



The Effectiveness of Voiceprints in Criminal Investigations and their Role in Achieving Justice

Dr. Kamal Amamra, Hassiba Benbouali University of Chlef, Chlef, Algeria.

ORCID: <https://orcid.org/0009-0000-4932-3730>

DOI: 10.5281/zenodo.23350212

Abstract

Forensic linguistics is a relatively young scientific field characterized by a proliferation of terminology and a broad range of concepts. It seeks to analyse spoken texts scientifically within the context of criminal justice, relying on rigorous, systematic analysis of texts and discourse to extract verifiable linguistic indicators that support the judiciary and law-enforcement agencies in cases where language plays a central role. This field also studies the linguistic fingerprint, drawing on methods inspired by text linguistics and discourse analysis. The voiceprint is a modern technique used in criminal and security investigations. It relies on analysing the unique characteristics of the human voice to establish identity. As technology advances, this technique has become an effective tool for detecting crimes and identifying perpetrators, thereby contributing to justice. This paper examines the effectiveness of the voiceprint and its role in criminal evidence, focusing on practical applications and the legal and scientific challenges, to uncover the linguistic evidence that helps establish or refute a defendant's guilt.

Keywords: Voiceprint, Forensic Linguistics, Judicial Linguistics, Criminal Investigations.

Introduction

Forensic voice comparison has evolved from early impressionistic methods into a standardised scientific framework that combines auditory-linguistic analysis, acoustic measurement, statistical modelling and validated automatic recognition systems to quantitatively assess the strength of evidence when matching recorded calls to suspects' voices. Recent literature confirms that the likelihood-ratio framework is the correct approach for evaluating evidence strength, using an “empirical demonstration” approach that requires relevant data, quantitative measurements, statistical modelling, and experimental testing under conditions similar to those of the case. International bodies have also established standard practice guidelines—such as OSAC (United States) and ENFSI (Europe)—that guide experts on analysis procedures, quality control, documentation and interpretation, reducing methodological and procedural risks in voice-identity cases.

Research Problem

Despite the growing reliance on voice evidence in criminal investigations, central methodological and legal problems arise. The study investigates how to ensure the scientific reliability of matching recordings to suspects' voices. Moreover, what international standards govern sample collection, verification, calibration and interpretation to provide the court with scientifically defensible results and limit the risk of wrongful conviction? The problem becomes more complex when recordings are short, noisy, or in a dialect different from the comparison samples, requiring selection of an appropriate reference population, empirical validation of the analysis system under case-like conditions, and an expert report that discloses the strength of the evidence and the associated uncertainty.



People often take language for granted, but for you and me it is anything but; we recognise the latent power in words and their meanings. This observation, inspired by the federal investigation series *Manhunt: Unabomber* reflects language's importance and its vital role in legal fields—language can convict or exonerate in the world of crime. This interplay between language, the judiciary, law, and crime gave rise to forensic linguistics, a diverse scientific field that overlaps with numerous disciplines. Its importance is tied to legal and judicial practice, making it an engaging and influential field; in addition, forensic linguistics connects to a range of linguistic and non-linguistic areas of knowledge, such as phonetics, lexicology, morphology, syntax, semantics, dialectology, functional, social, psychological and neurological linguistics, as well as computational linguistics, criminology and sociology, and law, among others (Antar Salhi, n.d., p. 1320).

Despite the importance of this scientific field, published research in Arabic remains very limited compared to what is available in English; the field is developing rapidly, with active efforts to define it, delineate its scope and applications, and highlight its importance. Among the most notable works published on this subject in Arabic is the book *Forensic Linguistics: An Introduction to Language, Crime, and Law*, translated by Muhammad ibn Nasser Al-Haqbani from the original by John Olsson in 2008; an article by Dr. Abd al-Majid Omar published in the *Naif Academy for Security Sciences journal* in 2009 titled “Forensic Linguistics: Its Origin, Development and Applications”; and the book *Forensic Linguistics: Its Definition, Fields and Applications* by Salih ibn Fahd Al-Usaimi, published in 2020. Nevertheless, the Arabic library still lacks sufficient sources and references in this field. Among the notable studies that sought to shed light on the extent of legal practitioners’ (judges’ and lawyers’) knowledge of forensic linguistics in the Arab world is the research conducted by Ahmed Nouredine Belarbi, who surveyed 100 legal practitioners from ten Arab countries to measure their level of knowledge of this field and the extent of its application in the courts. The study’s results showed that only a small number had superficial, limited knowledge of this area.

Concept of Forensic Linguistics

Forensic linguistics is a modern branch of applied linguistics that analyses language and its role in criminal and legal contexts. It focuses on linguistic texts associated with criminal cases, such as threatening letters, kidnapping, and terrorism, as well as audio recordings; verifying dialect authenticity; and attributing texts—whether written or spoken—to their authors. Linguistic analysis helps detect crimes, refute accusations, and present linguistic evidence in court (Al-Usaimi, 2020a, p. 4; Al-Rashoudi, 2022, p. 7; Coulthard et al., 2017, p. 15). Forensic linguistics occupies an important place within the field of applied linguistics, a field that researcher Abduh Al-Rajihi defined as “not merely a set of methods and procedures, but an independent science that links together various disciplines studying human linguistic activity, such as linguistics, psychology, sociology, and education,” affirming that this science rests on theoretical foundations (Al-Rajihi, 1995, p. 12). This definition confirms the interdisciplinary nature of this science, which combines the humanities (particularly linguistics) and legal sciences (specifically criminal aspects).

Defining Forensic/Judicial Linguistics

In the *Dictionary of Linguistic Terms (English–Arabic)*, the term “Forensic Linguistics” is defined as a branch of linguistics that employs linguistic tools in criminal investigations; linguistic usage in certain crimes is considered evidence for identifying perpetrators, such as analysing the writing style of a suspicious letter related to a crime, or



examining audio recordings as evidence (*Dictionary of Linguistic Terms*, n.d., p. 196). However, the most widely accepted technical definition of forensic linguistics comes from Asher (1994), who defines it as a branch of applied linguistics that uses linguistic methods in criminal investigations when language forms part of the evidence. This science aims to study, analyse, and evaluate linguistic evidence related to a crime to establish the identity of the perpetrator or suspect (Omar, 2008, p. 276). It is thus a science that studies crimes in which language plays a role and seeks to decode them by analysing spoken or written discourse containing threats, using established scientific tools (Hisham, 2019, p. 6). Although the term has been translated as “judicial linguistics,” it focuses primarily on criminal aspects and aligns with the technical meaning of Forensic (criminal, or related to legal proceedings). In contrast, the general meaning of 'Judicial' in English relates more broadly to the courts. Forensic linguists use linguistic knowledge to achieve justice and analyse written or spoken texts in various legal contexts. Their functions include investigating linguistic style to determine a writer's or speaker's identity and providing linguistic interpretations in court (Antar Salhi, n.d., p. 1311).

The Problem of Terminology

Forensic linguistics has several Arabic terms for a single concept, including forensic linguistics, criminal linguistics, the science of criminal, judicial, or legal language, judicial linguistics, and canonical linguistics. Al-Usaimi, author of *Forensic Linguistics: Its Definition, Fields and Applications*, argues that the most accurate translation of “Forensic Linguistics” is “forensic linguistics” (al-lisaniyyat al-jina'iyya), based on several considerations:

1. The word “Forensic” in the compound term means “criminal.”
2. The English term does not use the word “law” or “legal,” even though both concepts exist within the discipline; one could therefore say “judicial linguistics” when discussing the analysis of language in the judicial domain, or “legal linguistics” when discussing the analysis of language in the legal domain.
3. The word “criminal” is associated in the United States with the investigation of crime and offences, whereas in Britain it is associated with the investigation of the judiciary and law (Al-Usaimi, 2020b, p. 29; Al-Shahri, 2022, p. 761).

The Emergence of Forensic Linguistics

In the early 1980s, American linguists led by Roger Shuy laid the foundations of forensic linguistics (Shuy, 1997). These studies addressed a wide range of criminal cases and civil disputes in which language played a pivotal role; interestingly, most of these research efforts focused from the outset on language used in legal contexts (Levi, 1994; Belarbi, 2017, pp. 3–6). In Australia, this field emerged in the mid-1990s, when researchers began applying sociolinguistic theories to crime and legal disputes. These scholars focused on protecting individuals' rights during investigations and legal proceedings, particularly the challenges Australia's Aboriginal population faces in police and legal investigations (Eades, 1994, pp. 161–170).

How Did Forensic Linguistics Begin?

Pinpointing an exact date for the beginning of forensic linguistics as an independent science is difficult, as with any other science; its roots and early ideas are scattered across different places and times. Western researchers trace its earliest beginnings to *The Bible*, particularly *Genesis 27* (Omar, 2008, p. 277). The story recounts how the prophet Jacob, the younger son of the prophet Isaac, was destined to receive the title of firstborn, though he was



not in fact the eldest; rather, he imitated the voice of his older brother Esau, and Isaac — who had lost his sight in old age — failed to detect the deception and granted Jacob the title. This account exemplifies voice as an important means of personal identification, and can thus be regarded as one of the earliest references to forensic linguistics (Omar, 2008, p. 278). Gotterill, meanwhile, argued that this science dates back to ancient Greek and Roman times, as those civilisations were deeply concerned with disputes over “establishing the authenticity of the attribution of certain literary and dramatic works” to their authors, since writers frequently accused one another of plagiarism and forgery.

Defining the Voiceprint

In physics, sound is a vibration that propagates as longitudinal mechanical waves through a material medium; “it is a physical phenomenon produced by humans on various occasions through the speech apparatus, whereby human speech acquires properties that reflect individual characteristics” (Bawadi, 2005, p. 67). The voiceprint is a digital analysis of each individual's unique vocal characteristics—such as frequency, pitch, speed, and vocal register—that distinguish that person from others. Banks could thus verify a depositor's identity solely through their voice, and police could positively identify criminals whose conversations have been recorded, since the rate of frequency transmission differs from one person to another (Ladefoged, 2001, p. 214). Each individual has what linguists call an “idiolect,” a term referring to a person's personal language, as shown in their vocabulary, verbal behaviour, and particular manner of expression and speech. This concept is paired with another term, “sociolect,” used to describe the distinctive characteristics of a dialect or language associated with a group of individuals belonging to a single community — examples include the secret street language of drug trafficking, the language of organ trafficking, or the language of prostitution (Al-Fasi Al-Fihri, 2008, pp. 89–92; Omar, 2001, pp. 45–47).

Voiceprints are one tool sociolinguists use to analyse the individual characteristics of members of linguistic groups, aiming to identify precise features and extract traits shared among members of these groups. In forensic linguistics, both the “idiolect” and the “sociolect” are considered raw material for forensic evidence used to establish suspicion against a suspect—what is known as the “linguistic or speech fingerprint.” The voiceprint is a modern forensic technique that analyses an individual's verbal behaviour, manner of expression, and speech delivery style. This includes the phonetic, semantic, visual, social, psychological, and cultural characteristics that distinguish a person's language and that are, at the same time, connected to a legal case (Al-Hindi & Bani Amer, 2020, p. 212). The German professor Raimund Drommel, one of the foremost scholars of forensic linguistics, noted that “in many cases, a small sample of linguistic evidence can be sufficient to open a criminal case against a suspect — such as a personal dialect, the repeated use of a particular type of word or phrase, or distinctive syntactic structures” (Drommel, 2015, p. 166).

Voiceprint technology also uses advanced analytical tools to extract each person's unique vocal characteristics; voice-recognition systems rely on these traits and require the person to read a given text or utter specific words so the system can analyse their voice precisely (Salama, 2008, p. 232). Forensic analysts use these results to help detect crimes and identify perpetrators based on their voice. The voiceprint matters because it is an effective modern tool in criminal investigations, as it can establish or refute charges by matching an unknown voice to a suspect's. It relies on precise scientific criteria such as frequency, tone, rhythm, and articulation patterns, making it a powerful tool for identifying a defendant even



when traditional evidence such as fingerprints or photographs is difficult to rely on. Moreover, the effectiveness of the voiceprint depends on the quality of the audio recordings and the accuracy of the analysis, and factors such as background noise or deliberate attempts to alter the voice can affect it. For this reason, courts often use voiceprints as supporting evidence alongside other evidence in criminal cases, particularly in serious crimes such as murder and kidnapping (Sadiq, 2024, p. 42). Voiceprints have become widespread because people have accepted this technology in daily life and because speaker-recognition systems have rapidly improved in accuracy; so far, no two identical voices have ever been found.

Scientific Foundations of the Voiceprint

As forensic evidence, the voiceprint rests on the theory of forensic individualisation, as with fingerprints. Every voice has individual characteristics, and two people can rarely share the same capability and manner of articulation through the movement of the tongue, lips, and uvula (Kersta, 1962, p. 1254). Consequently, the human voice remains stable and unchanged throughout adulthood and into old age (Al-Ma'aytah, 2008, p. 558). The voiceprint also relies on artificial intelligence techniques as an aid in processing audio signals, whereby acoustic features are extracted, such as: Spectrogram, Pitch and Formants

Methods of Voiceprint Identification

Among the most prominent mechanisms used to determine the linguistic fingerprint of suspects and identify the perpetrator are the following approaches:

The Listening Method:

This method relies on specialised experts listening to audio recordings and attempting to link a particular voice to a specific suspect in the crime (Al-Tuwaisi, n.d., p. 79), or to match voices with their owners; however, it remains limited due to the absence of fixed standards, as it depends heavily on human expertise and the analyst's ability to interpret voiceprints. The expert relies on the defendant's verbal lexicon, since some criminals unconsciously select particular lexical items, whether along the paradigmatic axis (synonyms) or the syntagmatic axis (composition).

Direct Listening:

The human ear is a primary tool in speaker identification through analysis of vocal frequencies, including dialect, speech pattern, and target audience; experts therefore rely on the sense of hearing in addition to specialised techniques and devices to determine a speaker's identity (Al-Dhib & Al-Qudsi, 2017, p. 93). A suspect's syntactic composition can also serve as evidence against them, since a speaker's syntactic composition clearly reflects their personality, as stylistic studies have shown through the use of syntactic elements such as fronting and postponing, ellipsis, and predication.

The Visual Method:

This method relies on converting the transmitted sound signal into an "image" using the sense of sight (Al-Ghamdi, n.d.-a, p. 20); through this image, different voices can be compared to draw conclusions. The graphical representation used is the spectrogram, which emerged in the late 1930s and early 1940s during World War II. This technique is distinguished by its ability to analyse the voiceprint based on its frequency components and physical characteristics.

The Automatic Method

It is known as automatic voice recognition. This method uses computers to match linguistic voices, carried out with high efficiency and independently of human intervention. The computer relies on pre-programmed algorithms to compare speakers' recordings and



then assess the probability of the voice's source (Al-Ghamdi, n.d.-a, p. 20). This method is currently the standard because it is more objective than auditory methods, significantly reducing human bias and making it the most accurate choice.

Biometric Voice Recognition:

This method uses specialised computer systems to record and analyse the unique characteristics of a person's voice, comparing a newly recorded voice sample with previously stored reference samples to determine the speaker's identity (voice matching). This process relies entirely on machine processing and supports various security applications, such as secure access to online accounts or electronic door access for offices and homes.

Voice Recording Devices

Distinctive voices cannot be documented with full precision and security except through the use of specialised devices used during voice processing, including the following:

1. **Recording Device:** A dedicated tool for receiving sound via a microphone and storing it; it can also play back the recorded sound immediately after capture.
2. **Amplifier:** Helps relieve the pressure on the ear caused by using headphones and provides even sound distribution while preserving quality and clarity.
3. **Software:** A specialised application for the precise analysis of sound waves, displaying analysis results as graphical representations or during spectral processing, such as Speech Analyser software.
4. **Sound Pickup (Headphones/Microphone):** Headphones are used to transmit sound to the listener's ear, while the microphone is the primary means of capturing or transmitting sound through electronic connections.
5. **Computer:** Used as a visual tool for performing digital sound processing.
6. **Storage Media (Floppy or Hard Disk):** Used to save and retrieve audio data as needed.

The Spectrograph Device (Sound Spectrometer)

A device used in auditory phonetics to produce a visual image of speech sound, i.e., acoustic spectra and vibrations showing sound frequencies; it is printed on special paper in three dimensions — a horizontal dimension representing time, a vertical dimension representing frequencies, and a third dimension representing sound intensity, shown in black shading that darkens with increasing loudness. It is also called the sound spectrograph (Al-Usaimi, n.d.-a, p. 1437) — the acoustic spectrum of sound waves, or the visual image of speech sound as it appears in the frequency-domain plot in which the wave falls, with frequency represented on the horizontal axis and amplitude on the vertical axis (Al-Usaimi, n.d.-a, p. 1438). The spectrogram is still used today in phonetic studies and many applications, including speaker identification (Al-Fifi, 1445 AH, p. 22).

The spectrograph device analyses the human voice electronically. It converts it into readable visual lines, allowing comparison with suspects' voices and indicating the degree of match or difference. The way words or sentences are pronounced differs from one person to another. Individual differences are greater than the variations that may appear in a single person's speech — even if that person tries to alter their voice by whispering or pinching their nose while speaking, this does not change the fundamental features of their voiceprint. The same applies to attempts at vocal mimicry or speaking from deep in the throat: the voiceprint remains constant (Al-Abboudi, 2022, p. 38). Accordingly, it can be said that the voice has become a unique fingerprint through which a person's identity can be established using modern, precise techniques; these means contribute significantly to the detection of crimes,



particularly those related to extortion through telephone threats using cassette-tape recordings, as well as in cases of criminal conspiracy and defamation and slander committed through audio media.

The voiceprint is thus an effective means of establishing a defendant's identity and contributing to their arrest through audio recordings; a specialised expert compares these recordings with the defendant's recorded voice. Defendants have often been confronted with audio recordings during interrogation, which can lead them to confess guilt.

The "Auras" Device

Among the scientific devices that have recently appeared is one called "Auras." Experiments show it is extremely accurate, with an error rate of no more than 1%, meaning it is correct up to 99% of the time. This feature has made it the best among similar devices in distinguishing a large number of voices with unprecedented accuracy. The device identifies various vocal characteristics; it consists of a computer that analyses acoustic signals and stores each voice distinguishing features (Barhami, 2006, p. 558).

Advantages of the Voiceprint

Fingerprints — whether traditional or modern — represent an important type of forensic evidence and possess a set of unique characteristics that distinguish them from other types of evidence, as follows:

Immutability of the Biological Composition of the Fingerprint: A fingerprint has a unique feature that distinguishes it from other forensic evidence: the fine ridge lines that form the fingerprint never change; they form at a certain point in a person's life and remain the same throughout their lifetime. They cannot be altered even when exposed to accidents or external influences that might cause deformation, disease, or chemical burns. This stability, confirmed by scientific studies, makes the fingerprint reliable evidence that surpasses other means of criminal proof in evidentiary strength (Al-Ma'aytah, 2015, p. 150).

Uniqueness of the Biological Composition of the Fingerprint: In addition to its stability, the fingerprint has another important feature: its absolute uniqueness in biological composition. Modern scientific studies have confirmed that fingerprint composition differs entirely from one person to another, and even a single person's own fingerprints do not match one another. To this day, science has not found two identical fingerprints belonging to two different people (Al-Hiti, 2014, p. 112).

Other advantages include:

1. It does not take a long time to identify the person behind a voice, nor does it require specialised devices to capture biometric data from the person, such as fingerprint or iris scanners, telephone handsets, or the microphone attached to computers; the voiceprint has thus sped up the identity-verification process and does not require the presence of an employee (Al-Ghamdi, 2005, p. 17).
2. The ability to identify a person's psychological state.
3. The inability to imitate a voice convincingly: an imitated voice may resemble the original to the human ear, but computer systems use methods that allow them to distinguish between the original and the imitated voice.
4. The voiceprint can be used to identify and verify a person remotely (Al-Ghamdi, 2005, pp. 30–31).

Applications of the Voiceprint

The voiceprint is used in multiple fields, including:



1. **Security and Criminal Investigation:** Used to identify callers in cases of threats or extortion.
2. **Banking Services:** Some banks use voice authentication to let customers access accounts.
3. **Smart Voice Assistants:** Such as Siri and Google Assistant, which rely on recognising the user's voice to provide personalised services?

Advantages of the Voiceprint as Forensic Evidence

1. **Non-invasive:** Does not require biological sampling as with genetic fingerprinting.
2. **Speed of analysis:** Voices can be compared automatically within minutes.
3. **Availability of evidence:** Many crimes are recorded by telephones or audio surveillance systems. (Gonzalez-Rodriguez, 2017, pp. 92–99):

Case Studies on the Effectiveness of the Voiceprint

Scientific interest in using voice as forensic evidence began with the kidnapping case of the son of Colonel Charles Lindbergh in 1935, in which the voice of the defendant Hauptmann matched the voice that had called Colonel Lindbergh to demand ransom, contributing to the criminal investigation (Eriksson, n.d., p. 3; Solan & Tiersma, 2003, p. 373). (National Institute of Standards and Technology, 2020) The Assassination of Malcolm X (1965): Audio recordings of suspects were used, but the evidence was not conclusive due to the limitations of the technology available at the time (Al-Habib, 2022).

Criminal Cases Resolved Using the Voiceprint

The voiceprint has played a pivotal role in numerous criminal investigations worldwide by providing decisive evidence to identify perpetrators or exonerate suspects. The following notable case demonstrates this technology's effectiveness.

The Murder of a Minnesota Police Officer (1970)

This case is among the foundational cases in the history of judicial acceptance of the voiceprint as forensic evidence. The police department in St. Paul, Minnesota, received an emergency call requesting help for a pregnant woman; when two officers arrived at the address, one was killed by a high-calibre rifle shot. Police recorded the emergency call that lured the officer to the crime scene, then recorded the suspect's voice and compared the voiceprints of the two calls (North Dakota Law Review, 1972, pp. 584–585).

These cases make clear that the voiceprint is a multifaceted forensic tool and it can serve as the primary evidence for issuing an arrest warrant, as in the Minnesota case; as supporting evidence reinforcing witness testimony; or as part of the digital evidence framework in modern crimes, as in the “Craigslister Killer” case. Nevertheless, the accuracy of this technology remains tied to the quality of recordings and the analyst's expertise, underscoring the need to rely on specialised experts to ensure justice.

Legal Challenges

The voiceprint faces several challenges that include:

- The difficulty of proving the absence of manipulation in the age of deepfakes (Clark, 2023, pp. 201–210).
- Balancing security use with privacy protection (Harris, 2021, p. 63).
- Variation in standards among courts (Roberts, 2021, p. 147).

Disadvantages of the Voiceprint

1. The speaker's psychological state, which may affect the voiceprint.
2. Noise, since background noise can obscure or affect speech waves.



3. Advances in devices and technology have enabled fraudsters to alter vocal characteristics.
4. The voiceprint is subject to the possibility of error in user identification.
5. Voiceprint identification has been criticised for being limited to living persons rather than the deceased, and to healthy individuals rather than those with vocal-cord or respiratory conditions.

Research Findings

There is a pressing need to establish specialised research centres and coordination teams in forensic phonetics, and to create university programs focused on this field to train qualified professionals capable of obtaining a specialisation certificate in “forensic phonetics.” Such professionals could be integrated into various sectors, including the courts, military systems, judicial police, forensic evidence laboratories, and acoustic engineering centres.

Recommendations

1. **Adopt a Standardised Methodological Framework for Assessing the Strength of Voice Evidence:** Experts should be required to adopt the likelihood-ratio framework within an empirical-demonstration approach when comparing recordings, requiring relevant reference data, quantitative measurements, statistical modelling, and experimental testing under case-like conditions, ensuring a quantitative estimate of evidentiary strength and reducing subjectivity.
2. **Align National Procedures with International Practice Guidelines:** It is recommended that forensic laboratory protocols be aligned with the guidelines of international bodies such as ENFSI in Europe and OSAC in the United States, including analysis procedures, quality control, documentation, and reviewability, to ensure consistency of results and their cross-border judicial acceptance.
3. **Build Reference Voice Databases Representative of Local Contexts:** This involves developing data matrices containing labelled recordings covering diverse Arabic dialects, age groups, genders, formal and spontaneous speech patterns, and different recording environments, in order to reduce model bias and improve the validity of comparisons in real-world cases.
4. **Integrate Auditory-Linguistic Analysis with Acoustic Measurements and Automated Models:** Encourage a “hybrid system” combining the expertise of forensic linguistics in analysing dialect, style, and individual idiolect with spectral-acoustic analysis — such as formant measurements — statistical modelling, and validated automatic recognition systems, while reporting statistical uncertainty.
5. **Improve Recording Quality and the Integrity of the Chain of Custody:** Establish standards for collecting and preserving recordings: appropriate equipment, sufficient sampling rate, description of the recording environment, complete documentation of the chain of custody, disclosure of any digital processing performed, and the adoption of tools for detecting tampering, editing, and excessive compression.
6. **Develop Expert Competencies and Multidisciplinary Training:** Design accredited training programs for experts combining linguistics, phonetics, applied statistics, and machine learning, alongside the ethics of expert testimony and judicial communication, with periodic proficiency testing and inter-laboratory exchange of expertise.

7. **Raise Awareness Among Judges, Prosecutors, and Defence Counsel of the Limits of Voice Evidence:** Organise brief guidance materials and introductory sessions for judicial actors on the nature of voice comparison, the requirements for valid inference, influencing factors (noise, coding compression, stress, voice spoofing), and how to interpret likelihood ratios without overstating the strength of the evidence or falling into prosecutorial fallacy.
8. **Address Legal, Privacy, and Data-Protection Considerations:** Establish clear legal controls for obtaining, processing, and storing recordings, with judicial authorisation where required, data encryption, defined retention periods, identity-erasure mechanisms, and ensuring that procedures comply with defence rights and fair-trial standards.
9. **Exercise Caution Regarding Individual Idiolect and Social Dialects:** It is recommended not to rely on isolated stylistic or dialectal indicators as conclusive, but rather to evaluate them within a package of testable quantitative indicators, while warning against unsupported social or geographic generalisations not backed by representative data.
10. **Comprehensive, Judicially Reviewable Documentation:** Require experts to submit detailed reports including: description of the data, processing methods, criteria selected, statistical measures, uncertainty estimates, limitations, and sensitivity tests, allowing for reproduction and review by independent experts.
11. **Develop Tools and Techniques Resistant to Spoofing and Synthetic Generation:** Encourage research into detecting spoofed and AI-generated voices and multi-factor biometric verification controls, adopting additional checks when tampering or synthesis is suspected, and not relying on a single algorithmic result alone.
12. **Hierarchy and Integration of Evidentiary Proof:** Emphasise that the voiceprint is a technical indicator to be evaluated alongside other evidence (physical, digital, linguistic, circumstantial), and should not be presented in isolation without context, while highlighting its consistency or inconsistency with other indicators to form a balanced judicial conviction.

References

- [1] Al-Abboudi, A. *Al-Himaya Al-Qanuniyya Li-Wasa'il Al-Taqqaddum Al-'Ilmi Fi Al-Ithbat Al-Madani* [Legal Protection of Scientific Progress Tools in Civil Evidence]. Dar Al-Thaqafa, 2022.
- [2] Al-Dhib, I. G., and B. Al-Qudsi. "Dawr Al-Basma Al-Sawtiyya Wa-Al-Basariyya Wa-Mada Mashru'iyatiha Fi Al-Ithbat Al-Jaza'i" [The Role of Voice and Visual Prints and Their Legitimacy in Criminal Evidence]. *Majallat Jami'at Al-Ba'th*, vol. 52, 2017, p. 93.
- [3] Al-Fasi Al-Fihri, A. *Al-Lisaniyyat Wa-Al-Lugha Al-'Arabiyya: Qadaya Wasfiyya Wa-Nazariyya* [Linguistics and the Arabic Language: Descriptive and Theoretical Issues]. 2nd ed., Afriqiya Al-Sharq, 2008.
- [4] Al-Fifi, A. Y. *Madkhal Ila Al-Lisaniyyat Al-Hasubiyya — Mabahith Lughawiyya* [Introduction to Computational Linguistics: Linguistic Topics]. King Salman Global Academy for the Arabic Language, 1445 AH/2024.
- [5] Al-Ghamdi, M. M. *Al-Bayanat Al-Hayawiyya: Al-Basma Al-Sawtiyya* [Biometric Data: The Voiceprint]. Conference on Modern Networks in Combating Crime, Naif Arab University for Security Sciences, n.d.



- [6] Al-Ghamdi, M. M. *Al-Bayanat Al-Hayawiyya: Al-Taqqiyyat Al-Haditha Fi Mukafahat Al-Jarima* [Biometric Data: Modern Techniques in Combating Crime]. Dar Al-Jadeel, 2005.
- [7] Al-Habib, A. “Wafat Malcolm X: Al-Qissa Al-Kamila Min Al-Ightiyal Ila Bara’at Al-Muttahamin” [The Death of Malcolm X: The Full Story from Assassination to Acquittal]. *Al-Youm Al-Sabea*, 21 Feb. 2022.
- [8] Al-Hindi, N., and A. Bani Amer. “Al-Basma Al-Kalamiyya Bayna Al-Tatbiqat Al-Qada’iyya Al-Gharbiyya Wa-Al-‘Arabiyya” [The Voiceprint between Western and Arab Judicial Applications]. *Majallat Dirasat Al-‘Ulum Al-Insaniyya Wa-Al-Ijtima’iyya*, vol. 47, no. 4, 2020, p. 212.
- [9] Al-Hiti, M. H. M. *Al-Adilla Al-Jina’iyya Al-Maddiyya: Masadiruha, Anwa’uha, Usul Al-Ta’amul Ma’aha* [Physical Criminal Evidence: Sources, Types, and Handling Principles]. Dar Al-Kutub Al-Qanuniyya, 2014.
- [10] Al-Ma’aytah, M. *Al-Adilla Al-Jina’iyya Wa-Al-Tahqiq Al-Jina’i* [Criminal Evidence and Criminal Investigation]. Dar Al-Thaqafa, 2008.
- [11] Al-Ma’aytah, M. O. *Al-Adilla Al-Jina’iyya Wa-Al-Tahqiq Al-Jina’i* [Criminal Evidence and Criminal Investigation]. 3rd ed., Dar Al-Fikr, 2015.
- [12] Al-Rajihi, A. *‘Ilm Al-Lugha Al-Tatbiqi Wa-Ta’lim Al-‘Arabiyya* [Applied Linguistics and the Teaching of Arabic]. Dar Al-Ma’rifa Al-Jami’iyya, 1995.
- [13] Al-Rashoudi, I. A. “Al-Lisaniyyat Wa-Al-Sawtiyyat Al-Jina’iyya” [Forensic Linguistics and Phonetics]. *Majallat Ibn Khaldun*, no. 7, 2022, p. 7.
- [14] Al-Shahri, F. M. A. “Al-‘Alaqa Bayna Al-Lugha Wa-‘Ilm Al-Jarima” [The Relationship between Language and Criminology]. *Majallat Kulliyyat Al-Lugha Al-‘Arabiyya Bi-Itay Al-Barud*, no. 35, 2022, p. 761.
- [15] Al-Tuwaisi, A. I. “Basmal Al-Sawt: Simatuha Wa-Istikhdamatuha” [The Voiceprint: Its Features and Uses]. *Al-Majalla Al-‘Arabiyya Lil-Dirasat Al-Amniyya Wa-Al-Tadrib*, vol. 11, no. 22, n.d., p. 79.
- [16] Al-Usaimi, A. I. *Al-Mu’jam Al-Mawsu’i Li-Mustalahat Al-Lisaniyyat Al-Tatbiqiyya* [Encyclopedic Dictionary of Applied Linguistics Terminology]. Vol. 1, King Salman Global Academy for the Arabic Language, n.d.
- [17] Al-Usaimi, S. F. “Al-Lisaniyyat Al-Jina’iyya Wa-Dawruha Fi Al-Kashf ‘an Al-Jara’im” [Forensic Linguistics and Its Role in Crime Detection]. *Aleph*, no. 16, 2020, p. 4.
- [18] Al-Usaimi, S. F. *Al-Lisaniyyat Al-Jina’iyya: Ta’rifuha, Majalatuha, Wa-Tatbiqatuha* [Forensic Linguistics: Its Definition, Fields, and Applications]. 1st ed., Silsilat Dirasat, 2020.
- [19] Antar Salhi, A. I. “Tabi’at ‘Amal ‘Alim Al-Lugha Al-Jina’i: Qira’a Fi Thalath Qadaya Fi Tahqiq Nisbat Al-Nass” [The Nature of the Forensic Linguist’s Work: A Reading of Three Cases in Text-Authorship Attribution]. *Al-Majalla Al-‘Arabiyya Li-‘Ulum Al-Adilla Al-Jina’iyya Wa-Al-Tibb Al-Shar’i*, Naif Arab University for Security Sciences, n.d.
- [20] Baken, R. J. *Clinical Measurement of Speech and Voice*. 2nd ed., Singular, 2000.
- [21] Barhami, A. B. A. *Al-Shar’iyya Al-Ijra’iyya Lil-Adilla Al-‘Ilmiyya: Dirasa Tahliliyya Li-A’mal Al-Khibra* [The Procedural Legitimacy of Scientific Evidence: An Analytical Study of Expert Work]. Dar Al-Nahda Al-‘Arabiyya, 2006.
- [22] Bawadi, H. M. *Al-Wasa’il Al-‘Ilmiyya Al-Haditha Fi Al-Ithbat Al-Jina’i* [Modern Scientific Means in Criminal Evidence]. Alexandria, 2005.



- [23] Belarbi, A. N. *Al-Lisaniyyat Al-Jina'iyya: Dirasa Fi Al-Mafhum Wa-Al-Wazifa* [Forensic Linguistics: A Study of Concept and Function]. 1st ed., Dar Al-Nashr Al-Jami'i, 2017.
- [24] Clark, P. "Deepfake Challenges in Forensic Audio." *Journal of Forensic Science*, vol. 67, no. 3, 2023, pp. 201–10.
- [25] Coulthard, M., et al. *An Introduction to Forensic Linguistics: Language in Evidence*. Routledge, 2017.
- [26] Crystal, D. *A Dictionary of Linguistics and Phonetics*. 6th ed., Blackwell, 2008.
- [27] *Dictionary of Linguistic Terms (English–Arabic)*. n.d.
- [28] Drommel, R. H. *Sprachprofiling — Grundlagen Und Fallanalysen Zur Forensischen Linguistik*. Frank & Timme, 2015.
- [29] Eades, D. "Verbatim Courtroom Transcripts and Discourse Analysis." *Recent Developments in Forensic Linguistics*, edited by H. Kniffke, IAFL, 1994, pp. 161–70.
- [30] Eriksson, A. *Tutorial on Forensic Speech Science, Part I: Forensic Phonetics*. n.d.
- [31] European Network of Forensic Science Institutes. *Guidelines for Forensic Audio Analysis*. ENFSI, 2021.
- [32] Fant, G. *Acoustic Theory of Speech Production*. Mouton, 1970.
- [33] Goldman-Eisler, F. *Psycholinguistics: Experiments in Spontaneous Speech*. Academic Press, 1968.
- [34] Gonzalez-Rodriguez, J. "Forensic Voice Comparison and the Law." *IEEE Signal Processing Magazine*, vol. 34, no. 5, 2017, pp. 92–99.
- [35] Harris, L. *Privacy in Digital Forensics*. Stanford University Press, 2021.
- [36] Hisham, M. *'Ilm Al-Lugha Al-Jina'i, Al-Siyagha Al-Qanuniyya Wa-Taqniyyat Al-Tashri' Bi-Al-Maghrib* [Forensic Linguistics, Legal Drafting and Legislative Techniques in Morocco]. Faculty of Legal, Economic and Social Sciences, Ait Melloul, 2019.
- [37] Interpol. *Global Survey on Biometric Technologies in Policing*. Interpol General Secretariat, 2023.
- [38] Jacewicz, E., et al. "Regional Variation in Temporal Organisation of American English." *Journal of Phonetics*, vol. 38, no. 1, 2010.
- [39] Kent, R. D. *The Speech Sciences*. Singular, 1997.
- [40] Kersta, L. G. "Voiceprint Identification." *Nature*, vol. 196, 1962, pp. 1253–54.
- [41] Labov, W. *Principles of Linguistic Change*. Vol. 2, Blackwell, 2001.
- [42] Ladefoged, P. *A Course in Phonetics*. 4th ed., Thomson Learning, 2001.
- [43] Ladefoged, P. *Vowels and Consonants*. 2nd ed., Blackwell, 2005.
- [44] Linville, S. E. *Vocal Ageing*. Singular, 2001.
- [45] National Institute of Standards and Technology. *Speaker Recognition Evaluation Reports*. U.S. Department of Commerce, 2020.
- [46] National Institute of Standards and Technology. *Speaker Recognition Evaluation 2022*. U.S. Department of Commerce, 2022.
- [47] Nolan, F. *The Phonetic Bases of Speaker Recognition*. Cambridge University Press, 2005.
- [48] "Voiceprint Evidence Is Admissible in Criminal Trials." *North Dakota Law Review*, vol. 48, no. 4, 1972, pp. 584–85.
- [49] Ohala, J. J. "The Frequency Code Underlies the Sound-Symbolic Use of Voice Pitch." *Sound Symbolism*, edited by L. Hinton et al., Cambridge University Press, 1994.
- [50] Omar, A. M. *'Ilm Al-Dalala* [Semantics]. 4th ed., 'Alam Al-Kutub, 2001.



- [51] Omar, A. M. T. “‘Ilm Al-Lugha Al-Jina’i: Nash’atuhu Wa-Tatawwuruhi Wa-Tatbiqatuhu” [Forensic Linguistics: Its Origin, Development, and Applications]. *Al-Majalla Al-‘Arabiyya Lil-Dirasat Al-Amniyya Wa-Al-Tadrib*, vol. 23, no. 45, 2008, pp. 276–78.
- [52] Roberts, S. *Comparative Judicial Systems*. Columbia University Press, 2021.
- [53] Rose, P. *Forensic Speaker Identification*. Taylor & Francis, 2002.
- [54] Sachs, J., et al. “Anatomical and Cultural Determinants of Male and Female Speech.” *Language, Sex and Gender*, edited by J. Orasanu et al., New York Academy of Sciences, 1979.
- [55] Sadiq, H. A. *Athar Al-Sawtiyyat Al-Jina’iyya Fi Al-Kashf ‘an Al-Jarima* [The Impact of Forensic Phonetics on Crime Detection]. 2024.
- [56] Salama, S. *Masrah Al-Jarima* [Crime Scene]. 1st ed., Dar Al-Nahda Al-‘Arabiyya, 2008.
- [57] Shuy, R. “Ten Unanswered Questions about Miranda.” *International Journal of Speech, Language and the Law*, vol. 4, no. 2, 1997, pp. 174–90.
- [58] Smith, J. “Legal Admissibility of Voice Evidence: A Comparative Study.” *Journal of Forensic and Legal Studies*, vol. 45, 2023.
- [59] Solan, L., and P. Tiersma. *Hearing Voices: Speaker Identification in Court*. Brooklyn Law School, 2003.
- [60] Titze, I. R. *Principles of Voice Production*. Prentice Hall, 1994.

Author (s) Contribution Statement: Nil

Author (s) Acknowledgement: Nil

Author (s) Declaration: I declare that there is no competing interest in the content and authorship of this scholarly work.



The content of the article is licensed under Creative Commons Attribution 4.0 International License.