

Within-Speaker Voice Comparison of Drug-Affected Speech: A Forensic - phonetic Study¹

Ph.D. candidate Lect. Hiba Jebur Hamzah

hiba.hamzah@uobasrah.edu.iq

Prof. Balqis I.G Rashid (Ph.D.)

University of Basrah-College of Education for Human Sciences -Department of
English

balqis.gatta@uobasrah.edu.iq

Abstract :

The current study attempts to show how the forensic likelihood ratio (LR) is used to discriminate between drug-affected speech and recovery condition within an inter-speaker context. The study is based on estimating the LRs of the acoustic parameters for the database, which are : /ʔisʕaaf(ambulance)/, /baas/(bus), /mawz(bananas)/, /naas/(people), and /radʒdʒaal/(man). The study focuses on analysing the acoustic properties of particular parameters, namely: the F0, jitter, shimmer, HNR, and duration/ articulatory rate, which are extracted and statistically estimated via the use of Gaussian probability density. Individual LRs are estimated for each acoustic parameter, and then combined to obtain the total LR values for the whole word token, followed by evaluating the weight of the evidential strength of the acoustic evidence by adding 10 of the logarithms with the LR ($\log_{10}(\text{LR})$), prior and posterior odds, and finally to determining the conclusive decision throughout the posterior probability.

Key Words: Forensic-phonetic, Likelihood Ratio, prior odds, posterior odds, Bayes' Theorem

المقارنة الصوتية للمتحدث المتأثر بالمخدرات : دراسة صوتية جنائية

م/ هبة جبر حمزة

أ.د. بلقيس عيسى كاطع

جامعة البصرة /كلية التربية للعلوم الإنسانية/ قسم اللغة الإنجليزية

المستخلص:

تسعى الدراسة الحالية إلى توضيح كيفية توظيف نسبة الترجيح الجنائية (Likelihood Ratio: LR) في التمييز بين الكلام المتأثر بالمخدرات وحالة التعافي ضمن إطار المقارنة الصوتية بين المتحدثين. وتعتمد الدراسة على تقدير نسب الترجيح للمعايير الصوتية المستخلصة من قاعدة البيانات، والتي تضم الكلمات: ((اسعاف , باص , ناس , موز , رجال) . وتركز الدراسة على تحليل الخصائص الصوتية الفيزيائية لبعض المعايير الصوتية، والمتمثلة في التردد الأساسي (F0) ، والارتعاش الصوتي (Jitter) ، والتذبذب في شدة

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الصوت (Shimmer) ، ونسبة التوافقيات إلى الضوضاء (HNR) ، فضلاً عن المدة الزمنية/المعدل النطقي. وقد جرى استخراج هذه المعايير وتحليلها إحصائياً بالاعتماد على دالة الكثافة الاحتمالية الغاوسية (Gaussian Probability Density Function). كما تم تقدير نسب الترجيح الفردية لكل معيار صوتي على حدة، ثم دمجها للحصول على القيمة الكلية لنسبة الترجيح الخاصة بكل مفردة لغوية. أعقب ذلك تقييم القوة الإثباتية للأدلة الصوتية من خلال احتساب اللوغاريتم العشري لنسبة الترجيح (log10LR) إلى جانب الاحتمالات القبلية والبعدية، وصولاً إلى اتخاذ القرار النهائي استناداً إلى الاحتمال البعدي.

الكلمات المفتاحية: الصوتيات الجنائية , نسبة الترجيح , الاحتمالات القبلية , الاحتمالات البعدية , نظرية بايز

1. Introduction

People communicate with each other using “voice”. The principles that govern speech production and perception are difficult to express without referring to the use of physical concepts of the acoustic features (Hamzah & Rashid,2021). The speaker’s voice carries a lot of information; it is easier to realise whether the speaker is a male or female, which means sex is easily realized unless you insist to see who the talker is. This is the voice-quality characteristic that distinguishes between male and female voices. The state of health, sometimes we hear an abnormal voice for one of our relatives, such as a husky voice, immediately we know that they are suffering from a cold, or a problem with the vocal folds, and the emotional state can be understood from the speaker’s tone, if s/he is a thrilled ,depressed, or scared. All of these are common in our lifestyle, and we deal with such situations spontaneously. But what we do not realize is that the information that our voices carry is often used for forensic purposes. Voiceprint is a significant element, as are DNA and fingerprints, which together form the forensic trinity . In a crime scene , the detectives may look for evidence, for instance, finger/footprints or items thought to be left by the offenders, or recorded speech samples. Solely as DNA analysis can be used to identify a deceased individual, voice quality can similarly serve as a means of identifying a living person(Hamzah & Rashid,2023). Analysing speech samples exhibits whether the speaker was in a sober condition or under the effect of a substance that may lead him/her to do illegal issues. The present study is concerned with the drug -affected speech, that is through analysing recorded speech samples of addicts in the rehabilitation centers. The process of the analysis is based on investigating the variation in the acoustic values involving analysing the long term distribution/ (F0 and SD) and the total duration under the macro analysis of the whole word token as well as the micro-acoustic level which includes analysing the jitter, shimmer and The HNR, across three phases which are the withdrawal (the period when the speech is drug-affected) phase, the stabilization (the period of treatment) phase, and the recovery phase. The interval duration between phases is approximately five to seven days, and the total duration of their accommodation in the rehabilitation center is approximately fifteen days. The study is not based only on the voice identification of the acoustic properties, it

focuses on investigating the evidential strength of the speech samples that are believed to be uttered under the withdrawal condition (drug-affected condition) or in a sober condition (the recovery) that is throughout the application of the Likelihood Ratio framework (LR). To obtain the LR for each acoustic parameter, the study used the probability-density (Gaussian Distribution), $LR(W \setminus R) = \frac{P(E|W)}{P(E|R)}$ to estimate the LRs of the acoustic evidence under the withdrawal condition, and following the same equation to estimate the LRs of the acoustic evidence under the recovery condition as in $LR(R \setminus W) = \frac{P(E|R)}{P(E|W)}$. The essence of the LR is to evaluate the favor of one hypothesis over the other. In the present study, we estimate the LR for each acoustic parameter under the withdrawal and recovery phases, thereby combining the LRs of the acoustic evidence for a token to produce a total LR for the pronounced token under the withdrawal or recovery conditions. Because individual acoustic values provide only partial evidence regarding the underlying speech condition, therefore, the LRs are combined multiplicatively to integrate multiple sources of evidence into a single measure of evidential strength. The strength of the acoustic evidence (the LR value) aligns with the application of Bayes' Theorem. The essence of Bayes' Theorem is to confirm logically and legally the evidential strength, and to show a link between prior odds (which in this study equals (=1) (which is the prior beliefs (whether it is true that speech is under the influence of drugs or not), since it is within-speaker comparison, posterior odds indicate the updated beliefs after considering the acoustic evidence, to confirm the strength of evidence convert the estimated value into probability as in $p(H_{Withdrawal} | E) = \frac{LR_{Total}(w)}{1 + LR_{Total}(w)}$ = Posterior probability that support or against the target hypothesis (the withdrawal), and following the same mathematical procedure to estimate the probability in the recovery hypothesis $p(H_{Recovery} | E) = \frac{LR_{Total}(R)}{1 + LR_{Total}(R)}$.

2. The Statement of The Problem

The study tackles a significant phenomenon, which is drug-affected speech. In this study, a data sample is analysed and interpreted acoustically and forensically. The main goal is to find an answer to the question: is it possible to acoustically identify whether a speech sample is under the influence of drugs, instead of relying solely on the biochemical analysis?

3. The Hypotheses of the Study

1. The acoustic parameters exhibit variant values under the withdrawal and the recovery conditions.



2. If the addict is under the withdrawal influence but very recently s/he has taken a substance, the acoustic values appear as sober as normal speech when compared to the healthy consistent values of healthy people for the same sex and age, that is due to the coordination between the neuromotor systems (this means the control of the CNS, mentally and physically stable); however, the alternation exhibits after five days throughout the period of abstinence of the substances, in such cases the stabilization phase is considered as a withdrawal of the poisonous material.
3. The Likelihood ratio works as a forensic framework to determine the evidential strength of the acoustic evidence in favour of one hypothesis over the second(e.g. the withdrawal hypothesis is in favour of the recovery hypothesis and vice versa)

3. The Objectives of the Study

The present study aims to investigate the effect of substance abuse on speech. The main focus is on highlighting that speech (voiceprint) is considered forensic evidence, just like DNA , and fingerprints. An individual's voiceprint enables detectives to identify whether the speaker is a drug abuser or a sober person. Actually, such cases occurred when the offenders are arrested at a crime scene or in illegal situations, and they are in need of more time, at least approximately seven to ten days, to produce a conclusive decision of a regular drug abuser or a drug-free-person. The study intended to apply the LR forensic framework to confirm the evidential strength of acoustic evidence under each hypothesis(the withdrawal or the recovery), to tip the scales of justice in favour of one direction.

4 The procedure of the Study

This study is based on analysing the acoustic features of addicts' adolescent male (aged 14-18 years) speech samples, across three phases: the withdrawal, the stabilization, and the recovery. All the participants (addicts) are diagnosed with substance abuse. The researchers adopt a longitudinal observation of addicts carried out at: Al-Fayhaa Teaching Hospital (Al-Basrah Rehabilitation Centre for Addiction). The study highlights The study follows particular procedures in designing the research , as outlined below: The study focuses on a particular age category which is the adolescent male aged 14-18 years old, of whom are diagnosed with substance abuse. The data of the study are based on describing pictures to record their speech samples across the three phases, the relative time between phases five to seven days , and the total duration of their accommodation at the rehabilitation centre is approximately fifteen days. The researchers use the task of describing pictures to ensure that all participants produce corresponding utterances, and to obtain accurate results when comparing the acoustic parameters of the same speaker across the phases, while investigating the acoustic signals of the sample under the influence of drugs and during the recovery.



TELESIN is a compact wireless microphone designed essentially for clear audio recordings with smartphones; it is the primary device used for speech recording. We intended to break down the participants' utterances into syllables and segments to estimate the acoustic features namely: long-term distribution(F0 and SD) jitter, shimmer, HNR , and speech articulation for each addict throughout the three recording speech samples, when they are under the effect of drugs, the detoxification phase, and the recovery phase . The process of breaking down the participants' utterances is done by utilizing the software SOUNDFORGE, 2025). The researchers utilize the software computer program Praat version (6.4.27) (Boersma & Weenink,2025) to evaluate the addicts' speech acoustic signals across the three phases. The study is conducted with ethical consideration. Ethical protocols are initiated, by first registering the research proposal on the official website of the Iraqi Ministry of Health, and then official approval is obtained from the relevant authorities before entering the rehabilitation center for addiction treatment. All participants are informed about the aims of the study, taking their personal agreement in consideration to participate in this study. To reiterate privacy and anonymity , personal identifiers are removed, instead of their names, and coded with labels . It is noteworthy that, the label (AD-MC01 01) indicates an adolescent male. And it is noteworthy that both the researchers and the participants should benefit from the study. This actually occurred when some participants were asked to listen to their recorded voice samples to realize the variation between when they were under the influence of drugs, and then in recovery. All audio data is stored securely and accessed only by the researchers. Considering the participants are undergoing rehabilitation for drug abuse, special care is taken to avoid any form of psycho-pressure or harm. All speech samples are recorded in a respectful and non-intrusive manner.

5. Previous Studies

While many previous studies have investigated the influence of drugs on the acoustic properties of speech from a clinical perspective, the present study contributes a linguistic-forensic perspective by linking acoustic deviations to their forensic implications. Mirkove et al., (2017) present a study showing that the methadone-treated addicts can experience measurable vocal changes assessed through both perceptual and acoustic methods. The acoustic estimation of F0 of the voice of Methadone addicts (because they have taken it as a treatment for a long time) is showed that the average frequency corresponds to the normal one and variation between genders due to biological traits. Both jitter and shimmer do not deviate from the norms in men, although they show abnormality in women. The Institute of Applied and Mathematical Linguistics in Moscow has conducted a study by Potapova et al., in 2018 that investigates how drug intoxication affects the



speech of Russian native female speakers. The study aims to identify the phonetic cues that are capable of revealing an individual's intoxicated state solely through their speech, producing a valuable contribution to speech pathology.

In 2019, Shamei and Bird, conducted a study to investigate whether cannabis intoxication can be determined through measurable acoustic variation in speech. The research is based on the view that speech analysis can reveal physiological and mental states such as alcohol intoxication and schizophrenia. Geng et al, (2023) examine the influence of drug abuse on the acoustic features of Mandarin speech in Chinese male users. It involves (106 heroin users), (23 ketamine users), and (31 methamphetamine users) against 55 healthy controls. The study results show that drug abuse manifest significant changes in speech, including deviation in the F0, decreased loudness, lower cepstral peak prominence, and changes in formant energies

6. Likelihood Ratio Framework

The essence of the likelihood-ratio (LR) framework is to measure how strongly the available evidence supports one hypothesis compared to another. This demands clearly defining the two alternative hypotheses and identifying the relevant evidence. In forensic voice comparison, for example, the hypotheses typically state that the questioned speech was produced either by the suspect or by a different speaker. The evidence usually consists of estimated acoustic properties of the speech signal. In measuring drug-affected speech, the acoustic values of particular parameters namely: F0, jitter, shimmer, HNR, and speech rate are estimated. Thereby, the acoustic features are compared with those obtained from recovered/sober speech produced by the same speakers(addiction). This comparison aims to estimate the ratio of similarity and variation in acoustic values under various conditions of addiction and recovery. According to (Rose,2024,p.247) “ The essence of the LR is to estimate the strength of evidence in favour of one hypothesis over another.”That means if the ratio between the probability of the evidence (E) of the first hypothesis H1 is true and its probability of the second hypothesis H2 is true : $p(E | H1) / p(E | H2)$, the LR is used to show the degree of the evidence to change an individual's beliefs rationally in a hypothesis.

Probability estimation is essential in likelihood ratio analysis because it allows the observed acoustic value to be evaluated relative to the distribution of values under each hypothesis(withdrawal and recovery). Thereby , quantifying how typical or atypical the evidence is for each competing condition, $LR \frac{P(Evidence|H_1)}{P(Evidence|H_2)}$. The current study is based on the probability distribution, which is also known as “ the

normal distribution.” Or “ the Gaussian Distribution”(Walpole et al., 2012), following the formula of the probability density function of the normal (Gaussian Distribution) $f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-m)^2}{2\sigma^2}}$. The probability density function of the normal distribution is used to estimate the likelihood ratio of the observed acoustic values under each condition(drug/recovery). The probability density forms the basis for the LR estimation. Morrison,2009 states that the LRs provide a principled framework for evaluating the probability of the observed acoustic features under competing hypotheses.In forensic science, independent pieces of evidence are combined multiplicatively to get the total LR, as in $LR_{Total} = LR_{F0} \times LR_{Jitter} \times LR_{Shimmer} \times LR_{HNR} \times LR_{Duration}$, the combination of the LRs are necessary because each parameter captures a different aspect of speech, for example: f0 represents pitch , jitter and shimmer show frequency and amplitude instability, HNR represents noise and duration exhibits timing.

Another idea for evaluating the evidence is to add the LR values to the 10 logarithms as in $\log_{10}(LR)$, because the logarithm of the LR is called “ the weight of evidence”(Good,1950). A positive weight may be thought to tip the scale of justice toward the given hypothesis, when the $\log_{10}LR > 0$ supports the target hypothesis, but when $\log_{10}LR = 0$ shows a neutral value that does not change the scale of decision.

Prior odds are calculated as the ratio of the prior probabilities of the competing hypotheses, which is expressed as $P(H_1)|P(H_2)$. In the absence of external information, neutral prior odds are assumed to be equal 1:1, indicating plausibility of the withdrawal and the recovery conditions. These prior odds are then updated using the likelihood ratio to obtain posterior odds, as in $posterior\ odds = prior\ odds \times LR$. IN accordance with the Bayesian theorem, estimating the evidential strength of the acoustic evidence via the probability with the LR, as in $P(H|E) = \frac{LR}{1+LR}$ for each condition (the withdrawal(drug-affected speech and the recovery)

7. Data Analysis and Discussion

This section demonstrates the systematic interpretation of the forensic framework likelihood ratio findings of the acoustic evidence, which are produced by the male-adolescents aged from(14-18). The aim is to evaluate the evidential strength of the observed acoustic parameters by estimating how strongly they support one of the two speech hypotheses (the withdrawal or the recovery one). A comprehensive table is produced for each participant containing the token words produced under the withdrawal and recovery conditions, along with their corresponding acoustic values, and the computed probability values to derive the likelihood ratio, which



are subsequently explained in terms of their forensic significance. Sequentially, the analysis proceeds participant-by-participant, where the acoustic evidence of each token is assessed and interpreted individually, and then moves to the next participant, following the same analytical protocol. This approach confirms consistency and comparability across participants, drawing a clear line of intra-speaker variation between the withdrawal and recovery conditions, and showing the extent to which acoustic deviations can be reliably explained as forensic evidence, as follows:

Table:1

Forensic Likelihood results across the participants and tokens

participan t	Token	The withdrawal condition				The recovery condition			
		LR	Log ₁₀ L R	Prio r odds	Posteri or odds	LR	Log ₁₀ LR	Prio r odds	Posterior odds
AD-MC0 1	/ʔisʕaaf /	6.37	0.804	1	86	1.195	0.077	1	54.4%
	/baas/	2.91	0.46	1	74%	8.43	0.93	1	89%
	/mawz/	11.20	1.05	1	92%	19.80	1.30	1	95%
	/naas/	0.95	-0.02	1	49%	0.50	-0.3	1	33%
	/radʒdʒaal/	3.94	0.60	1	80%	0.26	-0.59	1	21%
AD-MC0 2	/ʔisʕaaf /		0.768	1	85.4%	306.4	2.486	1	99%
	/baas/	5.86	1.24	1	94.5%	0.057	-1.24	1	5.4%
	/mawz/	17.32	2.16	1	99.3%	0.0069	0.12	1	57%
	/naas/	145.1	-0.12	1	43%	1.32	-2.16	1	7%
	/radʒdʒaal/	10.03	1.00	1	90.3%	0.10	-1	1	9%
AD-MC0 3	/ʔisʕaaf /	11.89	1.075	1	92.2%	66.621,335,748,48	10.824	1	99.99%
	/baas/	0.162	-0.792	1	13.9	319.75	2.505	1	99.69%
	/mawz/	202.6	2.31	1	99.5%	109	2.04	1	99%



	/naas/	11.5	1.06	1	92%	10.7	1.03	1	9%
	/radʒdʒaal/	81.5	1.91	1	98%	71.8	1.86	1	98.6%
AD-MC04	/ʔisʕaaf/	3.66	0.565	1	78.6%	0.241	-0.613	1	19.4%
	/	9							
	/baas/	85.3	1.93	1	98.8%	5.18	0.17	1	83%
	/mawz/	16.4	1.21	1	94%	13.0	1.11	1	92.9%
	/naas/	35.0	1.54	1	97%	10.6	1.02	1	91%
	/radʒdʒaal/	34.0	1.53	1	97%	22.0	1.34	1	95%
AD-MC05	/ʔisʕaaf/	1.88	0.274	1	65%	66.02	1.82	1	98.5%
	/								
	/baas/	1.23	0.09	1	55%	210.89	2.32	1	99%
	/mawz/	6.46	0.81	1	87%	14.25	1.15	1	93%
	/naas/	9.83	0.99	1	91%	20.85	1.32	1	95%
	/radʒdʒaal/	4.54	0.66	1	82%	13.03	1.11	1	93%
AD-MC06	/ʔisʕaaf/	2.87	0.46	1	74%	23.36	1.37	1	96%
	/								
	/baas/	1.62	0.21	1	62%	134.18	2.13	1	99%
	/mawz/	2.64	0.42	1	73%	5.59	0.75	1	85%
	/naas/	5.08	0.71	1	85%	7.48	0.87	1	88%
	/raʒaal/	2.49	0.40	1	71%	15.84	1.19	1	94%

The estimation of the LR is based on the normal (Gaussian) distribution to calculate the probability values, for the production of the word tokens /ʔisʕaaf/, /baas/, /mawz/, /naas/, and /radʒdʒaal/. The significance of estimating the probability density is to determine how likely the observed acoustic value is under the withdrawal distribution and how likely the same value is under the recovery distribution, to get the ultimate value of the LR for each acoustic parameter, as in the equation $LR_{F0} = \frac{0.020037}{0.019808} = 1.012$, because the LR=1 indicates a neutral index that does not change the scale of decision, but if it is greater than 1 then it supports the target hypothesis. We follow the same protocol for calculating the LR of the acoustic evidence to obtain the LR under the withdrawal and the recovery conditions, as shown in the Table 1. In forensic science, independent pieces of evidence are combined multiplicatively to get the total likelihood ratio, as the LR that is mentioned in the above table for the tokens is the result of the combined LRS of the acoustic evidence under each condition, as in : $LR_{TOTAL} = LR_{F0} \times LR_{Jitter} \times LR_{Shimmer} \times LR_{HNR} \times LR_{Duration}$.



For the AD-MC01, the word token/?isʕaaf/ shows a stronger evidential support under the withdrawal condition($LR=6.37$, $\log_{10}LR=0.804$, Posterior probability=86%) compared with the recovery condition($LR=1.195$, $\log_{10}LR=0.077$. Posterior probability=54.4%). These findings indicate that the acoustic evidence is more consistent and more probable under the withdrawal (supports drug-affected speech) than the recovery hypothesis. The word token /baas/ demonstrates a moderate support under the withdrawal condition($LR=2.91$, $\log_{10}LR= 0.46$, posterior probability=74%), whereas the recovery condition exhibits a stronger evidential support($LR=8.43$, $\text{Log}_{10}LR= 0.93$, Posterior probability=89%), reflecting a clearer acoustic stabilization, and the speech sample is more probable under the recovery condition than drug-affected speech. For the word token/mawz/, both the withdrawal and the recovery conditions ,present strong evidential strength. The withdrawal condition shows that ($LR=11.20$, $\log_{10}LR=1.05$, posterior probability%) strongly supports the withdrawal hypothesis (that speech is impaired due to the effect of a substance); however, the values of the recovery condition($LR=19.80$, $\log_{10}LR=1.30$, posterior probability=95%) indicate that the speech sample/mawz/ is more probable under the recovery condition. The token /naas/ produces a weak to nearly neutral value that does not tip the scale of evidence, for the withdrawal condition($LR=0.95$, $\log_{10}LR=-0.02 < 0$ against the withdrawal hypothesis, posterior probability=49%) indicates a neutral value that does not produce a conclusive decision whether the speech sample is more probable towards each condition. Furthermore, the results of the recovery condition align with the withdrawal hypothesis ($LR=0.50$, $\text{Log}_{10}LR=-0.30$, and posterior probability=33%) against the recovery hypothesis, indicating that the speech sample is still impaired and it is more probable under the drug-affected condition. The word token /radʒdʒaal/ presents a moderate support for the withdrawal condition($LR= 3.94$, $\log_{10}LR=0.60$,and the posterior probability=80%). This indicates that the speech sample supports the withdrawal hypothesis(it is more probable under drug-affected speech condition). The recovery condition produces ($LR=0.26$, $\text{Log}_{10}LR=-0.59$, and the posterior probability=21%) this suggests that the acoustic profile is more consistent with the withdrawal hypothesis, drug-affected speech characteristics.

For the AD-MC02,the word token/?isʕaaf/ provides a strong support for both conditions, the withdrawal condition values exhibit (the $LR=5.86$, $\text{Log}_{10}LR=0.768$, and posterior probability=85.4%), indicating that the acoustic evidence is more probable under the drug-affected conditions. However, the recovery condition demonstrates a substantially stronger evidential strength of sober speech, (the $LR= 306.4$, $\text{Log}_{10}LR=2.486$, and the posterior probability=99%), indicating a highly stabilized acoustic profile during the

recovery. Furthermore, the word token/baas/ exhibits an extremely strong withdrawal-oriented evidence(LR=17.32, Log10LR= 1.24, and the posterior probability=94.5%), whereas the recovery condition produces an extremely weak support for the recovery condition(LR=0.057, log10LR=1.24, and the posterior probability=5.4%), disapproving the recovery hypothesis, with a persistent drug-affected acoustic profile.

For the word token/mawz/, the results of the LR estimation reveal an exceptionally strong evidential support for the withdrawal hypothesis (LR=145.1, Log10LR=2.16, and the posterior probability=99.3%), while the recovery condition presents extremely weak evidence(LR=0.0069, Log10LR=-2.16, and the posterior probability=7%). These values strongly favour the withdrawal hypothesis and indicate a severe acoustic perturbation. On the other hand, the results of LR estimation of the word token/naas/ display weak and inconclusive evidence under both conditions. The withdrawal condition produces (LR=0.76, log10LR=-0.12, and the posterior probability=43%), while the recovery condition exhibits (the LR=1.32, log10LR=0.12, and the posterior probability=57). The results indicate a marginal support for the recovery hypothesis, which does not logically or legally warrant a conclusive decision, and presents a limited discriminative capacity between the two conditions. The AD-MC02 wraps up the LR estimation of the word token/radz3aal/with a strong support for the withdrawal hypothesis rather than the recovery (the LR=10.03, log10LR=1.00, and the posterior hypothesis=90.3), whereas the recovery condition demonstrates weak evidence against the recovery hypothesis(the LR=0.10, log10LR=1, and the posterior probability= 9%). This indicates that the acoustic profile remained highly consistent with the withdrawal hypothesis (which means the speech sample across fifteen days of drug abstinence still showed the signs of addiction affecting the vocal apparatus).

Conversely, the AD-MC03 produces a variant scale between the withdrawal and the recovery conditions. The token/?isfaaf/ demonstrates a strong evidential support under both conditions, the withdrawal (LR=11.89, log10LR=1.075, and the posterior probability=92.2%), indicating that the speech sample is more probable under the withdrawal condition. The recovery condition also exhibits an extremely strong support towards the recovery hypothesis(the LR=66,621,335,748.48, log10LR=10.824, and the posterior probability=99.99%), indicating that the speech sample is in favor of the recovery hypothesis over the withdrawal(which means that the speech sample is sober and free of any substance effect). However, the token/baas/ shows weak evidence against the withdrawal hypothesis, as in (the LR=0.162,log10LR=-0.792, and the posterior probability=13.9%), the observed withdrawal profile is not strongly characteristic of the withdrawal distribution; it

provides evidence against the withdrawal hypothesis when compared with the recovery one. The recovery condition shows an extremely strong support ($LR=319.75$, $\log_{10}LR=2.505$, and the posterior probability= 99.69%), which means that the acoustic evidence of /baas/ is about 320 times more probable under the recovery than the withdrawal condition, and the posterior probability of 99.69% indicates a highly robust recovery-oriented acoustic profile. In contrast, the word token/mawz/ produces a strong evidential strength under both conditions. The withdrawal condition (the $LR=202.6$, $\log_{10}LR=2.31$, and the posterior probability= 99.5%), this represents a strong to very strong evidential support for the withdrawal hypothesis. The recovery condition exhibits that (the $LR=109$, $\log_{10}LR=2.04$, and the posterior probability= 99%). These findings indicate that the observed acoustic evidence is overwhelmingly discriminative, demonstrating the reliability of the probabilistic framework in capturing condition-specific acoustic variation. The token/naas/ produces a relatively balanced evidential strength between the conditions. The withdrawal condition shows (the $LR=11.5$, $\log_{10}LR=1.06$, and the posterior probability= 92%), whereas the recovery condition exhibits (the $LR=10.7$, $\log_{10}LR=1.03$, and the posterior probability= 91%). The findings reveal that both conditions exhibited strong but closely comparable acoustic evidence. The token/razaal/ reveals an extremely support under both conditions, the withdrawal condition (the $LR=81.5$, $\log_{10}LR=1.91$, and the posterior probability= 98%) while the recovery condition gets (the $LR=71.8$, $\log_{10}LR= 1.86$, and the posterior probability= 98.6%). These results indicate highly robust acoustic evidence and clear phase-related acoustic variation.

For the AD-MC04, the word token/?isʕaaf/ demonstrates a moderate support for the withdrawal hypothesis, ($LR=3.669$, $\log_{10}LR= 0.565$, and posterior probability= 78.6%). These values confirm that the acoustic evidence favors the withdrawal hypothesis over the recovery one. The recovery condition reveals that ($LR=0.241$, $\log_{10}LR= -0.613$, and posterior probability= 19.4%). These values are against the recovery condition, and produce a noticeable indication that the acoustic profile is still more consistent with the withdrawal-related speech characteristics. The token /baas/ shows a very strong support for the withdrawal hypothesis, ($LR=85.3$, $\log_{10}LR=1.93$, and posterior probability= 98.8%). These values ensure that the acoustic evidence favors the withdrawal hypothesis over the alternative hypothesis (recovery). On the other hand, the results of the acoustic evidence support the recovery hypothesis, ($LR= 5.18$, $\log_{10}LR=0.71$, and posterior probability= 83%). Acoustically, these values indicate an improvement in the acoustic parameter of the speech sample, and, forensically, reflect that the acoustic evidence is in favor of the recovery hypothesis over the drug-affected condition.



The token/mawz/ under the withdrawal condition produces strong evidential support for the withdrawal hypothesis (the $LR=16.4$, $\log_{10}LR=1.21$, and the posterior probability=94.5 %), reflecting a highly probable drug-affected condition, whereas the recovery condition shows that (the $LR=13.0$, $\log_{10}LR=1.11$, and the posterior probability=92.9%). These values reflect that the acoustic evidence is more probable under the recovery condition, and is in favor of the recovery hypothesis. The token/naas/ produces values under the withdrawal condition ($LR=35.0$, $\log_{10}LR=1.54$, and posterior probability=97%), indicating a strong evidential support for the withdrawal hypothesis and showing that the acoustic profile is highly probable under drug-affected speech, while, the recovery condition shows that (the $LR=10.6$, $\log_{10}LR=1.02$, and the posterior probability=91%), reflecting strong recovery-oriented evidence. The withdrawal condition values of the token/ radzdzaal/ show that (the $LR=34.0$, $\log_{10}LR=1.53$, and the posterior probability=97%), demonstrating strong support for the withdrawal hypothesis (drug-affected speech condition). The recovery condition produces ($LR=22.0$, $\log_{10}LR=1.34$, and posterior probability=95%), indicating a strong recovery support .

The AD-MC05 produces the token/?isʕaaf/ with a weak to moderate support for the withdrawal hypothesis with ($LR=1.88$, $\log_{10}LR=0.274$, and posterior probability=65%), which means the acoustic evidence slightly confirms approximately 45% (against the drug-affected speech and supports the recovery condition) the fact that the speech sample is under a drug-affected condition. The recovery condition produces (the $LR=66.02$, $\log_{10}LR=1.82$, and the posterior probability 98.5%), reflecting that the acoustic evidence is in favor of the recovery hypothesis over the withdrawal one. The token/baaʕ/ shows that the acoustic evidence exhibits a weak withdrawal support with (the $LR=1.23$, $\log_{10}LR=0.09$, and the posterior probability=55%), indicating a marginal support for the withdrawal hypothesis and in favor of the recovery one, while the recovery condition produces an extremely strong evidential support with (the $LR=210.89$, $\log_{10}LR=2.32$, and the posterior probability=99%). The values of the recovery condition indicate strong support, and the acoustic evidence favors the recovery hypothesis over the withdrawal hypothesis. The withdrawal condition produces a moderate evidential support for the token/mawz/ as in (the $LR=6.64$, $\log_{10}LR=0.81$, and the posterior probability=87%), while the recovery condition shows (the $LR=14.25$, $\log_{10}LR=1.15$, and the posterior probability=93%). These values suggest an observable recovery-related improvement in acoustic values. The $LR=20.85$, $\log_{10}LR=1.32$, and the posterior probability=95%, reflecting strong recovery-oriented evidence. The token/naas/ demonstrates a strong support under both conditions. The withdrawal condition produces ($LR=9.83$, $\log_{10}LR=0.99$, and



posterior probability=91%) while the recovery condition exhibits (LR=20,85, log10LR=1.32, and posterior probability=95%). These findings indicate that the acoustic profile under each hypothesis, the withdrawal, and the recovery are more stable and probabilistically stronger. On the other hand, the token/radzdaal/ displays a moderate to strong support for the withdrawal hypothesis with (the LR= 4.54, log10LR=0.66, and the posterior probability=82%), whereas the recovery condition exhibits a stronger support with (the LR=13.03, log10LR=1.11, and the posterior probability=93%). Forensically, the acoustic evidence supports each hypothesis, but the acoustic profile under the recovery hypothesis suggests a conclusive decision of free drug-affected speech.

The AD-MC06 produces the token/ʔisʔaaf/ with a moderate support for the withdrawal condition(the LR=2.87, log10LR=0.46, and the posterior probability=74%).These values support the withdrawal hypothesis, revealing that the acoustic evidence is under the drug-affect condition. The recovery condition demonstrates much stronger evidential support with (LR=23.36, log10LR=1.37, and posterior probability=96%). Conversely, the token/ baasʔ/ shows weak withdrawal-oriented evidence with LR(1.62, log10LR=0.21, and posterior probability=62% , these values indicate a marginal support for the withdrawal hypothesis, and slightly tend towards the recovery hypothesis. The recovery condition exhibits a stronger support with LR=134.18, log10LR=2.13, and posterior probability=99%. These findings strongly favor the recovery hypothesis and reflect substantial acoustic normalization. For the token/mawz/, the withdrawal condition shows a moderate support for the withdrawal hypothesis (LR=2.64, log10LR=0.42, and posterior probability=73%. This indicates that the evidential strength of the observed acoustic values supports that the speech sample was produced under the drug-affected condition. On the other hand, the estimated evidence of the recovery condition exhibits an observable evidential strength (LR=5.59, log10LR=0.75, and posterior probability=85%), these values are in favor of the recovery hypothesis and indicate an improved acoustic stability during the recovery. The token/naas/ offers a moderate to strong support for both conditions. Under the withdrawal condition, the acoustic evidence exhibits (LR=5.08, tlog10LR=0.71, and posterior probability=85%), while the recovery condition offers (LR=7.48, log10LR=0.87, and posterior probability=88%. These values reflect the consistency of the acoustic evidence under each hypothesis. The token/radzdaal/ demonstrates a moderate support for the withdrawal condition with (the LR=2.49, log10LR=0.40, and the posterior probability=71%), indicating that the acoustic evidence moderately favors the withdrawal-related speech characteristics. In contrast, the recovery condition offers a substantially stronger

evidential support with $LR=15.84$, $\log_{10}LR=1.19$, and posterior probability=94%, showing a clearer and more stable recovery-oriented acoustic profile.

8. Conclusion

The Likelihood ratio is a new paradigm in forensic voice comparison. It is based on a quantitative interpretation of the database. The implementation of the LR framework, along with the evaluation of the acoustic evidence, aims to assess the evidential strength of the observed acoustic parameters. The study highlights within-speaker voice comparison, which demands a systematic protocol to evaluate the speaker's voice sample under each condition (drug-affected condition/ the withdrawal one) or sober speech (the recovery) one. The study verifies how the Bayes' Theorem works to produce logical and legal interpretation under both conditions through showing how to rationally alter the prior beliefs in something when confirmed by the evidence. Because the study is based on within-speaker voice comparison, the prior beliefs (usually indicating the belief before estimating the acoustic evidence) are equal 1:1, which means both conditions, the withdrawal and the recovery are equally possible before the evidence. Thereby, estimating the posterior odds (the updated belief) that favors one hypothesis over the other.

The findings reveal that the discriminative evidential strength differs across the participants, which may be due to age differences. For instance, the AD-MC05 offers LRs for the acoustic evidence in favor of the recovery hypothesis over the withdrawal one, although the estimated LRs and posterior probabilities support the withdrawal hypothesis; however, this indicates weak and inconclusive forensic evidence of drug-affected speech. The lexical token/naas/ demonstrates weak or near-neutral evidential strength, reflecting a persistent overlap between the withdrawal and the recovery acoustic profile.

Forensically, the combination of the LR, $\log_{10}LR_{(W|R)}$ (the weight of the evidential strength), and the posterior probability (evidential strength) provides a statistically essential interpretation of the acoustic evidence and confirms the effectiveness of the Bayesian Likelihood ratio framework in distinguishing between the withdrawal and recovery speech. Furthermore, the findings illustrate that the acoustic phonetic parameters can function as reliable forensic indicators for evaluating drug-affected speech and support the development of a systematic forensic phonetic protocol for speaker profiling and evidential interpretation.

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