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THE EFFECTS OF VOCAL EFFORT ON BILABIAL CONTACT PRESSURE AND INTRAORAL AIR PRESSURE, AND THEIR DURATIONS

by

Danielle Nauman

A thesis submitted in partial fulfillment of the requirements for graduation with Honors in the Speech Pathology and Audiology

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Thesis Mentor

Spring 2018

All requirements for graduation with Honors in the Speech Pathology and Audiology have been completed.

Honors Program
Speech Pathology and Audiology Honors Advisor

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The Effects of Vocal Effort on

Bilabial Contact Pressure and Intraoral Air Pressure, and Their Durations

Danielle Nauman

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Abstract

Background: Following surgical removal of the larynx, patients choose an alternate speech-production mechanism. One substitute sound source option is an electrolarynx. However, removal of the larynx alters speech production. The lung-driven, pressurized airstream used to articulate speech is not available. Increasing global effort and exaggerating speech movements have been suggested, but the relationship between an individual's "effort level" and aerodynamic and kinematic correlates of exaggerated speech movements is not understood. Purpose: This study compared effects of varying speaking effort when using laryngeal speech on speech aerodynamics and kinematics to the same parameters exhibited during electrolaryngeal speech. Methods: Participants produced three bilabial consonants using conversational, clear, and electrolarynx speech modes. Bilabial contact pressure (BCP) peaks, intraoral air pressure (IOAP) peaks, and their durations were measured. Results: BCPs and BCP durations increased from conversational to clear to electrolaryngeal speech, for all phonemes studied. IOAP did not differ significantly as a function of speech mode, while IOAP duration was significantly lengthened during electrolarynx speech. Conclusions: Speech produced with an electrolarynx is different from laryngeal speech and appears associated with greater effort than conversational or clear speech. These results can be generalized to clinical instruction for electrolaryngeal speakers to produce more intelligible speech.

Keywords: Post-laryngectomy, vocal effort, bilabial contact pressure, intraoral air pressure, electrolarynx

Speech production is a complex sequence of motor acts that coordinates the respiratory, laryngeal, and articulatory systems. Through a wide array of articulator manipulations, various speech sounds (phonemes) are used to achieve speech production. Phonemes are often classified using three parameters: place, voicing, and manner. Manner is particularly important in regard to airflow. Vowels, on one end of the spectrum, are produced in a relatively open vocal tract, while stops are produced by creating a complete obstruction in the vocal tract, building up pressure, and then releasing. Fricatives and affricates are categorized between vowels and stops, with a partial constriction and resulting turbulence.

Place is another parameter that affects production. Sounds can range from the bilabial position, anterior in the vocal tract, to a more posterior position in the glottis. Articulators contribute to sounds based on both place and manner. While all articulators may be utilized in a given phrase, there are two especially important articulators when analyzing production of bilabial stop phonemes, like /p/ and /b/: the upper and lower lips. Bilabial stop consonants are produced by compressing the upper and lower lips, obstructing the vocal tract, and building up pressure, and then releasing as a burst. During the pressure buildup phase, stop production requires sufficient labial contact pressures. However, less than 20% of available interlabial contact pressures are utilized during connected speech (Hinton & Arokiasamy, 1997).

The laryngeal system is another important piece for typical speech production. Vibration of the vocal folds creates a sound source, that is then resonated through the vocal tract for speech sound production. However, in some cases, a person must have a total laryngectomy, or removal of the larynx. The most common reason for a laryngectomy is laryngeal cancer. In the United States this accounts for about 0.8% of new cancer diagnoses each year. For speech production, once this procedure is completed, there is no longer a sound source. In addition, there is a disconnect of the respiratory system and a loss of its function to facilitate speech production.

Traditionally, speech-language pathologists would instruct post-laryngectomized patients to use esophageal speech. This method requires taking air down the esophagus and letting it back out to vibrate the upper esophageal sphincter. However, in recent years, there have been easier methods for speakers to employ. Two more common approaches for post-laryngectomy speech are tracheoesophageal (TE) speech and electro-laryngeal (EL) speech. TE speech involves creating a shunt between the esophagus and trachea. A one-way valved prosthesis is inserted and serves two key functions: maintaining the opening and allowing air to pass from the lungs through the hole and into the esophagus. With the removal of the larynx, a disconnect of the respiratory system occurs. Creating a stoma reconnects the airway to allow for the use of a pressurized airstream for speech. As the air passes up into the esophagus, the upper esophageal sphincter vibrates as the sound source. The sound then continues to move up through the vocal tract to be modified by the oral cavity articulators.

Alternatively, an electrolarynx is an electro-mechanical instrument that serves as the sound source. With the push of a button, a small disk on the end of the electrolarynx vibrates and transmits energy into the neck tissue, which is passed up to the oral cavity to be shaped by articulators into speech sounds. Since electro-laryngeal communication provides an outside sound source, the respiratory system is still intact. A person can still employ respiratory drive (i.e., air still moves up the system through the trachea). However, there is no longer a requirement for this pressurized airstream from the lungs during speech production because of the external sound source. Consequently, speech produced with an electrolarynx is not typically produced with a buildup of intraoral air pressure.

Respiratory drive is important for the production of clear and intelligible speech. Post-laryngectomy speakers have been observed to alter the way that they articulate speech to be more intelligible. For TE speakers, strategies have included increased intraoral air pressure for stops and fricatives, prolonged consonants and vowels, and altered velopharyngeal activity (Searl, 2007). Individuals may also use “clear speech” strategies, which includes increased phoneme duration, increased intensity of stop bursts, and slower speaking rate (Searl & Evitts, 2013). The overall goal of implementing these strategies is to increase acoustic salience, for greater intelligibility. Huber and Chandrasekaran (2006) also suggested that speakers slowed their overall rate to increase salience.

Changing to clear speech strategies is the result of manipulations made to the mechanical parameters of speech. Searl & Evitts (2013) observed changes in intraoral air pressure and bilabial contact pressure when producing lingua-alveolar consonants. TE speakers in Searl & Evitts’ (2013) study generated greater bilabial contact pressures when compared to nonlaryngectomized speakers. He also noted that TE speakers generated higher intraoral air pressures (Searl, 2007). The relationship between these two events is questionable. That is, some hypothesize the reason for greater bilabial contact pressures is to contain the higher intraoral air pressures produced during TE speech (Searl, 2007; Hinton & Arokiasamy, 1997; Goozée, Murdoch, & Theodoros, 2002). If true, then EL speech would show no increase in bilabial contact pressures because of a lack of a pressurized airstream from the lungs.

Another possible explanation for increased bilabial contact pressure is because of an increase of overall articulatory effort and precision, known as the H & H Theory of Speech Production (Searl, 2013). The pressurized airstream from the respiratory system in this explanation would not matter because the greater pressures are a result of a more global increase in effort. This may reflect an exaggeration of articulatory movements to achieve an increased level of intelligibility. In 2014, Garnier, Bouhake, and Jeannin, described that lip compression forces increased with an overall global level of vocal effort, thus supporting this explanation for increased bilabial contact pressures.

Previous research suggests that the relationship between effort level, oral pressure, and bilabial contact pressures is not well understood. The effect of altered speaking effort on bilabial contact pressures and intraoral air pressures need further examination. Investigating bilabial contact pressures and intraoral air pressures during clear and conversational speech, when compared to speakers using electrolarynx will give us a better understanding of the relationship between these physiologic parameters. More specifically, the aims of this study are to look at the effect of speaking mode on bilabial contact pressures and intraoral air pressure, and whether bilabial contact pressures observed during electrolarynx speech differ from those during laryngeal speech.

Method

Participants

Participants were 11 female adults between the ages of 18 and 23 (*M*= 20 years). All participants spoke Standard American English as their primary language and reported no history of speech, language, or hearing difficulties. Participants were recruited from the department of communication sciences and disorders, which primarily consists of females. To maintain a homogenous group, all participants were female.

Stimuli

The experimental consonants were the bilabial phones produced in Standard American English (/p, b, m/). All participants produced the stimuli in VCV syllable formats (/apa/, /aba/, and /ama/). For a better understanding of the relation between articulatory adjustments and speech mode, these sounds were chosen because of their high degree of oral cavity obstruction during their production (with the exception of the nasal /m/). All stimuli were produced in a vowel environment to avoid the impact of other consonants on pressure values.

Instrumentation

BCP was measured using a Measurement Specialties Bilabial Compression Transducer (EPL-D12-10P). The sensing element on the transducer was 1/8 inch in diameter. It was located in the place of maximal bilabial contact for each participant. The transducer was mounted using a double-sided adhesive to a small piece of plastic that was connected to a base, maintaining its level at the mouth. It was also enclosed in a small piece of flexible plastic. The transducer was placed facing down, so contact would be made with the lower lip, to minimize the possibility of damage from contact with the teeth. The output of the transducer was routed to one channel of a multichannel digital biocommunication electronic differential amplifier.

To measure IOAP, a small (interdiameter = 1.77mm, length = 76mm) intramedic polyethylene tube was attached to a Honeywell Microswitch Pressure (143PC03D) transducer. Participants held the tube of the transducer in the right corner of their mouth. The output of the IOAP transducer was routed to one channel of a multichannel digital biocommunication electronic differential amplifier. Both pressure transducers were recorded on a lab PC computer.

Recording Procedures

Participants were only required to visit once for this study. The session consisted of two segments. The first was aligning the instrument to the participant. Finding the point of maximum contact was critical for an accurate representation of the bilabial contact pressures. The transducer was adjusted anteriorly and posteriorly while the participant repeated productions of /apa/ syllables. The position that yielded maximum pressure was determined as the point of maximum contact. Placement holders were used on the forehead and just above the upper lip to help maintain this position. Participants were also directed to hold the intraoral air pressure transducer in their right hand. They inserted the tube in the right corner of their mouth, just behind their teeth, above the tongue. The tube remained perpendicular to the direction of the airflow. Finally, a lapel microphone was attached to their clothing and recorded the session.

Recording was initiated in the second segment. All participants experienced the same order of speech mode: conversational, clear, and then electrolarynx. However, the stimuli were presented in random order. Each participant produced all three phones in the conversational mode before moving on to the clear mode, and then to the electrolarynx mode.

For conversational speech, participants were instructed to speak as though they would in everyday conversation. For clear speech, participants were instructed to speak as if they were speaking to someone who had a hearing loss or was maybe not understanding them. For the EL mode, participants received a mini lesson on how to use an electrolarynx before recording. They were instructed that neither air nor sound should escape from their oral cavity as they speak with it. They were given a couple minutes to test how to use it. The EL was held in place for them, so that they did not worry about its placement. Participants were given no instruction on strategy related to speaking mode (clarity, higher intelligibility, etc.).

Participants were instructed to produce the stimuli one at a time with a short pause in between each production, until they were told to stop. Participants were asked to stop after they had produced each stimulus 12 times. Each participant produced 108 phrases (3 phones x 12 repetitions x 3 speech modes), for a total of 1,188 phrases across 11 participants. Before each round, participants were reminded of the speech mode and phoneme.

Measures

Bilabial contact pressure and intraoral air pressure.

WinDaq Data Acquisition Software (Dataq Instruments, Akron, OH) was used during the data collection sessions. WinDaq Waveform Browser Software (Dataq Instruments, Akron, OH) enabled display of the pressure waveforms, acoustic signals, playback of the audio signal, and placement of the cursor to measure peak pressures. A cursor was placed at the minimum and maximum (Fig.1) BCP and IOAP position for each of the stimuli. Both were measured in volts and converted to centimeters of water pressure (cm/H2O), to the nearest hundredth. The consonants were easy to identify because of VCV syllable environment. This syllable shape allowed for a relatively open vocal tract (low air pressure and no contact pressure) before and after the production of the bilabial consonant. Both visualization of the waveform and audio playback confirmed the location of the peak pressures. Mean BCP and IOAP were calculated per phoneme in each speaking mode for each speaker. Duration of each waveform was also calculated using cursor placement at the minimum point and its voltage equivalent on the back side of that wave (Fig.1) Duration was measured in seconds, to the nearest tenth.

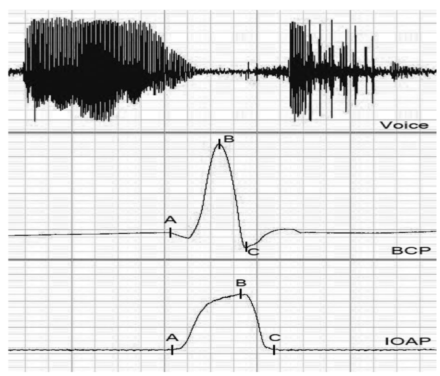

Figure 1. Sample waveform. Peak values were measured from point a to b and duration was measured from point a to c.

Results

For each sound, a one-way ANOVA was performed across speech modes for each measurement variable, separately (Table 1). For those ANOVAs which were at least significant at the 0.05 level, follow up Tukey's tests were applied to identify which pairs were significantly different (Table 2).

Bilabial Contact Pressure

Table 1 provides BCP group means and standard deviations for each phoneme and speaking mode. For /p/ and /b/, the EL speech mode was associated with significantly higher bilabial contact pressure than observed during conversational and clear speech modes (conv. $p < 0.01$) (clear $p < 0.05$). While the results for /m/ only approached significance ($p = .057$), Figure 2 shows BCP during EL speech was greater than conversational and clear speech modes, matching the patterns of /p/ and /b/. Even though no post hoc follow up was completed for /m/, the EL BCP values were twice as high as conversational speech. For all three phonemes, the EL speech mode was associated with noticeably more variability than during conversational and clear speech.

Bilabial Contact Pressure Duration

For /p/, the EL speech mode was associated with significantly higher bilabial contact pressure durations than observed during conversational and clear speech modes (conv. $p < 0.001$, clear $p < 0.01$). The EL speech mode for /b/ was associated with significantly higher bilabial contact pressure durations than observed during the conversational speech mode ($p = <0.05$). Although no significance was observed, /m/ BCP durations followed the same increasing pattern from conversational to clear to EL speech.

Intraoral Air Pressure

Table 1 provides IOAP group means and standard deviations for each phoneme and speaking mode. IOAP increased from conversational to clear speech modes, followed by a decrease in EL speech mode for all phonemes. Group means for /m/ showed slight pressure values, however, they are inconsequential. For /p/ and /b/, the EL speech mode was associated with noticeably more variability than during conversational and clear speech.

Intraoral Air Pressure Duration

For all three phonemes, the EL speech mode was associated with significantly higher bilabial contact pressure durations than observed during the conversational speech mode (/p/ $p < 0.05$; /b/ $p < 0.01$; /m/ $p < 0.05$). As seen in Figure 3, IOAP duration increased from conversational to clear to EL speech.

	Speech Mode (cm/H_2O)					
Phoneme	**Conversational**		**Clear**		**Electrolarynx**	
	BCP	IOAP	BCP	IOAP	BCP	IOAP
/p/	64.864 (25.788)	4.874 (1.430)	98.557 (42.757)	5.662 (2.100)	172.057 (111.349)	4.214 (3.588)
/b/	67.154 (33.637)	3.100 (1.601)	95.908 (41.718)	4.738 (2.352)	166.690 (90.569)	3.936 (3.803)
/m/	76.358 (34.112)	0.207 (0.145)	138.198 (78.382)	0.357 (0.277)	159.683 (101.514)	0.308 (0.373)

Note. SDs appear in parentheses.

Table 1. Means and standard deviations (cm H_2O) of peak bilateral contact pressure (BCP) and peak intraoral air pressure (IOAP) as a function of phoneme and speech mode.

Phoneme	**F value (*p* value)**	**Interaction** (*p* values) Con-Cl	Cl-EL	Con-EL
/p/				
BCP	8.097 (0.002) **	0.403	0.035*	0.001**
BCP Dur	14.01 (<0.001) ***	0.317	0.003**	<0.001***
IOAP	0.783 (0.467)			
IOAP Dur	4.655 (0.018) *	0.066	0.860	0.021*
/b/				
BCP	6.919 (0.004) **	0.595	0.038*	0.004**
BCP Dur	4.463 (0.021) *	0.414	0.222	0.016*
IOAP	0.895 (0.420)			
IOAP Dur	7.996 (0.002) **	0.125	0.142	0.001**
/m/				
BCP	3.188 (0.057)			
BCP Dur	2.706 (0.085)			
IOAP	0.744 (0.485)			
IOAP Dur	4.537 (0.020) *	0.064	0.904	0.025*

Note. Levels of significance are denoted by the following: *-0.05, **-0.01, ***-0.001.

Table 2. Results of statistical analyses of effect of speech mode on peak bilabial contact pressure (BCP), bilabial contact pressure duration (BCP Dur), peak intraoral air pressure (IOAP) and intraoral air pressure duration (IOAP Dur).

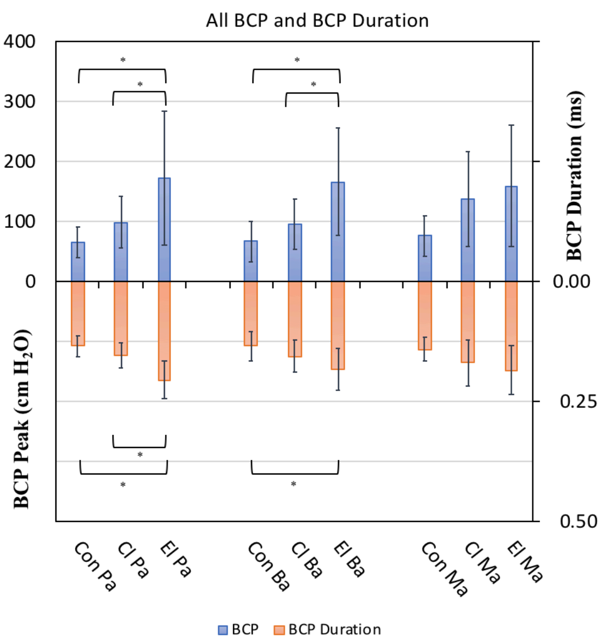

Figure 2. Means and standard deviations (cm H_2O) of peak bilateral contact pressure (BCP) and bilabial contact pressure duration as a function of phoneme and speech mode. Note. Duration values are multiplied by a factor of -1 for visual purposes.

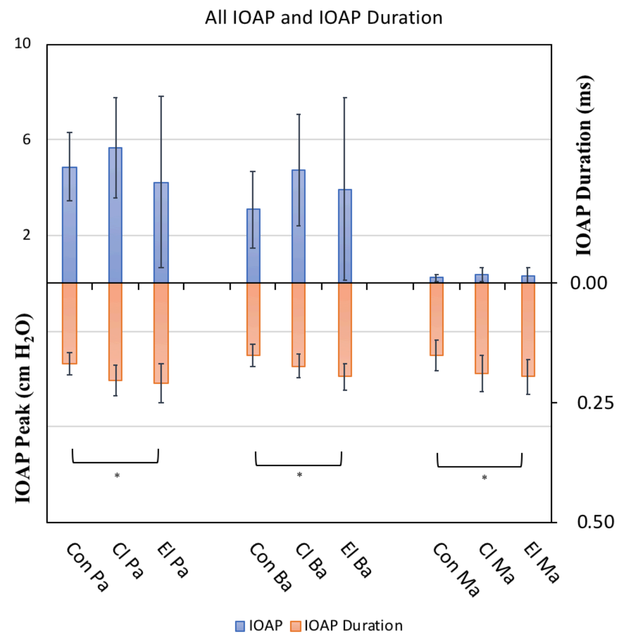

Figure 3. Means and standard deviations (cm H_2O) of peak intraoral air pressure (IOAP) and intraoral air pressure duration as a function of phoneme and speech mode. Note. Duration values are multiplied by a factor of -1 for visual purposes.

Discussion

In this study, changes in BCP, IOAP, and their durations for three bilabial stop consonants produced in conversational, clear, and EL speech modes were investigated. Consistent with Searl (2013), peak levels of BCP and IOAP tended to increase with clear speech. Clear speech was also characterized by longer durations of bilabial contact pressure and intraoral air pressure. Speech produced with an electrolarynx was associated with higher peak BCP and lower peak IOAP values than observed during laryngeal (conversational or clear) speech.

The pattern observed in comparing conversational to clear to EL speech across all phonemes, indicated that speakers vary lip compression force for different speaking modes. The BCP values for /p/ and /b/ in EL speech were significantly larger than conversational and clear speech. Even with no coaching, participants modified BCP for each speech mode. Although the increase from conversational to clear speech was not statistically significant, rising BCP values suggested that participants increased lip force to meet the perceived demands of clear speech. This effect may be significant with a larger sample size. BCP increases were greater for some phonemes than others (Searl, 2013), however, all phonemes showed the same increasing pattern for BCP. There are two theories that explain the relationship between BCP and IOAP. The H & H theory of speech production predicts greater articulatory effort is needed in order to produce clearer speech (Searl, 2013). Stop consonants are also associated with higher IOAP, which may require a tighter bilabial seal in order to contain the increased amount of oral pressure (Searl, 2007).

A similar pattern as a function of speech mode was observed for all BCP durations. EL speech for /p/ and /b/ was associated with BCP durations that were significantly longer than conversational speech. Additionally, BCP duration for /p/ in EL speech was significantly longer than for the clear speech mode. Searl (2013) also found that clear speech is characterized by a longer duration of phonemes and a slower speaking rate. While speech rate was not measured in this study, participants compressed their lips for longer in clear and EL speech than for conversational speech. Increasing duration (decreasing rate) is one strategy recommended to speakers to improve speech clarity. Over articulating during these speech modes to produce more intelligible speech could explain longer duration values.

While peak IOAP values were not significantly different across speech modes, the increase from conversational to clear speech and the decrease from clear to EL speech was expected. EL speech is associated with little to no IOAP. Participants were trained to valve at the level of the larynx in order to prevent leaking air into the oral cavity to mimic alaryngeal speech. While possible that speakers were allowing airflow into the oral cavity to generate oral pressures, it was evident that some/most participants generated pressure by reducing volume in the oral cavity, resulting in increased and measurable pressure values for EL speech. The waveforms of these productions look fundamentally different (Fig. 4). The conversational /p/ waveform had a longer onset before reaching its peak pressure, and quickly decreased after. However, the /p/ produced with closure at the vocal folds (i.e., no respiratory drive) were associated with a steeper incline and decline around the peak pressure. The difference in these waveforms is that the second is generated with pressure coming from changes in volume in the oral cavity, rather than lung-driven air pressure typically associated with conversational speech produced by a laryngeal speaker. Peak IOAP values for /m/ were minimal, as expected, due to the directional airflow change that occurs for nasal phoneme production. That is, /m/ is produced through an open nasal cavity and would not be expected to be associated with significant levels of intraoral air pressure. The lack of significance in these values may be due to the large amount of variability and may change with a larger sample size.

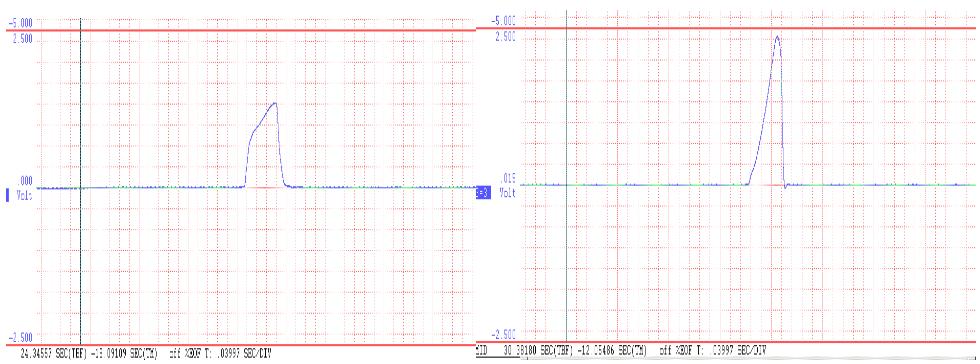

Figure 4. IOAP waveform differences between Conversational /p/ (left) and /p/ with closure at the vocal folds (right).

IOAP durations increased from conversational to clear to EL speech. All three phonemes /p, b, m/ were associated with significantly longer IOAP durations in EL speech than conversational speech. While EL IOAP durations were longer, it is important to note that IOAPs for EL speech are fundamentally different because they are generated in the oral cavity rather than in the lungs.

Because EL speech is produced without lung-generated pressure, participants may have generated this additional pressure to enhance intelligibility.

The higher levels of BCP and IOAP observed in clear speech compared to conversational speech would suggest an increase in effort involving both respiratory effort and closure force. Patterns observed in BCP and IOAP values may suggest a connection between the two, but causality cannot be concluded from this study. However, for /p/ and /b/, an increase in EL BCP was not mediated by increased levels of pressure in the oral cavity because insignificant amounts of IOAP were generated for EL speech. For /m/, even with the absence of IOAP, EL BCP still increased, suggesting participants were over articulating, rather than compensating for increased IOAP, a theory proposed by Searl (2007). Searl (2013), concluded that /n/ uses less reliance on the air pressure phenomenon to generate the principle acoustic features. While acoustic features were not measured in this study, clearly intelligible productions of /m/ were produced. The increased levels of bilabial contact pressure may be a reflection of the speakers attempt to exaggerate articulatory movements to optimize intelligibility.

The clinical implications of these findings may include incorporating the theory of adaptive variability, as discussed by Searl (2007). That is, individuals modify speech behaviors to the situation. Speakers in the current study modified bilabial contact pressure and intraoral air pressure when asked to assume they were talking to someone who is hard of hearing, presumably in an attempt to elevate the precision of articulation to make it more intelligible. Similarly, speakers exaggerated bilabial movements when asked to produce speech with an electrolarynx, presumably in an attempt to ensure intelligibility. Using instructions similar to those used for clear speech in the current study, and coaching speakers in the manipulation of bilabial contact pressure and intraoral air pressure peaks and durations may elicit clearer and more intelligible speech.

Future study will include more participants to more fully investigate the phenomena observed, especially given the degree of variability observed in some measures. Incorporation of intelligibility measures may also help indicate whether changes to physiologic parameters, like greater lip compression, improve clearness of speech. Measuring other articulators, such as the tongue, during speech may also indicate what else a speaker does to articulate clearer speech. Comparing BCP in speakers pre and post laryngectomy will further indicate changes in physiologic parameters during these three speech modes.

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