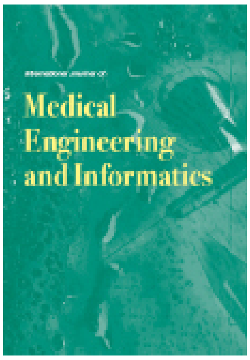

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Perception and confusion of speech in Algerian school children wearing hearing aids

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Perception and confusion of speech in Algerian school children wearing hearing aids

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Abstract: The paper discusses the performance of hearing impaired Algerian children in perception of features of the Arabic phonemes in comparison to their counterparts with normal hearing ability. The acoustic analysis of collected data demonstrates a presence of several articulation disorders at primary school children with average deafness and wearers of hearing aids, such as: the substitution, elision, assimilation, addition and deformation of Arabic consonants in continuous speech. The consonants prone to these disorders are the back consonants mainly the fricatives and sibilants. Therefore, school rehabilitation services should take into account these constraints to achieve better schooling of hearing impaired schoolchildren.

Keywords: average deafness; acoustic analysis; hearing aids; primary school; Arabic language.

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1 Introduction

Optimal language acquisition in children is closely linked to a healthy auditory system. A child with deafness problems presents language deficit, so learning problems that result in reduced academic achievement. Thereby, an understanding of the physiological processes involved in speech development and voice production in the child with hearing loss is a significant challenge for speech and language therapists, phoneticians and other specialists in the field. An evaluation of oral and written language and auditory skills of children with hearing impairment should be performed periodically in order to offer the child a better schooling. Moreover, the existence of a critical period for language development urges for the early intervention program and care of children with average hearing loss as they may encounter educational problems at school. So as early as the child receives hearing aid and a proper care as better are his/her chances to acquire normal speech (François et al., 2015; Wang et al., 2013; Fulcher et al., 2012; Geers, 2004; Talbot et al., 2012; Yoshinaga-Itano, 1999).

We have opted for this topic for several reasons mainly, the paucity of studies focusing on the employment of acoustic analysis tools to evaluate the influence of deafness on child's educational level progress. This is all the more important in Algeria, where we have noted the low priority paid to the issue of deafness in children at school, especially for mild to average hearing loss, and also for caring of a rehabilitation of language disorders at the Algerian schools.

Therefore, this study aims to provide information on the acoustic characteristics related to speech disorders, and to raise the awareness of the deaf learners, teachers and researchers on the utility of analysis and extraction of acoustic parameters, in order to assess hearing aids contribution in enhancing child performances at school. Such studies will also improve rehabilitation techniques by providing concrete and objective data on the nature of perception disorder of sounds, and the level of influence of the average hearing loss on child language development.

2 Methods

We have started by investigating at schools that have pupils with hearing impairment and wearing hearing aids. So we have visited a number of elementary schools in Algiers, and we have observed 19 cases having average deafness and wearing conventional hearing aids. In a second phase, we have recorded a speech corpus uttered by all the selected schoolchildren. This corpus consists of Arabic vowels in isolation and in consonantal context, through a set of phrases and syllables (consonant to the vowel – CV). The selection of CV samples must takes into account the phonetic oppositions linked to the features as voiced vs. unvoiced, plosive vs. fricative, nasal vs. oral (Ferrat and Guerti, 2017). The corpus of sounds has been registered by dictating the words to the children, without written support, to avoid possible errors from reading (difficulties to recognise graphic symbols). The phrases and words were also dictated to the patients by masking the movement of lips to prevent a possible labial reading. On average, we have taken 20 minutes of time with each patient, individually in an isolated room by using the same recording procedure. The same corpus was pronounced by ten other schoolchildren of the same age, without hearing loss. The phonetic code of the vowels and consonants used in our context is illustrated in Table 1. This study has received ethical approval for publication.

Table 1 Inventory of the used specific consonants and vowels

Phoneme	*Arabic character*	*Place of articulation*	*Voiced*	*Manner of articulation*		
				Emphatic	*Plosive*	*Fricative*
[θ]	ث	Interdental	–	–	–	+
[ṭ]	ط	Dental	–	+	+	–
[š]	ش	Palatal	–	–	–	+
[ṣ]	ص	Alveolar	–	+	–	+
[ḍ]	ض	Alveolar	+	+	+	–
[x]	خ	Velar	–	–	–	+
[ɣ]	غ	Velar	+	–	–	+
[q]	ق	Uvular	–	–	+	–
[ğ]	ج	Affricate	+	–	–	–
[Ɛ]	ع	Pharyngeal	+	–	–	+
[ḥ]	ح	Pharyngeal	–	–	–	+
[h]	ه	Glottal	+	–	–	+
[w]	و	Semi vowel bilabial	+	–	–	–
[ā, ī, ū]		Long vowels	+	–	–	–

To perform acoustic analysis of the recorded sounds, we have used the Praat (2015) software, a tool developed by Paul Boersma and David Weenink from the University of Amsterdam that enables an extraction of values of acoustic parameters of sounds. This software allowed us to compare the acoustic characteristics and the spectrographic curves of the sounds uttered by the patients with their normal counterparts. We have exploited the sonagraphic representations of sounds in order to detect possible pronunciation errors, such as deformation, elision, assimilation, addition and inversion of sounds in the act of speech.

3 Results

3.1 Acoustic analysis

An extraction of acoustic parameters is performed from the corpus of sounds uttered by all the patients, in comparison with their normal counterparts without hearing impairments. The results are shown in Table 2. The observation of the acoustic parameter values of the sounds shows:

- A significant increase in the values of pitch F_0 in patients. The patients tend to pronounce the sounds more acutely.
- An increase in values of formants F_1 and a decrease in values of formants F_2 in patients. Patients tend to accentuate their sounds. In other words, an emphasis often accompanies the speech of patients. In addition, there is a reduction of the vowel

triangle quite perceptible in patients, that is to say, a rapprochement between the levels of the formants.

- A limited duration of pronunciation of words. Patients tend to speak with a fairly fast rhythm.
- Normal values of jitter, shimmer and HNR taken from the patient's speech. This confirms that patients do not have physiological disorders in the organs of the vocal tract.

Table 2 Acoustic parameters values of normal/pathological cases

	Pronounced words	*F_0 (Hz)*	*F_1 (Hz)*	*F_2 (Hz)*	*F_3 (Hz)*	*Duration (ms)*	*Intensity (dB)*	*Jitter (%)*	*Shimmer (%)*	*HNR (dB)*
Normal	[Samaka]	249	720	1,920	2,890	720	84	0.36	3.14	18.54
	[Ḥammam]	244	730	2,156	2,920	889	84	0.38	3.83	19.96
Pathological	[Samaka]	350	800	1,715	2,636	557	82	0.49	3.81	19.44
	[Ḥammam]	346	845	1,784	2,740	740	83	0.55	3.11	18.38

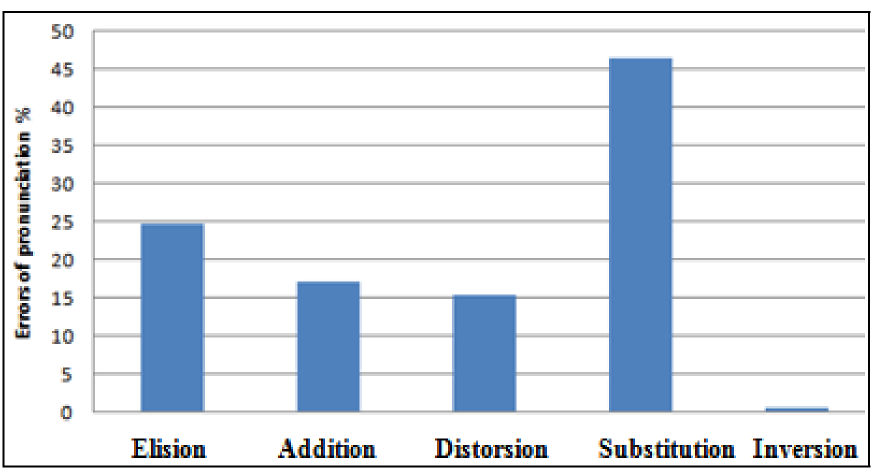
3.2 *Sonagraphic analysis*

The main impairments observed for the nineteen cases of children with average hearing loss and wearers of conventional hearing aids are summed up in Table 3 and Figure 1.

Table 3 Error rates by type of pronunciation disorders of the all cases studied

Pronunciation disorders	*Elision*	*Addition*	*Distortion*	*Substitution*	*Inversion*
Cases studied	24.7%	17.2%	15.4%	46.5%	0.6%

Figure 1 Error rates of pronunciation of sounds by the patients (see online version for colours)



The majority of the studied cases present significant errors of substitution of one consonant with another (Figure 1). This is in accordance with previous studies (Han et al., 2017). The majority of substituted consonants are (f, s, z, θ, x, ḥ, ɣ, k). It is also the same case for the deformed consonants. These consonants are mostly the fricative consonants that are produced at acute and high frequencies. They present turbulence peaks in high frequencies located between 2,000–8,000 Hz, which patients are unable to accurately perceive. The lateral consonant [l] is often pronounced with nasalisation and close to the nasal consonant [n]. In several cases, the patients replace the voiceless fricative [s] by the voiced fricative [z] which presents the same place of articulation. The majority of the omitted consonants are the posterior consonants (specific to Arabic language), the determinant [al] and the 'tanwin' at word-final positions. Some studies has already discussed this problem in the case of the English language, and have noted that children with hearing loss often cannot hear word endings such as -s or -ed. This leads to misuse of verb tense, pluralisation, non-agreement of subject and verb and possessives (Cannon and Kirby, 2013; Bloom and Lahey, 1978). In our study, this observation is also verified for the Arabic language.

Figure 2 Pronunciation of [ḥ] as voiced in the word [ḥammam] (bathroom) (see online version for colours)

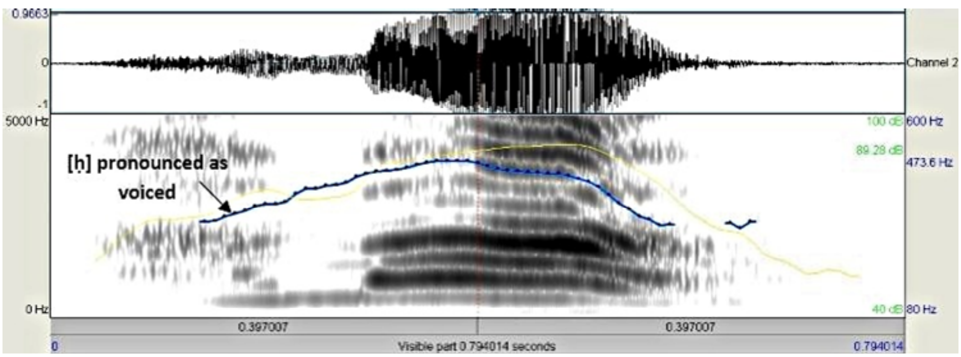
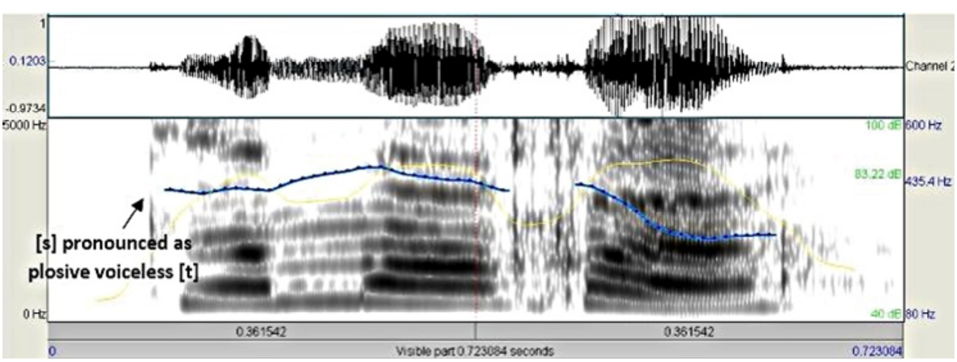


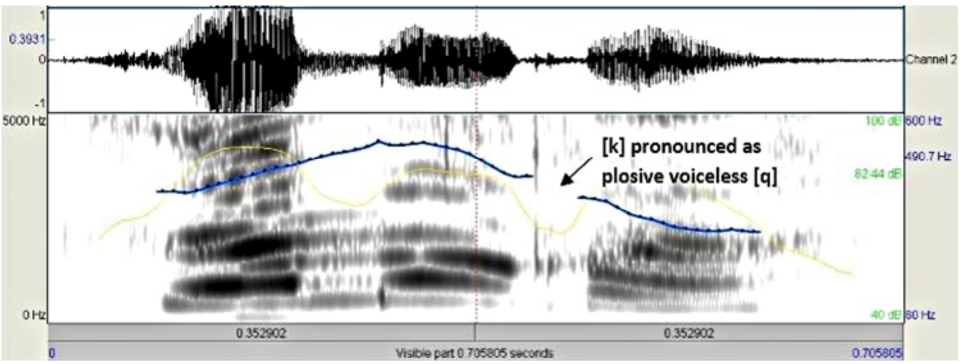
Figure 3 Pronunciation of [t] in place of [s] in the word [samaka] (fish) (see online version for colours)



In contrast, the majority of the added consonants are the anterior consonants. The errors of inversion are practically non-existent. The isolated vowels [a], [i], [u] are performed correctly. These are pronounced as voiced sounds, therefore at low frequencies, and with involving the lips, hence their easily identification. This is in agreement with results found in other languages (Hung et al., 2017).

In our study, we also noted that the patients with the least pronunciation errors were those who had worn hearing aids for five years or more. Those who have worn prosthesis for less than two years have highest rate of errors. This supports the need for screening and early management of deafness in school. Illustrative examples of errors observed on sonagraph are shown in Figures 2–4.

Figure 4 Pronunciation of [q] in place of [k] in the word [samaka] (fish) (see online version for colours)



4 Discussion

The 19 cases studied present significant errors of substitution from one consonant to another. The acoustic analysis of these consonants indicates that:

- The fricatives [f, s] have turbulence peaks of high intensity in a region between 4,000 to 8,000 Hz. So these consonants occur in very high frequencies that the patient is unable to perceive correctly, thus to discern the frequency transitions to these consonants. Some studies demonstrate that low frequencies below 400 Hz contain 60% of the energy of speech and contribute only to 5% of its intelligibility. In contrast, acute high frequencies over 1,000 Hz (particularly unvoiced fricative consonants) represent only 5% of the energy of the voice and contain 60% of the relevant data allowing its recognition (Hodgson and Skinner, 1986). Similarly, the frequencies of better intelligibility range from 400 to 4,000 Hz. More specifically, the frequency region around 2,000 Hz is highly relevant for the speech intelligibility.
- The nasal consonants have formantic transitions for F_1 and F_2 at about 300 Hz and 1,100 Hz respectively, so the same frequency band as the liquids [l, r] which are located in a diffuse band of frequencies between 200 Hz and 1,000 Hz. Hence, the confusions observed between these types of consonants. This is in agreement with findings from other studies in the field (Han et al., 2017; Healy et al., 2014; Phatak et al., 2009). Also, a previous study has shown that excessive nasality is often observed in the speech of the hearing impaired (Baudonck et al., 2015; Okalidou et al., 2017).

- The two observations noted above allow us to say that the child ignores, in many cases, the phonetic transitions in a continuous verbal flow and thus loses the adequate perception of many portions of sounds, due to the coarticulation phenomena (overlaps between sounds during speech act production). Researches carried out by Delattre et al. (1955) at the Haskins laboratories revealed that the essential indices used in the perception of consonants, and particularly of plosives, are the modifications that the frequencies undergo during the transitions of the vowel towards the consonant (VC) or from the CV. In other words, the phonetic transitions provide the most important information that we use in the perception of many consonants. This explains the high presence of consonants substitutions and confusion errors observed in this study. This observation is in agreement with results of a previous study (Chun et al., 2015).

The study of vocal formants reveals an increase in F_1 values and particularly a decrease in F_2 values. This variation in the formant values results in a reduction of the vowel triangle in the speech of the patients, that is to say, a rapprochement between the levels of the formants. This reduction has already been reported and commented on by other studies and for other languages (Ozbič and Kogovšek, 2010; Ryalls et al., 2003; Shukla, 1989; Verhoeven et al., 2016).

The majority of assimilated or deformed consonants produced by patients are fricatives. The majority of the non-pronounced consonants are the back consonants, while the main consonants added to the pronunciation of the words are the front consonants. There is a general agreement that the consonants produced in the front of the mouth are easier to assimilate since their places of articulation are visible, unlike the consonants produced in the back of the mouth, and the voicing mode of the vocal cords which depend solely on individual hearing. We have noticed the absence of inversion of the phonemes for the cases studied. This observation is explained by the fact that these patients do not suffer from speech comprehension problems.

We have observed that the patients who received a higher volume of speech therapy re-education program present fewer errors than the other patients. Thus, wearing hearing aids combined with an appropriate educational intervention can improve the language performance of the deaf child. Nevertheless, the conducted tests of the various Arabic sounds uttered by the patients demonstrate that the perception disorders may persist in spite of the presence of hearing aids, as the latter cannot replace the hearing abilities of the human ear, but it can significantly reduce the disorders of sounds identification and perception.

As far as the manner of articulation, the most consonants prone to disorders are the fricatives, sibilants in particular. The latter are at a high frequency level and acute and are not easily perceptible by hearing impaired children. Thus, relevant information necessary for speech comprehension is supported by the consonants with acute frequencies unlike the vowels in low frequencies. These results are in accordance with previous studies findings which indicate that the amplification of high frequencies improves speech recognition performance among deaf subjects with hearing loss in acute and high frequencies (Baer et al., 2002; Hornsby and Ricketts, 2003; Plyler and Fleck, 2006; Turner and Henry, 2002).

In addition, this study has shown that the rehabilitation technique used does not give much importance to posterior consonants, especially unvoiced fricative consonants, as well as the nasalisation characteristic. Indeed, we have found little improvement in these areas, after three years of rehabilitation. This is all the more significant as the number of posterior (back) consonants and unvoiced fricative in Arabic language is quite important. The presence of perceptual deficits in this class of sounds could significantly reduce the verbal communication.

5 Conclusions

The question asked in this work is to evaluate the degree of ability of a conventional hearing aid to help hearing impaired schoolchildren to identify and discriminate sounds and thereby develop their language behaviour. For this, we have used a set of acoustic characteristics extracted from the Praat software. The acoustic analysis allowed us to obtain concrete and objective data that allow us to evaluate the speech disorders for this category of children. We have observed that the most relevant disorders concern the fricative sounds at the high and acute frequencies, the nasals and the liquids.

The contribution of hearing aid is closely linked to residual hearing. Also, the study results indicate that children with average hearing loss present an important decrease in hearing ability. Wearing a hearing aid coupled with early rehabilitation will improves verbal communication and permits a better perception of the consonants and vowels of the language.

In perspective, this work, based on acoustic analysis, could be generalised to other categories of deafness. The study we have conducted allowed us to gather an important set of qualitative and quantitative data on perception disorders of sounds related to modes and places of articulations of the phonemes.

Finally, we have noted that children with average hearing loss in Algeria are enrolled in special classes with children having profound deafness who need a sign language to communicate, despite the large gap between the two categories. Children with average hearing loss can attend regular schools, but need special help, such as wearing hearing aids and appropriate strategy of speech therapy re-education, as opposed to children with profound hearing loss.

Nevertheless, one of the main objectives of this work is to prevent the onset or aggravation of disorders in children, through early detection and rehabilitation, and thus avoid serious, even dramatic, consequences for their psychic developments and their schooling.

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