Electropalatography Contact Patterns in the Production of Malay Consonants among Paralysed Patients

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Abstract: Various techniques are available for improving speech production among subjects with speech problems, including paralysed patients. In this study, electropalatography (EPG) that detects the tongue and hard palate contact during continuous speech is used as a therapeutic instrument for improving the production of speech among paralysed patient. Five paralysed subjects with different medical background had been chosen. All paralysed subjects were asked to wear a Reading Palate which has 62 electrodes as a sensor to detect the tongue and hard palate contacts. The electrode sensors were divided into four zones which are alveolar, postalveolar, palatal and velar zones. The signals of the electrodes were transferred to a computer and analysed using Articulate Assistant TM 1.18. The objective of this study is to determine the location of contact between the tongue and hard palate among five paralysed subjects during the production of bilabial, postalveolar, velar and glottal consonants. The contact patterns produced by the paralysed subject were compared with the contact pattern guideline of the Malay consonants. In conclusion, EPG is suitable to be used as a device to identify the difference in the contact pattern. Besides, EPG can also be used as an exercise instrument to train the muscle movement to improve the contact pattern.

Keywords: electropalatography; paralysis; tongue-hard palate contact; Malay consonant; speech rehabilitation.

1. INTRODUCTION

Muscle is a layer of tissue that protects bones and other internal organs. There are three types of muscle tissue; smooth muscle, cardiac muscle and skeletal muscle. The skeletal muscles can be controlled consciously and attached to the skeletal system (Sinnatamby, 1999). During body movement, the brain transmits a signal to the muscle. Failure of signal transmission will negatively affect the muscle movement according to the instructions from the brain, which is commonly experienced by paralysed patients (Raman et al., 1995).

Paralysis occurs following spinal cord injury (SCI), stroke and orthopaedics diseases. Patients with paralysis are unable to move certain parts or whole of the body (Murray et al., 2015). In addition, paralysis also affects the production of speech, known as aphasia (Peppen et al. 2004). The patient who suffers paralysis produces slurred sound during communication, which mostly due to the failure movement of the muscle that is attached to the speech organs.

The function of body movement can be improved by rehabilitation treatment. Typically, patients with paralysis will be referred to a rehabilitation centre to follow a regular rehabilitation treatment (Desrochers et al., 2017). Peppen et al., (2004) in their study, recorded that regular rehabilitation enhanced patient survival and independence. Two types of exercise help to improve motor or muscle movement, which is passive exercise and auto assisted exercise.

Besides improving the muscle movement, speech rehabilitation may also be required to improve speech disorder among paralysis patients. Speech therapy helps the paralysed patient to improve pitching, control voice volume, listening, voice quality, chewing and swallowing (Frost, 2001). Furthermore, speech therapy may help the paralysed patient to communicate clearly, and consequently, increase their confidence level (Pandarinath et al., 2017).

Electropalatography (EPG) is a suitable instrument used to train the muscle of speech organ during the production of the speech sound. The patient needs to place an artificial palate on his or her upper palate inside the mouth. The artificial palate is embedded with electrode sensors that detect the tongue and hard palate contact and transfer the signal to a computer in real-time.

During speech production, a speech therapist can monitor the location of the tongue and subsequently identify incorrect pronunciation. Besides, the speech therapist can also determine the ideal location for the tongue to produce more accurate sound. With the use of EPG, the patient will be able to compare contact failure with correct tongue-palate contact through the EPG monitor and can be trained to produce the correct contact pattern. Furthermore, there are studies which proved that EPG has potential benefit for diagnosing and treating patients with speech disorder such as Down syndrome (Wood et al., 2019), cleft palate (Yamamoto, 2019) and glossectomy (Hardcastle et al., 1992).

In this study, EPG is used to monitor the contact pattern in the production of bilabial, postalveolar, velar and glottal consonants in the Malay language. The different location between the tongue and hard palate contact plays an important role during the production of sound. This is because each of sound produce their own characteristic of contact pattern. The Malay language has 34 alphabets with 24 of the alphabets are original, and the remaining are adopted from other languages. The original alphabets consist of six vowels and 18 consonants (Zahid & Omar, 2006).

This paper presents the analysis of the EPG contact pattern of the paralysed patients and comparison to the healthy subjects. The comparison is made by referring to the EPG guideline contact patterns of the Malay Language established in previous studies (Zin et al. 2018).

2. METHODS

2.1 Subjects

Five paralysed subjects; Patient 1 (S1), Patient 2 (S2), Patient 3 (S3), Patient 4 (S4) and Patient 5 (S5) with different medical background were selected for this study with age ranging from 47 to 56 years old. All subjects had different timing for having the paralysis. All of the subjects were classified as hemiplegia. Additionally, P1, P2 and P5 use upper and lower full dentures due to being edentulous. Table 1 shows the details classification of the subject.

Table 1. Details of the paralysed subjects

Patient	Age (Year)	Gender	Years of Paralysis	Paralysis category
S1	54	Female	1	Right-Hemiplegia
S2	56	Male	2	Right-Hemiplegia
S3	52	Male	3	Left-Hemiplegia
S4	52	Male	3	Right-Hemiplegia
S5	47	Male	4 Month	Left-Hemiplegia

2.2 Procedure

Subjects were asked to come to the Dental Specialist Clinic at the Advanced Medical and Dental Institute (AMDI), Universiti Sains Malaysia (USM). The paralysed subject or guardian was asked to sign a consent form that was approved by the Human Research Ethics Committee (HREC) of USM following their agreement to participate in the study.

During data recording, subjects were asked to wear a fabricated Reading palate. The fabrication of Reading palate can be referred to previous studies (Zin et al., 2018). The Reading palate functions as a sensor and transmits the signal of the contact pattern data to a computer. The contact pattern data were displayed on the computer *via* Articulated Assistant TM 1.18 software. Before recording, subjects were required to place the training palate at least four hours. The training palate was used to accustom an unfamiliar object inside the mouth, which is essential for producing unbias data. Subjects were required to produce single consonants [b], [d], [g], [k], [ʧ], [ʤ], and [h] in a studio laboratory equipped with a soundproof system.

Mean calculation of lateral axis is designed to indicate whether more contacts were close to the midline of the palate or towards the sides. The mathematical calculation for the mean lateral is as below:

$$\frac{\sum_{n=1}^{8} abs(n-4.5)C_n}{4\sum_{n=1}^{8} C_n},$$

where *abs* is clarified as the absolute (unsigned) value, and C_n denotes the weighted sum of contacts in column *n*.

$$C_n = \sum_{m=1}^{8} c_{m,n} W_{m,n},$$

$c_{m,n}$ = contact value in m^th and n^th column {0,1}

$W_{m,n}$ = weight value in m^th and n^th column {0..1}

Meanwhile, mean asymmetry measure of the lateral axis is designed to indicate whether there is more contact towards one side or the other. The formula is as below:

$$\frac{\sum_{n=1}^{8} (n-0.5)C_n}{8\sum_{n=1}^{8} C_n},$$

where C_n denotes the weighted sum of contacts in column *n*.

$$C_n = \sum_{m=1}^{8} c_{m,n} W_{m,n},$$

$c_{m,n}$ = contact value in m^th and n^th column {0,1}

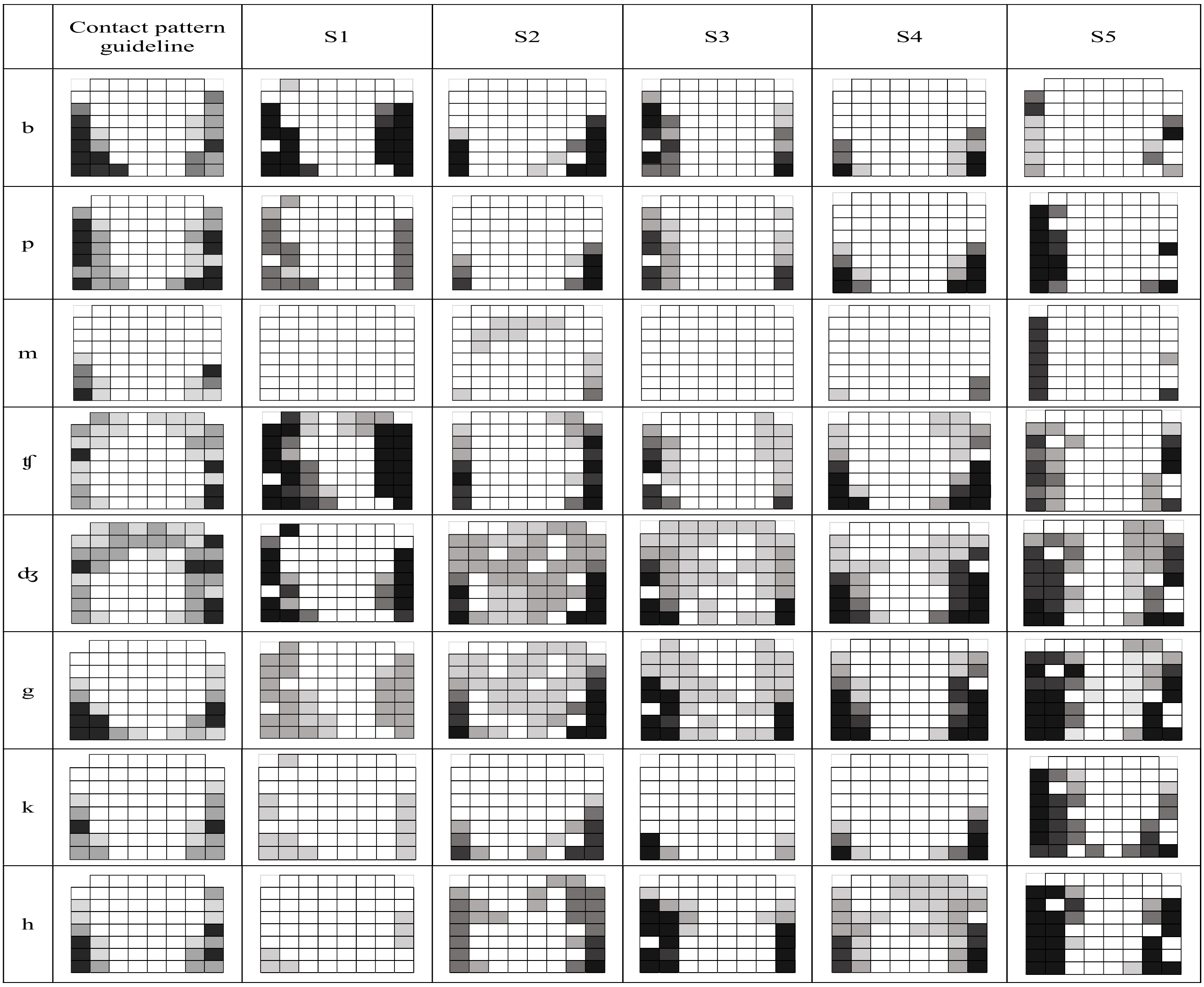
$W_{m,n}$ = weight value in m^th and n^th column {0..1}

3. RESULT

In this study, the guideline was used by a speech therapist to compare speech production of the paralysed patient. The contact pattern guideline was obtained from the contact patterns of the Malay consonants from 30 normal subjects. All paralysed subjects were asked to produce the Malay consonants as specified in Table 2.

Consonants [b] and [p] are categorised as a plosive bilabial consonant, whereas, consonant [m] is a nasal bilabial consonant. In the production of consonant [b], the contact pattern guideline recorded that there was one contact at the right side of the alveolar zone compared to paralysed subjects who had one contact at the left side of the hard palate, except S2 and S4. At the postalveolar zone, the contact pattern guideline had five contacts, two at the left side and three at the right side. S1 and S3 had almost similar contact pattern at the postalveolar zone. However, S3 had more contact at the left side than the right side, which was opposite compared to the contact pattern guideline. There were 11 contacts at the palatal zone for the contact pattern guideline with five contacts at the left side and six contacts on the right side. S1 recorded the same number of contacts, but S2 and S3 had produced lower contact, and even lower for S4 and S5. At the velar zone, there were five contacts for the contact pattern guideline, four contacts for S1, S2 and S4, three contacts for S3 and two contacts for S5.

Table 2. The production of Malay consonants of paralysed subject and normal subjects based on the guideline of the Malay consonants contact pattern (*Darker shading of the contact indicates stronger contact frequency value and lighter shading indicates lower contact frequency value).



	Contact pattern guideline	S1	S2	S3	S4	S5
b						
p						
m						
ʧ						
ʤ						
g						
k						
h						

All paralysed subjects produced contact at the lateral side of the hard palate in the production of consonant [p], which was similar to the contact pattern guideline. Referring to the contact pattern guideline, S1 and S3 had two contacts at the alveolar zone. Additionally, S3 had a similar position of contact pattern, with one contact at the left and one contact at the right, while S1 had two contacts at the left side.

At the postalveolar zone, there were symmetrical contact at left and right sides for the contact pattern guideline with four contacts, respectively. S1 had a similar pattern to the contact pattern guideline, but with a total of four contacts for both sides. Meanwhile, S3 had similar contact at the left side only. Additionally, there was no contact at the postalveolar for S2 and S4, and three contacts for S5. At the palatal zone, there were 12 contacts based on the contact pattern guideline. S5 had similar contact at the left side of the palatal zone with more definite frequency value compared to the contact pattern guideline. S1 and S3 had similar contact pattern at the right and left sides of the hard palate. At the velar zone, there were six contacts of the contact pattern guideline, four contacts by S1, S4 and S5, and three contacts by S3. S4 and S5 had symmetrical contact pattern with two contacts at the left and two contacts at the right sides.

In the production of consonant [m], the contact pattern guideline had no contact at the alveolar and postalveolar zone, six contacts at the palatal zone and four contacts at the velar zone. There was no contact for S1 and S3 for all zones in the production of consonant [m]. There were four contacts at the alveolar and postalveolar zones for S2, one contact at alveolar and two contacts at the postalveolar for S5. At the palatal zone, there were three contacts for S2, one contact for S4 and four contacts for S5. S4 recorded the most similar contact pattern compared to the guideline contact pattern.

In the production of consonant [ʧ], S1 had similar contact pattern at the alveolar zone. However, contacts at the velar zone were extended to the middle of the hard palate compared to the guideline. In addition, S2, S3, S4 and S5 showed almost similar contact pattern at the lateral side of the hard palate. The most similar contact pattern in the production of consonant [ʤ] was S1, while S2 and S3 had scattered contact at the hard palate. S4 and S5 had contacts at the lateral side of the hard palate, and S5 had an extended contact at the middle of the hard palate. Furthermore, most of the paralysed subjects showed a stronger frequency value at the lateral side of the hard palate in the production of consonants [ʧ] and [ʤ].

The guideline contact pattern for [g] and [k] recorded the contact at the posterior of the hard palate. However, S1, S4 and S5 recorded contacts at the lateral side of the hard palate while S2 and S3 had scattered contact at the hard palate in the production of consonant [g]. In the production of consonant [k], the contact pattern guideline was mostly at the palatal and velar zones. S1, S2, S3 and S4 recorded a similar contact pattern. However, S1 had extra contact at the alveolar zone, while S2 and S4 had extended contact at the middle of the velar zone. S5 had more contact at the left side of the hard palate. The velar plosive consonant is produced when the end of the tongue raises up and approaches the soft palate (Zahid & Omar, 2006). The muscles involved in raised the end of the tongue were palatoglosus, transverse and styloglosus (Bouchard et al., 2013 & Bilodeau-Mercure et al. 2016).

In the production of consonant [h], most contacts were recorded at the posterior-lateral of the palate. There was no contact at the central of the hard palate. S1 recorded a similar contact pattern at the lateral side of the hard palate, while S3 and S5 had extended contact at the middle of the postalveolar zone. The glottal fricative consonant is generated by the membrane of the vocal cord that approaches each other, and the airflow vibrates the vocal cord (Jiang et al., 2015). The muscle involves in moving the vocal cord are transverse arytenoid, posterior cricoarytenoid, lateral cricoarytenoid and thyroarytenoid (Bouchard et al., 2013).

Fig. 1 shows the percentage of contact pattern in the production of consonants [b], [p], [m], [ʤ], [ʧ], [g], [k] and [h]. In the production of consonant [b], the highest contact of the guideline was at the velar, followed by palatal, postalveolar and alveolar zones. All paralysed subjects recorded similar contact percentage except S5 who had the highest percentage of contact at the velar and palatal zones. Besides, S4 showed no contact at the alveolar and postalveolar zones.

In the production of consonant [p], the highest contact pattern of the contact pattern guideline was at the velar zone, and the lowest was at the alveolar zone. S3 produced similar contact percentage, with the highest percentage at the velar zone. S1 had the highest percentage at the postalveolar and velar zones, while S5 had the highest percentage at the palatal and velar zones. In the production of consonant [m], the highest contact was at the velar, followed by palatal zone, which was similar to S4. Although S5 had the highest percentage of contact at the velar zone similar to the guideline contact pattern, S5 had a percentage of contact at the alveolar and postalveolar zones which was contradictory to the guideline contact pattern. Additionally, S1 and S3 had no contact for all zones.

Fig. 1. Contact percentage of consonants [b], [p], [m], [ʤ], [ʧ], [g], [k] and [h] by paralysed patients and contact pattern guideline.

Based on the contact pattern guideline, the highest percentage of contact was at the alveolar zone, and the lowest contact was at the palatal zone in the production of consonant [ʧ]. Even though S1 had the highest contact at the alveolar zone, the lowest percentage of contact was at the postalveolar zone. S2 had the highest percentage contact at the alveolar and postalveolar zones, and S3 had the highest percentage of contact at the postalveolar zone. S4 and S5 had the highest percentage of contact at the velar zone, and the lowest percentage of contact was at the postalveolar zone for S4 and alveolar zone for S5. In the production of consonant [ʤ], the highest percentage of contact was at the alveolar zone, followed by postalveolar, velar and palatal zones based on the guideline. S3 had a similar percentage of contact to the guideline. However, S3 recorded a similar percentage of contact at the postalveolar and velar zones. S1, S2 and S4 had the highest percentage of contact at the velar zone while the lowest percentage of contact was at the alveolar zone for S1 and S4, and at the alveolar and palatal zones for S2. S5 recorded the highest percentage of contact at the postalveolar zone followed by velar, alveolar and palatal zone.

Based on the contact pattern guideline, the highest contact percentage was at the alveolar zone, followed by velar, postalveolar and palatal zones to produce consonant [g]. S1 had the highest percentage of contact at the palatal and velar zones, while S2, S3, and S4 had the highest percentage of contact at the velar zone. S5 had the highest percentage of contact at the postalveolar zone. Three paralysed subjects had their lowest percentage of contact at the alveolar zone, while S2 had the lowest percentage of contact at the postalveolar zone. In the production of consonant [k], all paralysed subjects had the highest contact percentage at the velar zone, which was similar to the guideline. In addition, S1 and S5 had the lowest percentage of contact at the alveolar zone.

In the production of consonant [h], S1 and S5 had the highest percentage of contact at the velar zone, which was similar to the percentage of contact for the guideline. The lowest percentage of contact for the guideline was at the alveolar zone. Similarly, S5 and S3 had the lowest contact percentage at the alveolar zone. S2 and S3 had the highest percentage of contact at the postalveolar zone while S4 had the highest percentage of contact at the alveolar zone.

4. DISCUSSION

The contact pattern guideline was used in this study to identify the differences of contact pattern among paralysed subjects toward the normal speakers. The findings indicated that the most similar contact pattern produced among the subjects were consonants [b] and [p]. Besides, S3 and S4 produced almost similar contact pattern to the contact pattern guideline. Both of these patients sustained paralysis for the third year following their injuries. Additionally, both patients followed regular therapy that has been conducted by a therapist. Even though they only received treatment on the upper and lower limb both subjects have their own initiative to improve speech production.

Another subject who had almost similar contact pattern with the contact pattern guideline was S5. He is a unique subject who had suffered from paralysis about four months before this study. This patient had shown some improvement in speech, particularly in the production of the alveolar consonant (Zin et al. 2019). This patient is highly motivated and has shown an impressive commitment during this study. S5 proved that positive mind helps paralysis patient to improve their daily routine in the short term (Roth et al., 2019).

Consonant [ʤ] was the most challenging consonant to be produced since the contact patterns were varied among the subjects. Most of the subjects showed different contact pattern compared to the contact pattern guideline. Additionally, Hwang et al. (2015) in their study stated that the Korean leaner had difficulty in producing /dð/, /b-v/, /s-θ/, /z-ʒ-ʤ/ in the production of English language even after the training process.

The number of muscles involved in the speech production influences the production of the tongue and hard palate contact pattern. This is because the muscle needs to move the tongue and other parts of speech organ during the speech production (Han et al., 2001). Besides, the paralysed patient also faced difficulties with swallowing saliva due to weak tongue movement leading to excessive saliva production affecting word pronunciation and speech production (Hiiemae & Palmer., 2013). Besides, the muscles that involved in the velar zone mostly produce different contact pattern to the contact pattern guideline. Schilling et al. (2019) reviewed that the palatoplasty surgical technique affects speech production, upper arch, maxillary growth and dental occlusion.

Additionally, exercise is an essential way to improve the ability of a muscle, including the muscle of speech (Peppen et al. 2004 & Parent et al., 2002). Other than monitoring the contact pattern, EPG can also be used as an exercise instrument to train the tongue and other muscle to produce better speech. A speech therapist may ask the paralysed subjects to produce and replicate similar contact pattern based on the guideline contact pattern. Pelland et al. (2019) stated that during the production of fricative and plosive consonants, levator veli palatine muscles was mostly used compared to the production of a nasal consonant. However, this study was conducted only with a pair of vowels.

The paralysed category also influences the tongue and hard palate contact pattern. S1, S2 and S4 were classified as right-hemiplegia paralysis. It was observed that S2 recorded the tongue and hard palate contact more on the right side of the hard palate in the production of consonants [b], [p], [ʧ], [g], [k] and [h]. Additionally, S4 had more contact at the right side of the hard palate for all consonants. Interestingly, even though S1 was classified as right-hemiplegia paralysis, most of the tongue and hard palate contacts were recorded on the left side of the hard palate. Meanwhile, S3 and S5 were classified as left hemiplegia paralysis. S3 and S5 showed more contacts at the left side for all consonants, as expected, except consonant [m] for S3 and consonant [ʤ] for S5.

In a study by Grazielle et al. (2012), there was no significant difference between right and left hemiplegia paralysis. However, this study shows that patient with right-hemiplegia paralysis produced more contact pattern at the right side of the hard palate, hence needing further study in embarking these differences.

5. CONCLUSIONS

In this study, EPG is used to determine the tongue and hard palate contact pattern among paralysed subjects during the production of consonants [b], [d], [g], [k], [ʧ], [ʤ], and [h]. There were five paralysed subjects with different medical background involved in this study. The contact patterns of the paralysed subjects were compared with the contact pattern guideline of the Malay speakers. S4 showed the most similar contact pattern to the guideline, followed by S3, and S5. This study shows that there were some differences in contact patterns among paralysed subjects, particularly in the alveolar and postalveolar zone. In comparison to the contact pattern guideline, the velar zone is considered as the most touchable zone for the paralysed subjects. Whereas, the postalveolar zone is the most difficult zone for the paralysed subjects. Additionally, the period of paralysis and its type, frequency of treatment, and motivation also plays an important role in improving the speech sound. Besides, the consonants that require a smaller number of functioned muscles produce more similar contact pattern to the contact pattern guideline. This study shows that the differences in contact patterns can be assessed using the electroplatography. Therefore, EPG is suitable to be used to improve speech production among paralysed patients.

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REFERENCES

Bilodeau-Mercure, M. and Tremblay, P., (2016). Age differences in sequential speech production: Articulatory and physiological factors. Journal of the American Geriatrics Society, 64(11), e177-e182.

Bouchard, K.E., Mesgarani, N., Johnson, K. and Chang, E.F., (2013). Functional organization of human sensorimotor cortex for speech articulation. Nature, 495(7441), 327.

Desrochers, P., Kairy, D., Pan, S., Corriveau, H. and Tousignant, M., (2017). Tai chi for upper limb rehabilitation in stroke patients: The patient's perspective. Disability and rehabilitation, 39(13), 1313-1319.

Frost, M., (2001). The role of physical, occupational, and speech therapy in hospice: Patient empowerment. American Journal of Hospice and Palliative Medicine®, 18(6), 397-402.

Grazielle, D. d. O., Amanda, F.V., Laélia, C. C.V., & Andréa, R. M., (2012). Factors associate with tongue pressure in post-stroke patient. Audiology Communication Research,22, 1-8.

Han, T.R., Paik, N.J., & Park, J.W. (2001). Quantifying swallowing function after stroke: A functional dysphagia scale based on video fluoroscopic. Archives of Physical Medicine and Rehabilitation, 82(3), 677–82

Hardcastle, W. J., & Edwards, S. (1992). EPG-based descriptions of apraxic speech errors. In Kent R. (ed). Intelligibility in speech disorders: Theory, measurement, and management. 287-328. Philadelphia: John Benjamins.

Hiiemae, K.M. and Palmer, J.B. (2003). Tongue movements in feeding and speech. Critical Reviews in Oral Biology & Medicine, 14(6), 413-429.

Hwang, Hyosung and Ho-young Lee. "The effect of high variability phonetic training on the production of English vowels and consonants." ICPhS (2015).

Jiang, C., Whitehill, T.L., McPherson, B. and Ng, M.L., (2015). Spectral features and perceptual judgment of place of affricate in Putonghua-speaking pre-adolescents with normal and cleft palate. International journal of pediatric otorhinolaryngology, 79(2), 179-185.

Murray, S.A., Ha, H. K., and Goldfarb, M. (2015). "An Assistive Control Approach for a Lower-Limb Exoskeleton to Facilitate Recovery of Walking Following Stroke", IEEE Trans. on Neural Syst. Rehabil. Eng., 441-449.

Pandarinath, C., et al. (2017). High performance communication by people with paralysis using an intracortical brain-computer interface. eLife, 6, 1-27.

Parent, R., King, S. and Fujimura, O., (2002), Issues with lip sync animation: can you read my lips? In Proceedings of Computer Animation 2002 (CA 2002), June, (3-10). IEEE.

Pelland, C.M., Feng, X., Borowitz, K.C., Meyer, C.H. and Blemker, S.S., (2019). A Dynamic Magnetic Resonance Imaging–Based Method to Examine in Vivo Levator Veli Palatini Muscle Function During Speech. Journal of Speech, Language, and Hearing Research, 62(8), 2713-2722.

Peppen, V. R. P. et al. (2004) 'The impact of physical therapy on functional outcomes after stroke: what's the evidence?', Clinical Rehabilitation, 18(8), 833–862.

Raman, A., Ruby, H., & Afandi, M. M., (1995). Fisiologi Manusia. 2nd ed. Selangor: Penerbit Fajar Bakti Sdn.Bhd.

Roth, K., Mueller, G., & Wyss, A. (2019). Experiences of peer counseling during inpatient rehabilitation of patients with spinal cord injuries. Spinal Cord Series and Cases, 5(1).

Schilling, G.R., Cardoso, M.C.D.A.F. and Maahs, M.A.P., (2019). Effect of palatoplasty on speech, dental occlusion issues and upper dental arch in children and adolescents with cleft palate: an integrative literature review. Revista CEFAC, 21(6).

Sinnatamby, C.S. (1999). Last's Anatomy Regional and Applied. 10th ed. London: Timothy Horne.

Wood, S.E., Timmins, C., Wishart, J., Hardcastle, W.J. and Cleland, J., 2019. Use of electropalatography in the treatment of speech disorders in children with Down syndrome: a randomized controlled trial. International journal of language & communication disorders, 54(2), 234-248.

Yamamoto, I., (2019). Tongue-palate contact patterns for Japanese speakers with and without cleft lip and palate. International journal of speech-language pathology, 1-8.

Zahid I., & M. S. Omar, M. S., Fonetik dan Fonologi: PTS Publication & Distributors Sdn Bhd, 2006.

Zin M. S. Suhaimi, M. F., Shakur M. F. N., Noor, S.N.F.M., Mohamad, A. F., and Zali, N. (2019). "Contact Pattern of Alveolar Consonants in the Malay Consonants of Paralysis Subject using Electropalatography", International Journal of Integrated Engineering, 11(3),100-108.

Zin, S. M., Suhaimi, F.M., Noor, S.N.F.M., Ismail, N., and Zali, N. (2016). "Analysis of consonant /s/ and syllables in Malay language using electropalatography" AIP Conference Proceedings, 1791, 020002-1 – 020002-6.

Zin, S. M., Suhaimi, F.M., Shakur, N.F.M, Noor, S.N.F.M., Mohamad, A. F., and Zali, N. (2018). The Malays /r/ Consonant Analysis based on Electropalatography. 2018IEEE-EMBS Conference on Biomedical Engineering and Sciences (IECBES2018), 447-450. IEEE.