MALAY LANGUAGE CONSONANTS CONTACT PATTERN BASED ON ELECTROPALATOGRAPHY EPG3 AND FLEX EPG SYSTEM

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by

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LIST OF UNITS AND SYMBOLS

%	Percent
^0C	degree Celsius
cm	Centimeter
GHz	Gigahertz
Hz	Hertz
m	Meter
MB	Megabyte
MHz	Megahertz
mm	Millimeter
ms	Milliseconds
pF	Picofarads
TM	Trademark
V	Volts

LIST OF ABBREVIATIONS

ADK	Accessory Development Kit
AFRONET	Africa Radiation Oncology Network
AMDI	Advanced Medical and Dental Institute
ANOVA	Analysis of Variance
AVR	Automatic Voltage Regulator
BLE	Bluetooth Low Energy
CLEFNET	Cleft Patient Network
CMOS	Complementary Metal Oxide Semiconductor
COM	Communication Port
ECG	Electrocardiography
EEG	Electroencephalography
EMG	Electromyography
EOG	Electrooculography
EPG	Electropalatography
GUI	Graphical User Interface
HREC	Human Research Ethics Committee
HUSM	Hospital Universiti Sains Malaysia
IBM	International Business Machines
IDE	Integrated Development Environment
IPA	International Phonetic Association
ISP	In System Programme
LED	Light Emitted Diode
LSD	Least Significant Difference
MRI	Magnetic Resonance Imaging
PCB	Printed Circuit Board
PDA	Personal Digital Assistant
POP	Plaster of Paris
QMUC	Queen Margaret University College
RISC	Reduced Instruction Set Computer
SGI	Group of Special Interest
SLT	Speech Language Therapist

SPM	Sijil Pelajaran Malaysia
SPP	Serial Port Protocol
SPSS	Statistical Package for the Social Sciences
SSD	Speech Sound Disorder
UK	United Kingdom
USA	United State of America
USM	Universiti Sains Malaysia
VCV	Vowel Consonant Vowel

CORAK HUBUNGAN KONSONAN BAHASA MALAYSIA BERDASARKAN SISTEM ELECTROPALATOGRAFI EPG3 DAN FLEX EPG

ABSTRAK

Electropalatography (EPG) ialah alat perubatan yang digunakan untuk mengesan corak hubungan antara lidah dan lelangit keras semasa pertuturan. Corak hubungan *EPG* dibina sebagai panduan bagi kajian pertuturan dan corak hubungan dalam penghasilan sebutan konsonan yang boleh dijadikan sebagai garis panduan kepada ahli terapi pertuturan semasa rawatan dijalankan. Dalam kajian ini, sistem *EPG*3 digunakan sebagai alat untuk membangunkan pangkalan data hubungan lidah dan lelangit dalam Bahasa Malaysia. Seramai 30 subjek bangsa Melayu yang tiada kesukaran dalam pertuturan atau pendengaran telah dipilih dalam kajian ini. Semua subjek diminta untuk memakai lelangit tiruan yang dikenali sebagai *Reading palate* untuk menghasilkan 15 jenis konsonan dalam Bahasa Malaysia bagi kajian ini. Hasil menunjukkan lebih banyak hubungan antara lidah dan lelangit di bahagian *posterio*r lelangit bagi pengeluaran konsonan *bilabial*, *velar* dan *glottal*. Sementara itu, bagi penghasilan konsonan *alveolar* dan *postalveolar*, corak hubungan antara lidah dan lelangit lebih banyak berlaku di bahagian *anterior* lelangit keras. Selain itu, kajian ini juga melibatkan pembangunan reka bentuk sistem *EPG* baru yang dikenali sebagai sistem *Flex EPG*. Pembangunan sistem *EPG* baru dilengkapi teknologi Bluetooth, dimana ia mengatasi kekurangan utama yang terdapat pada sistem *EPG3*. Pembangunan sistem *Flex EPG* ini diklasifikasikan kepada dua bahagian iaitu komponen perkakasan *Flex EPG* dan konfigurasi perisian *Flex EPG*. Bagi perkakasan *Flex EPG,* ia terdiri daripada lelangit tiruan dikenali sebagai *Flex EPG palat*e dan litar elektronik. Semasa pengambilan data, *Flex EPG palate* digunakan untuk mengenalpasti corak hubungan lidah dan lelangit keras melalui isyarat elektronik. Imbasan corak hubungan lidah dan lelangit keras dipaparkan, disimpan dan dianalisis pada komputer melalui teknologi *Bluetooth*. Dapatan kajian ini menunjukkan tidak terdapat perbezaan yang signifikan antara subjek bagi penghasilan konsonan Bahasa Malaysia menggunakan sistem *Flex EPG*. Selain itu, dapatan kajian ini juga menunjukkan corak hubungan antara lidah dan lelangit keras hampir sama antara kedua-dua sistem *EPG3* dan *Flex EPG*. Kesimpulannya, corak hubungan lidah dan lelangit keras berpotensi untuk diaplikasikan dimasa hadapan sebagai panduan semasa terapi pertuturan untuk Bahasa Malaysia.

MALAY LANGUAGE CONSONANTS CONTACT PATTERN BASED ON ELECTROPALATOGRAPHY EPG3 AND FLEX EPG SYSTEM

ABSTRACT

Electropalatography (EPG) is a medical instrument used in detecting contact pattern between the tongue and hard palate during a continuous speech. EPG contact pattern was built as a guideline for speech study and can be used to guide speech therapist during a treatment. In this study, the EPG3 system is used as an instrument for developing the Malay language consonants contact pattern. Thirty (30) Malay subjects without speech or hearing difficulties were selected in this study. All subjects were required to wear Reading palate and produce 15 Malay consonants in this study. The results indicate in the production of bilabial, velar and glottal cosonants, more contacts were located at the posterior of the hard palate. Meanwhile, in the production of alveolar and postalveolar consonants, the contact pattern were more on the anterior part of the hard palate. Besides, the design and development of new EPG system, namely Flex EPG system was also included in this study. The new EPG system features a Bluetooth technology, which overcomes the major lack of the EPG3 system. The development architecture of the Flex EPG system can be classified into two parts which are the Flex EPG hardware components and the Flex EPG software configuration. Additionally, the Flex EPG hardware consists of the Flex EPG palate and the electronic circuit. For the data collection, the Flex EPG palate was used to detect the tongue and hard palate contact by identifying the electrodes signal. The patterns of the contact are transmitted to a computer for display, storage, and analysis *via* a Bluetooth module. The result recorded no significant difference between the subjects in the production of Malay consonants using the Flex EPG system.

Additionally, there are almost similarity of the contact pattern according to palate zone among subjects using both EPG3 and Flex EPG system. In conclusion, average contact pattern of the Malay consonants can potentially be used for future applications such as speech therapy for the Malay speakers.

CHAPTER 1

INTRODUCTION

This chapter introduces the background of this research and brief information regarding electropalatography. The scopes and objectives of this research are also stated in this chapter. Additionally, the outline of this thesis is also included at the end of this chapter.

1.1 Background of Study

In medical field, various types of equipment are used for monitoring and diagnosing of patient health such as electrocardiography (ECG), electroencephalography (EEG), electromyography (EMG), electrooculography (EOG), and electropalatography (EPG) (Khandpur, 2005). These equipments are used for several different applications. ECG is used to measure and record heartbeat by electrical potentials on the body surface associated with heart muscle activity. EEG is used for diagnosing and recording the electrical activity of the brain by means of an electrode placed on the skeletal and muscles, whereas EMG is used to study and diagnose the health of muscles and nerve cells.

EPG is an instrument used to record the details of the timing and location of tongue contact with hard palate during a continuous speech. The first EPG palate known as the Kay palate was marketed in the United State of America (USA). It consists of 96 gold contacts embedded in the palate. Another EPG system available in the market is EPG3. EPG3 consists of an artificial palate known as the Reading palate and the EPG software called Articulate Assistant^{TM} 1.18. The Reading palate consists of 62 silver electrodes that are embedded on the palate for contact detection. EPG is widely used in European such as the United Kingdom, USA, and Germany (Wrench, 2007). Eventhough EPG is considered very useful in Europe, the usage of this instrument is still limited in Asian countries especially in Malaysia. Currently, the only studies conducted in Malaysia are by Sudirman et al., (2007) and Noor et al., (2008).

In Malaysia, speech therapists mostly rely on their auditory perception in order to assess patient's speech. The speech sound that the speech therapist heard is based on the anatomical and the physiological knowledge of the tongue movement (Yuzaidey et al., 2018). This technique is quite complex and requires imagination on how the tongue moves from one position to another, especially in producing sentences during the speech. This technique has few disadvantages that may contribute towards inconsistent results of the speech analysis. Hence, EPG is a suitable instrument that can be used to study the contact pattern between the tongue and hard palate with a real-time visual feedback (McAuliffe et al., 2008).

EPG now has become well established in many experimental phonetic laboratories and speech. Most of the problems associated with the technique in the early stages of EPG development include unwanted capacitance, effect between closely bunched wires, saliva bridging of adjacent electrodes and suitable material for the palate (Wrench, 2007). However, further improvement of the EPG device is still ongoing to ensure the system is safe, robust and incorporate latest or new technology. EPG can be upgraded and incorporates current technology available in medical field such as Bluetooth technology, telemedicine, and mobile application.

The main purpose of utilising latest technology allows transfer of data either from patient to a computer or from one computer to another computer. Estimating by 2020, there will be more than 50 billion medical devices that will be connected to the internet as wireless technology. This is because wireless technology can reduce operating cost and offer low data at minimal power for wireless sensors and actuators network applications (Balid et al., 2016).

1.2 Research Problem

Currently, speech therapy conducted in Malaysia is based on perceptual analysis rather than quantitatively assessed. One of the main reason speech therapist in Malaysia do not use EPG system in speech treatment is because there is no established EPG contact pattern between the tongue and hard palate, particularly for Malay language. The only available studies were conducted by Noor et al. (2008) which focused on the contact pattern in the production of Kelantanese dialect among cleft palate patient, and study by Surdirman et al. (2007) on EPG hardware using LED display.

Furthermore, there is an established EPG system that has been used known as EPG3. However, EPG3 is not manufactured in Malaysia. It is only available in Hospital Universiti Sains Malaysia (HUSM), which is imported from the UK. Difficulty in obtaining spare parts and periodical maintenance makes EPG3 less utilised. EPG3 maintenance involves several parts such as multiplexer, a scanner unit, and a computer. Therefore, the design of EPG3 is suitable for laboratory use and not suitable for clinical used especially for special needs patients such as paralysed patient. There were several attempts in developing a flexible circuit of EPG including by Shibata et al., (1978) and Fletcher et al., (2005). However, it was very difficult to obtain the approval from the Medical Device Safety Board due to several regulation issues particularly on the selection of materials (Wrench, 2007). Additionally, Baldoli et al. (2017) highlights and focuses on the materials used for electrode sensors. They used a piezoresistive textile to detect the contact pattern between tongue and hard palate. Nevertheless, until now there is no portable EPG system that has been successfully developed.

1.3 Research Objectives

The general objective of this study is to establish a Malay language contact pattern using tongue-palate contact and to develop a flexible EPG system. The specific objectives of this study are:

i. To identify tongue and hard palate contact of Malay consonants based on EPG3 as reference for speech therapist
ii. To design and develop the hardware component and software interface of the Flex EPG system
iii. To identify tongue and hard palate contact of the Malay consonants using the Flex EPG system
iv. To compare the contact pattern of Malay consonants between EPG3 and the new EPG system

1.4 Scope of Research

This study starts with the recruitment of 30 Malay subjects from Advanced Medical and Dental Institute (AMDI) clinic who speak Malay language as their first language. The EPG3 consist of the Reading palate is used in this study to detect contact pattern between tongue and hard palate for each subject. In developing the Malay language contact pattern, 15 original Malay consonants are used in this study. Based on the results, it is expected that the average contact pattern of the Malay consonants can be used for future applications such as a reference for speech therapy for the Malay speakers during the treatment.

1.5 Significant of the Research

The average contact pattern in the production of Malay consonants in this research will assist the speech therapists and other researchers as a reference for contact pattern guideline during the treatment and for Malay language analysis. Besides, this study also hopes that the new EPG system will help to overcome the disadvantages of EPG3 and the development of new technology in line with the latest technology in medical devices. The improvement of this study is important to ensure that the new EPG system can be commercialised in Malaysia, since the new EPG system can be manufactured and supplied by a local company.

1.6 Thesis Outline

This thesis is structured in seven chapters. A brief explanation of each chapter is as the following:

Chapter 2 includes the literature review and the use of EPG. This chapter explains the theory of articulation and the organ used during the articulation. Besides that, the explanation regarding the Malay consonant is also included in this chapter.

Chapter 3 describes the subjects involved, materials and methods used to fabricate the artificial palate of the subjects participated in this research. This chapter also includes the process and procedure of developing the contact pattern guideline for Malay language pattern using the electropalatography system namely EPG3.

Chapter 4 discusses the result of the contact pattern for 15 consonants in the Malay language. This chapter also discusses the average pattern during the production of the Malay consonant. The average pattern represents the contact pattern in the production of the Malay consonants.

Chapter 5 presents the new development of the EPG system, the Flex EPG. The development of the Flex EPG includes the hardware component and the software interface. The advantages and disadvantage of this Flex EPG system is also discussed in this chapter.

Chapter 6 discusses the contact pattern of tongue and hard palate using the Flex EPG system. Besides, the comparison of the contact pattern between EPG3 and the Flex EPG system on a subject basis are discussed in this chapter.

Chapter 7 concludes the research finding of this thesis. Improvement of the system and future work are also highlighted in this chapter.

CHAPTER 2

LITERATURE REVIEW

This chapter describes the theory of language, the articulation process, and the articulator involves in the production of speech. The history of Electropalatography (EPG) and the used of the EPG are also discussed in this chapter. Besides, the new technology of medical instrumentation is also highlighted in this chapter.

2.1 Articulation Process

The articulation process involves the function of several human systems such as respiratory system and articulation organs. The respiratory system that involves in the production of speech are lungs, throat, vellum, mouth, and nose. There are many types of sound during the production of speech and each sound has their own characteristic (Zahid & Omar, 2012). The characteristic of sound depends on the manner and the place of articulation. Additionally, the manner of articulation depends on the organ involved during the production of sound (Hewlett & Beck, 2006). Figure 2.1 shows the organs involve in the production of sound.

During articulation, a set of organs are involved in the production of speech sound known as articulators (Westbury & Hashi, 1997). It plays an important role in producing the different sound during the production of speech. There are two types of articulators; active articulator and passive articulator (Zahid & Omar, 2012). The lips, tongue, soft palate, and lower teeth are classified as an active articulator. The passive articulator is the static organ such as upper teeth and hard palate.

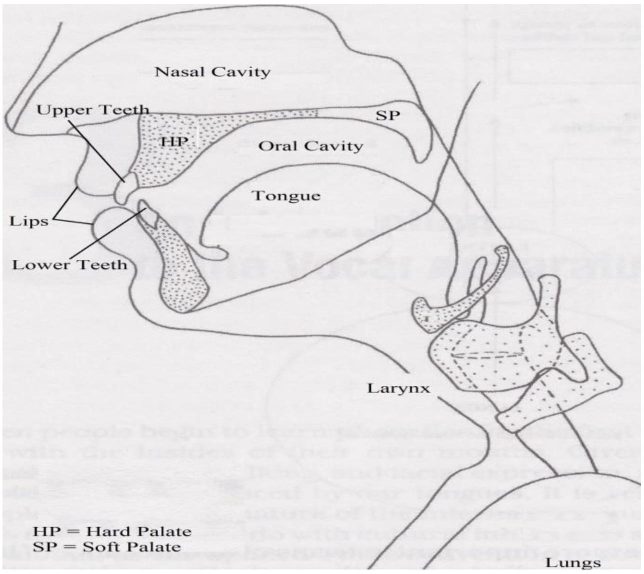


Figure 2.1 The articulation organ involved in the production of speech (Adapted from Hewlett & Beck, 2006)

The productions of sound begin from the lungs. The air flows from the lungs through throat and end at the mouth or nose (Hewlett & Beck, 2006). Vocal cord is an important organ during the production. The vocal cord has two small membranes in the throat that produce the sound. Vocal cords vibrate rapidly (more than 100 times per second) when it stretched tight and close together. This situation creates a louder sound. However, in a relaxed situation, the sound tone down, like a whisper. Besides that, the vocal cord also affects the pitch of the sound. Pitching is a measure of voice production either it produces a high or low sound (Verhoeven et al. 2019)

The second articulator involves during the production of speech is the lips. The lips are the active articulator. The movement of lips involved orbicularis oris and buccinators muscles during the articulation. Other than up and down movement, the muscles also allow the lips to become rounded and stretched widely to produce different sound during the articulation.

Lips are used in the production of the labial articulation. There are two common types of labial articulation; bilabial and labiodental consonants. Bilabial consonant uses lips during the articulation. Meanwhile, labiodental is articulated with the lower lip approaching the upper teeth. Consonants [b] and [p] are classified as bilabial articulation, and consonants [f] and [v] are classified as labiodental consonant.

Another articulator is the teeth. Teeth are the hardest part of the body besides bone and embedded in the upper and lower jaws. Besides playing a role in chewing, teeth are also important in speech. Normal adults have 32 permanent teeth which are incisors, canines, premolar, and molar (Sinnatamby, 1999). Teeth are divided into upper teeth which is active articulator and lower teeth, which is passive articulator. According to Stone et al. (2008), teeth plays an important role in the production of the fricative consonant. The finding of the study stated that during the production of fricative consonant, there were differences between a patient who wears denture and patient who does not wear a denture.

On the other hand, the structure of the hard palate is made up of the palatine process of the maxilla and horizontal plate of palatine bone. There are three immovable junctions between two maxillary and palatine bones namely suture; intermaxillary, interpalatine, and palatomaxillary sutures.

The hard palate is an important speech articulator because four out of eight places of articulation are placed on the hard palate (IPA, 2001). The abnormal hard palate such as in cleft palate cases will affect the production of sound. Wendy et al. (2018) in their study stated that there were differences in hearing and speech difficulties, and facial appearance for people with cleft palate.

Meanwhile, the soft palate continues to the back of the hard palate. The posterior part of the soft palate surface attaches to the posterior wall of the pharynx (Hewlett & Beck, 2006). During swallowing, the soft palate moves up and approaches the pharynx. Soft palate consists of a palatine aponeurosis, muscular part, mucosa, muscle of uvula and palatopharyngeus (Sinnatamby, 1999). During the production of a nasal consonant, the soft palate blocked the air through the oral cavity.

The tongue is known as a taste sensor. In addition, tongue are also classified as an active articulator and plays an important role in producing almost all sounds either consonant or vowel in all languages. There are three different parts of the tongue; the tips of the tongue, the blade of the tongue and the back of the tongue (Sinnatamby, 1999). During the speech, the tongue moves around and the different sound occurs when the tongue is placed at the different place of articulation.

The upper jaw is called maxilla and lower jaw is known as mandible. The upper jaw and lower jaw are connected by masseter muscle (Sinnatamby, 1999). The upper jaw is a passive articulator meanwhile the lower jaw is an active articulator. The lower jaw moves up and down to allow the mouth to open and close and helps the tongue move to higher or lower positions during the articulation (Hewlett & Beck, 2006). Besides that, the movement of the jaw also creates different size of the mouth cavity (IPA, 2001). The movement of lower jaw influences the sound production.

Nasal cavity is placed behind the two nostrils and forms the interiors of the nose and responsible in sense of smell. Additionally, the nasal cavity plays a major role in respiration and speech production. Nasal cavity consists of the middle nasal concha, inferior nasal concha, nasal concha, internal naris, and nasopharynx

(Sinnatamby, 1999). In the production of nasal consonant, the air flows from lungs out to nose and produce nasalance sound.

2.2 Language

Communication is an important medium utilises by and between human to represent objects, actions, idea, and situation. Communication consists of language and non-language components. Language is generated with a combination of word and sentence. Meanwhile, the combination of vowel and consonant produces word (Zahid & Omar, 2012).

The Malay language is one of the languages used in the world. The Malay language was used for 10,000 years known as Austronesian language and Malayo-Polynesia language (Melebek & Moain, 2016). The Malay language consists of 32 alphabets whereas 26 of them are consonants and eight are vowel. Sixteen (16) out of 26 being the original consonant and the rest from other languages (Zahid & Omar, 2012).

Each consonant and vowel have their own sound of language known as phonetic. Vowel is divided into three types; vowel at the front ([a], [e], [i]), vowel at the center ([ə]), and vowel at the back ([o], [u]). Pronunciation of vowel involves tongue, oral cavity, size and shape of the lips (Zahid & Omar, 2012).

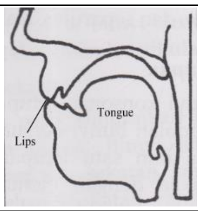
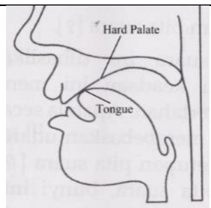
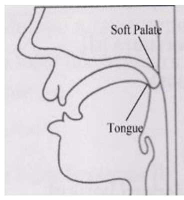
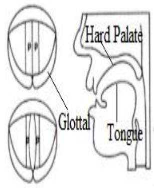
Malay consonants are divided into six types of the manner articulation, which are plosive consonants ([b], [d], [g], [k], [p], [t],[ʔ]), fricative consonants ([f], [h], [s], [v], [z], [ʃ], [ʒ], [x], [ɣ]), affricate consonants ([ʧ], [ʤ]), nasal consonants [m], [n], [ŋ], [ɲ]), lateral approximant consonant ([l]), approximant consonant ([r]) and semivowel consonant ([w], [j]) (Zahid & Omar, 2012). Each manner of articulation has a different sound production, different in the organ involves, and different in the classification of sound.

Besides the manner of articulation, the place of articulation also plays an important role during the production of different sound language. In the Malay language, there are six places of articulation during the production. The places of articulation are bilabial, alveolar, postalveolar, palatal, velar and glottal (Zahid & Omar, 2012).

2.2.1 Plosive Consonant

In the production of a plosive consonant, the airs accumulate at the oral cavity. The soft palate rises up to block the air through the nasal cavity. During the production of a plosive consonant, the lips are close together and the air flows that retained in the oral cavity is released immediately (Hewlett & Beck, 2006). There are six consonants categorised as plosive consonants which are ([b], [d], [g], [k], [p], [t], [ʔ]). Table 2.1 shows the plosive consonant according to the place of articulation and voice group.

Table 2.1 The plosive consonants according to the place of articulation. (Adapted from Zahid and Omar, 2012)

Category	Bilabial	Alveolar	Velar	Glottal
Voiceless	p	T	K	ʔ
Voiced	b	D	G	
Place of articulation				

During the articulation of the bilabial plosive consonant, upper and lower lips become close and the soft palate rise up closed to the nasal cavity. This situation causes the airs from the lungs to stop at the oral cavity. During the production of a bilabial plosive consonant, the airs is released immediately resulting into two situations when the air is released either vibrating the vocal cord or not. Production of sound with vibration at the vocal cord known as voiced, whereas production without vibration known as voiceless (Zahid & Omar, 2012). Consonant [b] is categorised as a voiced bilabial plosive consonant, while consonant [p] is known as a voiceless bilabial plosive consonant.

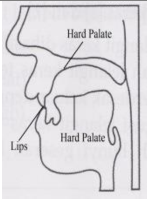
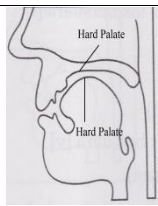
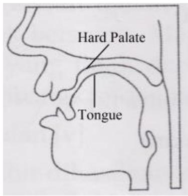
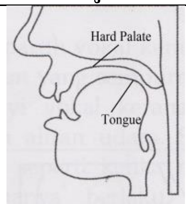
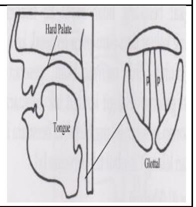
Other type of plosive consonant is alveolar consonant. Alveolar plosive consonant is divided into voiced ([d]) and voiceless ([t]). The alveolar plosive consonant is produced when the tongue tip is closed to the alveolar zone of the hard palate and the soft palate rise up to the nasal cavity. On the other hand, the velar plosive consonant is generated from the end of the tongue that raises up and approached the soft palate. There are two consonants classified as velar plosive consonant; consonant [g] (voiced consonant) and consonant [k] (voiceless consonant).

Another place of articulation for plosive consonant is at the glottal area. The glottal plosive consonant [ʔ] is generated by the membranes of the vocal cord that are close together and the air flows that retained in the glottal is released immediately.

2.2.2 Fricative Consonant

In the Malay language, there are nine consonants categorised as fricative consonant which are consonants [f], [h], [s], [v], [z], [ʃ], [ʒ], [x], and [y]. Consonant [h] and consonant [s] are originally from the Malay language and the rest are from other languages such as English and Arabic (Zahid & Omar, 2012). Table 2.2 shows the fricative consonants according to the place of articulation.

Table 2.2 The fricative consonants according to the place of articulation. (Adapted from Zahid and Omar, 2012)

Category	Labio-dental	Alveolar	Postalveolar	Velar	Glottal
Voiceless	f	s	ʃ	X	
Voiced	v	z	ʒ	ɣ	h
Place of articulation					

Labio-dental fricative consonant is produced when there is a narrow space between lower teeth and upper lip. The air flows through the narrow space resulting in a friction sound. Labio-dental fricative sound is divided into voiceless consonant (consonant [f]) and voiced consonant (consonant [v]).

Alveolar fricative consonant occurs when the anterior of tongue approach the alveolar of the hard palate. The air flows through space producing the friction sound. Two consonants are classified in this group which are consonant [s] (voiceless) and consonant [z] (voiced).

The third place of articulation for fricative consonant is at the postalveolar area of the hard palate. The postalveolar fricative consonant is produced when the anterior of tongue approach the middle of the hard palate. The air flows through the narrow space and generates turbulence. There are two consonants classified into this group which is voiceless consonant [ʃ] and voiced consonant [ʒ] (Zahid & Omar, 2012).

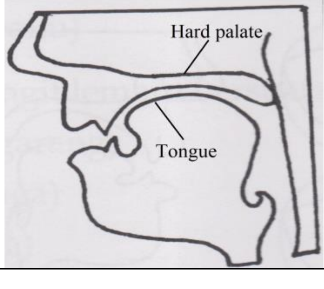
On the other hand, velar fricative consonant is produced when the posterior of the tongue approaches the soft palate. The air flows through the narrow space between the tongue and soft palate and generates the friction sound. There are two types of velar friction, which are voiceless [x] and voiced consonant [ɣ].

Another place of articulation for fricative consonant is at the glottal area. The glottal fricative consonant is generated by the membrane of the vocal cord that approaches each other and the air flows vibrates the vocal cord. According to (Zahid & Omar, 2012), consonant [h] is not identified as voiceless or voiced consonant because the sound is generated from the vocal cord. However, this study classified consonant [h] as voiced consonant because during the production of single consonant [h], the vocal cord vibrates.

2.2.3 Affricate Consonant

Another manner of articulation in the production of the Malay language sound is an affricate consonant. There are two consonants classified as affricate consonants which is consonant [ʧ] and consonant [ʤ]. Table 2.3 shows the affricate sound according to the place of articulation. Consonant [ʧ] is categorised as voiceless consonant, while consonant [ʤ] is a voiced consonant. The affricate sound is generated by the anterior of the tongue that rises up to the anterior of the hard palate. Meanwhile, the soft palate rises up and approached the throat. The air flows through the oral cavity is released slowly and produced affricate sound (Zahid & Omar, 2012).

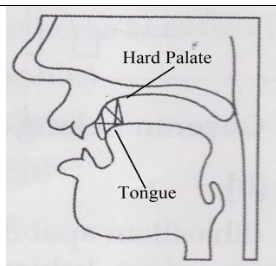
Table 2.3 The affricate consonant according to the place of articulation. (Adapted from Zahid and Omar, 2012)

Category	Postalveolar
Voiceless	ʧ
Voiced	ʤ
Place of articulation	

2.2.4 Approximant Consonant

Consonant [r] is the only approximant consonant in the Malay language. Table 2.4 shows the approximant consonant according to the place of articulation. The consonant is produced when air flows vibrate the anterior of tongue in the oral cavity and the posterior of tongue rise up to the hard palate (Zahid & Omar, 2012).

Table 2.4 The approximant consonant according to the place of articulation. (Adapted from Zahid and Omar, 2012)

Category	Postalveolar
Voiced	R
Place of articulation	

In American English, there are two ways in the production of consonant [r] which is retroflex or bunched. In retroflex, the tip of the tongue is curled up and back towards the rear part of the alveolar ridge. Meanwhile for the production of bunched sound, the body of the tongue will move back towards the hard palate (Zhou et al., 2008). Both ways of pronunciation are acceptable as it depends on the speaker's dialect, physical references and the placement of /r/ in a word.

2.2.5 Nasal Consonant

In the Malay language, nasal consonant is classified into bilabial consonant [m], alveolar consonant [n], postalveolar consonant [ɲ] and velar consonant [ŋ] (Table 2.5). Nasal consonant occurs when the soft palate is placed at the lower position and enables the air flows through the nasal cavity (Zahid & Omar, 2012).

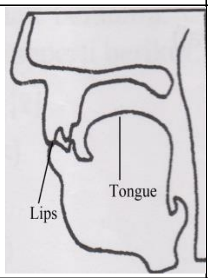
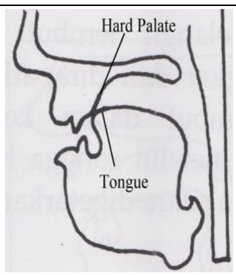
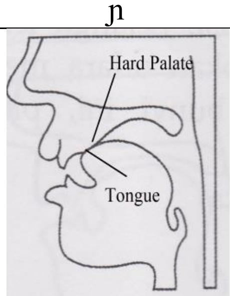
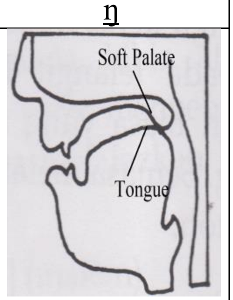
Consonant [m] is classified as a bilabial nasal consonant. In the production of consonant [m], the lower and upper lips are sealed, the soft palate moves down to the lower position and the air flows through the nasal cavity. The air flows vibrate the vocal cord and produce voiced consonant.

Meanwhile, consonant [n] is an alveolar nasal consonant. During the production of consonant [n], the anterior of the tongue approaches the anterior of the hard palate. The tongue blocks the air flows from entering the oral cavity.

Another nasal consonant is consonant [ɲ]. Consonant [ɲ] is produced when the anterior of the tongue approaches the middle of the hard palate. During the production of a postalveolar nasal consonant, soft palate moves to the lower position and enables the air flows entering the nasal cavity.

The final consonant classified as a nasal consonant is consonant [ŋ̰]. During the production of consonant [ŋ], the posterior of the tongue approaches soft palate and blocked the air flows to enter the oral cavity. The sound occurs when the air moves out through the nasal. Meanwhile, consonant [ŋ̰] is classified as a velar nasal consonant.

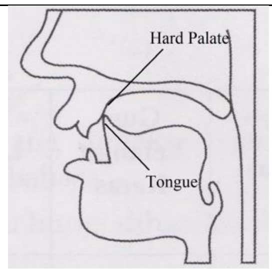
Table 2.5 The nasal consonants according to the place of articulation. (Adapted from Zahid and Omar, 2012)

<table>
<tr><td>Category</td><td>Bilabial</td><td>Alveolar</td><td>Postalveolar</td><td>Velar</td></tr>
<tr><td>Voiced</td><td>m</td><td>N</td><td>ɲ</td><td>ŋ̰</td></tr>
<tr><td>Place of articulation</td><td></td><td></td><td></td><td></td></tr>
</table>

2.2.6 Lateral Approximant

Consonant [l] is categorised as alveolar lateral approximant consonant. Table 2.6 shows the place of articulation for the production of consonant [l]. This sound is generated by the anterior part of the tongue which approach the middle of the hard palate and the soft palate moves toward the throat (Zahid & Omar, 2012).

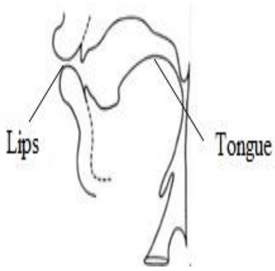
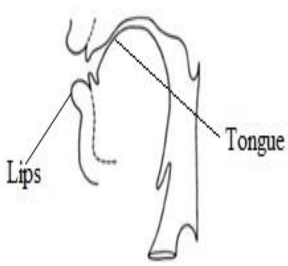
Table 2.6 The lateral approximant consonant according to the place of articulation. (Adapted from Zahid and Omar, 2012)

Category	Alveolar
Voiced	l
Place of articulation	

2.2.7 Semi Vowel

Semi vowel consonant is categorised as bilabial ([w]) and alveolar consonant ([j]). During the production of semi vowel consonant, the position of the tongue is same as the producing vowel consonant. However, the position of the tongue changed after halfway during the production semi vowel consonant.

Table 2.7 The semi vowel consonant according to the place of articulation. (Adapted from Zahid and Omar, 2012)

Category	Bilabial	Alveolar
Consonant	w	J
Place of articulation		

2.3 Instrument Used in Speech Analysis and Therapy

Many methods can be used to determine the speech sound such as a conventional and modern methods. A conventional method allows the researcher to record a sound and replay using a computer namely auditory feedback (Clark et al., 1993; Zahid & Omar, 2012). The researchers must have the expertise to determine the place of articulation during the production of sound in order to assess using auditory feedback. A study among school-age students to determine the remediation of /r/ articulation showed a significant difference when using speech tool (R-appliance) compared to the auditory feedback. Better results were produced using speech tool compared to auditory feedback. In addition, better results were produced in a study where both methods were combined.

Magnetic Resonance Imaging (MRI) and Electropalatography (EPG) are the other modern alternatives to determine the place of articulation. Masaki et al. (2008) conducted a research on the MRI-based analysis of consonants /r/ and /l/ in the English language. The researchers compared the result between American English speaker and Japanese speaker. Their study shows the advantage of using MRI. Among the primary advantage of MRI is a non-invasive system which permits the accumulation of data from many subjects (Masaki et al., 2008). Additionally, the output is in three-dimensional (3D) and easier to see the image of place of articulation. However, the cost of this method is considered high.

Besides MRI, Electropalatography is another modern method that can be used to study the place of articulation. EPG also provides dynamic real-time visual feedback of the location and timing of tongue contacts with the hard palate (Hardcastle et al., 1989). There are many studies involving EPG as an instrument in phonetic research.

Hardcastle (1972) has conducted a study about the use of Electropalatography in phonetic research. The findings show that the EPG provides real-time information of contact pattern on the tongue and hard palate. Moreover, it is a convenient technique to determine the contact pattern during a continuous speech. Besides, EPG reduces inaccurate result compared to the conventional method. In term of cost, EPG is cheaper compared to the MRI method (Hewlett & Beck, 2006).

2.4 Introduction of Electropalatography

Electropalatography (EPG) is defined as a safe and convenient equipment used in determining contact pattern between the tongue and hard palate during continuous speech (Hardcastle et al., 1989). This is supported by Kelly et al. (2000) and Wrench (2007), who claimed that EPG is an effective tool used for research and clinical setting for diagnosing and treating speech disorder (Kelly et al., 2000; Wrench, 2007)

Hence, electropalatography is categorised as a medical instrument used to analyse the contact pattern between the tongue and hard palate with a real-time visual feedback. EPG was used since the late 1960s. During that time, few individuals and companies had realised the potential of EPG as a therapeutic and pedagogy instrument. Despite that, it failed to be marketed and considered expensive to be manufactured. However, some researchers believed that EPG has the potential and suitable for analysing the tongue movements toward the hard palate compared to other traditional methods. EPG uses an artificial palate that is fitted towards the hard palate. The artificial palate has a number of electrodes which will detect the contact between the tongue and hard palate. In order to produce an accurate speech production, the artificial palate must be made as thin as possible (Hardcastle et al., 1989).

2.5 Early Development of Electropalatography

Electropalatography has been developed in the United States of America (USA) by Fletcher in the early 1970's, known as Kay Palatometer (Fletcher, 1988). Kay Palatometer produces an artificial palate named as Kay Palate. It consists of 100 gold electrodes mounted on the surface of a vacuum acrylic, where 96 gold electrodes are placed on the artificial hard palate and the other four are positioned at each buccal surface of the teeth to allow permanent contact with the buccal mucosa of the cheeks.

Figure 2.2 shows the position of the electrodes, the 96 electrodes are focused at the anterior of the hard palate and extended at the lateral of the hard palate. The electrodes surface contacts are soldered to a 1.5 m length of fine copper wire and grouped together with 50 contacts on the left and another 50 contacts on the right. The copper wires exited behind the third molars. The 1.5 m copper wire is sealed into a flexible tubing and soldered to a connector plug, and connected to a computer. The computer displays the contacts between the tongue and hard palate through a monitor, which produces 100 frames per second.

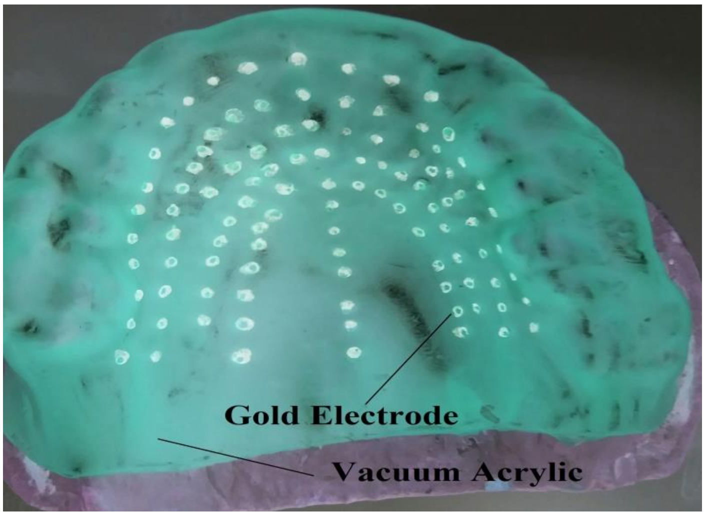


Figure 2.2 The Kay Palate (Adapted from Wrench, 2007)

However, the Kay Palatometer system had to be discontinued because of high manufacturing cost mainly due to the usage of gold as the electrodes for the palate. The cost of producing electrodes made of gold is higher compared to silver. Moreover, the high-cost issue had become a burden, especially for the lower and middle-class subjects. Furthermore, the USA economy was on the decline particularly during that time due to the Vietnam War in 1965 (Keling et al., 2016).

After the failure in developing Kay Palatometer, the team members developed a new EPG system (Samuel et al., 2005). It was a flexible printed circuit for the EPG palate. The purpose of this development is to save time for manufacturing the artificial palate. The flexible circuit consists of 116 contacts in three intercouple lobes with 36 contacts at the right, 36 contacts at the left posterior of the palate, and another 44 contacts at the lateral of the palate (Figure 2.3).

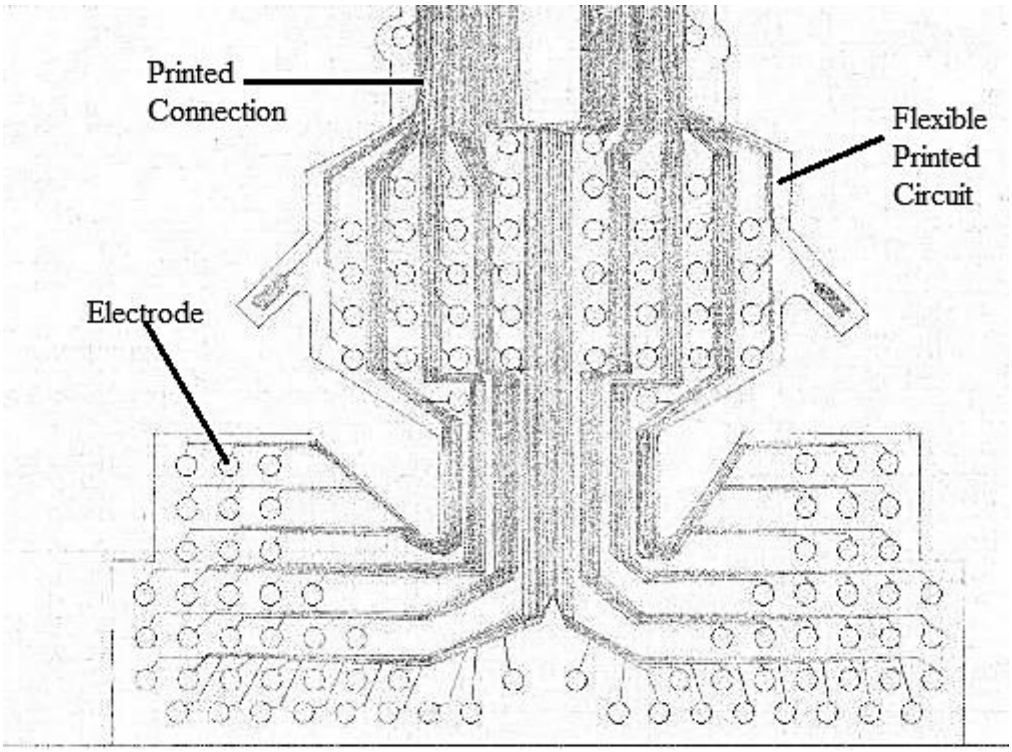


Figure 2.3 The flexible printed circuit (Adapted from Wrench, 2007)

However, this new design also failed to be commercialised due to several limitations such as the flexible printed circuit was unable to be moulded into a small, malformed or high arched palate. Secondly, it was difficult to determine the differences between subjects due to high contact numbers. There were differences between subjects, and the circuit needs to be trimmed to fit each subject properly. The flexible printed circuit also has limited adjustability in electrodes placement as the integrated leads were limited in their reach, and presence of blind spot on the palatal surface where contacts cannot be placed due to the presence of cutouts and tracks. This flexible circuit also has a problem with regards to safety approval since the materials used are exposed within the oral cavity (Wrench, 2007).

In the late 1970s, Japan was the first Asian country to develop a device, which can detect contacts between the tongue and hard palate, known as Rion DP-01 (Figure 2.4) and the artificial palate called Rion Palate (Shibata et al., 1978). It consists of 62 gold electrodes and the palate design did not cover all teeth surfaces as the Kay palate, but it used Adams Clasps clips around the teeth to fit the palate properly during continuous speech.

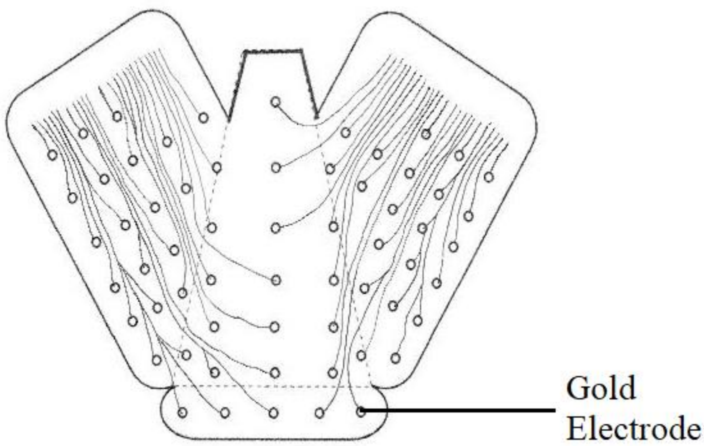


Figure 2.4 The Rion Palate (Adapted from Wrench, 2007)

Rion DP-01 uses Light Emitting Diodes (LED) dependent on direct activation. The sampling rate interpretation is 64 frames per second. The contact patterns and the sounds can be recorded for immediate replay onto a magnetic tape for later analysis (Michi et al., 1993; Suzuki, 1989). The data can be either in real-time or frame by frame. The feedback of the Rion DP-01 system may also be combined with other parameters such as the Multi-Function Speech Training Aid (Michi et al., 1993). The disadvantages of Rion DP-01 system are the high cost of the gold electrodes and time-consuming during manufacturing, which is similar to the Kay Palatometer system.

Therefore, Takinishi et al. (1984) conducted a new research for developing a flexible palate with the aimed to reduce the manufacturing cost. The flexible design was in a range of six sizes and may be fitted without the need for subject impression model (Takinishi & Hattori, 1984). The advantages of the flexible design include cost and time-saving. However, this flexible palate was discontinued because the circuit material was not in accordance with the safety regulation.

In 1980s, the Speech Research Laboratory at the Reading University has developed a new device as a phonetic research tool in Speech and Language Therapy Clinic called Reading system (Gibbon & Hardcastle, 1987). The artificial palate for this system is named as the Reading palate (Figure 2.5).

It consists of 62 silver electrodes, where 31 electrodes are positioned at the left side and another 31 electrodes are at the right side of the palate. The Reading palate is divided into eight rows, where the first row contains six electrodes, while the remaining rows contain eight electrodes. The silver electrode is placed on an acrylic and soldered to a 0.5 m copper wire. Every electrode end is soldered to the circuit board.

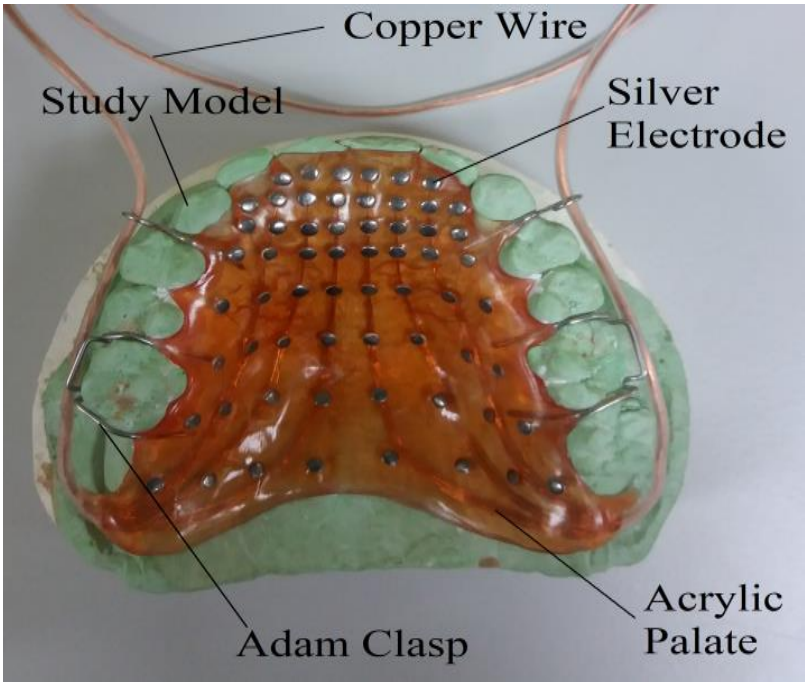


Figure 2.5 The Reading palate

During a speech, the circuit board is connected to a computer. The early version of the Reading system is EPG2 (Arnfield & Jones, 1996). EPG2 is more suitable for therapy since it provides data in real-time. It detects 64 frames per second (Hardcastle et al., 1989). Along with the development of technology, EPG2 has been upgraded to EPG3. The number of electrodes used in EPG3 is similar to the EPG2 and it also uses a computer to display and analyse the data. However, EPG3 detects 100 frames per second and the circuit board has to be connected to a multiplexer. This multiplexer will transfer the data to the computer. EPG3 can be combined with a microphone and sound system during the data collection. A computer software known as Articulate Assistant^{TM} 1.18 was developed in 2003 for data analysis of the EPG3. The software can be installed on a computer.

In contrast, EPG also has several disadvantages. Until now there is no flexible circuit of EPG that has been successfully developed. Even though there were many attempts in developing the flexible circuit, is it very difficult to obtain the approval