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A Feasibility Study of Monitoring Tongue to Palate Contacts for Instantaneous Bio-Feedback during Speech by Electroglottographic Equipment

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Abstract

This publication adapts a master's thesis by this author completed in 2023 at the University of Southern Mississippi. It describes a potentially beneficial outcome of unexpected electrical signals that may not be noticed during regular electroglottography (EGG) with the electrodes on the throat. It appears that there is a measurable electrical signal from the EGG equipment when electrodes are placed over the frontal cheek (belly of zygomatic muscle), and the tongue is elevated to contact the hard palate, or the tongue is lowered to break the contact. Therefore, this phenomenon is designated as unconventional electro-glottography (UEGG, Dr. Steven Cloud, private communication, July 17, 2022).

Two distinctive patterns of waveforms were obtained in this study that showed two visually different transitions: (1) when the tongue tip was raised from the oral floor to touch the hard palate, and (2) when the tongue tip detached from the hard palate to return to the oral floor. These transitional patterns were observed during silent maneuvers as well as during spoken utterances that involved touching and detaching between the hard palate and the tongue. The UEGG signal transitions and corresponding spectrographic transitions of spoken utterances appeared to be closely synchronized. Therefore, various applications of this basic concept, including therapeutic bio-feedback, may be possible for evaluating normal as well as abnormal lingual contacts with the hard palate during speech production through future investigations. Such applications of UEGG may be preferable to conventional electro-palatography (EPG) that requires intraoral electrodes.

Keywords: Lingual, Articulation, EGG, Laryngography, Unconventional, Exploratory

1. Introduction

An important class of errors in speech articulation is imprecise consonants [9]. Sometimes imprecise consonants may occur depending upon palato-lingual contact or separation. Some phonemes in English require palato-lingual contact such as /l/. Some other phonemes such as /r/ in English require palato-lingual separation [27]. Therefore, monitoring of the palato-lingual contact is important in SLP.

Electro-palatography

Palato-lingual contacts or separations are not usually visible or obvious from outside of the oral cavity [2]. One possible approach to monitoring palato-lingual contact is electro-palatography (EPG). EPG involves placement of electrodes on the hard palate inside the mouth to monitor palatolingual articulation during speech production [22]. EPG is useful to correct some sound production errors by using real-time bio-feedback [30]. EPG is sometimes used to supplement ultrasonography [1]. Biofeedback via EPG is feasible even when hearing impairment disrupts auditory feedback [8]. Use of EPG in dysphagia and craniofacial anomaly has also been reported [17].

Table 1. Potential of monitoring palato-lingual contact

Method	Size	Speed	Mechanism	Signal	Testable	Intraoral
UEGG	**Small**	**fast**	**impedance**	**strong**	**This study**	**No**
EPG	**Small**	**fast**	**conductivity**	**strong**	**Yes**	**Yes**
EEG	**Small**	**fast**	**neural**	**weak**	**not found**	**No**
EMG	**Small**	**fast**	**muscular**	**weak**	**not found**	**No**
USG	**Small**	**medium**	**ultrasonic**	**weak**	**not found**	**No**
VFS	**Large**	**medium**	**X-ray**	**weak**	**not found**	**No**
fMRI	**Large**	**medium**	**resonance**	**weak**	**not found**	**No**
MRI	**Large**	**slow**	**resonance**	**weak**	**not found**	**No**
PET	**Large**	**slow**	**radioactivity**	**weak**	**not found**	**No**
CAT	**Large**	**slow**	**X-ray**	**weak**	**not found**	**No**

Since EPG requires intra-oral electrodes, it may be regarded as an invasive procedure. The intra-oral electrodes for EPG require proper fitting inside the oral space. They are often custom-made for each individual. Such custom-made electrodes are often expensive, not readily available, and may involve considerable delay before actual data collection. Furthermore, there is some inconvenience of enduring the composite set of palatal electrodes for EPG inside the mouth and the associated wiring and connections to the recording system while talking. Therefore, EPG may not be considered to be a popular system in SLP clinics [27]. A literature review was conducted to explore the existence of alternative procedures. The potential of those procedures for this study are considered here and summarized in Table-1.

<u>Other Procedures</u>
There are some reports of magnetic resonance imaging to study articulation [11]. Such massive pieces of equipment are generally beyond the affordability scope of typical speech clinics. Furthermore, there is not much indication in the literature for these procedures to be capable of detecting tongue to palate contact with adequate precision to study speech articulation [27]. Endoscopic visualization of the oro-nasal passage, the larynx, and the pharynx are common in many speech clinics [27]. When inserted into the nasal passage, palato-lingual contact cannot be visualized. When inserted into the oral passage, proper articulation of the tongue is not possible. Therefore, these techniques were not considered any further for this study.

<u>Ultrasonography</u>
For visualizing internal organs, ultrasonography (USG) uses ultra high frequency vibrations that are far above the limit of human auditory sensation [18]. For such high frequency vibrations, the wavelength of propagation in biologic tissue is extremely small, and the direction of propagation is very linear. It is possible to project energy at ultrasonic frequencies nearly analogous to light beams and to create images of internal organs, including the tongue [28]. Movements of the tongue can be captured like a movie at around 30 frames per second [18].

Ultrasonic imaging may in principle display contour and motion and approximate profile of the tongue during articulation but unlike electricity, ultrasound gets reflected at the tissue to air boundary. USG normally is limited within a tissue boundary, such as the tongue alone, and contact with the hard palate may not be detected precisely by USG [24]. No report has been noted of precise detection or monitoring of tongue to palate contact [27]. Therefore, USG was not considered for this study.

<u>Electro-myography</u>
Electro-myography (EMG) monitors small voltages in the order of a few millivolts from electro-chemical impulses in muscle cells [3]. EMG procedures are known to be useful to study dysphagia [31] and lingual movements in dysarthria [20]. EMG

generally requires some abrasion of the skin before attaching the electrodes. Although EMG with electrodes attached to the outer skin surface are not particularly challenging to set up, the use of needle or hook electrodes may be a little painful or uncomfortable and impractical without adequate training and the skill of the clinician to insert electrodes into structures like the tongue, the throat, or the larynx [6]. Furthermore, this technique is not easily applicable to determine contacts between the tongue tip and the alveolar ridge. No rationale was found in the literature supporting any mechanism to monitor palato-lingual contact by electro-myography. Therefore, this option was not explored any further.

Electro-glottography

Electro-glottography (EGG) may be erroneously confused with EMG [2]. EGG involves the placement of two electrodes on the external anterior surface of the throat to monitor vocal abduction and adduction during phonation, shown in Figure-1. Its underlying principle is computation of the electrical impedance of any passive tissue to tissue contact. Whereas EMG depends on electro-chemical changes during muscular activity, EGG provides higher signal to noise ratios, and relatively less sensitivity to skin conditions compared to EMG [3]. Therefore, unlike EMG, EGG may not require any abrasion of the skin before placing the electrodes. EGG may be regarded as less invasive compared to EPG as the electrodes are not placed within the oral cavity.

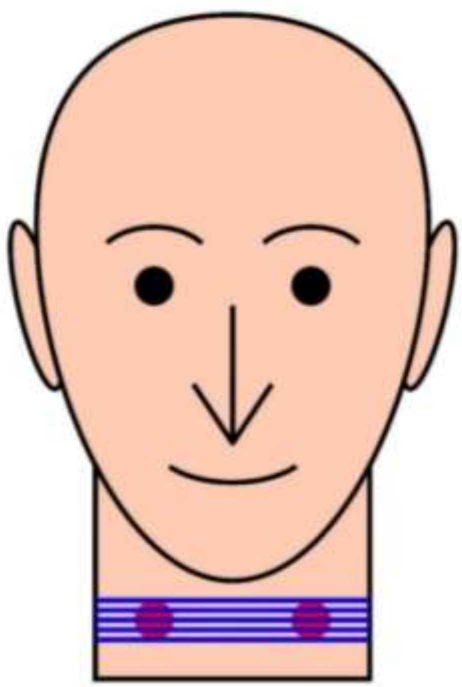

Fig 1. Two electrodes are usually placed on the anterior surface of the throat for EGG.

EGG has often been used by SLP clinicians to synchronize phonatory vibration of the vocal folds with stroboscopic illumination during videostroboscopy [5]. Hence, EGG is preferred to detect abnormalities in vocal fold vibration and it may be used to study intonation contours, and even to detect hormonal effects on voice [13]. Therefore, EGG has been used during treatments of voice disorders [15]. EGG is useful to supplement EMG during laryngeal evaluation [21]. Analysis of vibratory signals of EGG can be used to estimate various parameters for vocal tract models [23]. Conventional EGG equipment is used in numerous situations even with slant placement of electrodes, and so forth, maintaining its primary intent to assess laryngeal vibrations [12]. Therefore, many modern clinics for speech-language pathology (SLP) have conventional EGG equipment. That is primarily because EGG is relatively more affordable and practical for SLP clinics compared to larger pieces of equipment like MRI or X-ray.

The utility of EGG for palato-lingual contact has not been reported in the common literature [4, 7, 10, 14, 16]. That is understandable, since any electrical signals created from movements of non-laryngeal tissues are traditionally treated as artifactual or undesirable noise in the EGG output signal.

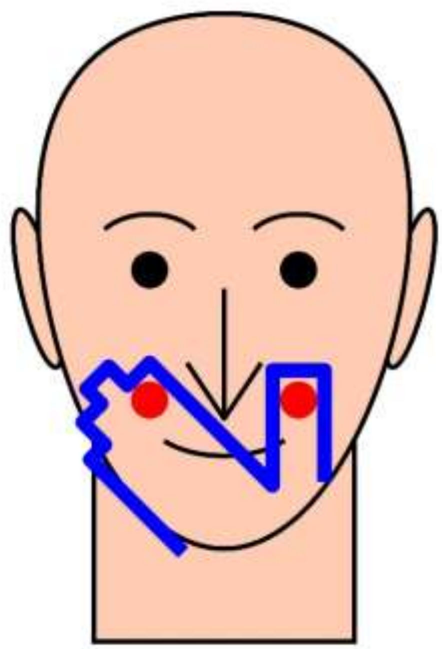

Fig 2. This study explored UEGG by placement of two EGG electrodes on the cheek.

<u>Unconventional EGG</u>

It may be hypothesized that the facial skin surface could be a convenient placement site for EGG electrodes where significant electrical signals may exist from articulatory tissue-to-tissue interactions such as lingual-palatal contacts. It is already known that the conventional EGG signal depends on the contact and disconnection between the vocal fold tissue [7]. Therefore, a similar signal is expected from the contact and disconnect between the tongue and the hard palate if the EGG electrodes are positioned nearby. Since the tongue is a major articulator during speech production [26], a correlation between the EGG signal and the speech signal may be confirmed by experimental verification. Therefore, this study hypothesized that if EGG electrodes are placed on the cheek, over the belly of the zygomatic muscle, it may be possible to extract useful signals correlated to articulation involving contacts between the tongue and the hard palate. This unconventional EGG (abbreviated as UEGG, Dr. Steven Cloud, private communication, July 17, 2022) is the focus of this study. The following three research questions were tested in this study:

1) Can UEGG indicate when the tongue contacts the hard palate in a human?
2) Can UEGG indicate when the tongue disconnects from the hard palate?
3) Is there any correlation between the UEGG signal and the speech signal?

2. Methods

Participant

This study was approved by the Institutional Review Board of the University of Southern Mississippi. One male individual voluntarily provided informed consent to participate in this study, To protect the identity of this individual, only minimal details are provided in Table-2. The participant is a healthy male of around 70 years of age, Asian race, socio-economic status within the middle class, postgraduate education, academic profession, no habits of smoking or drinking, and no remarkable features in anatomy or physiology.

Table 2. Basic characteristics of the participant in this study

Measure	Value
Age	Around 70 years*
Gender	Male
Race	Asian*
Proficiency in English	Fluent
Socio-economic status	Middle class
Educational Level	Postgraduate*
Profession	Academic*
Smoking	No
Drinking	No
Anatomy	Unremarkable
Physiology	Unremarkable
Health	Unremarkable

* More precise details are not available to protect his identity.

Protocol

The participant was seated comfortably in a recliner with armrests. As shown in Figure-2, two EGG electrodes were placed symmetrically on the cheeks (over the belly of the zygomatic muscle). The participant was instructed to gently keep the electrodes supported by slight finger pressure while the elbows were resting on the armrests of the chair. The participant was encouraged to remain in a relaxed position. Slight readjustments of the posture helped to settle the participant into a comfortable position.

The data collection was initiated by asking the participant to follow two modes: (1) Slowly, clearly, and silently repeat tongue to palate contact and detachment several times; (2) Naturally and clearly repeat the utterance "ala" like a contraction of the utterance, "ah large." This activity required touching the alveolar ridge of the palate with the tongue shown in Figure-3. A few practice trials and demonstrations were conducted before actual data collection to ensure the participant could easily understand and follow the experimental protocol. Each trial required a few seconds of recording the UEGG signal and the acoustic signal of the utterance. Several seconds of rest were included before each recording. The participant was provided with a visual signal approximately one second before the beginning of the recording. This signal helped the participant to avoid any other irrelevant activity during the recording, such as swallowing saliva or throat clearing. If such activities could not be avoided during a trial recording and the recording showed the data is corrupted and then that recording was rejected. The participant was encouraged to pause at any time to avoid discomfort or fatigue. This entire session required less than one hour.

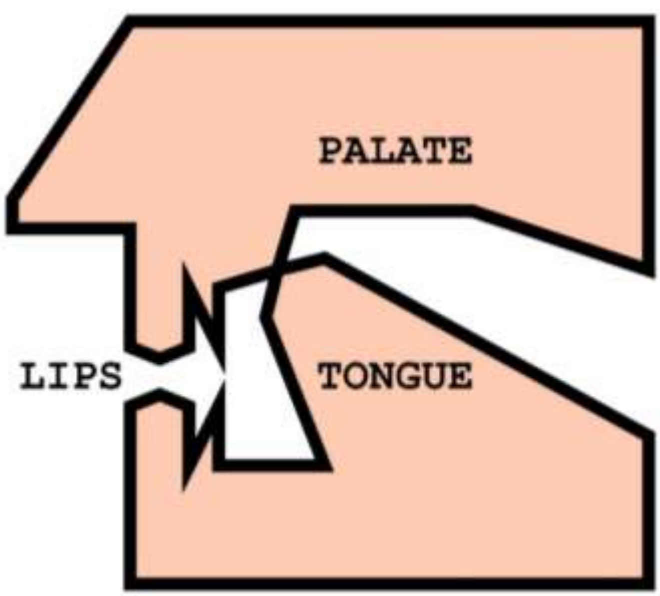

Fig 3. A sagittal section to show a typical tongue to palate contact for /l/ sound.

Electrode Location

The electrode location was selected to be on the cheeks, over the belly of the zygomatic muscles, to receive the strongest possible signal from the palato-lingual contact. This location is approximately central between the lips, eyes, and the temporomandibular joint (TMJ), to ensure the least interference from other unrelated muscular activities .

Target Utterance

The target utterance was "ala" like a contraction of the utterance "ah large." This utterance was selected to provide the strongest possible signal to the electrodes as it required both contact and detachment between the tongue and the hard palate. The utterance "ala" contained the /l/ phoneme as it is the voiced alveolar lateral approximant [25]. The utterance, "ala" contained the initial and final /a/ sounds as in "hot" to produce the maximally low back unrounded cardinal vowel [25]. Although many other utterances are possible, other utterances were not selected to avoid various problems during this preliminary investigation. For example, the utterance "ama" may not present a strong signal due to a dehydrated labial surface. The utterance "aga" may not present a strong signal due to the remote location of the contact between the posterior part of the tongue and the velum with respect to the electrodes over the belly of the zygomatic muscle. The utterance "ata" may not present a detectable signal due to the short duration of the plosive. Some of these potential issues are presented in Table-3.

Table 3. Comparison between several target utterances

Utter	Place	Vowel	Contact	Duration	Lips	Distance	OK
ALA	**Alveolar**	**Ok**	**Ok**	**Ok**	**Ok**	**Ok**	**Yes**
ILI	**Alveolar**	**Too High**					**No**
AMA	**Labial**		**Too Dry**				**No**
ADA	**Alveolar**			**Too Short**			**No**
OLO	**Alveolar**				**Too Active**		**No**
AGA	**Velar**					**Too Far**	**No**

Instrument

For UEGG data collection, this study utilized a currently available model EG2-PCX2 Electro-glottograph, manufactured by Glottal Enterprises Inc (http://www.glottal.com). As shown in Figure-1, EGG applications commonly involve symmetrical placements of two electrodes on the throat to monitor vocal fold abduction and adduction; whereas the same two EGG electrodes were attached symmetrically on the cheeks in this UEGG study, shown in Figure-3. The instrument was connected to a microphone to receive the acoustic output of the utterance simultaneously. The microphone was held near the mouth of the participant. The instrument was connected to a computer via a USB interface. The USB interface sent the UEGG signal and the microphone signal to the computer simultaneously like the left and right channels of a stereo input at 44,100 samples per second. MATLAB (https://www.mathworks.com/) software was used to capture, store, analyze, and display these signals.

3. RESULTS

Figure 4 shows one example of the UEGG signal when the participant silently elevated the tongue to contact the hard palate as if starting a sustained utterance of /l/. Similarly, Figure 5 shows one example of the UEGG signal when the participant silently lowered the tongue, detaching from the hard palate, as if finishing a sustained utterance of /l/. The shapes of the UEGG signals were consistently similar when repeated. In each of these recordings, there was a baseline at the beginning, followed by a sharp spike, and then an oscillatory return to the baseline. The initial baseline in Figure 4 corresponded to the tongue resting near the floor of the mouth. During this phase, the tongue was not in contact with the palate, and the impedance between the electrodes was high. Near the midpoint of the display in Figure 4, the tongue rose to touch the hard palate. Consequently, the impedance between the electrodes dropped. This was reflected in the sharp drop from the baseline in the UEGG waveform.

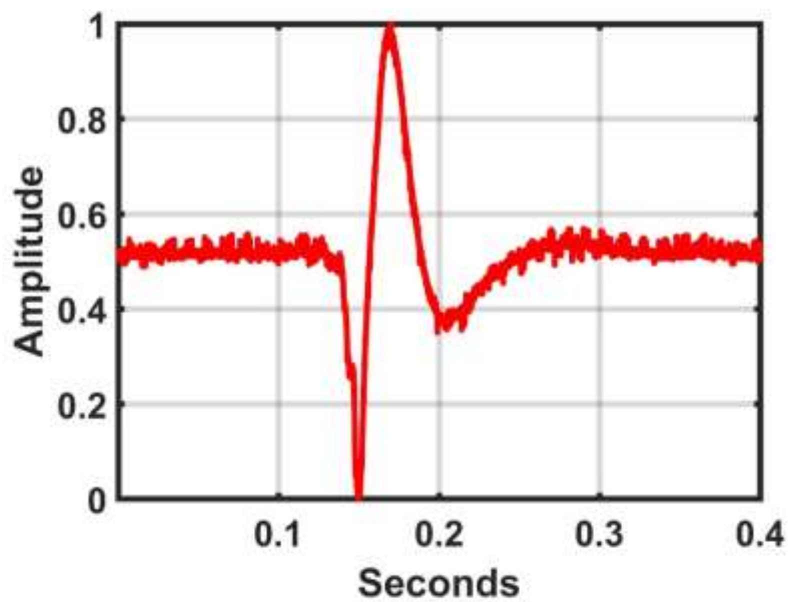

Fig 4. An example of the UEGG signal when the tongue silently contacts the hard palate.

Unlike Figure 4, the initial baseline in Figure 5 corresponded to the tongue contacting the hard palate. During this phase, the impedance between the electrodes was low. Near the midpoint of the display in Figure 5, the tongue detached from the hard palate. Consequently, the impedance between the electrodes increased. This was reflected in the sharp rise from the baseline in the UEGG waveform. In the final phase of the display, in both Figures 4 and 5, the waveform returned to the baseline, presenting an oscillatory decay. This oscillatory decay was anticipated due to the blocked low frequency response of the electronic equipment [19]. According to these results, the UEGG signal can provide a valid visual indication when the tongue touches the hard palate or detaches from the hard palate. The signal to noise ratio (SNR) was computed from the ratio between the standard deviation of the waveform near the baseline and the standard deviation of the waveform near the spike. This SNR ranged between 30-40 dB, confirming that UEGG can provide a reliable signal that is visually obvious.

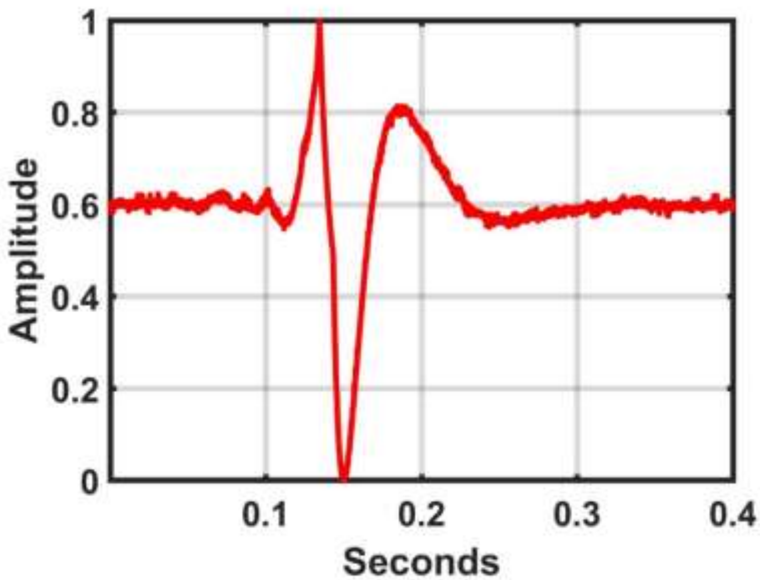

Fig 5. Typical UEGG signal when the tongue silently detaches from the hard palate.

Figure 6 shows an example of the UEGG signal and the spectrogram of the acoustic output when the participant said, "ala" like a contraction of uttering "ah large." The shapes of the UEGG signals and the spectrograms were consistently similar when repeated. The utterance of "ala" required touching the hard palate with the tongue, followed by the detachment of the tongue from the hard palate. When starting the /l/ phoneme, the touching of the hard palate by the tongue was reflected in the UEGG signal, dropping from the baseline. Then the UEGG signal returned to the baseline by oscillatory decay due to low frequency filtering characteristics in the electronic hardware. When finishing the /l/ phoneme, the detachment of the tongue from the hard palate was reflected in the UEGG signal, rising from the baseline. Then the UEGG signal returned to the baseline by oscillatory decay due to the low frequency filtering characteristic in the electronic hardware. If the electronic hardware was not intended to block low frequencies in the UEGG signal, excluding DC, then the displayed waveform would have appeared like a square wave as the tongue was raised and lowered to utter "ala" [19]. The rise and fall of the tongue were reflected by visually obvious changes in the spectrogram simultaneously.

The instant marked a1 in Figure 6 corresponded to the 50% level of the rising acoustic transition of the spectrogram, at the beginning of the /l/ in the utterance "ALA." The instant marked a2 in this graph corresponded to the 50% level of the falling acoustic transition of the spectrogram, at the finishing of the /l/ in the utterance "ALA." The instant marked u1 in this graph corresponded to the negative peak of the UEGG waveform, indicating when the tongue touched the hard palate. The instant marked u2 in this graph corresponded to the positive peak of the UEGG waveform when the tongue detached from the hard palate.

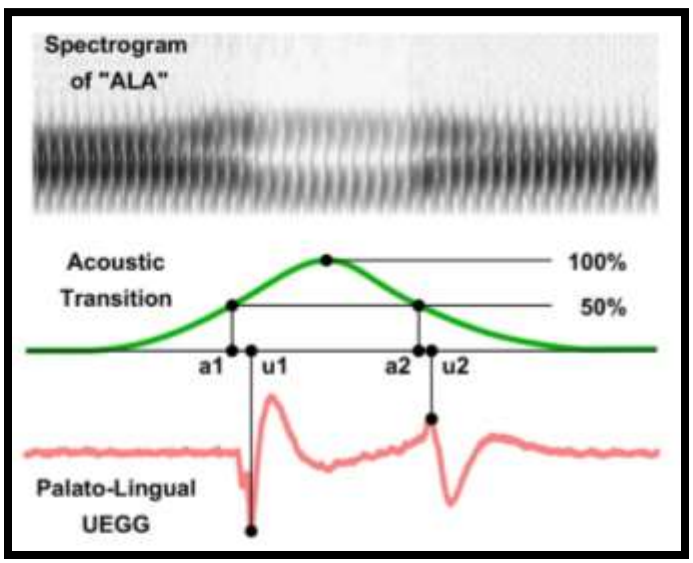

Fig 6. Typical UEGG signal and the spectrogram when uttering "ala" like "ah large."

The correlation coefficient between the instants a1 and u1 (see Figure 6) ranged between 0.90 to 0.98. This range of correlation is considered to be high [29]. According to this range of high correlation, the UEGG signal can provide a valid indication when the tongue touches the hard palate near the beginning of the /l/ sound. Similar results were observed for the instants a2 and u2 (see Figure 6) when the tongue detaches from the hard palate near the completion of the /l/ sound.

The standard deviation of the interval between a1 and u1 (see Figure 6) ranged between 5 to 13 milliseconds. This is a measure of jitter. Since this is a relatively small jitter compared to typical rates of syllables, this result confirmed that UEGG is a reliable predictor of the instant when the tongue touches the hard palate near the beginning of the /l/ sound. Similar results were observed for the instants a2 and u2 (see Figure 6) when the tongue detaches from the hard palate near the completion of the /l/ sound. These results are summarized in Table-4.

4. Discussion

According to our preliminary results, UEGG appears to be a reliable and valid procedure to monitor palato-lingual contact in humans. UEGG may be preferable to conventional electro-palatography (EPG) that requires intraoral electrodes. Further studies are needed to generalize our findings to various populations with and without any disorders. Further studies are needed to evaluate the efficacy of this procedure for bio-feedback to assist treatments of articulatory errors in certain individuals.

Table 4. Some psychometric properties of UEGG

Measure	Value	Remarks
Reliability (Jitter)	5-13 milliseconds	Acoustic to UEGG
Reliability (SNR)	30-40 dB	Visually identifiable
Validity (Visual)	Qualitative evidence	Tongue motion vs UEGG
Validity (UEGG vs Sound)	correlation 0.90-0.98	Tongue rise vs spectrum
Validity (UEGG vs Sound)	correlation 0.90-0.98	Tongue drop vs spectrum

This preliminary study adopted a single subject design, which is a common practice in exploratory research. This single subject design minimized demands of overhead, time, and associated expenses. The rationales behind the single subject design were as follows. A proof of the concept in humans was the goal. Finding individual differences was not a goal. Normative data may be produced through one or more future projects. Generalizations may be studied by one or more future projects. The efficacy of UEGG as a bio-feedback tool may also be included in one or more future projects. Future replication studies should add more participants to determine and interpret any patterns of systematic variation among the participants, the effects of age, gender, education, socio-economic status, race, ethnicity, dialect, native language, health status, and so forth.

The variability of lingual pressure on the hard palate affecting the UEGG waveform may require detailed exploration. Alternative arrangements should be explored to support the placement of electrodes, including the use of temporary adhesives or rubber straps to support the electrodes. Such supports might be useful for certain individuals. It would also be helpful to identify any discomfort to some individuals, depending on conditions and sensitivities of the facial skin. Future studies should focus on other places of valving or tissue to tissue contacts and detachments in the vocal tract. Some examples include stop constants involving labial, alveolar, palatal, velar, or glottal articulations, while uttering "pa, ta, ka, ha," etc. Any relative advantages or disadvantages of positioning the electrodes should be explored. The electrodes may be placed on one side of the face, under the chin, on the muscles of mastication, and so forth to detect the existence of useful and unexplored signals. Pharyngeal activities during swallowing may also be studied.

The oscillatory decay of the UEGG waveform due to its inherent low frequency cutoff helped determine the point of transition very precisely [19]. The position of the peaks of the UEGG pulse provided clearly identifiable instants of contact and detachment. Any modifications of the electronic hardware to eliminate or adjust low frequency cutoff may involve active efforts and collaborative support from the manufacturers.

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