales de phrases de plus faible intensité que ceux de l'anglais. On a posé l'hypothèse que, dans ces langues SOV, plus de gain pour l'input de faible niveau (finale de phrases) serait nécessaire que quand on écoute ou on parle l'anglais. Cent deux participants bilingues malentendants (71 femmes et 31 hommes) parlant l'anglais ainsi qu'une autre langue de structure SOV et consultant pour une évaluation clinique de routine de leur appareil auditif furent évalués. On a donné à chacun des participants le contrôle sur le module NOAH dédié aux appareils auditifs et on leur a demandé d'ajuster la quantité de gain nécessaire pour les inputs de faible volume lors de l'écoute de fichiers .wav d'un passage verbal sans changement d'intonation dans sa langue, autre que l'anglais, ainsi qu'en écoutant un fichier .wav semblable en anglais. Les différences dans la quantité de gain désirée pour les inputs à faible volume pour chacun des 102 participants ont été enregistrées à 1000 Hz. L'information clinique a été fournie au sujet du changement possible de la quantité de gain de l'appareil auditif en fonction d'une langue qui a, de façon inhérente, des finales de phrases moins intenses que l'anglais. Les résultats indiquent que les langues qui ont un ordre de mots SOV ont besoin d'environ 3dB de plus de gain pour des mots de faible intensité trouvés dans une position finale de phrase (verbe) que pour des langues possédant un ordre de mots SVO, comme l'anglais. Cette constatation, basée sur les aspects supra-segmentaux de la langue, ne serait pas perceptible à partir des mesures conventionnelles de l'IIP.

KEY WORDS

HEARING AIDS

LANGUAGES

AMPLIFICATION

COMPRESSION

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Introduction

The use of speech as an input to a hearing aid has been well studied over the years. Among them, Cox and Moore (1988) and Cornelisse, Gagné & Seewald (1991) have calculated the long term average speech spectrum (LTASS) in an effort to determine both the output and the gain required for hearing loss in order to establish sufficient audibility. The calculations required for audibility are essentially ones involving the estimate of a person's frequency by frequency acuity (e.g., the audiogram), the electro-acoustic features of a hearing aid (specifically gain and output), and the intensity and spectral energy distribution of the input. Altering some of the electro-acoustic parameters of a hearing aid, within the limits of its technology, can often place amplified speech into a region that is both audible and does not exceed a person's loudness discomfort level. While the nature of the audiogram tends to be well defined, as does the nature of the electro-acoustic manipulation of the hearing aid, the precise nature of the speech input to the hearing aid still requires some study. Specifically, how does the specification of the electro-acoustic parameters in a hearing aid vary as a function of different non-English languages?

Byrne et al. (1994) studied the long term average speech spectra of 12 languages from around the world (including several dialects totalling 18 samples) and found that "The similarity of the LTASS across samples demonstrates that it is reasonable to propose a universal LTASS, which should be satisfactory for many purposes and applications to most, if not all, languages." (p. 2119). This is actually not too surprising since all language samples emanated from a human vocal tract that has a similar range of outputs. A low back vowel in Portuguese is articulated in a similar manner to a Chinese one. The issue however is not the similarity in LTASS, which is predictably the same throughout the world, but the differences in the frequency bands that carry differing levels of speech clarity. These band importance functions such as the speech intelligibility index (SII) can, and do, vary throughout the world.

Based on the work of Studebaker and Sherbecoe (1991), the SII, and its predecessor the articulation index (AI), have been shown to be quite useful in the determination of which sounds tend to contribute known amounts towards the audibility and thereby, the intelligibility. These can be language specific and are well defined measures of the importance for various bands contributing towards the intelligibility of the language (ANSI, 1997).

The language specific SII can be quite useful and show differences that can be useful to make changes in the frequency response of hearing aids. Specifically Kewley-Port, Burkle, & Lee (2007) and Wong, Hola, Chua, & Soli (2007) have shown an increased importance of the SII for the lower frequency bands in Chinese due to the phonological importance of tones (occurring on the vowels). An increased gain in the low-frequency region for Chinese would serve to improve intelligibility, at least in quiet situations. It is predicted that in the next few years more work will undoubtedly be done in calculating non-English SII measures. These calculations will be important and will provide important frequency response shaping information. A discussion of how changes in the SII may affect the frequency response settings can be found in Chasin (2008a).

Nevertheless, the SII only provides part of the picture. The SII has some limitations and these include being based on only the phoneme, or at most, short utterances. The SII provides no information on the larger syntactic or morphological structures in spoken language. Some languages such as Japanese, and to a lesser extent, Vietnamese, have a rigid consonant-vowel-consonant (CVC) morphological structure. Does a hearing aid require a faster release time on the compressor than would be the case in English such that the quieter consonant achieves sufficient audibility if it follows an intense vowel? The SII would provide no information on this.

Another linguistic issue that cannot be observed in a SII measure, and that is the subject of this study, refers to the importance of the word order within a sentence. In English, there is a SVO word order. Due to lung volume constraints, sentence final utterances are less intense than those found sentence initially we simply run out of air. Sentence final nouns such as objects locally increase the intensity. Content words such as nouns are typically more intense than function words such as pre-positions, adjectives and verbs. Languages with a SVO word order typically have a greater sentence-final intensity than other languages that have no sentence final nouns. In contrast, SOV languages tend to have the quieter "post-positions", verbs and adjectives in a sentence final position that is inherently less intense such that these words risk not being as audible as sentence initial words and nouns. This phenomenon is shown schematically in Figure 1a., Figures 1b and 1c show actual data using the spectral analysis program PRAAT. Figure 1b shows the English sentence "My mother is at home" with a sentence final noun 'home'. Figure 1c shows the Korean sentence "A pretty picture is hanging on the wall" with a sentence final (present progressive) verb 'hanging'.

In many cases, people will be bi- or multi-lingual. Clinically, one can set a hearing aid to have one program

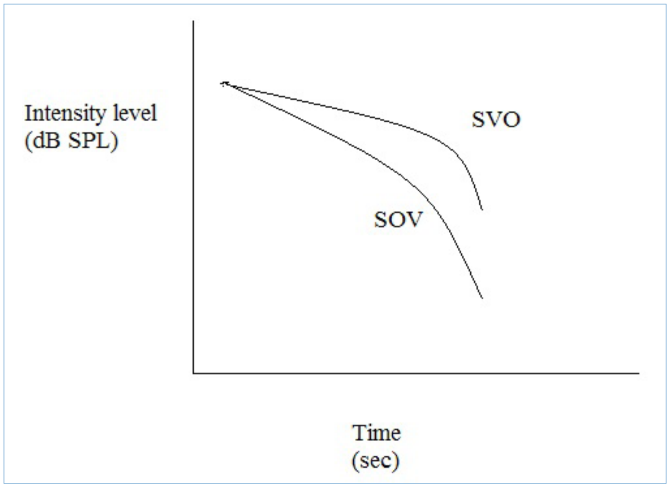

Figure 1a. A stylized decrease in speaking intensity as a function of time where sentence final segments and words are less intense than those in a sentence initial location. This natural decrease in vocal intensity is exacerbated in those languages that have a SOV word order with no content words (e.g., objects) near the end of the sentence.

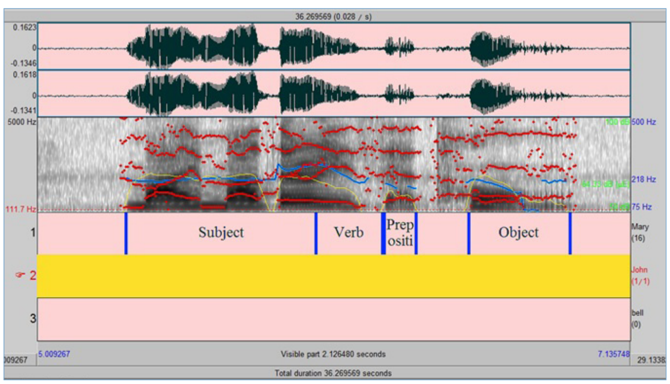

Figure 1b. PRAAT output showing the English (SVO) sentence 'My mother is at home.' http://www.fon.hum.uva.nl/praat/.

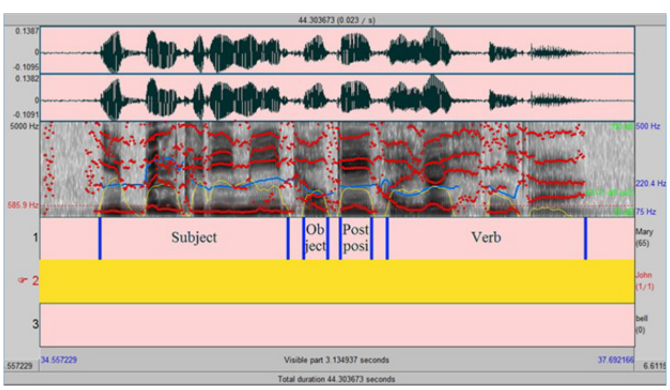

Figure 1c. PRAAT output showing the Korean (SOV) sentence "A pretty picture is hanging on the wall', with a sentence final verb. http://www.fon.hum.uva.nl/praat/.

function as "speech in quiet for English" and another program to function as "speech in quiet for Turkish" or other language. A list of commonly spoken languages that have a SOV word order is shown in Table 1.

Table 1. Examples of five languages that have a SOV word order with sentence final intensities being significantly quieter than for English. *Hindi and Urdu are considered to be the same language despite having different alphabets and different cultural roots.

Hindi-Urdu*
Turkish
Iranian/Farsi
Japanese
Korean

When it comes to assessing those language cues for hard of hearing people that are not represented in the SII, there is virtually no information in the literature. Chasin (2008a) provides some preliminary data as does Chasin (2011) but the analysis in the supra-segmental area for hard of hearing people is still in its infancy.

The purpose of this study is to determine how much, if any, additional amplification is required for hard of hearing bilingual speakers for soft-level inputs such as those found in a sentence final position in SOV languages. This would have ramifications for other soft-level inputs such as sibilants and other obstruent sounds but this has not specifically been studied in this paper. In contrast, the fitting characteristics of the obstruent sounds such as fricatives, affricates and stops would show up in measures of the SII, if they are linguistically distinctive in a particular language. This would relate to an increase in gain in the higher frequency region, probably above 3000 Hz.

It is hypothesized that in non-English languages that have a SOV syntactic structure, more hearing aid gain is required for soft-level (sentence final) inputs than for English given the same audiometric configuration. Accordingly the null hypothesis is that there should be no gain differences between English and SOV languages for soft-level inputs for a given hearing loss. Preliminary pilot work performed by Chasin (2008b) shows that the difference in hearing aid gain required for soft-level inputs for the languages mentioned in Table 1 are not statistically different and as such have been grouped together under the general heading of SOV languages.

Method

One hundred and two subjects who were clinical patients in a Toronto area audiology and otolaryngology practice (71 female and 31 male) were assessed over a twenty month time period. Each of the subjects spoke a SOV language as their first language and also spoke English with sufficient fluency, and cognitive ability to be able to understand instructions provided in English. In many cases, the subjects also spoke a third or even a fourth language. All subjects were provided with both written and oral information concerning the goals of the study and participation was entirely voluntary. The subjects had all agreed to have a hearing aid evaluation because of the degree of non-treatable or sensori-neural hearing loss, and the perceived need for amplification in some part of their daily lives. Audiometric configuration varied but all 102 subjects had at least a 45 dB HL hearing loss at 1000 Hz and were fitted with semi-occluding or fully occluding earmolds. None of the subjects had a hearing loss in excess of 85 dB HL at 1000 Hz. The audiometric high frequency hearing loss acuities ranged from 40 dB HL to "no response" at 4000 Hz.

Subjects who were not interested, had a severe to profound hearing loss, had limited English, or had cognitive difficulties (as reported by a family member) were excluded from the study. It is quite possible that for those people with severe and profound hearing losses, the gain for soft-level inputs would be very large for reasons of audibility rather than linguistic preference.

Digital recordings (.wav files) of cold running speech were made for English and five commonly used languages in a large metropolitan area that have a SOV word order. Shown in Table 1, these five languages were Hindi-Urdu, Turkish, Iranian/Farsi, Japanese and Korean. Linguistically, Hindi and Urdu are considered to be the same language despite having different alphabets and having different cultural roots. Using a MXL 770 condenser microphone and an M-Audio Firewire 410 audio digital recording interface, recordings were made using Pro-Tools 10 software spectral analysis and manipulation software (www.avid.com/US/products/Pro-Tools-Software) in a clinical sound treated audiometric booth. All .wav files were assessed spectrographically to ensure that there was no saturation effects and no DC offset bias (Adobe Audition CS5.5, www.adobe.com/products/audition.html). The .wav files were routed to KRK VXT 4 monitors (www.krksys.com) mounted at ± 45 degrees at ear level.

Between 2008 and 2010, the 102 bilingual (English and one of the five SOV languages being studied) hard of hearing subjects were recruited. These participants agreed to purchase bilateral hearing aids through the audiology dispensing clinic and were fit with hearing aids, initially according to the Desired Sensation Level approach (Scollie et al., 2005), and then with slight adjustments to the frequency response that may have been useful for issues concerning the naturalness of speech. These were all first time users. The "slight adjustments" in frequency response were made while listening to the English .wav files. Gain for soft, medium and high level inputs was specified. The subjects then were given control (via the NOAH module) over the amount of gain for soft-level inputs until they were satisfied with the quality of the sound. Specifically, the subjects were asked to "adjust the sound by using the 'up' and 'down' arrows on the computer keyboard until you feel that sound is the most comfortable" while listening to first, recorded English, and then a recorded sample of their second SOV language. They were allowed to do this for as long as they desired. This was stored in the first program of the hearing aid. The reason for first adjusting the amount of gain for soft-level inputs was to familiarize the subjects to the expected sound quality that they may expect from hearing aids, since they were all first time hearing aid users. This was an ergonomic finding from Chasin (2008b).

The same process was duplicated with their second SOV language (while listening to their SOV language) only this time the subjects adjusted the gain for soft-level inputs themselves without any input from the audiologist. This was stored in the second program of the hearing aid.

The difference at 1000 Hz was calculated between programs one and two for each subject such that they served as their own control. Since each of the subjects had at least a 45 dB HL hearing loss at 1000 Hz, all were prescribed and fit with at least 15 dB of gain at this frequency. The choice of a measurement at 1000 Hz was partly arbitrary but fulfilled the two requirements that all subjects required amplification at this frequency and that all subjects had measureable hearing thresholds at this frequency. Slightly different results would probably be obtained if a different metric was utilized. A paired t-test was performed and tests were carried out at the $\alpha = .05$ level of significance.

For this study the English program was always set up first. This was done because the initial fitting of the hearing aids was associated with the necessary explanation and counselling. The hearing aid fitter was only conversant in English so it was clinically reasonable to continue with the English program first and the non-English SOV language second. There may be an order effect and this clinical decision may have ramifications as a source of error in this study.

All hearing aid fittings were performed with a probe tube microphone situated in the ear canal, and all measured differences selected on the NOAH module during the experiment were validated by probe tube microphone measures. This is in accordance with standard audiology practice at this clinical facility. Since this was a clinical research program, there were a number of different hearing aid models used, but all had the capability to have the gain for soft, medium and high level inputs specified separately.

Results

The raw data are shown in Figure 2 and the results are shown in Table 2. There is significant evidence to reject the null hypothesis that there should be no gain differences between English and SOV languages for soft-level inputs, ($p < .001$). For those languages assessed that possess a SOV word order, in order to hear the final elements of a sentence with sufficient audibility, more hearing aid gain is required for soft sounds. This amounts to approximately 3 dB greater gain (at 1000 Hz) than for a SOV language such as English.

An improved audibility for soft sounds, such as those that may be found at certain quieter syntactic locations, does not necessarily mean improved communication ability in noisy social environments. Depending on the individual, this may only be the first of several steps in the rehabilitative pathway.

Discussion

Modern hearing aids have the capability of having more than one program that can be independently adjusted for any number of listening situations. They can also be adjusted for listening to different languages, within certain limits.

Differences that can be observed on a SII or similar measure are those that may result in changes in the frequency response. This may include an increased low frequency gain for improved audibility of sonorants that may carry tonal information, an increase in the amount of gain locally at 3000 Hz for Slavic languages due the importance of palatalization that manifests itself in the third formant region (around 3000 Hz), or Arabic that has a proliferation of important high frequency cues because of the phonological importance of the various high frequency stops and affricates.

In contrast, differences at the syntactic or supra-segmental level where most of the nouns are clustered near the beginning of a sentence (e.g., SOV languages) appear to require more hearing aid gain for (sentence final) soft-level inputs. This ensures that sentence final elements are sufficiently audible to add to improved intelligibility.

Table 2. Statistical analysis showing significant evidence to reject the null hypothesis of no difference between the amount of gain for soft-level inputs, for the two syntactic linguistic forms.

t	df	Sig. (2-tailed)	Mean diff.	Lower CI limit	Upper CI limit
10.368	101	P <0.001	3.068	2.482	3.656

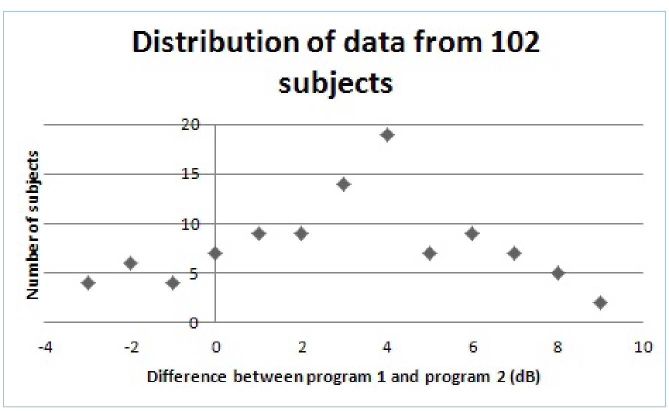

Figure 2: Raw data for all 102 subjects showing the difference for each subject between the English and the second SOV language, for the amount of desired gain for soft-level inputs.

There is a lack of research examining some supra-segmental elements in speech on hearing aid fittings. A literature review indicated no other research has been performed in this area other than Chasin (2008a; 2011. Of the small body of research that is marginally relevant to this area, all work has been performed at the phoneme level only, such as alterations in the SII for a particular language (Kewley-Port et al., 2007, and Wong et al., 2007). Phoneme level changes, as observed in language specific SII measures, will only result in frequency response changes. While this is an important area of research that has direct clinical ramifications, these studies only assess a portion of the language specific settings that might be required by a non-English speaker.

An area of future work involves whether these preference-selected settings that were obtained at the initial hearing aid fitting were actually preferred at a later point in time (e.g., six months or longer). Preliminary research indicates that that is indeed the case but the data are only based on a small sample. Another area of future work, and a possible source of error in this present study, is the order of adjustment. In this study the English program was set up initially, followed by the non-English SOV program. Although this was performed based on reasons of clinical expediency, the order of presentation and programming will be studied in greater depth in future studies.

This study, as well as the work of Kewley-Port et al. (2007) and Wong et al. (2007) has been performed for "speech in quiet" settings. It is quite possible that these suggested changes to the frequency response (in the case of SII phoneme level differences) or the amount of gain for soft-level inputs (in the case of SOV syntactic differences) are minimized in a noisier environment. For example, while Kewley-Port and Wong and colleagues suggest an increase in the amount of gain for low frequency (sonorant) sounds in tonal languages such as Chinese, the reduction in signal to noise ratio (with slightly greater gain being provided to background noise), may act in the opposite direction. It is quite possible that SII based- research that indicates a low frequency extension in gain relative to English may be possible, in conjunction with an algorithm that utilizes a technique such as modulation rate analysis that could help distinguish between low frequency environmental noise and low frequency speech information.

All hearing aids in this study have wide dynamic range compression; however some use varying time constants in various channels while others do not and this may have affected the subjects' preferences of their chosen settings. This is an uncontrolled feature of this work. However, given that the data have still achieved statistical significance, even while using potentially different technologies, these results can be viewed with greater clinical significance than if this study would have been done with potentially more similar hearing aids. A further modification of this study is being contemplated in using a virtual hearing aid that is entirely software driven. Truly identical hearing aid responses can be obtained within a well-controlled paradigm where all changes in the "compression engine" of the software can be implemented.

Another limitation is the preliminary finding from Chasin (2008b) that all SOV languages can be grouped together. It is quite possible that with better controls of the compression system (as suggested below) that subtle differences can be found between the various SOV languages that were missed on earlier analysis.

There are many elements of languages that have yet to be examined in sufficient detail and these include the nature of the release times for the hearing aid compressor for those languages that have a rigid morphology such as the Japanese CVCV structure. A more rapid release time may be appropriate for those languages such that the less intense intervocalic consonants achieve sufficient audibility.

Use of a virtual generic hearing aid in future studies may not only reduce the variability in the data but also be able to be implemented for a wide range of assessment of clinical audiology questions.

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