

# Aspects of Pharyngeal Coarticulation



# Aspects of Pharyngeal Coarticulation

## **Academisch proefschrift**

ter verkrijging van de graad van doctor

aan de Universiteit van Amsterdam,

op gezag van de Rector Magnificus

prof. dr. J.J.M. Franse

ten overstaan van een door het

college voor promoties ingestelde commissie

in het openbaar te verdedigen in de Aula der Universiteit

op dinsdag 27 februari 2001 te 12.00 uur

*door*

**Ahmed Mostafa Saleh Elgendy**

geboren te Alexandria-Egypte

Published by  
LOT  
Trans 10  
3512 JK Utrecht  
The Netherlands  
phone: +31 30 253 6006  
fax: +31 30 253 6000  
e-mail: [lot@let.uu.nl](mailto:lot@let.uu.nl)  
<http://www.let.uu.nl/LOT/>

Aspects of Pharyngeal Coarticulation/ Ahmed M. Elgendy

Cover design: A.M. Elgendy

ISBN: 90-76912-10-6

Copyright © 2001 by Ahmed Elgendy. All rights reserved.

Printed in the Netherlands

# Contents

<b>Acknowledgements</b>	<b>vi</b>
<b>Overview</b>	<b>vii</b>
<b>PART 1: ON DEFINING PHARYNGEAL ARTICULATION</b>	<b>1</b>
<b>1 Pharyngeal articulation</b>	<b>3</b>
Abstract	3
1.1. Introduction	3
1.1.1. The use of the pharynx in speech production	3
1.1.2. Primary versus secondary pharyngeal articulation	6
1.1.2.1. Pharyngeal articulation in Arabic	7
1.2. Outlines of the structure of the Arabic language	9
1.3. Diglossia	10
1.4. Outlines of the phonology of Colloquial Egyptian Arabic	11
1.4.1. Speech sound system	11
1.4.2. Stress and syllabic structure	12
1.4.3. Quantity	12
1.4.4. Emphasis as a prosodic parameter	12
1.5. The problem of defining pharyngeal articulation	13
1.5.1. Pharyngeal articulation and pharyngealization in Arabic	13
1.5.2. Pharyngeal consonants in emphatic environment	14
1.6. The structure of the pharynx	15
1.7. Mechanism of pharyngeal articulation	16
1.8. Physiological and anatomical accounts related to pharyngeal articulation	17
1.8.1. The Pharynx	17
1.8.2. The Tongue	19
1.8.3. The Jaw	19
1.8.4. The Larynx	20
1.8.5. Relation between laryngeal activities and jaw position	22
1.9. Coarticulation	23
1.9.1. Sources of coarticulation	23
1.9.2. Models of coarticulation	26
1.10. Statement of the problem	27
1.10.1. Pharyngeal articulation and sound change	28
1.10.2. Pharyngeal articulation in pathological speech	30
1.10.3. Jaw and pharynx interaction	30
1.10.4. Pharyngeal coarticulation	31
1.11. Review of the literature on pharyngeal articulation in Arabic	32
1.11.1. Physiological data on pharyngeal consonants production	32
1.11.2. Acoustic and perceptual studies on Arabic pharyngeals	40
1.11.3. The phonology of pharyngeal consonants in Arabic	42
1.12. Scope of the present study	43
<b>2 Dynamic aspects of pharyngeal coarticulation</b>	<b>45</b>
Abstract	45
2.1. Introduction	46

2.2. Experimental procedures	47
2.2.1. Fiberscope: preparation and insertion	47
2.2.2. Subjects	49
2.2.3. Speech material	49
2.2.4. Data recording	50
2.2.5. Synchronizing	50
2.2.6. Data analysis	52
2.2.6.1. Film processing	52
2.2.6.2. Spectrographic analysis	52
2.2.6.3. Data reduction procedures	52
2.3. Results	53
2.3.1. The state of the velum	54
2.3.2. The state of the pharyngeal wall	55
2.3.3. The state of the epiglottis cartilage	59
2.3.4. The state of the glottis	67
2.4. Discussion	73
2.4.1. Pharyngeal articulation and deglutition	73
2.4.1.1. The shape of the vocal tract during swallowing	73
2.4.1.2. Mandible position and the shape of the tongue during swallowing	75
2.4.1.3. The muscles involved in the pharyngeal phase of swallowing	76
2.4.1.4. Mechanism of pharyngeal coarticulation	76
2.4.1.5. The synergies of pharyngeal articulation and deglutition	79
2.4.1.6. Innervation of swallowing	80
2.4.2. Interaction between pharyngeal, laryngeal and nasal articulation	80
2.4.2.1. Velopharyngeal port opening and closing gestures	80
2.4.2.2. Laryngeal constriction and bending of the epiglottis	81
2.4.2.3. Pharyngeal wall displacement	82
2.4.3. Explaining inter-speakers variability	83
2.4.4. True pharyngeal consonants	83
2.4.5. The shape of the glottis during pharyngeal articulation	83
2.4.6. Cleft palate speech and pharyngeal articulation	84
2.4.7. Summary	84
2.5. Conclusion	85
Appendix 2.1	87
<b>3 Jaw contribution to the timing control of pharyngeal consonant production</b>	<b>89</b>
Abstract	89
3.1. Introduction	90
3.1.1. The role of the jaw in speech production	90
3.1.1.1. Jaw height, sonority and speech development	91
3.1.1.2. Jaw height and prosody	93
3.1.1.3. The jaw and articulatory modeling of speech	93
3.1.2. Jaw dynamics and pharyngeal articulation in Arabic	95
3.1.2.1. The role of the jaw in Arabic consonant production	95
3.1.2.2. The role of the jaw in Arabic prosody	97
3.1.3. Hypothesis	98
3.2. Experimental procedures	98
3.2.1. Setup for jaw kinematics registrations	98
3.2.2. Speech material	99
3.2.3. Data registration and reduction	100
3.2.4. Experimental design	101

3.3. Results	103
3.3.1. Experiment I: inherent jaw height for consonants	103
3.3.2. Experiment II: classification of consonants jaw height	107
3.3.3. Experiment III: position effect on jaw displacement	112
3.3.4. Experiment IV: effect of pharyngeal consonant on vowel jaw height	113
3.3.5. Experiment V: effect of inherent vowel jaw height on consonants	116
3.3.6. Summary of the results	119
3.4. Discussion	120
3.5. Conclusion	123
Appendix 3.1	125
Appendix 3.2	126
<b>4 Acoustic attributes of articulatory dynamics in the pharynx</b>	<b>129</b>
Abstract	129
4.1. Introduction	130
4.2. Background	131
4.3. Experimental procedures	132
4.3.1. Speech material	133
4.3.2. Recordings	133
4.3.3. Data analysis	135
4.4. Results and discussion	136
4.4.1. Fundamental frequency for [ʔ] and [l]	136
4.4.2. Formants frequencies	139
4.4.3. F1 amplitude and bandwidth	142
4.4.3.1. Nasal and oral airflow of pharyngeal consonants in Egyptian Arabic	148
4.4.4. The duration of the vowel in the vicinity of a pharyngeal consonant	149
4.5. Conclusion	154
Appendix 4.1	156
Appendix 4.2	157
<b>PART 2: TOWARDS MODELING PHARYNGEAL ARTICULATION</b>	<b>159</b>
<b>5 Dynamic modeling of pharyngeal articulation</b>	<b>161</b>
Abstract	161
5.1. Introduction	162
5.1.1. Modeling pharyngeal articulation	163
5.2. The Model	165
5.2.1. The cognitive plan: the “Concept”	166
5.2.1.1. Arabic word structure in relation to pharyngeal articulation	167
5.2.2. The articulatory plan	168
5.2.3. The motor plan	170
5.3. Dynamic modeling of pharyngeal articulation	171
5.4. Vocal tract configuration for pharyngeal consonants	173
5.4.1. Dynamics of pharyngeal articulation	173
5.4.1.1. Shape change in the back cavity	174
5.4.1.2. Jaw Dynamics	174
5.5. Components integration	174
5.6. Modeling	177
5.6.1. Acoustic modeling of pharyngeal articulation	180
5.6.2. Nasal oral air flow during pharyngeals	180
5.6.3. Acoustic and perceptual data on Arabic pharyngeals	181

5.6.4. Acoustic affiliations of the articulatory dynamics for pharyngeal consonant production	182
5.7. Towards acoustic modeling of pharyngeal consonants	182
5.8. Concluding remarks	183
5.9. Testing the model	184
<b>6 The acquisition of pharyngeal articulation</b>	<b>187</b>
Abstract	187
6.1. Introduction	188
6.1.1. Adults	189
6.1.2. Children	190
6.1.3. Hypothesis	190
6.2. Background	190
6.2.1. Phonological development	191
6.2.1.1. Lexical acquisition	192
6.2.1.2. Phonology acquisition	193
6.2.1.3. Arabic children with two unrelated phonologies	194
6.3. Experimental procedures	194
6.3.1. Subjects	194
6.3.2. Recordings	195
6.3.3. Material	197
6.3.4. Data Analysis	198
6.4. Results	199
6.4.1. Children	199
6.4.2. Adult	208
6.5. Discussion	209
6.6. Conclusion	211
Appendix 6.1.a	213
Appendix 6.1.b	214
Appendix 6.2.a	215
Appendix 6.2.b	216
<b>7 Phonetic basis of Arabic phonotactics</b>	<b>217</b>
Abstract	217
7.1. Introduction	218
7.1.1. Universal aspects of phonological structure	218
7.1.2. Co-occurrence restrictions	219
7.2. Background	222
7.2.1. Phonotactics of pharyngeal consonants	222
7.2.2. The phonology of pharyngeal consonant in Arabic	225
7.3. Hypotheses	226
7.4. Data analysis	226
7.4.1. Consonants arrangement in the Matrix	227
7.4.2. Special cases in the consonants inventory of CEA	229
7.5. Analysis procedures	230
7.5.1. Corpus	230
7.5.2. Statistical analysis	230
7.6. Results	232
7.6.1. Long vowels context	232
7.6.2. Short vowel context	235
7.6.3. Manner of articulation	240

7.6.4. Pharyngeal consonants in relation to other consonants	242
7.6.5. Statistical results	245
7.6.5.1. Jaw height classification	245
7.6.5.2. Manner of articulation classification	246
7.7. Discussion	249
7.8. Conclusion	256
Appendix 7.1	258
Appendix 7.2	260
<b>8 General discussion and conclusion</b>	<b>283</b>
Abstract	283
8.1. Introduction	284
8.2. Defining pharyngeal articulation in Arabic	284
8.2.1. Dynamic aspects of pharyngeal coarticulation	285
8.2.1.1. The secondary role of the tongue during pharyngeal articulation	287
8.2.1.2. The secondary role of the pharynx during emphatic consonants	287
8.3. Acoustic affiliations of pharyngeal articulation dynamics	288
8.4. Jaw contribution to pharyngeal consonant production	288
8.5. Modeling pharyngeal articulation	289
8.6. Co-occurrence restrictions affecting pharyngeal consonants	290
8.7. General conclusion	291
8.8. Future research	291
<b>References</b>	<b>293</b>
<b>Summary</b>	<b>313</b>
<b>Samenvatting</b>	<b>315</b>
<b>Arabic Summary</b>	<b>317</b>
<b>Index</b>	<b>319</b>



## Acknowledgments

This work might not have materialized without the support and contributions of many people. I learned a great deal from the members of my examining committee and those who commented on the reading version of this dissertation, John Ohala, Paul Boersma, Manfred Woidich, Harry Stroomer, Hartmut Traummüller, Muhammad Bakalla, Rob van Son and Björn Lindblom. I am grateful to the colleagues of the Institute of Phonetic Sciences of the University of Amsterdam for providing an intellectually stimulating atmosphere and a cross-disciplinary setting crucial to this study at its final stage. Thanks are due to Barbertje Streefkerk, Caroline Schwippert, David Weenink, Dirk Jaasma and Ton Wempe for the technical and practical help I received from them in several occasions.

Very special thanks go to Louis Pols for comments on the final draft of the manuscript, numerous valuable discussions, moral support as well as for his understanding to my situation upon moving from Stockholm University to join his team in Amsterdam. Here I got the opportunity to have freedom of thoughts and expression.

Many of the ideas presented in this book were refined by discussions over several years with many people, Abeer Alwan, Anders Löfqvist, Anna-Lena Happanen, Ashraf Al-Khayri, Eva Holmberg, Eva Gårding, Gärda Ericsson, Jared Bernstein, Jeanette Blomquist, Jim Lubker, Johan Liljencrants, Karl-Erik Spens, Kenneth Stevens, Kiel Norlin, Lennart Nord, Louis Goldstein, Marian Macchi, Mary Beckman, Mats Blomberg, Nina Grønnum-Thorsen, Nobuyuki Nonaka, Patricia Keating, Peter Branderud, Robert Bannert, Robert Port, Salman Al-Ani, Sidney Wood, Stuart Davis, the late Vicky Fromkin, and many other colleagues at Utrecht University, Stockholm University and KTH.

I am particularly indebted to Björn Fritzell and Per-Åke Lindstad for providing me with their medical expertise and their facilities during the years 1985 and 1986 while collecting the data for the fiberoptic experiment in Huddinge University Hospital, Sweden. Thanks also are due to Katherine Harris, Hajeme Hirose, Peter Ladefoged and John Ohala for their invaluable comments and illuminations on parts of my video films during the ICSLP'92 conference in Canada.

I am grateful to Mohamed Mrayati for supplying me with some of his computer-generated database on Arabic phonotactics. My sincere thanks also go to the tens of informants provided me with the bulk of the test material used in various experiments, especially those who had to suffer from the fiberoptic tube stuck in their nose for hours, and those wonderful bilingual children who increased my inquisitiveness in speech communication.

I am grateful to the Stockholm University for granting me the doctoral scholarship to support this project during the years 1989-1994.

