Institute of Phonetic Sciences,
University of Amsterdam,
Proceedings 24 (2001), 189-194.

SUMMARIES OF PH.D. THESES DEFENDED IN 2000-2001

TRACHEOESOPHAGEAL SPEECH. A MULTIDIMENSIONAL ASSESSMENT OF VOICE QUALITY

author: Corina J. van As
promotor: Louis C.W. Pols
co-promotores: Frans J.M. Hilgers and Florien J. Koopmans-van Beinum
date of defence: September 26th, 2001

Summary

Annually, approximately 250 total laryngectomies are carried out in the Netherlands. During this surgical procedure, the entire larynx is removed, mostly because of laryngeal or hypopharyngeal cancer. With this removal of the larynx, also the vocal cords are removed, and consequently the natural voice is lost. During a total laryngectomy, caudally, the larynx is separated from the trachea and the remaining tracheal stump is sutured to the skin of the lower neck. This tracheal opening into the neck is called the tracheostoma or plain 'stoma'. Posterior, the larynx is detached from the pharynx. The remaining pharyngeal mucosa and musculature is sutured together in order to re-establish the digestive tract (see also Figures 2.2 and 2.3).

In the majority of the laryngectomized patients, voice rehabilitation is nowadays achieved by means of a voice prosthesis. This device is a one-way valve, placed into a fistula between the trachea and the esophagus, allowing air to pass from the trachea into the esophagus and preventing fluids/food from entering the trachea and lungs. The air insufflated into the esophagus causes vibrations of the pharyngoesophageal mucosa and the resulting sound enables tracheoesophageal speech production.

The anatomy and morphology of the new voice source (neoglottis) are highly variable: the neoglottis can be situated at different levels in the pharyngoesophageal segment (mostly at the level of the cricopharyngeus muscle and/or the middle and inferior constrictor pharyngeus muscles) and has no uniform anatomical size, shape, or location. The neoglottis also does not have the flexibility and volitional controllability of the glottis. Obviously, the neoglottis plays an important role in tracheoesophageal voice production and its characteristics must influence the quality of the voice. However, at present the knowledge about the relations between the neoglottic characteristics and tracheoesophageal voice quality is still limited.

In this thesis, tracheoesophageal voice quality is investigated both perceptually (subjective) and acoustically (objective), and the anatomical and morphologic characteristics of the neoglottis are investigated with videofluoroscopy and digital high-speed imaging. With this multidimensional study insight should be gained into the anatomical and morphologic characteristics of the neoglottis in relation to tracheoesophageal voice quality.

In chapter 1, a short introduction is given about total laryngectomy. The anatomical situation after total laryngectomy and its implications are described briefly. Then, the aims of the thesis and specific research questions are presented, followed by a description of the outline of this thesis.

In chapter 2, the different aspects of total laryngectomy are described in detail. First, classification, demographics, etiology, symptoms and treatment options of laryngeal cancer are described. Then, a historical overview about total laryngectomy is given, the surgical procedure itself is described, and additional surgical procedures, such as pharyngeal reconstruction and radical neck dissection are clarified. Furthermore, the three most widely used methods of voice rehabilitation after total laryngectomy (tracheoesophageal speech, esophageal speech, and the use of an electrolarynx) are explained. Then, the localization and characteristics of the new sound source, the surgical techniques used to influence this sound source, and the mechanism of tracheoesophageal voice production are described. The chapter ends with a section about other physical and psychosocial consequences of total laryngectomy.

In chapter 3, the patients participating in this study are described in detail. In a table, all sociodemographic and clinical patient characteristics are given. Furthermore, for each part of our study an overview of the clinical and sociodemographic factors is shown, since not all patients were able to participate in each part of the study. Additionally, the subgroups used for investigation of the sociodemographic and clinical factors are specified.

Chapter 4 reports about the results of the perceptual evaluations. These evaluations were carried out by 20 naive and 4 trained expert listeners (speech pathologists) on read-aloud text. For the naive listeners, 19 perceptual scales, and for the trained listeners 20 perceptual scales were used for the perceptual evaluations. In addition to the perceptual scale judgments, the trained expert listeners also gave an overall judgment of the voice quality (good, reasonable or poor). On the basis of this overall voice quality judgment, the voice quality was considered to be good in 14 patients, reasonable in 14, and poor in 12 patients.

The results of the perceptual evaluations of the naive listeners showed that they judged the voices reliably and that they perceived tracheoesophageal speech as very deviant. They did not differentiate between the different perceptual scales regarding voice quality. Statistical analysis revealed only two perceptual dimensions for the judgments of the naive raters: pitch and voice quality.

The results of the perceptual evaluations of the trained expert listeners showed that they also judged tracheoesophageal speech reliably, but that they rated the perceptual scales more positively than the naive raters did. Statistical analysis revealed four perceptual dimensions for the trained raters: pitch, voice quality, tonicity and tempo.

Based on the factor analyses in this study, a reduced number of scales for perceptual evaluation of tracheoesophageal speech is proposed. For the naive listeners 4 scales are sufficient and for expert listeners 8 scales are sufficient as a minimal basic

subset that covers the underlying dimensions sufficiently. This reduction makes perceptual evaluations easier applicable in clinical practice.

Although perceptual judgments are considered to be the 'gold standard' for evaluation of voice quality, despite the possible simplifications proposed, it remains a subjective and time-consuming method of evaluation. Objective acoustic analyses, providing quick and reliable measures of voice quality, are therefore an interesting point of investigation in relation to the perceptual evaluations of voice quality.

In chapter 5 the results of acoustic analyses are described. First of all two packages for acoustic analyses were compared: MDVP (Multi Dimensional Voice Program, Kay Elemetrics, Lincoln Park, NJ, USA) and Praat (A System for doing Phonetics by Computer, www.praat.org). It was decided to use Praat, since it enabled reliable pitch extraction in a larger number of voice samples.

The acoustic analyses consisted of 'acoustic signal typing' into four different signal types based on a narrow band spectrogram, in which type I shows the best harmonic structure and type IV is barely harmonic. Furthermore, seven acoustic parameters were calculated.

Acoustic signal typing resulted in 7 type I signals, 13 type II signals, 11 type III signals and 8 type IV signals. The acoustic parameters based on pitch detection algorithms (*fundamental frequency, standard deviation of fundamental frequency*, and *jitter*) could be calculated for 30 out of the 39 voice samples. The remaining 9 voice samples contained no clear periodicity and thereby no fundamental frequency. However, the four acoustic parameters not based on pitch extraction (*percentage of voiced, harmonics-to-noise ratio, glottal-to-noise excitation ratio,* and *band energy difference*) could be calculated for the entire patient group.

Since acoustic analyses can only be considered valuable when they show relations with perceptual evaluations, this chapter also includes investigation of the relations between the acoustic analyses and the perceptual evaluations. It was found that the overall judgment of voice quality was significantly related to the acoustic signal typing: type IV signals were never perceived as good, while type I signals were never perceived as poor. Furthermore, moderate to strong correlations were found between the perceptual dimension pitch and the *fundamental frequency*; the perceptual dimension voice quality and the *percentage of voiced, harmonics-to-noise ratio* and *band energy difference*; and between the perceptual dimension tonicity and the *glottal-to-noise excitation ratio*. These relations suggest that acoustic parameters can be used to replace some of the perceptual evaluations.

In addition to the acoustic measures, also *maximum phonation time* was calculated and related to the perceptual evaluations. Results showed that the better the overall voice quality was, the longer the *maximum phonation time* was. Also, *maximum phonation time* was related to the perceptual scales *jerking-fluent* and *unintelligible-intelligible*, showing that a longer maximum phonation time was related to more fluent and better intelligible speech.

As a result of this study, acoustical analysis, complemented with maximum phonation time, has proven to be a valuable adjunct to perceptual evaluation, with the program Praat as the better choice for experienced investigators.

In chapter 6 the results of videofluoroscopy are described. The videofluoroscopy recordings were obtained in lateral view, during voice production of the sustained vowel /a/. The recordings were evaluated using a newly developed evaluation protocol, consisting of visual assessments and quantitative measures. In order to

obtain the quantitative measures, digitized images of a relevant lateral view of the neoglottis at rest and during phonation were used.

Both the visual assessments and the quantitative measures showed a large variability in the anatomical and morphologic characteristics among the patients. Comparison of the quantitative measures at rest and during phonation showed that in patients after standard total laryngectomy, the *maximal subneoglottic distance at rest* and the *prominence of the neoglottic bar at rest* became significantly larger during phonation, indicating a dynamic change from rest to phonation. Also, the *cervical level of the neoglottis* tended to shift up one half vertebrae from rest to phonation.

Relations between the visual assessments and the quantitative measures showed that part of the visual assessments could be replaced by the more objective and consistent quantitative measures.

Overall, it can be stated, that the standardized evaluation form that was developed (using clear dichotomies and anatomical landmarks for the visual assessments of the situation at rest, when swallowing and during phonation separately), facilitates consensus judgment considerably, and that some of the descriptive visual assessments can be replaced by objective quantitative measures of the neoglottis.

Chapter 7 reports about the results of videofluoroscopy, in relation to the results of the perceptual evaluations of the trained expert raters, the results of the acoustic analyses, and the sociodemographic and clinical factors.

A good overall voice quality and a positive judgment on the perceptual dimension voice quality were related to the *presence of a neoglottic bar during phonation* and to *a normotonic or slightly hypertonic neoglottis*. Some of the more specific perceptual scales were related to *stasis of barium on the neoglottis during phonation* and *regurgitation of barium during phonation*. Also, good voice quality was related to a good neoglottic closure as indicated by some of the quantitative measures of the neoglottis.

The acoustic signal type was better and the percentage of voiced was higher when a neoglottic bar was present. Regurgitation of barium during phonation and hypotonicity of the neoglottis were related to a lower fundamental frequency. Furthermore, the acoustic signal type was better when the neoglottic closure was better according to the quantitative measures of the neoglottis. Also, moderate to strong correlations were found between the quantitative measures and the acoustic measures.

Regarding the sociodemographic and clinical factors, relations were found for the extent of surgery (better neoglottic characteristics in the group after standard total laryngectomy in comparison to the group after partial or full pharyngeal reconstruction), and for neck dissection and age (more favorable neoglottic characteristics in the group that did not undergo radical neck dissection and in the younger age group).

Overall, it can be stated that the developed protocol is useful for the evaluation of anatomical and morphologic characteristics of the neoglottis in relation to voice quality (perceptual evaluation and acoustic analyses) and that the use of quantitative measures is promising towards a more standardized evaluation of videofluoroscopy recordings in tracheoesophageal speech.

Chapter 8 is a methodological and descriptive chapter on the use of digital high-speed imaging for the evaluation of anatomical and morphologic characteristics of the neoglottis as seen from above ("bird's-eye view"). In normal laryngeal voices the use

of stroboscopy in order to obtain a slow-motion image of vocal fold vibration is rather common in clinical practice. Digital high-speed imaging has the clear advantage over the more widely applied stroboscopy, that it does not require regular vibrations of the voice source in order to obtain reliable dynamic recordings of these vibrations. Since the vibrations of the neoglottis are often irregular, we chose to use digital high-speed imaging with 2000 frames per second, instead of stroboscopy. Digital high-speed imaging is at present still more used as a research tool, but is developing towards a clinically useful instrument rapidly. To the best of our knowledge, the present study was the first one to investigate the usefulness of digital high-speed imaging for investigation of the vibratory behavior of the neoglottis.

The recordings were obtained with a rigid endoscope transorally, while the patient was phonating a sustained vowel /a/. The recordings were evaluated by means of a newly developed assessment form.

The results of the visual assessments showed a wide variability in all anatomical and morphologic characteristics of the neoglottis studied. Various different *shapes of the neoglottis* and *locations of the vibration* were observed, the *amount of saliva* seen was variable and differed among the patients, the *closure phase* differed, and a *mucosal wave* was strong in some cases, but weak or absent in others. The *vibration of the neoglottis* was irregular in 66% of the patients.

Overall, digital high-speed imaging appeared to be a useful tool for obtaining more insight in the anatomical and morphologic characteristics of the neoglottis, not only in those with a regular vibration, but also in those with an irregular vibration. Useful recordings could be obtained for the majority of the patients.

In chapter 9 the results of the visual assessments of high-speed digital imaging, are related to the results of the perceptual evaluations of the trained expert raters, the results of the acoustic analyses, the results of videofluoroscopy, and the sociodemographic and clinical factors.

A good overall voice quality was related to the *visibility of the origin of the neoglottis*. In relation to the more specific perceptual scales, the visual assessments of the *amount of saliva*, the *origin of the neoglottis*, the *shape of the neoglottis* and the *regularity of the vibration* appeared to be of importance.

The acoustic signal type was better when *the amount of saliva* was smaller and when the *origin of the neoglottis* was visible. In relation to the acoustic measures, the *amount of saliva*, the *shape of the neoglottis*, and the *regularity of the vibration* were found to have some influence.

The *presence of a neoglottic bar at rest, regurgitation of barium during phonation*, and the *tonicity of the neoglottis* judged in the videofluoroscopy recordings were found to be related to the *amount of saliva* judged in digital high-speed recordings. The *presence of a neoglottic bar at rest* judged in videofluoroscopy recordings was related to the *visibility of the origin of the neoglottis* and to the *shape of the neoglottis* judged in digital high-speed imaging. Furthermore, some quantitative measures obtained from the videofluoroscopy recordings were related to the *amount of saliva* judged in the digital high-speed imaging recordings.

Regarding the sociodemographic and clinical factors, relations were found for the extent of surgery (better neoglottic characteristics in the group after standard total laryngectomy in comparison to the group after partial or full pharyngeal reconstruction), and whether or not a myotomy has been carried out.

This study shows that digital high-speed imaging can provide valuable extra information about the neoglottic characteristics in relation to tracheoesophageal voice

quality. In relation to videofluoroscopy it can be seen partly as additional information and partly as an overlap. Future possibilities for automated objective analyses of the high-speed recordings will increase their usefulness for research and in clinical practice even more.

This thesis ends with chapter 10 in which the results are discussed in relation to the aims presented in chapter 1, a proposal is formulated for a clinical evaluation protocol and the general conclusions are presented. The chapter ends with future perspectives and suggestions for further research into this subject.

The clinical evaluation protocol that is formulated, is based on the studies described in this thesis and consists of a basic subset of perceptual scales, some acoustic parameters, and videofluoroscopy recordings. Depending on the goal of the evaluations, other methods of investigation, such as manometry or the Voice Handicap Index, can be added, or the number of perceptual scales or acoustic parameters studied can be enlarged. Although digital high-speed imaging has proven to give valuable information complementary to videofluoroscopy, it is not included in the basis protocol, since it is not yet widely used as a clinical diagnostic tool and still under development towards that.

In general, it can be concluded that, although tracheoesophageal speech is the best possible and generally well functional communication method presently available, it is still considerably deviant from normal speech. Especially perceptual judgments of naive raters show this deviancy. The perceptual judgments of the trained speech-language pathologists were more positive than those of the naive listeners. This could of course be expected since the speech-language pathologists are used to this type of speech and they have an extensive knowledge about the anatomy and morphology of the new voice source. The judgments of the speech-language pathologists are therefore more relevant in relation to clinical practice and more useful to serve as a standard for the other evaluation methods used in the present study.

Acoustic analyses confirmed the deviant voice quality found by means of the perceptual evaluations. The moderate to strong correlations between the perceptual evaluations and the acoustic measures show that part of the acoustic measures is suitable to replace the more subjective and time-consuming perceptual evaluations. An acoustic signal typing system as proposed in this thesis also showed to be relevant in relation to voice quality.

Furthermore, a number of parameters were found that related voice quality in some way to the anatomy and morphology of the neoglottis. These parameters can serve as a basis for future research and for evaluation of tracheoesophageal speech in clinical practice. The improved knowledge about neoglottic characteristics that are important for voice quality, might, in future, lead to adjustments of surgical techniques at the time of surgery, in order to achieve optimal and predictable voice quality. Furthermore, at a secondary stage it might be possible to develop surgical techniques based on the knowledge obtained in this study.

Institute of Phonetic Sciences,
University of Amsterdam,
Proceedings 24 (2001), 195–196.

Mechanical aspects of hearing

author: Jan S.C. van Dijk
promotor: Louis C.W. Pols
copromotor: Egbert de Boer
date of defence: February 20th 2001

Summary

In this work we studied several models that describe the filter properties of the inner ear. In order to explain the observed frequency selectivity in a healthy cochlea, it appears to be necessary to introduce additional forces, caused by outer hair cells, in those models. Proposals for such forces are made.

In the first chapter we started with a brief survey of the peripheral auditory system. An important part of this system is the cochlea, the receptor organ of hearing. Inside this organ sound is translated into a neural message.

In the second chapter the basilar membrane is conceived as a system of parallel fibres or beams. The forced motion of an isolated membrane fibre is described. In order to do that we applied a description in terms of eigenvibrations. The lowest order eigenvibration of a beam mainly models the local properties of the basilar membrane. Because the lengths of successive beams increase as a function of the distance to the stapes, the basilar membrane represents a frequency analysing system. Results of this chapter slightly differ from what is found in the literature.

An important part of the direct environment of the basilar membrane is fluid or is fluid-like and incompressible. This implies that the pressure in the environment of the membrane has to obey Laplace's equation. Consequences of this property are the topic of chapter 3. We first formulated a two-dimensional boundary value problem for the pressure in the cochlear fluids. The difference between the equation of motion for the basilar membrane and the equation for the surrounding fluid yields an inhomogeneous mixed type boundary condition. Formal properties of the model and properties of the solution are discussed. Until now we neglected singularities that are caused by the motion of the basilar membrane. In consequence of this, the solutions according to the method(s) from this section are of limited importance. It appears that a three-dimensional approach hardly leads to new insight.

In the frequency domain the boundary condition for the pressure at the membrane has the shape of a homogeneous equation. In chapter 4 we solved this equation as an equation in the complex plane and looked for consequences. From the solution filter characteristics for an arbitrary point of the membrane are determined. In order to model hair cell activity, an extension of the equation for the pressure is proposed. Results that follow from the extended equation bear a comfortable resemblance with actual results of measurements.

The (mean) height of the cochlear scalae is rather small. This offers the opportunity to approximate the normal derivative of the pressure at the membrane by a term proportional to the second derivative of the pressure along the membrane. The approximation modifies the mixed boundary condition for the pressure at the

membrane in a second order equation. This equation belongs to the well-known class of long-wave or transmission-line equations. In chapter 5 we investigated properties in consequence of this way of working. From a mathematical point of view, the approximation can be justified 'far' from the point of resonance. However, near the point of resonance we are not able to prove the validity of the approximation. The equation is applicable as a substitute for the mixed type boundary condition for the pressure. This simplifies the boundary value problem for the pressure enormously. Because equations of this kind are often used in applications, we investigated properties of solutions from different points of view. An ordering of the results shows a systematic overview of the main features according to this approach. In the last part of this section we introduced in the equation of the pressure an additional term, that could simulate consequences of hair cell activity. Both filter characteristics and impulse characteristics for an arbitrarily point of the membrane are determined.

The first part of the last chapter gives a generalisation of the main results from chapter 3. In this part it holds too that the presence of singular points sets bounds to the general validity of the methods used. The generalisation offers the opportunity to incorporate additional forces in the equation of motion for the basilar membrane from a quite general point of view. Some proposals for additional forces from the literature will be discussed. In the second part examples of systems of coupled filters will be given. This part is closely related to results from chapter 4 and 5. We applied the classical technique of conformal mapping. This yields, both in the analytical and in the approximate case, a system of filters that is applicable in practice. The chapter ends with examples of known sound stimuli in terms of peripheral activity patterns. These patterns are a natural spectro-temporal image of the stimulus of the auditory nerve.

Institute of Phonetic Sciences,
University of Amsterdam,
Proceedings 24 (2001), 197-199.

ASPECTS OF PHARYNGEAL COARTICULATION

author: Ahmed M. Elgendy
promotor: Louis C.W. Pols
date of defence: February 27th, 2001

Summary

This investigation deals with pharyngeal articulation in general, with a focus on its dynamic aspects as observed in spoken contemporary Egyptian Arabic. Pharyngeal articulation as a linguistically distinct speech sounds is rarely used among the languages of the world. In Arabic, however, the pharynx is frequently used to produce distinct phonemes both as primary as well as secondary place of articulation, i.e., true pharyngeal and pharyngealized consonants, respectively. When designing the present study we aimed to resolve the confusion found in the literature concerning the phonetic description of pharyngeal and pharyngealized articulation. The following is an overview of the scope of the present study. This book comprises two parts which contain eight chapters. Part 1 includes an introductory chapter and three other chapters describing various experiments we conducted to investigate several aspects of pharyngeal articulation and coarticulation in Arabic. Part II comprises one chapter which presents a model of pharyngeal articulation, two other chapters which report two experiments intended to test the model and a final chapter for general discussion and a main conclusion.

Chapter 1 provides a general introduction to the structure of the Arabic language. We also search for a definition of pharyngeal articulation and give a brief account on the anatomy and physiology of the pharynx to substantiate that definition. In order to motivate the present study, we state some phonetic and phonological observations concerning pharyngeal articulation, nasalization and laryngealization. We relate, based on x-ray pictures available from some previous studies, the peculiar shape of the tongue and the relatively unusually large jaw opening associated with pharyngeal consonant production, to the complexity of pharyngeal consonant production. Our main hypothesis is derived from some anecdotical observations, both phonetic and phonological in nature, and are stated and are supported by basic knowledge about the acoustics of pharyngeal articulation. The way pharyngeal consonants are pronounced by bilingual speakers of Greek and Italian minorities in Egypt, by non-native speakers learning Arabic as a second language and by young native children, prompts us to examine the process of acquisition of pharyngeal consonants by native and non-native speakers of Arabic. In addition some phonological observations such as vowel lowering and vowel /a/ insertion before pharyngeal consonants are also stated. Perceptual judgement, when listening to utterances containing pharyngeal consonant, indicates a substantial degree of nasality associated with pharyngeal consonant

production. One of the aims of this study is to verify whether there exists a connection between nasal and pharyngeal articulation.

We address the questions: is pharyngeal articulation simple or complex? Does pharyngeal articulation involve only retraction of the tongue root in order to reduce the size of the pharyngeal cavity as it is implicitly understood according to some previous studies? The problem treated in the thesis are stated in chapter 1 together with our formulated hypothesis. A brief account on theories of coarticulation is also given in chapter 1.

Chapter 2 reports on the experiment we conducted to investigate the shape of the back cavity during pharyngeal consonant production. We use a video registration of motion pictures of the top view of the three pharyngeal compartments, i.e., naso-, oro- and laryngeo-pharynx using the fiberoptic technique. The articulatory dynamics, associated with the production of a set of consonants that take place in the back cavity of the vocal tract, were monitored using a nasal fiberscope. The findings could provide a rigorous account on the nature of interaction between nasal, pharyngeal and laryngeal articulation. Also, the results revealed the mechanically complex process of pharyngeal consonant production which turned out to be an activity involving several other articulators than the tongue in their articulation.

Chapter 3 deals with the kinematics of the jaw trajectory. The movements of the mandible and the lips were studied in order to determine whether there is any specific movement pattern associated with the production of various pharyngeal consonants at different constriction locations in the pharynx. It is commonly known that during the production of most of the oral consonants the primary gesture is that made by the tongue. The role of the jaw is considered to be secondary in this case. The main question addressed in this chapter is whether the jaw is involved in pharyngeal consonants production. The behavior of the jaw indicated that pharyngeal consonants do involve the jaw in their production. Therefore we proceeded further to investigate the acoustical aspects of pharyngeal articulation.

Chapter 4 is devoted to the acoustic characteristics of pharyngeal articulation, particularly to provide support for the physiological and kinematics data collected and reported in the previous chapters. Acoustic analysis was carried out on the same set of pharyngeal and laryngeal consonants. The main findings show that the acoustic signal reflects, to a certain extent, some of the physiological features characterizing pharyngeal consonant production which were manifested as articulatory gestures. The acoustic and physiological data obtained from our experiments and from other studies, enabled us to construct a model of pharyngeal articulation.

Chapter 5 describes how we can dynamically model pharyngeal articulation to account for pharyngeal coarticulation. The findings gathered from the series of experiments we conducted were integrated in order to construct a dynamic model of pharyngeal coarticulation. The model was tested first by examining its ability to account for the delay observed in the acquisition of pharyngeal articulation by native speakers, and second by examining the model viability to predict the constraints on the distribution patterns in Colloquial Egyptian Arabic. A delay in the acquisition time of this set of speech sounds may also occur due to the excessive degree of jaw lowering which is a tedious act for children to acquire until a later period of time. The pharyngeal consonants are mechanically complex segments and they exert severe constraints on the co-occurrence restrictions among consonants in Arabic. This in turn affects the entire structure of Arabic language on various levels.

Chapter 6 investigates the acquisition of pharyngeal consonant production by bilingual children. Our previous findings on the characteristics of pharyngeal articulation gave rise to the question whether native and non-native speakers of Arabic may encounter any difficulty while acquiring pharyngeal consonants, and if so, why and in what way? We attempted to capture a solution for that problem by explaining the effect of the complex pharyngeal consonants on the development of the motor skills of native children in terms of the process of acquisition of pharyngeal articulation.

Chapter 7 examines the phonotactics of Colloquial Egyptian Arabic. We focused on the pharyngeal consonants distribution patterns and the type of restrictions imposed on this class of speech sounds. It appeared clearly that the mechanical factor has a severe impact on the production of the true pharyngeal consonants. The probable effect this factor might exert on the surrounding consonants in a word, made it worthwhile to examine the distribution of this class of speech sounds in relation to the overall structure of the language under investigation. Thus, the distribution patterns of the pharyngeal consonants were stated in terms of a set of rules governing the phonotactics of spoken Egyptian Arabic. The results of this investigation pointed out the predominant effect of the mechanical constraints, rather than the perceptual (acoustic) constraints, on shaping the overall structure of the entire language system.

A general conclusion is offered in chapter 8. In this final chapter, the main findings we obtained are discussed and gathered to support our definition of pharyngeal articulation/coarticulation and the innovated phonetic classification of Arabic consonants we offered. The limitations the present study suffered from, are stated and some suggestions for future research work evoked by our study, are presented.