

Received : 15/03/2026

Accepted : 21/05/2026

Representation of Arabic Pharyngeal Sounds among Tamahaq Speakers in AL-Hoggar: A Comparative Study Using ChatGPT

Zineb Felli¹

Laboratory of Scientific and Cultural Heritage of Tamanghasset Region, Faculty of Letters and Languages

University of Tamanghasset Amine ELokkal EL hadj Moussa Eg Akhamouk, Algeria

felli.zineb@univ-tam.dz

Abstract

This study investigates the role of artificial intelligence (AI), particularly ChatGPT, in the phonetic representation of Arabic guttural consonants produced by Tamahaq-speaking learners of Arabic in AL-Hoggar region. As a pilot exploratory study, it combines contrastive analysis, error analysis, International Phonetic Alphabet (IPA)-based transcription, and acoustic analysis using Praat software to evaluate the relative accuracy of AI-generated phonetic representations.

The acoustic analysis focused on formant frequencies (F1/F2), duration measurements, and spectrographic observation. The findings indicate that ChatGPT provides relatively accurate phonetic approximations for several consonants; however, important limitations remain, especially with pharyngeal consonants that are phonetically marked in Arabic.

The study concludes that AI can support phonetic analysis and IPA-based transcription, although expert verification remains necessary.

Keywords : Arabic guttural consonants, Tamahaq, ChatGPT, contrastive analysis, Praat.

1. Introduction

Recent advances in artificial intelligence and speech-processing technologies have significantly influenced linguistic research, particularly in areas related to phonetic analysis, speech recognition, and language modeling. AI-based systems are increasingly used to support linguistic investigation through automated transcription, pattern recognition, and speech analysis across different languages and dialects.

In the field of Arabic phonetics, the computational representation of speech sounds remains particularly challenging due to the articulatory and acoustic complexity of several Arabic consonants, especially guttural and pharyngeal sounds. These challenges become more evident in multilingual and under-resourced linguistic contexts, where local speech varieties and cross-linguistic phonological transfer may influence pronunciation patterns.

Within this framework, the present study investigates the role of artificial intelligence in the phonetic representation of Arabic guttural consonants among Tamahaq-speaking learners of

¹ felli.zineb@univ-tam.dz

Arabic in Al-Hoggar region of Algeria. More specifically, the study examines the extent to which AI-generated International Phonetic Alphabet (IPA) transcriptions produced by ChatGPT can reflect actual learner pronunciation in a cross-linguistic context involving Arabic and Tamahaq.

To strengthen the reliability of the analysis, the study combines contrastive analysis, error analysis, and instrumental acoustic analysis using Praat software. Acoustic measurements and spectrographic observations are used to support the interpretation of AI-generated phonetic representations and to examine selected articulatory and acoustic variations in learner speech.

2. Theoretical Background

2.1. Phonetic Representation and the IPA

Phonetic representation plays a fundamental role in linguistic analysis by providing a standardized system for describing speech sounds. The International Phonetic Alphabet (IPA) offers a consistent framework in which each speech sound is assigned a unique symbol, allowing for accurate comparison across languages and dialects.

According to Ladefoged and Johnson (2015), phonetic transcription is an essential tool in the scientific description of speech, as it enables researchers to capture subtle phonetic distinctions that may carry functional or phonological significance. The IPA is particularly useful in the study of consonantal systems, vowel quality, and prosodic features such as stress and intonation (International Phonetic Association, 1999).

2.2. Arabic Guttural Consonants

Arabic phonological tradition, as described in classical works such as Sibawayh (1955) and Ibn Jinni (1945), classifies consonants according to their place of articulation in the vocal tract, including a group traditionally referred to as guttural sounds.

In modern phonetic terminology, these sounds include:

- 1- /ʔ/ همزة ع (glottal stop)
- 2- /h/ هـ (voiceless glottal fricative)
- 3- /ʕ/ ع (voiced pharyngeal fricative)
- 4- /ħ/ ح (voiceless pharyngeal fricative)
- 5- /ɣ/ غ (voiced uvular fricative)
- 6- /x/ خ (voiceless uvular/velar fricative)

These consonants are among the most phonetically marked segments in Arabic and are known for their articulatory complexity, especially for non-native speakers whose first languages do not contain similar phonetic categories.

2.3. Phonological System of Tamahaq

Tamahaq, as a variety of the (Berber/Amazigh) language, exhibits a consonantal system that shares certain phonetic characteristics with Arabic while differing in the distribution and functional load of several consonants. Previous descriptive studies of Tamahaq varieties indicate that its phonological system includes consonants such as /h/, /ɣ/, and /x/, which are articulated with relatively stable realizations in comparison with other consonantal categories (Heath, 2005).

The consonant /h/ / ʕ / in Tamahaq is generally reported as a glottal fricative with a realization comparable to its Arabic counterpart, although its distribution may vary depending on phonological context, and also the dorsal fricative /ɣ/ / ɣ / is widely attested in Tamahaq phonological descriptions and is typically realized as a voiced fricative produced with a narrowing of the airflow between the back of the tongue and the velar region, accompanied by vocal cord vibration during articulation (Basset, A., 1968, p. 4).

Similarly, the consonant /x/ / ɣː / (voiceless velar fricative) is present in Tamahaq and is described as having an articulation close to that of Arabic /x/, with relatively comparable acoustic properties (Basset, 1968, p. 4).

Overall, the comparison between Arabic and Tamahaq suggests a partial overlap in dorsal and fricative consonants, while highlighting differences in the presence and distribution of Arabic pharyngeal consonants such as /ʕ/ and /ħ/, which are either absent or not fully stabilized in Tamahaq phonology (Basset, R., 1908).

This partial overlap is important for the present study, as it may influence the production and phonetic realization of Arabic sounds by Tamahaq-speaking learners, particularly in contexts involving cross-linguistic phonological transfer.

2.4. Artificial Intelligence and Phonetic Analysis

A. Definition of Artificial Intelligence (AI)

Artificial intelligence refers to computational systems designed to simulate human cognitive abilities such as learning, reasoning, and pattern recognition. In linguistics, AI technologies are increasingly used in speech processing, transcription, and language analysis.

According to Russell and Norvig (2021), AI systems operate as agents that perceive and interpret input data to achieve specific goals. In the field of natural language processing (NLP), AI-based models have demonstrated variable performance across languages and linguistic tasks.

Recent studies have shown that large language models such as ChatGPT may exhibit limitations when dealing with fine-grained phonetic transcription, particularly in under-resourced languages and dialect-sensitive contexts (Khondaker et al., 2023). Similarly, Arabic speech processing remains challenging due to dialectal variation and phonetic complexity (Aldarmaki et al., 2022).

Speech recognition systems rely on acoustic feature extraction, including frequency, duration, and spectral patterns, to model speech sounds. However, phonetic-level accuracy especially for consonants such as /ʕ/ and /ħ/ remains a major challenge in computational systems.

In addition to AI-based transcription, instrumental phonetic analysis using acoustic software such as Praat has become an important methodological approach in evaluating speech production accuracy through formant frequencies, duration measurements, and spectrographic analysis.

Therefore, while AI tools can support phonetic analysis and transcription, their outputs should be interpreted as approximations rather than definitive phonetic representations.

B. Speech Recognition Technology

Artificial intelligence relies heavily on the accurate representation of speech sounds in order to analyze, recognize, and sometimes generate spoken language. In this context, phonetic representation especially through the IPA plays a central role in speech processing technologies.

Automatic speech recognition systems typically begin by extracting acoustic features from the speech signal, followed by acoustic modeling and decoding processes that map the signal into linguistic units. This enables computer systems to perceive and interpret spoken language, execute commands, and distinguish sounds according to their acoustic properties. Such technology is particularly relevant to Arabic, where sounds such as /ʕ/ and /h/ may appear similar to non-native speakers but differ substantially in articulation and acoustic realization.

To identify such sounds, speech recognition systems generally rely on the analysis of features such as waveform, intensity, duration, spectral shape, frequency, and pitch. Recent work in Arabic speech technology also shows that phonetic and diacritic-sensitive modeling remains an important challenge in Arabic ASR, especially when linguistic detail is essential to the task (Aldarmaki et al., 2022).

Accordingly, AI-based tools may provide useful support in phonetic analysis and representation, but their performance remains dependent on the quality, specificity, and linguistic adequacy of the data on which they are trained.

3. Methodology

This study adopts a descriptive-analytical design supported by contrastive analysis, error analysis, and acoustic phonetic analysis in order to investigate the phonetic representation of Arabic guttural consonants among Tamahaq-speaking learners of Arabic in Al-Hoggar region. It also evaluates the extent to which ChatGPT can assist in the phonetic transcription of these sounds using the International Phonetic Alphabet (IPA).

Given the limited sample size and the exploratory nature of the topic, the study is framed as a pilot exploratory study. This design is particularly relevant in light of recent interest in AI-assisted linguistic analysis, especially in Arabic-related language tasks, where computational tools continue to show both promise and limitations (Russell & Norvig, 2021, p. 34).

Khondaker et al. (2023) found that ChatGPT does not perform equally well across Arabic NLP tasks and tends to be weaker when dealing with Arabic dialectal variation, which suggests that its linguistic output should be interpreted with caution in specialized Arabic phonetic contexts.

3.2. Research Problem

With the rapid expansion of artificial intelligence and its increasing use in language-related applications, questions have emerged regarding its effectiveness in phonetic analysis, especially in under-researched multilingual contexts.

In the case of Tamahaq-speaking learners of Arabic in Al-Hoggar region, the study seeks to examine whether artificial intelligence can contribute to the identification and representation

of phonetic phenomena, particularly those related to Arabic guttural consonants, and whether such tools can provide reliable phonetic transcription for research and pedagogical purposes. This concern is consistent with recent research in Arabic speech technology, which shows that the accurate computational representation of Arabic phonetic detail remains a challenging task (Aldarmaki et al., 2022, p. 80). This challenge is also reflected in recent Arabic speech-processing research, which confirms that dialect diversity and phonological variation continue to complicate AI-based recognition and representation tasks (Talafta et al., 2025).

3.3. Research Questions:

The study seeks to answer the following questions:

- 1- What role can artificial intelligence play in analyzing phonetic phenomena among Tamahaq-speaking learners of Arabic in Al-Hoggar region?
- 2- To what extent can AI-based tools contribute to the phonetic representation of Arabic guttural consonants through IPA transcription?
- 3- What phonetic similarities and differences exist between Arabic and Tamahaq with regard to these consonants?
- 4- Can ChatGPT generate sufficiently accurate phonetic representations of these sounds?
- 5- To what extent can artificial intelligence facilitate and accelerate phonetic analysis in contrastive linguistic research?

3.4. Research Hypotheses

This study is based on the following main hypothesis:

Artificial intelligence can contribute to the analysis and phonetic representation of Arabic guttural consonants among Tamahaq-speaking learners of Arabic through IPA transcription, although its output remains subject to expert verification.

The following sub-hypotheses are also proposed:

- 1- Arabic and Tamahaq share certain phonetic features, while differing in the realization and distribution of some consonants.
- 2- AI-based tools such as ChatGPT can provide useful phonetic approximations.
- 3- The phonetic output generated by AI is not consistently reliable and therefore requires specialist review.
- 4- Artificial intelligence can facilitate comparative phonetic analysis and support contrastive studies between Arabic and Tamahaq.

3.5. Objectives of the Study

This study aims to:

- 1- Examine the role of artificial intelligence in the phonetic analysis of Arabic guttural consonants among Tamahaq speakers in Al-Hoggar region.
- 2- Evaluate the usefulness of **ChatGPT** in representing these sounds through **IPA** transcription.
- 3- Identify the main phonetic similarities and differences between Arabic and Tamahaq at the level of consonantal systems.

- 4- Explore the pedagogical and analytical value of AI-assisted phonetic transcription in Arabic language research.
- 5- Provide recommendations for the use of AI tools in phonetic and contrastive linguistic studies.

3.6. Significance of the Study

Given the importance of artificial intelligence in analyzing phonetic phenomena among non-native speakers of Arabic in Al-Hoggar region in particular, and in language teaching in general, it has attracted the attention of many linguists and researchers. Numerous studies have been conducted in this field, including the present study.

The significance of this study can be identified from both scientific and practical perspectives:

A. Scientific Significance:

Artificial intelligence plays an important role in analyzing phonetic phenomena among non-native speakers of Arabic through developments in computational linguistics. This study contributes to enriching the field of language teaching in general, and Arabic as a second language in particular, due to its close relationship with technology and information science.

B. Practical Significance:

The study aims to encourage those responsible for Arabic language teaching programs for non-native speakers in Al-Hoggar region to innovate and improve the use of intelligent applications in language education. It also seeks to benefit from the results of this study in enhancing the quality of such applications in language teaching and computational linguistics. This is particularly important because recent large-scale evaluations have shown that **ChatGPT** performance in Arabic **NLP** remains inconsistent across tasks and dialectal varieties, reinforcing the need for expert supervision in Arabic phonetic and linguistic research (Khondaker et al., 2023).

3.7. Contrastive Analysis

Contrastive analysis is a linguistic approach that compares two languages in order to identify similarities and differences, particularly at phonological, morphological, syntactic, or lexical levels. It has been widely used in applied linguistics and second language studies to explain areas of potential difficulty resulting from first-language interference.

According to Robert Lado (1957), elements that are similar between the learner's native language and the target language tend to be easier to acquire, whereas those that differ are more likely to cause learning difficulties.

In the present study, contrastive analysis is used to compare Arabic and Tamahaq with specific reference to Arabic guttural consonants. The aim is to identify shared and non-shared consonantal features. This comparison helps explain phonetic deviations observed in learner production and in AI-generated IPA transcription.

3.8. Error Analysis

Error analysis is a methodological approach concerned with identifying, describing, and interpreting errors produced by language learners. Unlike contrastive analysis, which predicts difficulties, error analysis focuses on actual learner output.

As emphasized by Corder (1981), learner errors are not simply signs of failure but important indicators of the language acquisition process.

In this study, error analysis is used to examine inaccurate realizations of Arabic guttural consonants produced by Tamahaq speakers and reflected in AI-generated transcription. It allows classification of deviations such as substitution, approximation, omission, or distortion. Thus, error analysis complements contrastive analysis by linking theoretical prediction with actual performance data in both human and AI outputs.

3.9. Acoustic Analysis Using Praat:

In addition to contrastive analysis and error analysis, the present study incorporates instrumental acoustic analysis using Praat software in order to provide objective phonetic evidence for the production of Arabic guttural consonants by Tamahaq-speaking learners (Boersma & Weenink, 2024).

Selected speech samples were analyzed through spectrographic visualization and acoustic measurements. The analysis focused primarily on formant frequencies (F1 and F2) and consonant duration as key acoustic indicators of articulatory variation (Ladefoged & Johnson, 2015).

Spectrograms were used to observe energy distribution and phonetic realization patterns, particularly for pharyngeal consonants such as /ʕ/ and /ħ/. Mean acoustic values were calculated in order to examine variation across the selected consonants and support comparative phonetic interpretation.

This acoustic component supports the interpretation of AI-generated **IPA** transcriptions and strengthens the reliability of the overall phonetic analysis.

3.10. Participants and Sampling

The study population consisted of Tamahaq-speaking participants from Al-Hoggar region of Algeria. A total of ten (**10**) participants were included in the study. Since the research focuses on a specific linguistic group relevant to the phonetic phenomenon under investigation, a purposive sampling technique was adopted.

The participants were selected on the basis of their relevance to the study objectives, particularly their status as Tamahaq speakers with varying degrees of exposure to Arabic. Their ages ranged from **08** to **60** years old, and their exposure to Arabic occurred through formal schooling, religious instruction, media consumption, and daily social interaction.

Although the sample size remains limited, it was considered appropriate for the exploratory and pilot nature of the present study. The findings should therefore be interpreted cautiously and cannot be generalized beyond the present sample.

3.11. Data Collection Instruments

Three main sources of data were used in this study:

1. A phonetic elicitation test

A phonetic elicitation test was designed specifically for the purposes of the study. It included seventeen (17) Arabic lexical items containing guttural consonants occurring in word-initial, medial, and final positions. The test was used to examine how these sounds were produced and represented by Tamahaq-speaking participants.

2. AI-generated phonetic transcription

The same lexical items were submitted to **ChatGPT** (OpenAI) in order to obtain phonetic representations using the International Phonetic Alphabet (**IPA**). The prompts used required the system to provide **IPA** transcriptions of the selected Arabic words based on its learned linguistic patterns. The outputs generated by the system represent probabilistic approximations of phonetic forms rather than results derived directly from instrumental phonetic measurement.

These AI-generated outputs were then manually compared with the expected phonetic realizations in Arabic as well as with participant productions in Tamahaq. It is important to note that the role of **ChatGPT** (OpenAI) in this study was strictly analytical and exploratory, serving as a computational tool for comparison rather than a source of definitive phonetic ground truth.

3. Supporting theoretical sources

Relevant linguistic and phonetic references were used to support the theoretical and analytical interpretation of the data. The use of the **IPA** as an analytical framework is well established in phonetic research because it provides a systematic method for representing and comparing speech sounds across languages (Ladefoged & Johnson, 2015, p. 42).

3.12. Data Collection Procedure:

The data collection process was conducted in several stages.

First, a list of Arabic lexical items containing guttural consonants was prepared. These words were selected according to their relevance to the phonetic focus of the study and their distribution across different word positions.

Second, the selected lexical items were administered orally to the participants through a phonetic elicitation task. The participants were asked to pronounce the Arabic words individually, allowing the researcher to observe and analyze their pronunciation patterns.

Third, the same lexical items were entered into ChatGPT (OpenAI) in order to obtain phonetic transcriptions in IPA. The AI-generated outputs were then compared with the expected Arabic phonetic forms and interpreted in light of both contrastive analysis and error analysis.

The participants' productions were audio-recorded for subsequent phonetic observation and comparative analysis. The recorded productions were subsequently processed and examined using Praat software in order to support acoustic observation and spectrographic analysis.

3.13. Data Analysis Procedure

The collected data were analyzed qualitatively and comparatively through four complementary procedures:

1. Descriptive phonetic analysis

This procedure was used to examine the pronunciation patterns of Arabic guttural consonants as produced by the participants.

2. Contrastive analysis

This analysis aimed to identify similarities and differences between Arabic and Tamahaq in the realization of guttural consonants.

3. Error analysis

Error analysis was employed to identify recurring deviations and interpret them in relation to possible first-language interference and phonetic transfer.

4. Instrumental acoustic analysis

Instrumental acoustic analysis was conducted using Praat software in order to examine selected acoustic properties of Tamahaq consonants, including formant frequencies (F1 and F2), duration, and spectrographic characteristics. This procedure was used to support and validate the qualitative phonetic observations obtained through contrastive and error analysis. In addition, the phonetic transcriptions generated by ChatGPT (OpenAI) were evaluated according to their approximation to the expected Arabic phonetic forms. The analysis focused on the extent to which the AI-generated outputs reflected the intended Tamahaq sounds.

The present evaluation remains exploratory in nature, particularly given the limited sample size and the restricted acoustic dataset. Consequently, the findings should be interpreted as preliminary rather than definitive.

This evaluative step is particularly relevant because recent Arabic speech-processing research continues to report substantial challenges in modeling fine-grained phonetic and phonological distinctions computationally (Aldarmaki et al., 2022; Talafha et al., 2025).

3.14. Ethical Considerations:

Participants were informed of the purpose of the study prior to data collection. Their participation was voluntary, and the data collected were used exclusively for academic and research purposes. No personally identifying information was included in the analysis or reporting of the findings.

3.15. Limitations of the Study:

This study presents several methodological limitations.

First, the sample size is relatively small, which limits the generalizability of the findings. Second, the study focuses on a specific regional and linguistic context, namely Tamahaq-speaking learners of Arabic in Al-Hoggar region. Third, the evaluation of AI-generated phonetic transcription remains partly dependent on expert linguistic judgment.

Furthermore, although the study incorporated preliminary instrumental acoustic analysis using Praat software, the acoustic investigation remained limited in scope and was restricted to selected formant measurements, duration analysis, and spectrographic observation. More extensive acoustic modeling and larger datasets may provide deeper phonetic validation in future research.

For these reasons, the findings should be interpreted as exploratory rather than definitive.

4. Results and Analysis

4.1. Contrastive Analysis between Arabic and Tamahaq

4.1.1. Arabic and Tamahaq Guttural Consonants: Similarities and Differences

A contrastive examination of Arabic and Tamahaq demonstrates that the two languages share certain guttural consonants, although they do not possess identical phonetic inventories.

In Arabic, the group of guttural consonants traditionally includes the following sounds:

- 1- /ʔ/ همزة glottal stop
- 2- /ħ/ ح voiceless glottal fricative
- 3- /ʕ/ ع voiced pharyngeal fricative
- 4- /ħ/ ح voiceless pharyngeal fricative
- 5- /ʁ/ غ voiced uvular fricative
- 6- /x/ خ voiceless velar/uvular fricative

These consonants occupy an important place in the Arabic consonantal system and are characterized by articulatory properties (Abu-Chacra, 2007, pp. 1–27), that may present difficulty for non-native speakers.

In Tamahaq, by contrast, the inventory of corresponding guttural consonants appears more limited. Based on the contrastive examination conducted in this study and the consulted linguistic descriptions, Tamahaq includes sounds comparable to Arabic /ħ/, /ʁ/, and in some cases /ʕ/, whereas other Arabic consonants such as /ħ/ and the phonological use of /ʔ/ appear less stable or less systematically represented.

This partial overlap suggests that Tamahaq-speaking learners of Arabic may experience varying degrees of phonetic difficulty depending on the specific consonant involved.

4.1.2. Vowel Correspondences between Arabic and Tamahaq

In addition to consonantal differences, the comparison between Arabic and Tamahaq also reveals certain similarities and differences in their vowel systems. Arabic is characterized by a relatively stable vowel inventory consisting of three short vowels (/a/, /u/, /i/) and their corresponding long vowels (/a:/, /u:/, /i:/) (Kepuska & Alshaari, 2020, pp. 96–97).

Tamahaq likewise exhibits vowel distinctions involving both short and long realizations, accompanied by additional phonetic variation in actual speech production (Basset, 1968, pp. 1–3; Prasse, 1972, pp. 45–49).

The comparison suggests that although some vowels in the two languages are broadly comparable, their phonetic realization and distribution may differ across linguistic contexts. Studies on Amazigh phonology further indicate that vowel variation may interact with surrounding consonantal structures and influence articulatory realization in connected speech (Chaker, 1995, pp. 22–25).

This distinction is particularly relevant because vowel environment may influence the articulation, acoustic realization, and perception of adjacent consonants, including Arabic guttural sounds.

4.1.3. Predicted Phonetic Difficulties Based on the Contrastive Analysis

The contrastive analysis suggests that Tamahaq-speaking learners of Arabic may encounter phonetic difficulties particularly with Arabic sounds that are either absent, less stable, or functionally different in Tamahaq.

The predicted areas of difficulty include the following:

- A.** Substitution or weakening of unfamiliar Arabic guttural consonants, especially /ħ/ and /ʕ/.
- B.** Positional difficulty, particularly when these consonants occur in word-medial or word-final positions.
- C.** Phonological transfer from the Tamahaq sound system, including the tendency to simplify unfamiliar consonantal patterns or approximate them using more accessible sounds.
- D.** Interaction between consonants and vowels, especially in cases where vowel quality influences the acoustic realization of adjacent guttural consonants.

These predictions provided the basis for the practical phonetic and acoustic analysis presented in the following sections.

4.2. Practical Phonetic and Acoustic Analysis of ChatGPT-Based Representation

4.2.1. Overview of the Test

An oral phonetic elicitation test was conducted on a sample of ten (10) Tamahaq-speaking participants. Seventeen Arabic lexical items containing guttural consonants in word-initial, medial, and final positions were selected.

The participants were asked to pronounce the selected words individually. Simultaneously, the same lexical items were submitted to **ChatGPT** (OpenAI) in order to obtain **IPA**-based phonetic transcriptions.

The resulting AI-generated outputs were then compared with both the expected Arabic phonetic forms and the participants' productions.

3.2.2. Accuracy of AI-Based Phonetic Representation

The following table presents the phonetic test results together with the corresponding IPA transcriptions generated by ChatGPT. It compares the standard Arabic pronunciation, the Tamahaq-influenced realizations produced by the participants, and the phonetic representations provided by the AI system in order to evaluate the extent to which Arabic guttural consonants produced by Tamahaq-speaking learners were accurately represented.

Table N°1. Comparative Representation of Arabic Guttural Consonants Produced by Tamahaq Speakers and Transcribed by ChatGP

Arabic word	phoneme	Arabic pronunciation	Tamahaq pronunciation	Phonetic Transcription « APA »	Transcription Accuracy Rate
أَكَلَ	/ʔ/	ʔakala	ʔakala	/ʔakal/	Accurate
قَرَأَ	/ʔ/	qaraʔa	qaraʔa	/qaraʔ/	Accurate
سَأَلَ	/ʔ /	saʔala	saʔala	/saʔal/	Accurate
هَرَبَ	/h/	haraba	Haraba	/ha:raib/	Accurate
سَهَرَ	/h/	sahara	Sahara	/sə'hɑ:rɑ/	Accurate
وَجْهَ	/h/	wajh	Wjah	/wajh/	Accurate
عَلِمَ	/ʕ/	ʕalam	ɣalam	/ɣa:lim/	Accurate
عَمَرَ	/ʕ/	ʕomar	ɣo:mar	/ru:mar/	Inaccurate
سَعِدَ	/ʕ/	saʕi:d	Saɣ:d	/saʕi:d/	Inaccurate
حَسَنَ	/h /	hasan	Xasan	/'hæsan/	Inaccurate
بَحَرَ	//h	bahr	Baxr	/ba:'hɑ:r/	Inaccurate
جُرْحَ	//h	djurh	jurx	/dʒɔ:rx/	Inaccurate
عَرِيبَ	/ɣ/	ɣari:b	ɣri:b	/ɣa'ri:b/	Accurate
صَغِيرَ	/ɣ/	Saɣi:r	sɣer	/sʕa'ɣ i:r/	Accurate
خُبَرَ	/x/	xubz	xbz	/xubz/	Accurate
خَلِيلَ	/x/	xalil	Xa:lil	/xa'li:l/	Accurate
دَخَلَ	/x/	daxala	daxal	/daxal/	Accurate

Note:

Accuracy in this table refers to the relative adequacy of ChatGPT's phonetic representation in approximating the intended Arabic Tamahaq sound within the context of the present study, rather than strict one-to-one phonetic equivalence. Based on the tabulated results, transcription accuracy rates were subsequently calculated and visually represented in Figure 1 in order to provide a clearer comparison of ChatGPT's performance across Arabic guttural consonants produced by Tamahaq-speaking learners

Table N° 2. ChatGPT IPA Transcription Accuracy Across Arabic guttural consonants

phoneme	Accurate Cases	Total Cases	Accuracy Rate
/ʔ/	3	3	100 %
/ħ /	3	3	100 %
/ʕ/	1	3	33,3 %
/h /	0	3	00 %
/x /	3	3	100 %
/ɣ/	2	2	100 %

Table N° 2 summarizes the transcription accuracy rates obtained for each Arabic guttural consonant. The results reveal noticeable variation across consonants, particularly between pharyngeal and non-pharyngeal sounds.

Figure N° 1. Accuracy Rates Across of Arabic guttural consonants



As illustrated in **Figure N° 1**, The bar chart demonstrates clear variation in **ChatGPT** transcription accuracy across Arabic guttural consonants such as /ʔ/, /ħ/, /ɣ/, and /x/ achieved full transcription accuracy, pharyngeal consonants such as /ʕ/ and /h/ showed substantially lower accuracy rates. In particular, /h/ exhibited complete transcription failure across all tested items. These findings suggest that consonants involving stronger pharyngeal constriction and greater articulatory complexity present a greater challenge for AI-based phonetic representation systems.

This observation is further supported by praat-based acoustic analysis presented in the following sections.

4.2.3. Sound-by-Sound Interpretation of the Results

A. Hamza /ʔ/ ء

The results show that **ChatGPT** performed relatively well in representing /ʔ/ in words such as **ʔakala** أَكَلَ, qaraʔa قَرَأَ, and saʔala سَأَلَ. In these cases, the glottal stop was represented with acceptable phonetic clarity.

This may be explained by the fact that the glottal stop is relatively identifiable in certain lexical environments and can often be approximated more consistently in AI-generated transcription.

Acoustic observations from Praat spectrograms indicate a relatively stable glottal closure pattern, which supports the observed accuracy in AI transcription.

B. Hā' /h/ هاء، هـ

The sound /h/ also showed relatively strong performance in the tested items, such as haraba, sahara, and wajh. In these examples, **ChatGPT** generally succeeded in producing an acceptable broad phonetic representation.

This suggests that sounds with wider cross-linguistic familiarity may be easier for AI systems to approximate than more language-specific Arabic consonants.

C. 'Ayn /ʕ/ عين، ع

The results for /ʕ/ were more mixed. While one case was represented acceptably, other items such as 'umar and sa'id were represented less accurately.

This is an important finding because /ʕ/ is one of the most distinctive and difficult consonants in Arabic, both for non-native speakers and for computational systems. Its articulatory and acoustic complexity makes it especially vulnerable to approximation, omission, or substitution. The observed inaccuracies therefore support the view that AI-generated transcription may struggle when dealing with Arabic consonants that lack clear equivalents in more dominant training languages.

Acoustic analysis reveals greater variability in formant transitions and spectral structure, which may explain the reduced accuracy in AI representation of this sound.

D. Ḥā' /ħ/ حاء، حـ

The sound /ħ/ was among the most problematic sounds in the dataset. Several items involving this consonant were represented inaccurately.

This confirms the contrastive prediction that Tamahaq-speaking learners may encounter difficulty with this sound and that AI systems may also struggle to represent it consistently. Since /ħ/ has no straightforward equivalent in English and is highly dependent on precise articulatory and phonetic distinction, it presents a challenge both for learners and for AI-based transcription systems.

Spectrogram analysis confirms weak acoustic stability and diffuse energy distribution, which aligns with the observed difficulty in both learner production and AI transcription.

E. Ghayn /ɣ/ غين، غ

ChatGPT showed comparatively better performance with /ɣ/ in the tested examples, where the outputs were closer to the expected pronunciation.

This may reflect the fact that this sound has at least partial acoustic approximability in some multilingual contexts, even if it is not always fully stable in AI-generated output.

F. Khā' /x/ خاء، خ

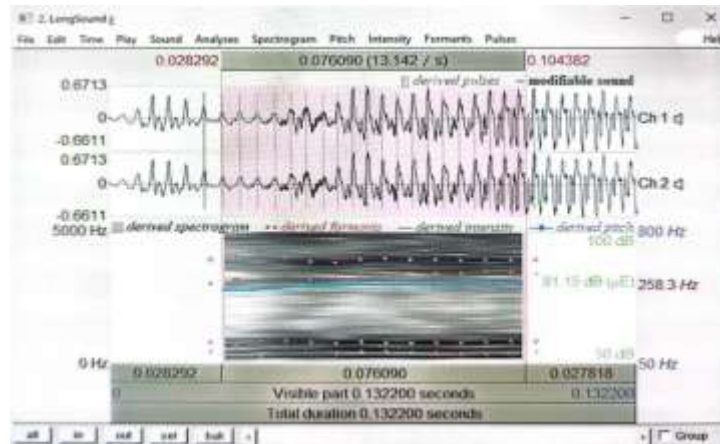
The sound /x/ خاء was also represented with relatively good accuracy in the tested items such as **xubz** خُبْز, **xalil** خَلِيل, and **daxala** دَخَلَ.

This indicates that some Arabic dorsal/fricative consonants may be more accessible to AI transcription systems than strongly pharyngealized or pharyngeal consonants such as /ʕ/ ayin ع and Ḥā' /ħ/ . هاء

Praat-based acoustic inspection shows clearer spectral cues, which may account for the comparatively higher transcription accuracy.

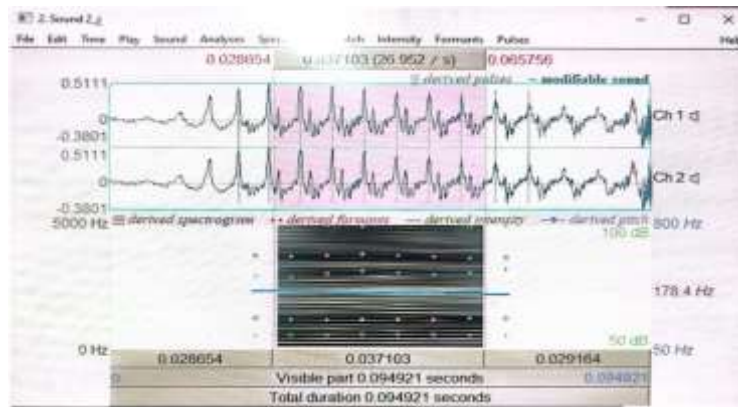
3.2.4. Spectrographic Analysis of Arabic Guttural Consonants:

Figure N° 2: Spectrogram of the substituted velar [ɣ] in the production of /sub. ʕumar/ (عُمَرَ) by a bilingual Tamahaq speaker



The spectrogram reveals reduced pharyngeal resonance and spectral characteristics approaching velar articulation, indicating phonetic substitution toward [ɣ].

Figure N° 3: Spectrogram of the native velar /ɣ/ in the production of /nat. yari:b/ (يَرِيْب) by a bilingual Tamahaq speaker:



The spectrogram displays relatively stable velar frication patterns and clearer spectral energy concentration, consistent with canonical /ɣ/ realization.

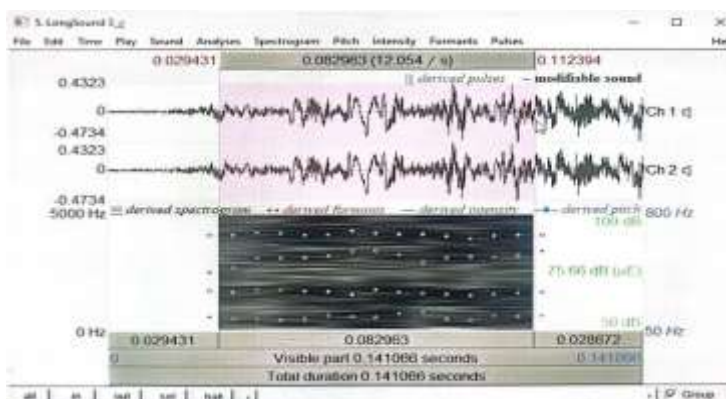
Figure N° 4: Spectrogram of the substituted velar [x] in the production of /sub. hasan/ (حَسَن) by a bilingual Tamahaq speaker:

The spectrogram
high-frequency
energy and
pharyngeal
suggesting a
velar realization



shows diffuse
frication
reduced
constriction,
shift toward
[x].

Figure N° 5: Spectrogram of the native velar /x/ in the production of /nat. xali:l/ (خَلِيل) by a bilingual Tamahaq speaker:



The spectrogram demonstrates stable velar frication with clearer acoustic concentration patterns, supporting the observed transcription accuracy for /x/.

3.2.5. Quantitative Acoustic Analysis

Table N° 3 presents the mean acoustic measurements extracted from Praat, including F1, F2, and duration values for selected Arabic guttural consonants and their substituted realizations produced by Tamahaq-speaking learners.

Table N° 3. Mean Acoustic Properties (F1, F2, and Duration) of selected Arabic Guttural Consonants Produced by Tamahaq Speakers

Arabic sound & word	Actual Realization by Tamahaq Speaker	Mean F1 (Hz)	Mean F2 (Hz)	Mean Duration (sec)
/ʕ/ in Omar عُمر	Substituted Velar [ɣ]	477,02	1377,98	0,760
/ɣ/ in Gharib غريب	Standard Velar [ɣ]	582,19	1204,74	0,037
/ħ/ in Hasan حسن	Substituted Velar [ɣ]	1197,39	1535,14	0,078
/x/ in Khalil خليل	Standard Velar [x]	586,94	1643,24	0,082

3.2.6. Acoustic Interpretation of Pharyngeal-to-Velar Substitution and A Representation

To support the qualitative findings related to phonological interference, instrumental acoustic measurements of the first (F1) and second (F2) formants, together with segment duration, were extracted using Praat software. The analysis focused on the Arabic pharyngeal consonants /ʕ/ and /ħ/ and their substituted velar realizations [ɣ] and [x] produced by Tamahaq-speaking learners of Arabic. The corresponding acoustic values are summarized in Table N°3.

For the voiced pharyngeal consonant /ʕ/ in the word “ʕumar,” عُمَر the spectrographic analysis revealed a shift toward a velar realization [ɣ]. Comparison with the native velar consonant /ɣ/ in “ɣari:b” غَرِيب demonstrated similarities in spectral structure and formant behavior. As shown in Table X, the substituted realization exhibited an F1 value of 477.02 Hz and an F2 value of 1377.98 Hz, which may reflect reduced pharyngeal constriction compared with canonical Arabic /ʕ/. The duration of the substituted segment (0.760 sec) was considerably longer than that observed for the native velar realization in “ɣari:b” غَرِيب (0.037 sec), suggesting increased articulatory effort and phonological instability during production.

A similar phonetic shift was observed for the voiceless pharyngeal consonant /ħ/ in “ħasan,” حَسَن which was acoustically realized as the velar fricative [x]. Spectrographic inspection and formant analysis yielded an F1 value of 1197.39 Hz and an F2 value of 1535.14 Hz. The spectrogram displayed stronger high-frequency frication energy, consistent with velar or post-velar constriction. These acoustic properties showed relative proximity to the native velar /x/ in “xali:l” خَلِيل (F2: 1643.24 Hz). In contrast to the previous case, duration values were relatively similar between the substituted and native velar realizations (0.078 sec vs. 0.082 sec), indicating a more stable substitution pattern.

From the perspective of artificial intelligence, the findings reveal that ChatGPT showed limited sensitivity to these acoustic deviations. Despite the spectrographic and formant-based differences observed in learner production, the AI system generated canonical IPA representations such as [ʕumar] عُمَر and [ħasan] حَسَن , relying primarily on standard orthographic forms rather than actual acoustic realization. This finding suggests that text-based large language models may not adequately capture fine-grained phonetic variation in under-resourced spoken varieties such as the Al-Hoggar Tamahaq-Arabic context.

3.2.7. General Discussion

The findings of the present study reveal that the phonetic representation of Arabic guttural consonants produced by Tamahaq speakers cannot be adequately explained through contrastive analysis alone. Although the contrastive comparison between Arabic and Tamahaq helped identify major phonological similarities and differences between the two languages, it did not fully account for the specific pronunciation patterns observed in the participants' actual productions.

In this respect, error analysis proved particularly useful, as it made it possible to identify the concrete deviations that occurred in the realization of certain Arabic guttural consonants. While contrastive analysis allowed the researcher to predict possible areas of difficulty based on first-language interference, error analysis provided a more precise account of how these difficulties were manifested in actual pronunciation.

The results also show that the participants, despite sharing the same broad linguistic background as Tamahaq speakers, did not always exhibit identical phonetic behavior. This suggests that the production of Arabic guttural consonants may vary from one speaker to

another depending on factors such as degree of exposure to Arabic, individual pronunciation habits, and the extent of phonological transfer from the mother tongue.

From the perspective of artificial intelligence, the findings indicate that ChatGPT demonstrated a relatively useful but limited capacity in representing Arabic guttural consonants through IPA transcription. Its performance was stronger in cases where the Tamahaq sounds were more acoustically salient or supported by clearer phonetic cues, as confirmed by Praat-based spectrographic analysis. Consonants such as /x/ and /ɣ/ showed more stable acoustic patterns, whereas pharyngeal consonants such as /ʕ/ and /ħ/ exhibited greater variability in both AI transcription and acoustic realization.

Human pronunciation deviations and AI transcription inaccuracies should not be interpreted as equivalent phenomena, as they arise from fundamentally different mechanisms. Speaker variation may result from articulatory transfer, bilingual phonological influence, and individual pronunciation habits. By contrast, AI-related inaccuracies are more likely associated with limitations in probabilistic language modeling and the insufficient representation of fine-grained phonetic distinctions in multilingual training data.

Acoustic evidence derived from formant analysis (F1 and F2) and spectrogram inspection further confirms that sounds with less stable spectral structures tend to be less accurately represented by AI systems. This highlights a direct relationship between acoustic clarity and the reliability of AI-generated phonetic transcription.

This limitation may be explained by the fact that many AI-based language systems are primarily trained on large multilingual datasets in which fine-grained Arabic phonetic detail remains underrepresented. As a result, the phonetic output generated by such systems may sometimes reflect approximation strategies influenced by more dominant phonological models rather than accurate Arabic-specific phonetic representation.

One possible explanation for these findings lies in the resource imbalance underlying current AI language models. ChatGPT has been primarily trained on massive datasets dominated by English and other resource-rich languages, whereas Tamahaq belongs to the category of under-resourced languages. Consequently, the system lacks sufficient phonetic corpora representing the speech varieties of AL-Hoggar region and the specific phonetic interaction between Tamahaq and Arabic.

In addition, current large language models remain fundamentally text-based systems rather than true acoustic-processing models. When generating IPA transcription, ChatGPT does not directly analyze acoustic frequencies or speech-wave properties; instead, it relies mainly on probabilistic textual prediction derived from standardized written forms. As a result, the system tends to reproduce canonical Arabic phonetic representations such as [ʕ] and [ħ], while failing to capture actual pronunciation shifts and phonetic substitutions produced by Tamahaq-speaking learners.

Overall, the study suggests that artificial intelligence can serve as a supportive analytical tool in phonetic and contrastive linguistic research, especially for preliminary transcription and exploratory analysis. However, it cannot yet be considered a fully reliable substitute for specialist phonetic expertise. For this reason, AI-generated phonetic transcription should be used with caution and should ideally be reviewed and validated by researchers trained in acoustic phonetics and instrumental analysis.

5. Conclusion

This study investigated the role of artificial intelligence in the phonetic analysis and representation of Arabic guttural consonants produced by Tamahaq-speaking learners of Arabic in Al-Hoggar region. By combining contrastive analysis, error analysis, AI-generated IPA transcription, and instrumental acoustic analysis using Praat software, the research assessed the extent to which ChatGPT can assist in the phonetic representation of these sounds.

The findings indicate that ChatGPT provides relatively useful phonetic approximations; however, its performance remains partial and not fully reliable. The system demonstrated higher accuracy with certain consonants than others, and its limitations were particularly evident with phonetically marked Arabic sounds that are also computationally challenging to model. Acoustic evidence derived from spectrographic inspection and formant analysis further confirmed variability in the realization of these consonants.

Consequently, the study concludes that artificial intelligence can serve as a supplementary tool in phonetic analysis, while expert verification remains essential, especially in research contexts involving Arabic phonetics, learner speech, and cross-linguistic interference. The study's main hypothesis is therefore partially supported.

6. Recommendations

Based on the results of this study, the following recommendations are proposed:

- 1- Integration of authentic Arabic phonetic datasets into AI model training to enhance transcription accuracy.
- 2- Development of AI tools that are more sensitive to Arabic phonological structures, particularly guttural consonants and learner-induced variation.
- 3- Encouragement of supervised use of AI tools in phonetic and contrastive linguistic research, ensuring expert validation.
- 4- Combining AI-assisted analysis with dedicated phonetic software (e.g., Praat) in future research.
- 5- Expanding future studies to include larger participant samples and more diverse linguistic backgrounds.
- 6- Strengthening the application of IPA-based transcription in Arabic phonetic analysis and language teaching to ensure consistency and precision.

Bibliography

Abu-Chacra, F. (2007). *Arabic: An essential grammar*. Routledge.

Aldarmaki, H., Ullah, A., Ram, S., & Zaki, N. (2022). *Unsupervised automatic speech recognition: A review*. *Speech Communication*, 139, 76–91.

<https://doi.org/10.1016/j.specom.2022.02.005>

Basset, A. (1986). *Initiation à la langue des Touaregs de l'Aïr*. Fraternité Charles de Foucauld.

Basset, R. (1908). *Grammaire, dialogues et dictionnaire touaregs*. Adolphe Jourdan.

- Boersma, P., & Weenink, D. (2024). *Praat: Doing phonetics by computer [Computer software]*. University of Amsterdam. <http://www.praat.org/>
- Chaker, S. (1995). *Linguistique berbère: Études de syntaxe et de diachronie*. Peeters Publishers.
- Corder, S. P. (1981). *Error analysis and interlanguage*. Oxford University Press.
- Heath, J. (2005). *A grammar of Tamashek (Tuareg of Mali)*. Mouton de Gruyter.
- Ibn Jinni, A. F. U. (1945). *Sirr ṣināʿat al-ʿarab* (Vol. 1). Mustafa al-Bābī al-Ḥalabī.
- International Phonetic Association. (1999). *Handbook of the International Phonetic Association: A guide to the use of the International Phonetic Alphabet*. Cambridge University Press.
- Kepuska, V., & Alshaari, M. (2020). Using formants to compare short and long vowels in Modern Standard Arabic. *Journal of Computer and Communications*, 8(5), 96–106. <https://doi.org/10.4236/jcc.2020.85006>
- Khondaker, M. T. I., Waheed, A., Nagoudi, E. B., & Abdul-Mageed, M. (2023). GPTAraEval: A comprehensive evaluation of ChatGPT on Arabic NLP. In *Proceedings of the 2023 Conference on Empirical Methods in Natural Language Processing* (pp. 220–247). Association for Computational Linguistics. <https://doi.org/10.18653/v1/2023.emnlp-main.16>
- Ladefoged, P., & Johnson, K. (2015). *A course in phonetics* (7th ed.). Cengage Learning.
- Lado, R. (1957). *Linguistics across cultures: Applied linguistics for language teachers*. University of Michigan Press.
- Mattar, B., Fayed, M., & Khalafallah, A. (2025). AraS2P: Arabic speech-to-phonemes system. In *Proceedings of the Third Arabic Natural Language Processing Conference: Shared Tasks* (pp. 469–474). Association for Computational Linguistics. <https://doi.org/10.18653/v1/2025.arabicalp-sharedtasks.65>
- Poole, D., Mackworth, A., & Goebel, R. (1998). *Computational intelligence: A logical approach*. Oxford University Press.
- Prasse, K.-G. (1972). *Manuel de grammaire touarègue (Tahaggart)*. Akademisk Forlag.
- Russell, S., & Norvig, P. (2021). *Artificial intelligence: A modern approach* (4th ed.). Pearson.
- Sibawayh. (1955). *Al-Kitāb* (M. Shākir, Ed.). Dār al-Fikr al-ʿArabī
- Talafha, B., Toyin, H. O., Sullivan, P., Elmadany, A. A., Juma, A., Djanibekov, A., Zhang, C., Alshehhi, H., Aldarmaki, H., Jarrar, M., Habash, N., & Abdul-Mageed, M. (2025). NADI 2025: The first multidialectal Arabic speech processing shared task. In *Proceedings of the Third Arabic Natural Language Processing Conference: Shared Tasks* (pp. 720–733). Association for Computational Linguistics. <https://doi.org/10.18653/v1/2025.arabicalp-sharedtasks.99>