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Invariance of Contact Quotient Across Face Mask-Wearing and Non-Wearing Individuals: A Forensic Viewpoint

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***Abstract*—An electroglottographic (EGG) study was conducted to examine the effect of different face-covering conditions on vocal fold contact characteristics. Sustained vowel sounds ([a], [i], [u], [Ə], [e], [o]) from thirty participants (15 males and 15 females) under four conditions: without a face covering, with an N-95 mask, with a tight cotton mask, and with a handkerchief covering were considered for analysis. The contact quotient (CQ), representing the proportion of the glottal cycle during which the vocal folds are in contact, was measured using EGG. Results indicated that CQ values remained consistent across all face-covering conditions, suggesting that mask usage does not influence vocal fold contact behavior. However, a statistically significant difference in CQ was observed between genders, with mean CQ values of 0.754 for males and 0.819 for females. These findings indicate that CQ is a robust and stable parameter, unaffected by external vocal disguise through face coverings..**

***Keywords*—Electroglottography, EGG, voice analysis, face wears, contact quotient**

I. Introduction

The COVID-19 pandemic imposed the usage of face masks for many individuals. It was required to wear face masks in order to limit the spread of respiratory illnesses during pandemic. However, it also somewhat limits the ability to transmit speech [1]. Various kinds of crimes rose throughout this epidemic time [24]. Criminals used face mask like every other individual, and committed crime. Money extortion on vaccines and injections, spreading fake insurance schemes, fake phone call requests for charity or donations, sexual harassment of women on phone calls such type of crimes emerged during pandemic. In above listed crimes, phone calls and eventually the voice of a person was the only evidence to build the identity of the criminal. A thorough analysis [1-8, 29] of the speech samples taken during the pandemic, revealed the varied impacts of face masks that may be held accountable. If the crimes were committed by the accused wherein human conversation was conducted by wearing a face mask, then that was the alarming situation as mask quality influenced speech samples [2, 3].

Speech researchers were intrigued by this topic, all around the world. Acoustic effect [3-5], deterioration of speech intelligibility [6], variation in spectral characteristics [7] was observed in the speech after wearing the mask. In [8], they presented the effect of face wears on formant frequencies, HNR ratio and energy.

In forensic voice analysis, semi-automatic method, comprised of oral plus human assisted software analysis approach is employed which is the most accepted one in the court of law (Law Enforcement Development Group, 1975). Two speech samples one is questioned, collected at the scene of crime and the other is controlled, collected after arresting the accused are compared auditory and spectrographically. The controlled samples should be collected in the same mode and in the same medium as that of the questioned voice. The suspect/accused provides his voice sample on his consent, no forcing for voice samples is expected. In this situation suppose a person, committing crime wears the face mask and while giving the controlled voice samples he/she denies to wear the face mask then according to the researched data available, the two voice samples will not have the comparable features, as the earlier one is affected due to face covering [1-8]. In this regard some other voice related parameters need to be measured which will be compared in addition to the auditory and spectrographic findings. In this paper, we have attempted to study the Electroglottographic signals obtained from multiple participants to identify the parameters that will remain unchanged even if the face masks are worn.

Electroglottography (EGG) is the low cost and noninvasive technique which does the indirect investigation of vocal folds. In EGG the high frequency, low ampere current is passed between two electrodes that are placed externally on the neck, on each side of the thyroid cartilage at vocal fold level [9, 10]. The contacting and de-contacting of the vocal folds causes variations in the electrical impedance across the larynx, resulting in a variation in current between the two electrodes was studied by Baken [11].

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This variation in the current flow has been found to be related to changes in vocal fold contact area [12]. The quantitative analysis of EGG waveform for clinical and in basic voice area started from measuring the larynx closed quotient [13] or contact quotient [14].

Contact quotient, measured by electroglottogram, is the ratio of the duration of vocal fold contact of the total vibratory cycle [15]. Abdul-latif Hamdan, et al [16] in their study have reached to a conclusion that the mean CQ-contact quotient during sustained /e/ vowel is not affected by fasting and non-fasting subjects. A study by Li-Hsin Ning showed that CQ is important in predicting the age of a voice [17]. Kankare E. et al in their study discussed on how CQ is different for different types of phonation i.e. for breathy, normal, pressed phonation [15]. As reported by Verdolini et. al. contact time of the vocal folds differed significantly between the different types of phonation [22]. CQ parameter has been used to distinguish between voice registers [18] and also to classify the subjects into different age groups [19]. It is claimed that because the contact quotient is connected to the physiological characteristic of the vocal fold contact area, voice disguise techniques like speaking while wearing a face mask will not affect it. Knowing this, in the present study we aimed to analyse the CQ parameter of the signals coming from the larynx when subjects are producing the sustained sounds with and without face wears.

The present study makes a novel contribution by investigating whether different face-covering conditions influence CQ during sustained vowel production. By examining male and female participants under four masking conditions (no mask, N-95 mask, tight cotton mask, and handkerchief), this work provides empirical evidence that CQ remains stable irrespective of external facial coverings. Importantly, the observed gender-based differences in CQ further enrich the understanding of physiological variability in phonation. From a forensic perspective, these findings highlight the robustness of CQ as a potential biometric parameter for speaker identification, even when the speaker's voice is acoustically disguised by a face covering. This study thus bridges a crucial gap between voice disguise research and physiological voice analysis, supporting the application of EGG-derived measures as reliable indicators in forensic phonetic investigations.

II. Materials And Methodology

Fifteen male and fifteen female participants (S-1 to S-30) aged between 21 to 24 years, contributed their voice for this study.

The participants were not having any kind of neurological, voice disorders and no hearing problem. On the recording day all the participants were having good health. The participants were asked to vocalize six sustained vowels [a], [i], [u], [Ə], [e] and [o] for three times each in four different conditions i.e. without face wear, with N95 mask, with cotton mask and with handkerchief. The upright posture was maintained by each participant while recording.

Recordings were carried out using Dr. Speech vocal assessment, Tiger EGG module software and hardware Electroglottograph instrument. Alcohol swab was used to clean the skin area covering the thyroid lamina. Two gold plated EGG electrodes, having 100Hz to 1500Hz frequency response and 3.2 cm in diameter (for adult) were considered for EGG tests. These electrodes were coated with conductive gel for improving the signal quality and were attached to a neckband. This neckband was then tied to the neck of the participant, placing electrodes on both sides of the thyroid lamina. The electroglottographic signal was acquired using vocal assessment software. An EGG signal amplifier was used to receive a good signal quality. Four sessions of sustained phonation of six vowels were conducted for each participant. First is without any face mask (normal), second was with N95 mask (N95), thirdly with tight cotton mask (CM) and lastly with handkerchief tied around mouth (HF). Six vowels three times each, in four different situations, in total seventy-two EGG recordings were performed for each participant. The Electroglottograph device and EGG module software were verified to be calibrated.

CQ were evaluated automatically from the EGG signal with vocal assessment analysis software. The middle portion of each phonation was selected for the evaluation of CQ parameter to avoid the irregularities at the beginning and ending positions of the phonation. CQ values were obtained at same threshold level for each participant. Mean CQ value was calculated from the three successive recordings of each vowel in each condition.

To analyse the variance in CQ values, we carried out the ANOVA test. It is a statistical method used to compare the means of two or more groups to determine if there are statistically significant differences among them. ANOVA assesses whether the variability between group means is larger than the variability within the groups, taking into account the sample sizes and variances of the groups. ANOVA tests the null hypothesis that all group means are equal against the alternative hypothesis that at least one group mean is different.

It provides an F-statistic, which is the ratio of the between-group variability to the within-group variability. If the F-statistic is large enough to reject the null hypothesis at a given significance level, it suggests that there are significant differences among the group means. ANOVA is widely used in various fields such as psychology, biology, sociology, economics, and engineering to analyze experimental or observational data with multiple groups or treatments. It allows researchers to make comparisons and draw conclusions about the effects of different factors or treatments on the dependent variable. ANOVA relies on several assumptions for its validity. It's crucial to assess whether these assumptions are met before interpreting the results. The key assumptions of ANOVA include Normality. In present study, data normality was checked using the Shapiro test and Jarque-bera test. R and SPSS softwares were used for graphs and statistical analysis.

III. Results And Discussion

The mean CQ values for all six sustained vowels were calculated in four different conditions from the three successive readings of CQ. Mean CQ values and coefficient of variation (CV) in mean CQ values for all 30 subjects for vowel [i] are given in Table 1. The mean CQ values for sustained vowel [i] in Table 1 showed very little fluctuation, which is consistent with the observation of very little change in mean CQ values. Table 1 also indicated that the Coefficient of variation in mean CQ values was less than 5%.

TABLE I
Mean CQ values in four different conditions for vowel [i]

Subjects (n=30)	Mean CQ				Mean CQ	CV
	Normal	N-95	CM	HF		
S-1 F	0.7751	0.7855	0.7761	0.7569	0.7734	1.55
S-2 M	0.8282	0.8164	0.8179	0.8224	0.821225	0.65
S-3 F	0.7295	0.7281	0.7376	0.7337	0.732225	0.59
S-4 M	0.805	0.8092	0.8038	0.8304	0.8121	1.53
S-5 M	0.8409	0.816	0.8517	0.8534	0.8405	2.05
S-6 F	0.7547	0.7502	0.7716	0.7406	0.754275	1.72
S-7 F	0.7764	0.7666	0.7521	0.7714	0.766625	1.37
S-8 F	0.7929	0.7489	0.8095	0.761	0.778075	3.60
S-9 M	0.8273	0.8236	0.8152	0.8111	0.8193	0.91
S-10 M	0.7925	0.8064	0.8114	0.7838	0.798525	1.59
S-11 F	0.7241	0.7254	0.7126	0.7379	0.725	1.43
S-12 F	0.7701	0.7755	0.7508	0.7512	0.7619	1.68
S-13 M	0.8176	0.8257	0.8148	0.8107	0.8172	0.78
S-14 F	0.7455	0.767	0.7487	0.7062	0.74185	3.45
S-15 M	0.8345	0.8169	0.8206	0.8296	0.8254	0.98
S-16 F	0.7215	0.7509	0.7509	0.7733	0.74915	2.84
S-17 F	0.7051	0.7211	0.6846	0.7025	0.703325	2.13
S-18 F	0.7597	0.7516	0.7392	0.7198	0.742575	2.34
S-19 F	0.7382	0.7234	0.744	0.7433	0.737225	1.30
S-20 F	0.791	0.778	0.7442	0.7644	0.7694	2.60
S-21 F	0.7384	0.7665	0.7772	0.7635	0.7614	2.16
S-22 M	0.8356	0.826	0.839	0.8227	0.830825	0.93
S-23 M	0.8026	0.8074	0.8014	0.8065	0.804475	0.36
S-24 M	0.8026	0.7988	0.8046	0.8024	0.8021	0.30
S-25 M	0.8204	0.8043	0.8146	0.8127	0.813	0.82
S-26 M	0.8268	0.8159	0.8278	0.819	0.822375	0.71
S-27 M	0.8175	0.8123	0.8347	0.8012	0.816425	1.71
S-28 M	0.8036	0.8074	0.8109	0.8041	0.8065	0.42
S-29 M	0.8183	0.8042	0.8267	0.8156	0.8162	1.14
S-30 F	0.7306	0.7698	0.7482	0.7385	0.746775	2.27

The box plot in Figure 1 shows the distribution of CQ values among participants, divided further by gender and experimental condition. An additional noteworthy observation emerging from the present data is the clear gender-based distinction in CQ values. Consistent with earlier findings reported by Awan and Awan [23], male participants demonstrated higher CQ values compared to female participants (Table 1, Figure 1), reflecting underlying physiological differences in vocal fold structure and vibratory patterns.

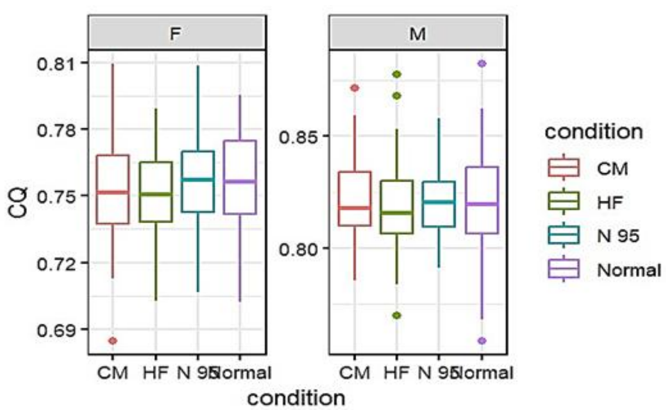

Figure 1: Boxplot of CQ by Condition and gender

The spider chart for Subject S-2 (male) is shown in Figure 2, depicting CQ values for six sustained vowels in each of the four face-covering conditions: [a], [i], [u], [·], [e], and [o]. The chart illustrates that CQ values remained highly consistent across all conditions, indicating no appreciable variation attributable to the use of masks or other facial coverings.

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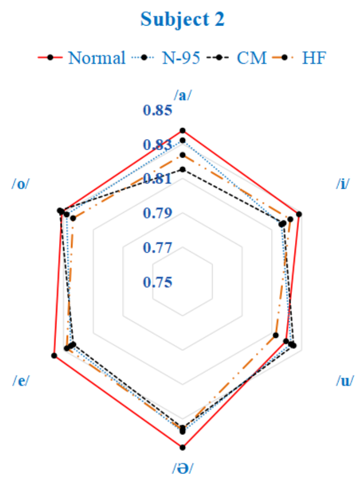

Figure 2: Spider chart showing invariance of CQs in six vowels for subject no.2

Figure 3 presents the mean CQ values for the vowel [a] produced under the normal (no mask) condition by all 30 participants. The plot also includes one-standard-deviation intervals around the mean CQ values for each subject, providing a visual representation of intra-speaker variability. Consistent with the patterns summarized in Table 1, Figure 3 demonstrates that the variability in mean CQ values across participants remained within an acceptable and expected physiological range, further supporting the stability and reliability of CQ as a measurement parameter.

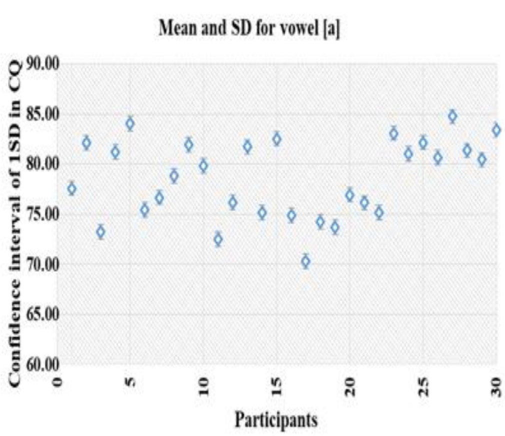

Figure 3: Standard deviation of one sigma in mean CQ

Table 2 is the vocal assessment window of EGG signal of subject S-2 male, for vowel [i], where many parameters including mean F0 and CQ are seen. There was 7 to 10% change observed around the mean F0 (fundamental frequency) values in the collected data, but did not have any remarkable effect on the CQ parameter. The paper by Lebowitz A, Baken RJ. [20] showed that variation of F0 have remarkably little effect on CQ $_{EGG}$ values. In Table 2 Mean F0 (Hz) is 145.84 and CQ (%) is 80.92 for vowel [i] in CM condition and for vowel [i] in normal condition, the Mean F0 decreased to 133.83, almost 9.2% lowering seen, however the CQ value was 80.50, comparatively shown less variation.

Density plot for CQ is shown in Figure 4 which visualized the normality of data and spread of CQ. To confirm normality, we have done Jarque-bera and Shapiro test (Table 3). Both tests ascertained that the data follows normality within specific condition and gender. The data obeys normality, as shown in Table 3, with p-values >.05 for every combination of sex and condition. The applicability of parametric or non-parametric approaches is determined by normality. For additional analysis, we can use the parametric test in this situation.

TABLE II
VOCAL ASSESSMENT WINDOW SHOWING LITTLE VARIATION IN CQ VALUES.

Habitual F0 (Hz)	145.70	NNE (dB)	-20.06	CQ (%)	80.92
Jitter (%)	0.49	HNR (dB)	22.88	CI	-0.17
Shimmer (%)	2.94	SNR (dB)	21.83	OR (%)	58.52
F0 Tremor (Hz)	2.31	Amp Tremor (Hz)	3.39	CR (%)	41.39
				CQP (%)	1.32
				CIP (%)	27.19
Mean F0 (Hz)	145.84				
SD F0 (Hz)	1.62				
Max F0 (Hz)	150.51				
Min F0 (Hz)	141.35				

Vowel [i] using CM

Habitual F0 (Hz)	132.98	NNE (dB)	-18.08	CQ (%)	80.50
Jitter (%)	0.65	HNR (dB)	21.25	CI	-0.28
Shimmer (%)	3.42	SNR (dB)	19.85	OR (%)	63.87
F0 Tremor (Hz)	1.76	Amp Tremor (Hz)	2.43	CR (%)	36.03
				CQP (%)	1.80
				CIP (%)	16.24
Mean F0 (Hz)	133.83				
SD F0 (Hz)	2.42				
Max F0 (Hz)	141.35				
Min F0 (Hz)	128.95				

Vowel [i] Normal

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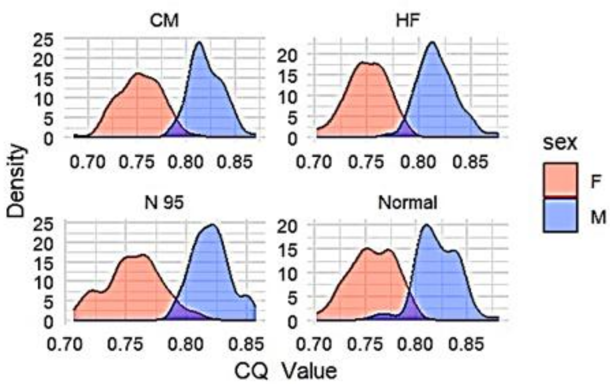

Figure 4: Density plot of CQ by sex and condition

More importantly, Fig. 4 demonstrated the difference in mean CQ between males and females. We used the statistical tool ANOVA and conducted a test to demonstrate it statistically. According to the procedure's description, it explains that we have 720 observations overall for each different combination of factors. For the purpose of determining whether there are any significant differences between and within factors, we perform a multi-factor ANOVA. Three factors are available, each with varying levels of significance: sex (two for male and female) and condition (four for Normal, HF, N95, and CM). Vowels is the final component; it has six levels as /a/,/i/,/ə/,/u/,/e/ and /o/.

TABLE III
P-VALUE OF NORMALITY TEST FOR CQ VALUES.CQ VALUES.

Sex	Condition	Jarque-bera-test p-value	Shapiro-test p-value
F	CM	0.81575536	0.76356137
F	HF	0.45599518	0.48389598
F	N 95	0.72857167	0.37984691
F	Normal	0.28571689	0.13284319
M	CM	0.34770180	0.24902073
M	HF	0.05016956	0.13357290
M	N 95	0.37268979	0.16527297
M	Normal	0.25000241	0.03671133

TABLE IV-A
RESULTS OF ANOVA TEST

Descriptive Statistics for n=30
Dependent Variable: CQ

condition	sex	Mean	Std. Deviation	N
CM	F	0.7524	.02218	90
	M	0.8207	.01697	90
	Total	0.7866	.03949	180
HF	F	0.7506	.01937	90
	M	0.8177	.01863	90
	Total	0.7842	.03862	180
N 95	F	0.7562	.02303	90
	M	0.8205	.01531	90
	Total	0.7884	.03771	180
Normal	F	0.7567	.02221	90
	M	0.8212	.02015	90
	Total	0.7889	.03863	180
Total	F	0.7540	.02180	360
	M	0.8200	.01783	360
	Total	0.7870	.03858	720

The results of the one-way ANOVA are summarized in Tables 4a and 4b. The ANOVA output indicated a statistically significant main effect for the factor Sex, confirming that CQ values differed reliably between male and female participants. In contrast, no significant effect was observed for the factor Condition ($p = 0.069$), suggesting that the four face-covering conditions did not produce meaningful variation in CQ values at the $\alpha = 0.05$ significance level. Furthermore, no interaction effect between Condition and Sex was detected, indicating that the influence of face coverings on CQ did not differ between male and female speakers.

TABLE IV-B
RESULTS OF ANOVA TEST

Tests of Between-Subjects Effects forn=30
Dependent Variable: CQ

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.789	7	.113	284.642	.000
Intercept	445.951	1	445.951	1126854.920	.000
condition	.002	3	.001	2.075	.102
sex	.786	1	.786	1984.982	.000
condition * sex	.001	3	.000	.430	.732
Error	.282	712	.000		
Total	447.021	720			
Corrected Total	1.070	719			

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Table 4b presents the ANOVA results within the gender factor. The significance value ($p < 0.001$) demonstrates a robust difference in CQ values between male and female participants, substantiating the gender dependency of CQ. This is visually supported in Figure 5, which illustrates the separation in CQ distributions, with females exhibiting higher CQ values than males.

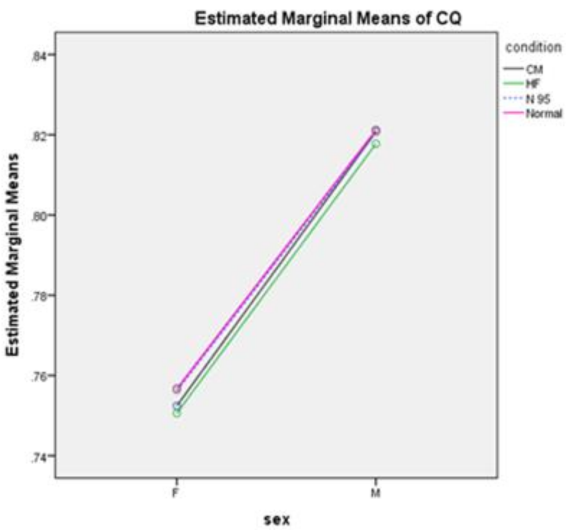

Figure 5: Showing differences in mean CQ for male and female participants

It can be deduced from the results that, instead of using different types of face wears during phonation, the vocal fold contact quotient CQ obtained using electroglottographic signals remained unchanged. This has an application in forensic speaker verification process, where only one accused and one suspect are to be matched auditorily and spectrographically. Speech samples are attentively listened to in auditory analysis to extract the person's linguistic and phonetic characteristics. In spectrographic analysis formant [21] frequencies produced through the vocal tract are compared.

In [8] they unveiled that how formant frequencies get shifted in the speech samples when face masks are used. In this particular case it is much difficult to compare the questioned and controlled speech samples on the basis of formant frequencies. However, on the basis of invariance of the vocal fold contact area i.e. CQ, we can form our opinion about the similarity or dissimilarity of source of voice. Along with the auditory analysis which is purely a subjective analysis, EGG analysis which is an objective technique, can become corroborative evidence.

As EGG is a non-invasive technique an accused person can be called on in the laboratory for doing the tests with proper guidance to the investigating officer. EGG analysis surely can become supportive evidence along with the voice analysis report. The study's limitation is that because CQ does not differ significantly between individuals, we are unable to utilize it to distinguish the speaker from the group of suspects.

There are some cases in which accused person in questioned voice speaks in high pitch for communication and while giving his voice sample after an arrest he speaks in very low pitch. In this situation formants did get shift towards the higher frequency sides in high pitch samples than the low pitch samples, again creating the difficulties in matching the formant frequencies. Our future scope of work is to look for the CQ values in the regard when a person is speaking in varied pitch, which could be a helping hand to establish the speaker is same or not. Thus, present study reiterated that the CQ parameter can have a small but important role in identifying the origin of voice source.

Furthermore, in forensic speaker identification, one of the major challenges lies in detecting the authenticity of a voice when it has been deliberately or unintentionally disguised. Conventional acoustic parameters, such as formant frequencies, spectral tilt, and harmonic-to-noise ratio, are often susceptible to external modifications caused by vocal tract filtering, recording conditions, or physical obstructions like masks [25; 26]. These variations can obscure or distort acoustic cues essential for accurate speaker verification. In contrast, EGG-based parameters, including CQ, directly reflect the vibratory characteristics of the vocal folds, thereby offering a disguise-resistant physiological metric that remains largely unaffected by external coverings. Earlier studies have emphasized the value of EGG in both clinical and forensic applications due to its robustness and reproducibility. Baken and Orlikoff [27] highlighted that EGG provides a noninvasive and reliable representation of vocal fold contact behavior, minimally affected by environmental or acoustic conditions. Childers and Krishnamurthy [28] further demonstrated that glottal waveform parameters derived from EGG, such as CQ and open quotient (OQ), can effectively characterize individual phonatory types and may serve as potential biometric markers. Considering our previous study [8] we can infer that, although masks can attenuate higher frequency components of speech, there is negligible influence on glottal closure or sub-glottal pressure.

Overall, the study bridges a critical gap in forensic phonetic research by providing empirical evidence of the mask-invariant nature of CQ and its potential as a disguise-resistant biometric feature. The integration of EGG-derived physiological measures with traditional acoustic analysis could substantially enhance the robustness of forensic voice identification systems.

IV. CONCLUSION

The present study demonstrates that the contact quotient (CQ), obtained through Electroglottography (EGG), remains a consistent and robust indicator of vocal fold contact behavior across different face-covering conditions—no mask, N-95 mask, tight cotton mask, and handkerchief. Statistical analysis using one-way ANOVA revealed no significant difference ($p > 0.05$) in CQ values across the four conditions, confirming that external face coverings do not alter vocal fold contact dynamics. However, a statistically significant difference ($p < 0.05$) was observed between male and female participants, with females exhibiting higher CQ values. These findings highlight the potential forensic utility of CQ as a disguise-resistant physiological marker for speaker identification, especially in cases where acoustic features are compromised or intentionally masked.

Despite its promising implications, the study is limited by a relatively small sample size and the inclusion of only sustained vowel phonations, which may not fully represent natural speech. Future research should expand to spontaneous and emotional speech contexts, explore other EGG parameters such as open quotient and speed quotient, and incorporate a wider demographic representation on broader age distribution. Similar to how other researchers examined the impact of stress on fundamental frequency (*f0*), we would also like to investigate how varied *f0* affect CQ characteristics. Integrating CQ data with acoustic and articulatory analyses could further enhance the development of robust multimodal forensic voice identification systems resistant to voice disguise attempts.

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