Phonetic Complexity

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Complexity?

- Concept of complexity : evokes a number of elements with numerous and various relationships.
- Elements, data, observations difficult to analyze, to explain
- For speech production: It usually refers to the difficulty to produce given segments or specific sound sequences.
- Does it depend on the entire task or on a specific part of it? , the programming of speech,

Does the complexity depend upon the type of speech, the nature of task, the context ?

- Type of verbal communication
  - Nature of information to be transmitted
  - Prior knowledge
  - Neutral - Emotional
  - Conversation (informal to formal)
  - Natural vs « lab speech with all its variants »

- Nature of task
  - Free speech
  - Reading aloud
  - Naming
  - Repeating,

- Context, Circumstances
  - Ecological
  - Face to face
  - Distant
  - Experimental conditions (silent, noisy....), with various devices...)

Phonetic complexity

- The concept of phonetic complexity is not easily defined
  - Theory–driven vs data-driven approaches

- Often confused with phonological complexity
  - SPE vs Maddieson's Patterns of sounds and the UPSID database

- Which level is relevant to characterize phonetic complexity?
  - Features, gestures, phonemes, phones and allophones
  - Syllables, types of syllables, position in the syllable, in the word, in the syntaxic goup, in the sentence, phonotactic constraints
  - Consonantal sequences, number and type of consonants in these groups, number of syllables (open, close),
  - Frequency of phonemic sequences

- Perplexity between what seems phonologically relevant and the physical properties of actual speech sounds

Complexity

- Phonological complexity:
  - The definition of phonological complexity varies depending on the theoretical framework: economy of features, hierarchical representation, markedness issue…(SPE # OT)
- Principle of economy of description: what relation, if any
  - To production conditions
  - To production ease
  - Or to production cost?
- The concept of phonetic complexity embraces many additionnal interrelated dimensions:
  - ....

Complexity?: which dimensions?

- *Speech = output*
- Cognitive load:
  - From intention to message?
  - Cognitive level, Linguistic competence
- Neural level:
  - Cortical, transmission, afferent/efferent circuitry
- Execution issue:
  - Neuro-muscular level
  - Articulation
  - Physiology
  - Coordination

Execution: Articulation

Articulators:

- Mass of articulator
- Inertial properties of articulator
- Mobility, speed of articulator
- Simultaneous activity of multiple sets of articulators
- Overlapping of activities: coproduction

- Target
  - Trajectories
  - Gestures
  - Distance from neutral position

Execution: Articulation

- Energy expenditure
- Articulatory control
- Phasing

- **Difficulty to attain or to maintain certain adjustments**:
  - Degree of stiffness
  - Particular skills
    - Aerodynamic requirements
    - Type of movement : ballistic vs fine tuned

Execution issue: Physiology

- **Number** of physiological systems and subsystems involved
- **Degree** of participation of the various muscles which are recruited to achieve a given articulatory target
- **Coordination** between respiratory, laryngeal, pharyngeal, nasal, oral and labial systems and sub-systems
  - **Spatial** coordination
  - **Temporal** coordination: timing of tasks, phasing of gestures
- **Coproduction** constraints
  - Compensatory mechanisms : feedback, reflex loop,
  - Central control vs peripheral adjustments

Production issue: Physiology

- **Competition** with vital functions
  - Respiration, chewing, swallowing…
  - Speech = a load on respiration
- **Control** mechanisms: nature of afferent information vs virtual trajectories…
  - Interactions between the cognitive and neuro-muscular levels
  - Correction procedures to reach the goal
- **Economy** of effort > **Cost** minimization vs Distinctiveness

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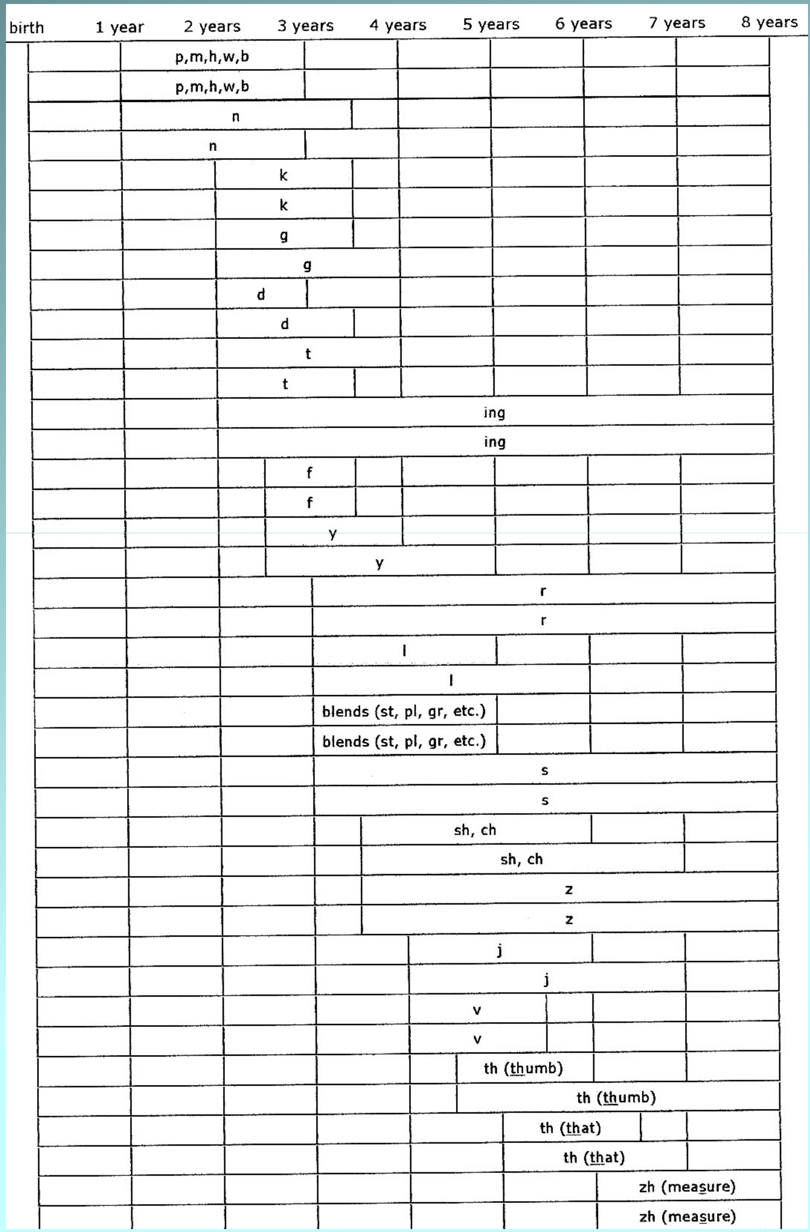
- Are there levels of difficulty which can be identified?

Phonetic complexity?

- In search for evidence of phonetic complexity?
- Any link to performance differences at various stages of speech acquisition?
- Does phonetic complexity help to explain the emergence of phonological systems as reflected in the phoneme inventories of the languages of the world?
- Or and to differences in speech perturbation due to a number of pathological conditions?

Acquisition chart by Bowen, 1998



- **Speech acquisition**
- The children generally master the speech sounds over a 5-7 years period of time. One may consider that the progresion of acquisition is a fair indication of the growing difficulty to program, to execute and to control the production of certain sounds.

Speech acquisition

- Jakobson (1949): first attempt to link formal linguistic theory to empirical study of language acquisition. Theory of developmental order of acquisition
- Jakobson proposes that the concept of maximal contrast dictates the order of acquisition of phonological oppositions.
- In general, the broad contrasts are acquired first. Gradually the contrasts become more subtle.
  - Consonant vs Vowel ; maximum closure > maximum open > [pa]
  - Voiceless > Voiced (Nasal) >p/m
  - Stops > Fricatives > Affricates
  - Front C > Back C - Labial > Alveolar > Velar

Speech acquisition

- Dinnsen et al., (1990): Large review of english speaking children performance
  - Five different levels of sound classes in terms of Chomsky & Halle's features:

Level A:	[consonantal]
	[sonorant]
	[coronal]
Level B:	[voice]
	[anterior]
Level C:	[continuant]
	[delayed release]
Level D:	[nasal]
Level E:	All features, all contrasts

Feature based approach to phonetic complexity of individual segments,

For words, an Index of phonetic complexity by Jakielski

Index of Phonetic Complexity. IPC Metrix , Jakielski (1998)

#	Factor	No score (easy)	One point each (difficult)
1	Consonant by place	Labials/coronals/glottals	Dorsals
2	Consonant by manner	Stops/nasals/glides	Fricatives/affricates/liquids
3	Vowel by class	Monothongs/diphthongs	Rhotics
4	Word shape	Ends with vowel	Ends with consonant
5	Word length (number of syllables)	Monosyllabic/ Bisyllabic	>/= Three syllables
6	Singleton consonants by place	Reduplicated, e.g., VC–VC	Variegated, e.g., VC-CV
7	Contiguous consonants	No clusters	Clusters
8	Cluster type	Homorganic	Heterorganic

- Each word is assigned a sum of scores along eight phonetic factors
- Easy = early mastered
- Difficult= not occuring in the babbling stage
- Although very often cited
- No clear scientific motivation
- Poor explanatory power

Phonological / Phonetic deviations

- Strong parallelism between delay in phonology development in children with some specific language problems and the progression of acquisition by normal children.
- Strong link between phonological complexity and production errors.
- Concerning some speech pathologies, latest acquired structures are the first to be affected.

Voicing: pig > big; car > gar

Final devoicing: red > ret; bag>back

Final deletion: home> hoe; calf> cah

Velar fronting: kiss > tiss ; give >div

Palatal fronting: ship < sip

Cluster reduction: spider > pider

Gliding of liquids: real > weal; leg > yeg

Stopping: funny > punny; jump > dump

Speech acquisition: hierarchy

- These inventories and typologies dealing with the progression of acquisition of speech sounds give a descriptive view of the process,
- …..But these featural accounts of phonetic classes do not explain why some segments are mastered earlier than others.
- What motivates the observed hierarchy?
  - Articulatory ease?
  - Maximum perceptual distinctiveness?
  - Frequency of occurrence?
- What factors could play a role ?
- Do the phonemic inventories of the languages of the world reflect a similar trend?

Phoneme inventories

- The UPSID database documents 921 different segments in 451 languages (Maddieson & Precoda, 1990)
- The inventories in the languages of the world range in size from only 11 (6 c + 5 v) to 141 (95 c + 46 v)
- 70% of the Languages have between 20 and 37
- Average number of segments used contrastively= 31
- Not random samples drawn from a universal set of possible segments
- In individual languages, the choice of V and C is systematic and lawful
- Tends to favor a small core of phonetic properties
  - Languages tend to have 70% obstruents and 30% sonorants
  - Favor open/close contrasts over front/back and rounding contrasts
- Extreme articulations are avoided
- Speech drastically underexploits the full phonetic capabilities of the human vocal tract

Phoneme inventories: Vowels

- Languages are expected to adopt vowels that are most easily produced and which make best use of oral space for phonetic contrast

- After Maddieson (1984):
  - Mid V (40, 5%) > High V (39%) > Low V (20,5%)
  - Front V (40%) > Back V (37,8%) > Central (22,2%)
    - Central V are usually low (70%)
  - Unrounded V (61,5%) > Rounded V (38,5%)
    - Front V = unrounded (94%) ; Back V = rounded (93,5%)

Vowels

- /i/ (91,5%), /ɑ/ (88%), /u/ (83,9%): Most widespread
- Lip and Jaw; Linguapalatal contact

- Followed by midvowels / ε, o/
- Diametrically contrasted by lingualalatal contact with no lip rounding in / ε / and lip rounding without linguapalatal in /o/

- The same hierarchy is observed in speech acquisition

- Then length contrast

- Less represented : V with other properties involving nasalization,pharyngalization, breathy voice.....

Consonants

- Stops: the optimal consonants
  - Voiceless – if 2 C :Voice contrast
  - Bilabial, dental or alveolar, velar place of articulation
    - If a /p/ likely to have a /k/; if a /k/ likely to have a /t/
    - Equally true for the voiced counterparts
    - Law of repartition already mentionned by jakobson
- Almost all languages have at least one voiced nasal
  - Dental/alveolar: /n/
  - bilabial are also frequent: /m/
  - If a velar nasal: then /m,n/ too
- At least one fricative: /s/ , then /z/ and /ʃ/
- Laterals come next /l/, then /r/
- Latest: / θ /

- Examination of the articulatory gestures that produce consonants reveals a systematic order growing out of lawful physical relationships.
  - Function of type of gesture,
  - of articulators,
  - of linguapalatal contact place
  - and airstream passageway configuration.
- Fricatives are more difficult to produce than stops

Consonants:Physiological complexity

- Production of fricatives requires more precision : It involves a large numner of muscles and systems (much more complex in that sense) than the production of stops
- Fricatives: /s/
  - Coordinated action of many muscular systems
    - Concave lingual configuration
      - Styloglossus, Palatoglossus
    - Lateral seal
      - Verticalis, Posterior Genioglossus
  - Grooved central passageway more difficult to establish and to maintain
      - Verticalis, Transverse, Inferior lingual
  - Forwards and upwards movement of the mandible:
      - Temporalis, Masseter, Internal and external Pterygoids
  - Lips spreading:
      - Buccinator, Zygomaticus major and minor

What motivates the hierarchy?

- **Phonemic inventories in the languages of the world**
- Some segments and sequences appear more often in the languages of the world.
- The less represented are also those who are acquired later
- And which are deviant first in speech perturbation (experimental and some pathological conditions)

- **What are the selection criteria?**
  - Language **independent** biological constraints ?
  - Articulatory **simplicity ?**
  - Perceptual **distinctiveness ?**

- **Can articulatory and/or physiological constraints explain it?**
- To attempt answering these questions, it seems necessary to identify the underlying physiological and articulatory dimensions that phonetic complexity encompasses.

- **Necessity to develop a physiological theory of speech production or a physiological theory of phonetics**

Towards a physiological theory of phonetics

- A theory is a body of principles for explaining a set of related observations.
- It gives a systematic account of a phenomenon by specifying the relations between a number of variables.
- It makes definitive predictions about the results of future observations.
- A theory is explanatory as well as descriptive while a model is only descriptive.
- The function of a phonetic theory is to relate linguistic descriptions (abstract) with the facts of speech (physical).

Towards a physiological theory of phonetics

- A physiological theory of phonetics aims at corrrelating the articulatory parameters controlling the production of phonetic segments (and to certain limit the “phonetic” features) with the physiological mechanisms responsible for the generation of the gestures accomplished by the various articulators during speech production.

- A physiological theory of phonetics theory should provide:
  - the tools to foster a relevant and insightful explanation of speech production processes by any speaker of any language of the world
  - A body of principles for explaining a set of phenomena
  - An optimal set of relevant physiological parameters
  - Concepts for describing in a structured manner the speech sounds
  - Enable the categorization of speech sounds on a parametric basis

Towards a physiological theory of phonetics

- A physiological theory should enable:
  - Identification of the relevant phonetic parameters:
    - Articulatory
    - Physiological
  - Quantitative measurement of the contribution of the various agonistic and antagonistic muscles to the execution of articulatory gestures
  - Gradual quantitative scaling of the articulatory and physiological parameters from normal to deviant speech
  - Objective measurement of inter-speaker and inter-language differences

- The theory must also explain how the coordination among systems and between gestures is implemented and how it is controlled.

Towards a physiological theory of phonetics

- In this theoretical approach, articulation refers to the changing surface configurations of the vocal tract and physiology to the means by which these changes are achieved.
- The theory should give an explicit account of the relationship between physiological mechanisms and articulatory categories and how they contribute to the emergence of natural classes, such as consonants, vowels, stops, fricatives, taps.....
- A physiological theory of phonetics built on these premices will prove useful to the linguistic description of languages and as well as to language didactics, speech synthesis and speech rehabilitation.
- As a first step, we will review the articulatory and physiological parameters controlling the production of the speech sounds
  - Aerodynamic, lingual, mandibular, labial, pharyngeal, and laryngeal

Aerodynamic parameters

- **Direction of airflow**
  - Ingressiv
  - Egressiv
- **Mechanism**
  - Pulmonic
  - Laryngeal
  - Velaric
- **Airflow**
  - Central
  - Lateral
  - Laminar
  - Turbulent
- **Air Pressure**
  - Subglottal pressure
  - Oral pressure
  - Transglottal pressure

- Phonetic parameters: Egressive – Ingressive
  - Pulmonic
  - Glottalic
  - velaric

- Physiological parameters:
  - **Pulmonic egressive**: Control of subglottal pressure= Internal Intercostals
  - and accessory expiratory muscles
  - in synergy with inhalation muscles
  - **Pulmonic ingressive** (not used contrastively)

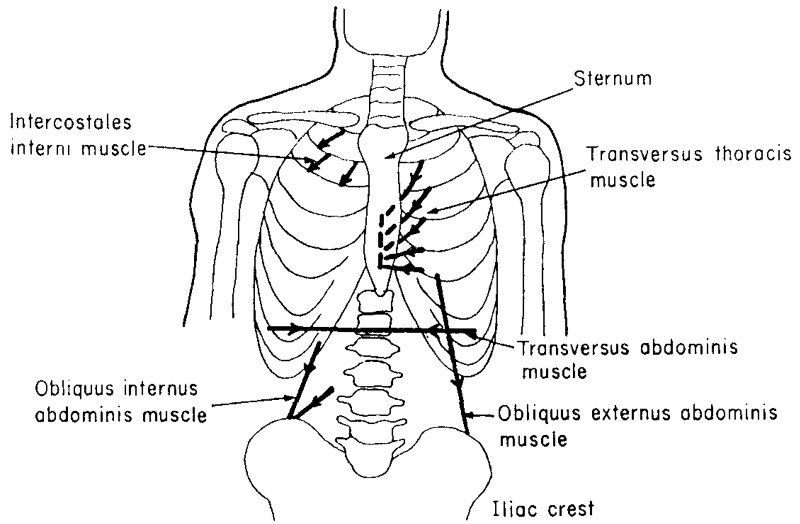
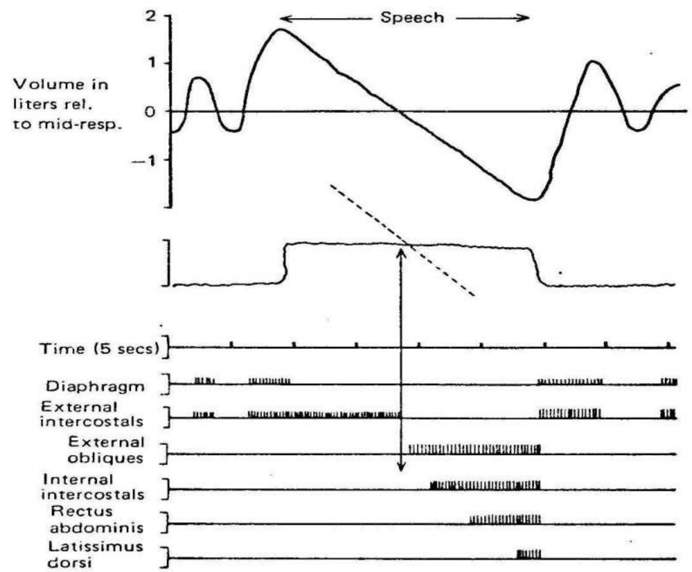


Fig. 8 Some possible directions of movement of the thoracic cage during contraction of some muscles of exhalation. (Intercostales interni muscles extend towards the sternum.)

Figure 2-80 Diagram illustrating sequence of muscle activity during speech production and during passive breathing (after Draper *et al.*, 1959).



Aerodynamic parameters

- Physiological parameters:

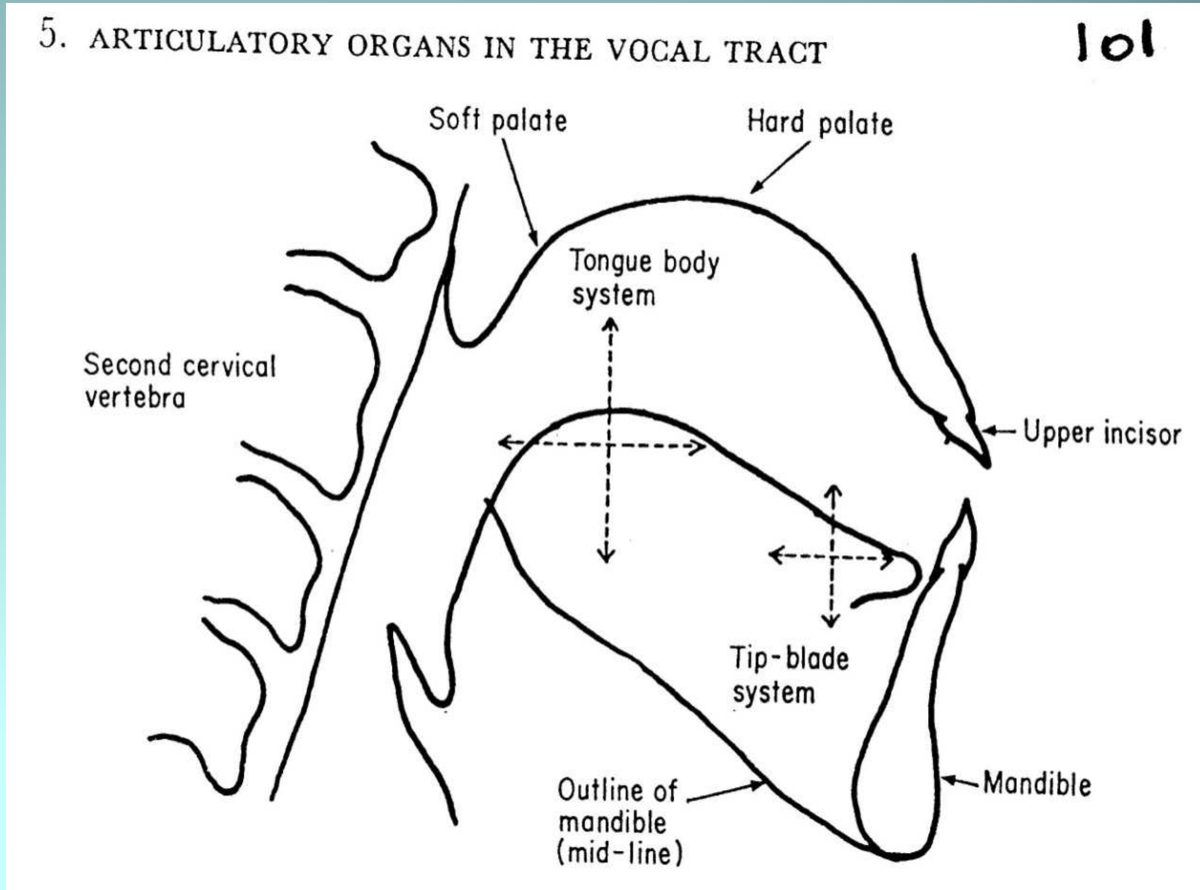
  - Glottalic egressive: Stylopharyngeus, Digastricus and Suprahyoid muscles (see Larynx: upwards)

  - Glottalic ingressive: Sternocleidohyoid, Sternothyroid, Omohyoid, Omothyroid (see larynx: downwards)

  - Velaric ingressive: See lingual physiological parameters (vertical and horizontal dimensions)

Lingual articulatory parameters

- ***Horizontal displacement:***
  - ***Forward-Backward / Backward-Forward***
- Apex
- Tongue body
-

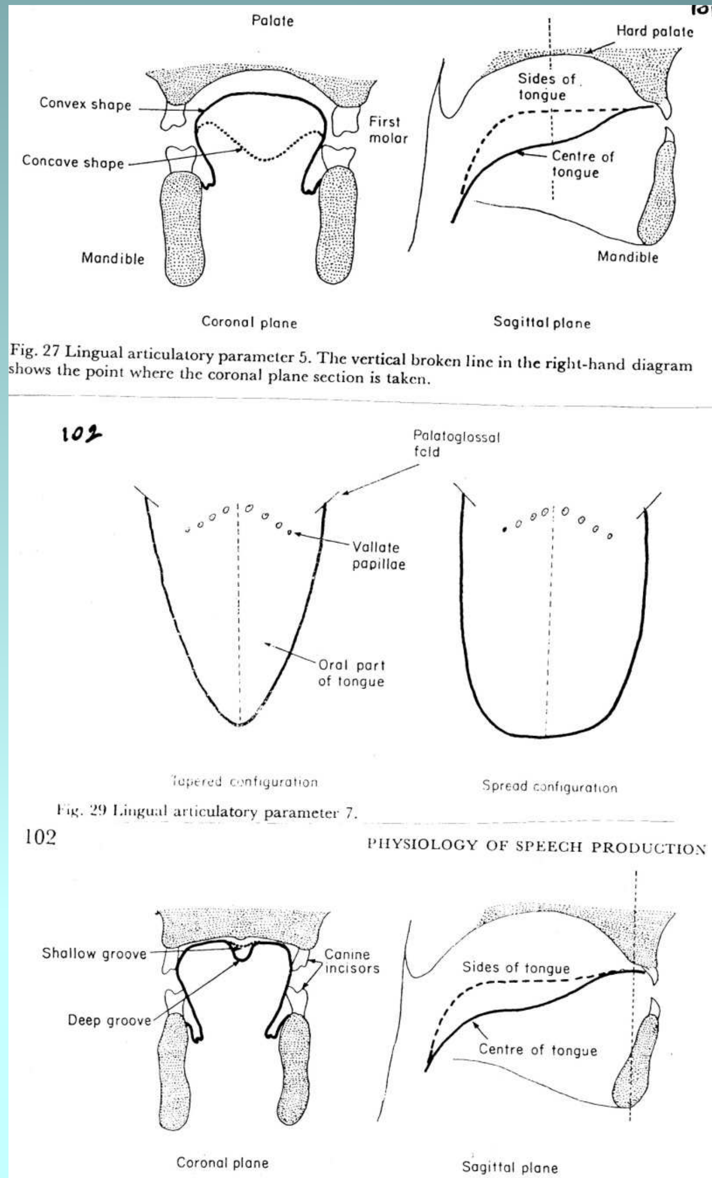


- ***Vertical displacement* :**
  - **Upwards/Downwards**
  - **Downwards-Upwards**
- Tongue body
- Apex
-

Lingual articulatory parameters

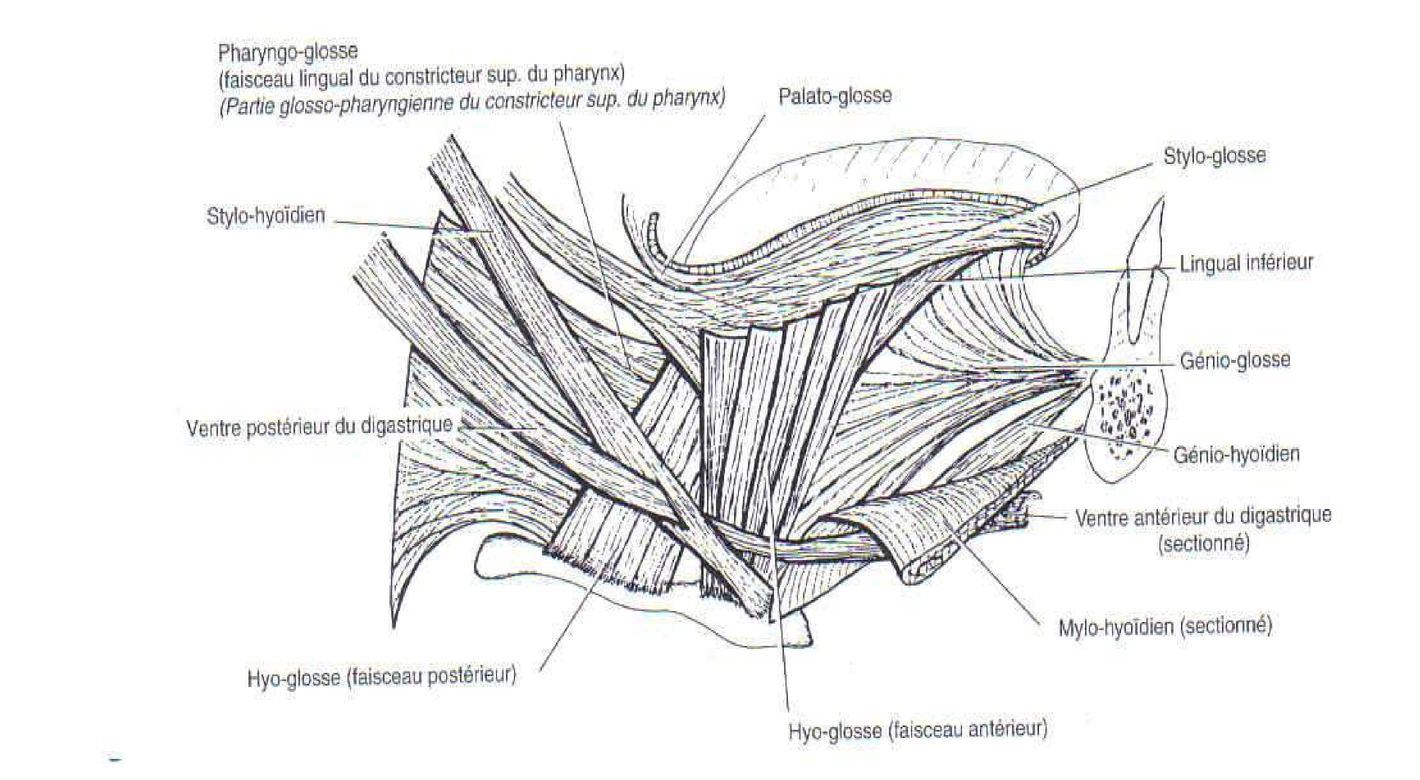
- ***Transverse cross-sectionnal configuration:***
  - **Convex/concave** Tongue
    Body
    Apex

- ***Surface plan :***
  - **Spread-Tapered**
    Tongue
    Dorsum



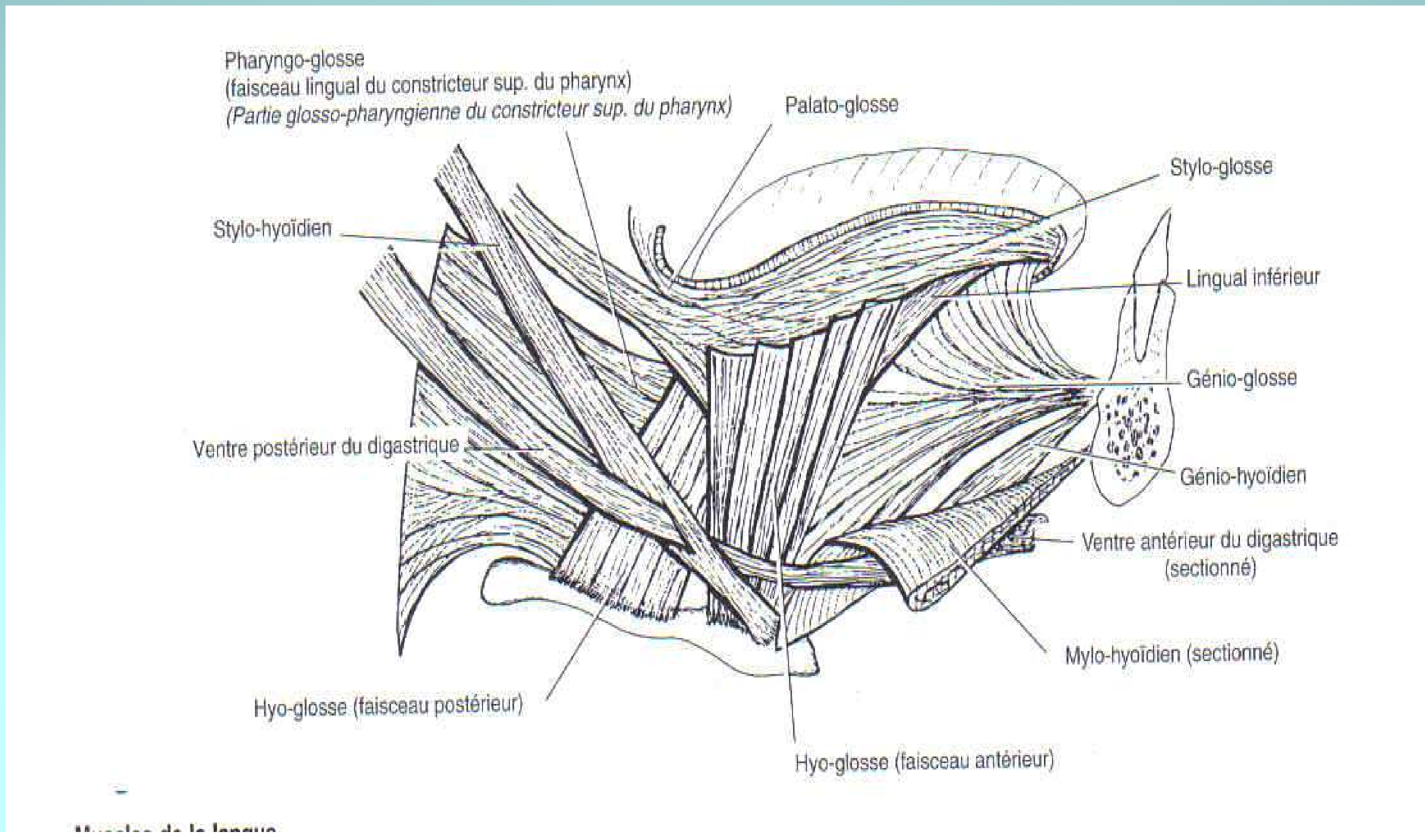
Lingual physiological parameters

- ***Horizontal displacement***
- Forward
- Body : + Posterior Genioglossus ; Anterior Digastricus ;Suprahyoids -Infrahyoids
- Apex : +Transverse ; Posterior Genioglossus
-



Lingual physiological parameters

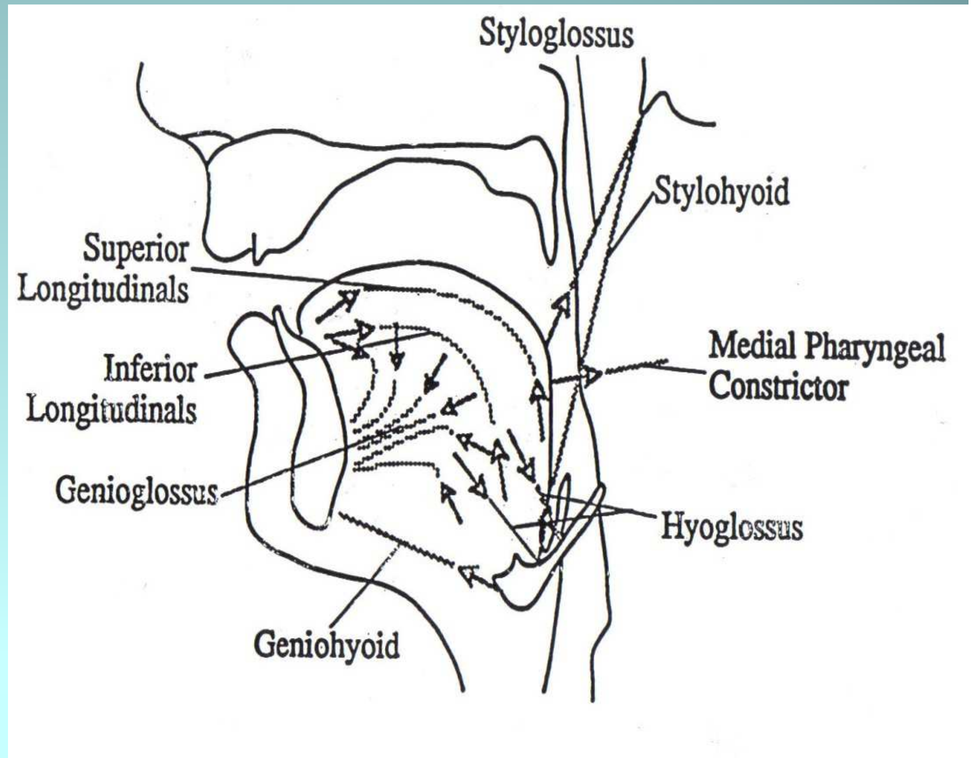
- Backward
- Body : +Styloglossus +Anterior Genioglossus ;Superior and Middle Constrictor of the Pharynx -Thyrohyoid
- Apex :+Longitudinal ;Hyoglossus (post)



Lingual physiological parameters

- ***Vertical displacement:***
- Upwards
- **Body** : +Styloglossus +Palatoglossus -inferior Lingual
- **Apex** : +Superior Lingual ;Posterior Genioglossus

- Downwards
- **Body** : +Hyoglossus ; Infra-hyoïd
- **Apex** : +Inferior Lingual +Anterior Genioglossus



Lingual physiological parameters

- **Configuration :**

  Concave:
- Body : +Styloglossus +Palatoglossus
  +Transverse -Hyoglossus
- Apex : +Transverse +Vertical
  ;Styloglossus ;Palatoglossus
- -Inferior Lingual
- ***Convex:***
- Body : +Hyoglossus ;Inferior Lingual
- ***Spread:***
  Dorsum : +Vertical
- ***Tappered:***
- Dorsum : +Transverse -Hyoglossus

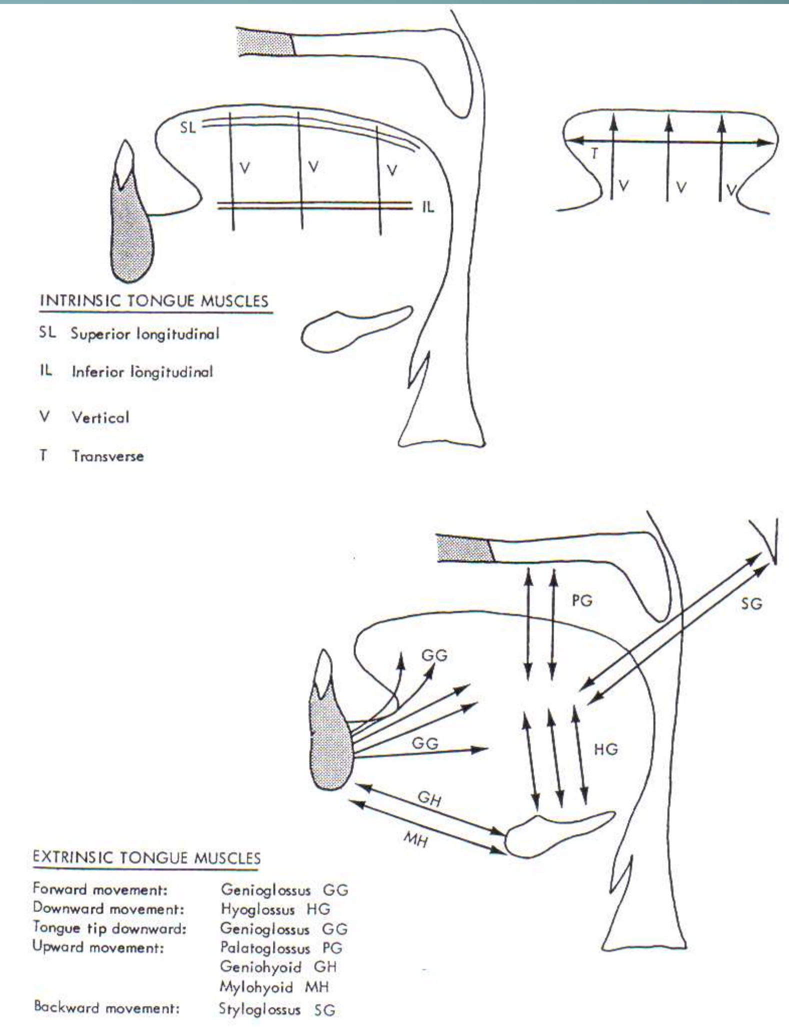


figure 7.14
Schematic view of the direction in which extrinsic and intrinsic muscle fibers run through the tongue.

Mandibular articulatory parameters

Vertical :

Upwards -Downwards

Horizontal :

Protrusion – Retraction

In fact, vertical+horizontal displacement result in a **translatory and rotational** movement

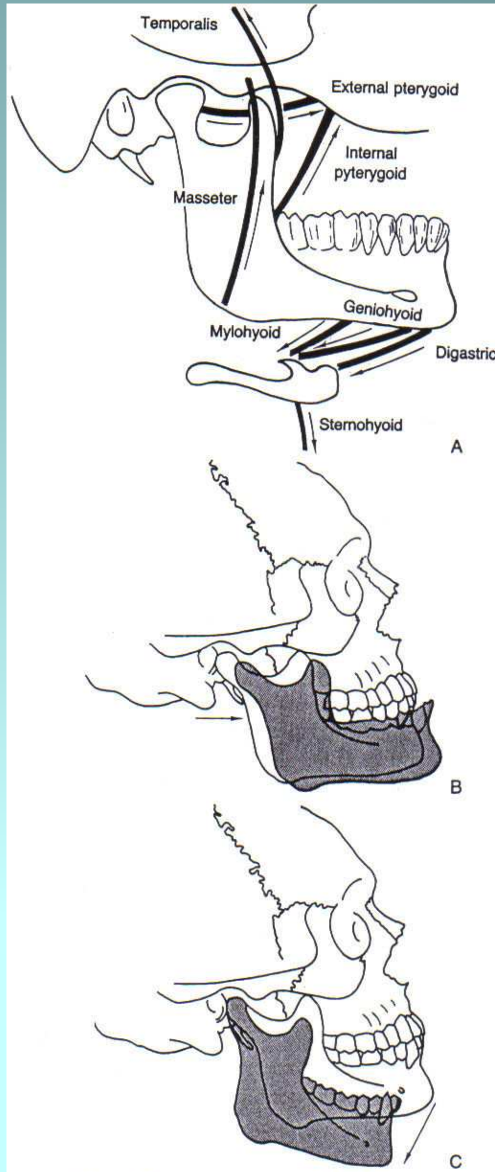


Figure 4-76 Summary of muscle actions (A), illustration of translatory motion of the mandible (B), and rotational motion (C).

Mandibular physiological parameters

Vertical :

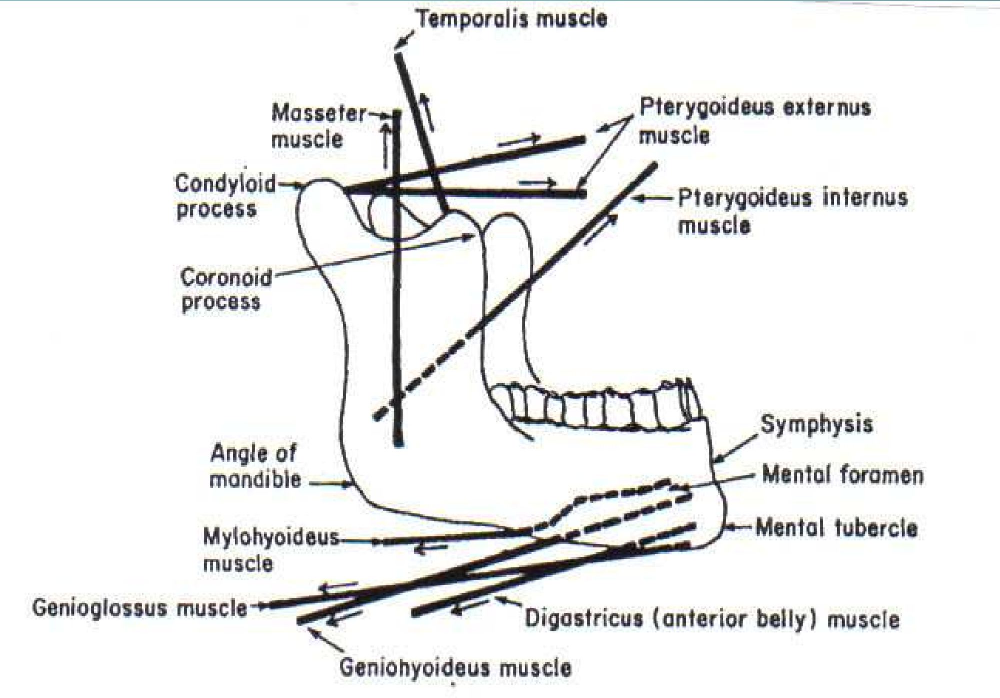
Upwards: +Internal Pterygoid
+Masseter
+Temporalis
;AnteriorDigastricus

Downwards : +External Pterygoid
+Geniohyoid
;Posterior Digastricus
;Mylohyoid ;Platysma
;Genioglossus ;

Horizontal:

Protrusion : +Internal Pterygoid
+External Pterygoid

Retraction : +Temporalis
+Geniohyoid
+Posterior Digastricus
+Mylohyoid
+Genioglossus



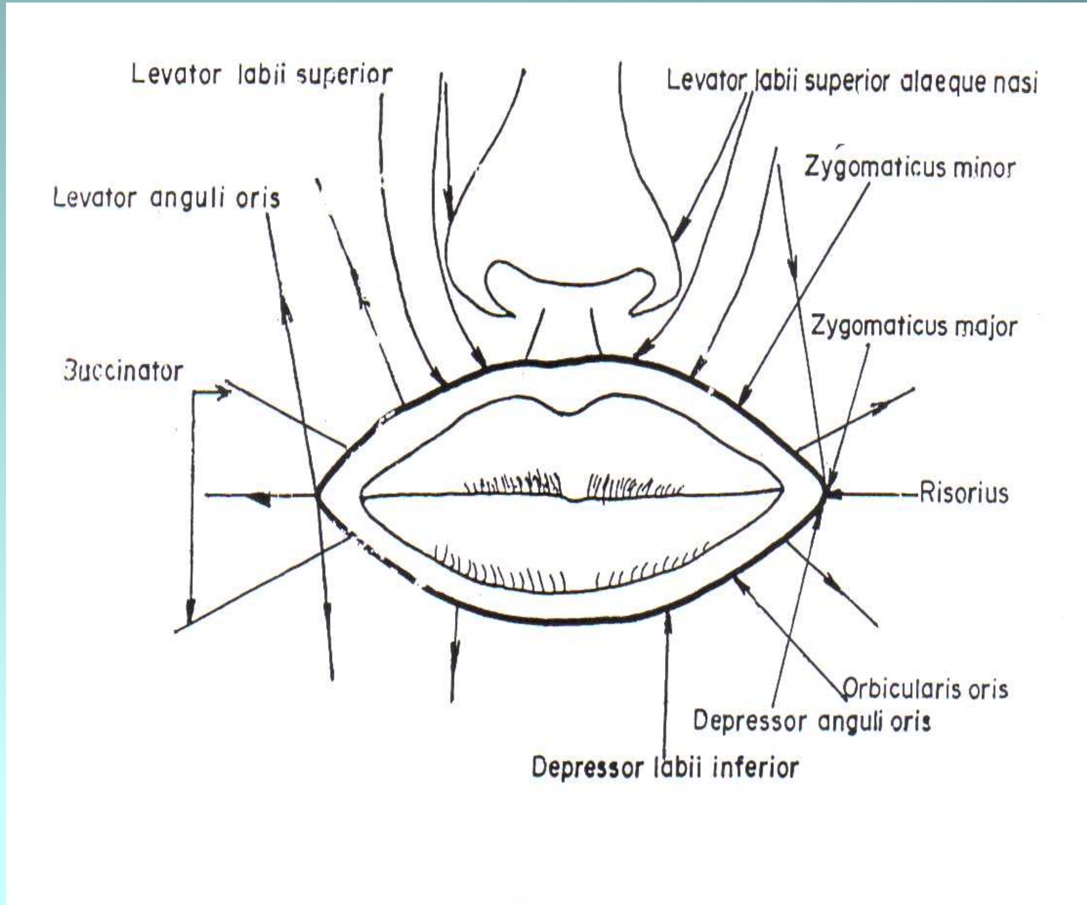
30 Lateral view of mandible showing the main structural parts and the movements of mandible when the various mandibular muscles contract from fixed origins.

Labial Articulatory Parameters

- **Aperture :**
- Vertical :
- Open - closed
- Horizontal :
- Spread – Compressed
- **Horizontal displacement :**
- Protruded – Evert

Labial Physiological Parameters

- ***Vertical :***
  - **Open** : +Mentalis ;Depressor Anguli Oris ;Mandibular Depressor Orbicularis -Mentalis
  - **closed** :
  - +Orbicularis Oris
  - ;Levator Anguli Oris ;Mentalis ;Mandibular Elevators

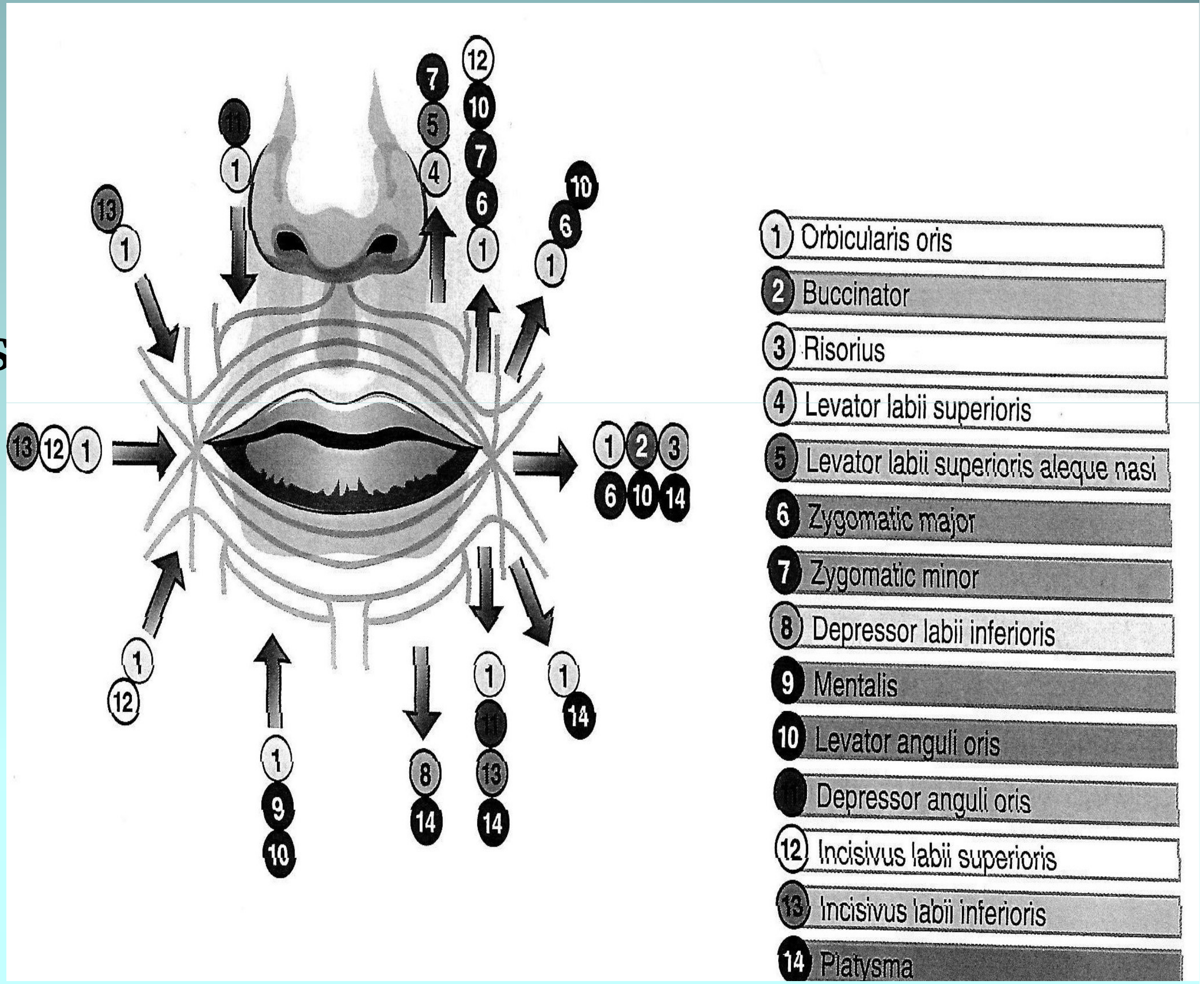


Labial Physiological Parameters

- ***Horizontal:***

- **Protruded** : +Orbicularis Oris ;Mentalis ;Platysma
- -Buccinator -Risorius

- **Evert** :
- +Labii Compressor +Buccinator ;Orbicularis ;Zygomaticus minor



Articulatory parameters of the pharynx

- **Velum :**
  - Vertical
    - Upwards – Downwards
  - Tension
    - Tense – Lax
- **Pharyngeal walls displacement :**
  - Horizontal
    - Forward
- **Pharyngeal wall tension:**
    - Tense - Lax

Physiological parameters of the pharynx

- **Velum :**
  - **Upwards** :
  - +Levator palatini
    +Musculus uvulae
  - **Downwards** :
    +Palatoglosssus
    +Palatopharyngeus
  -
  - **Tension** :
  - +Tensor palatini
-

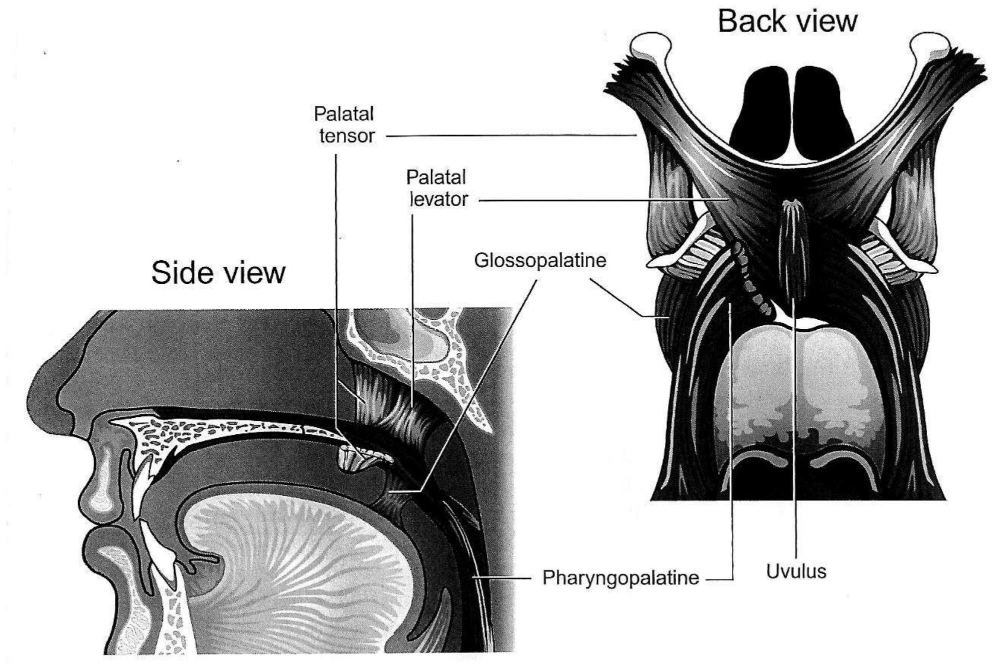


Figure 4-10. Muscles of the velum.

Physiological parameters of the pharynx

- **Pharyngeal Walls :**

Forward :
+Palatopharyngeus
+Salpingopharyngeus
;Stylopharyngeus
;Superior constrictor of the Pharynx

Tension:
+ inferior, middle , Superior constrictors

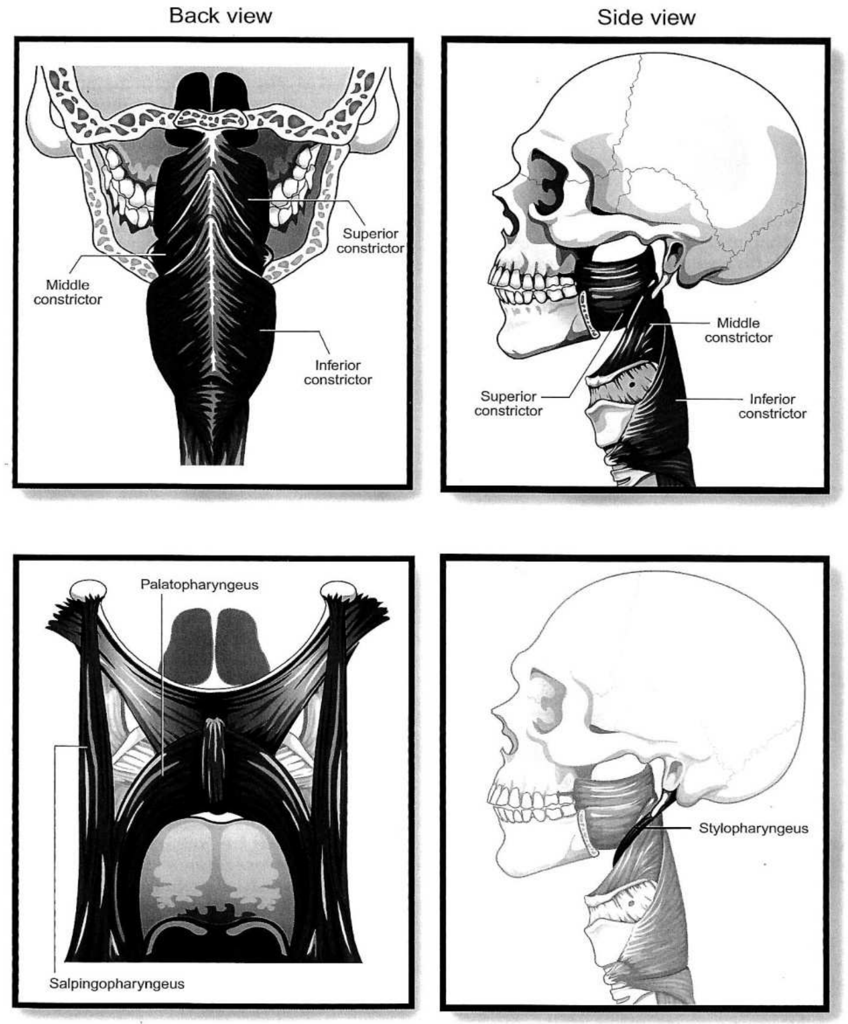


Figure 4-8. Muscles of the pharynx.

182

Articulatory parameters of the Larynx

- **Displacements**
- *Vertical : Height of the larynx*
- Upwards – Downwards
-
- *Medial Plane : Glottal Aperture*
- Adduction – Abduction
-
- **Vocal Folds :**
- *Length*
- *Tension*
- *Compression*
-
- **Ventricular Folds : ?**

Physiological parameters of the larynx

- **Height of the larynx :**
- Extrinsic laryngeal muscles
- **Upwards** : Suprahyoid muscles
- **Downwards** : Infrahyoid muscles

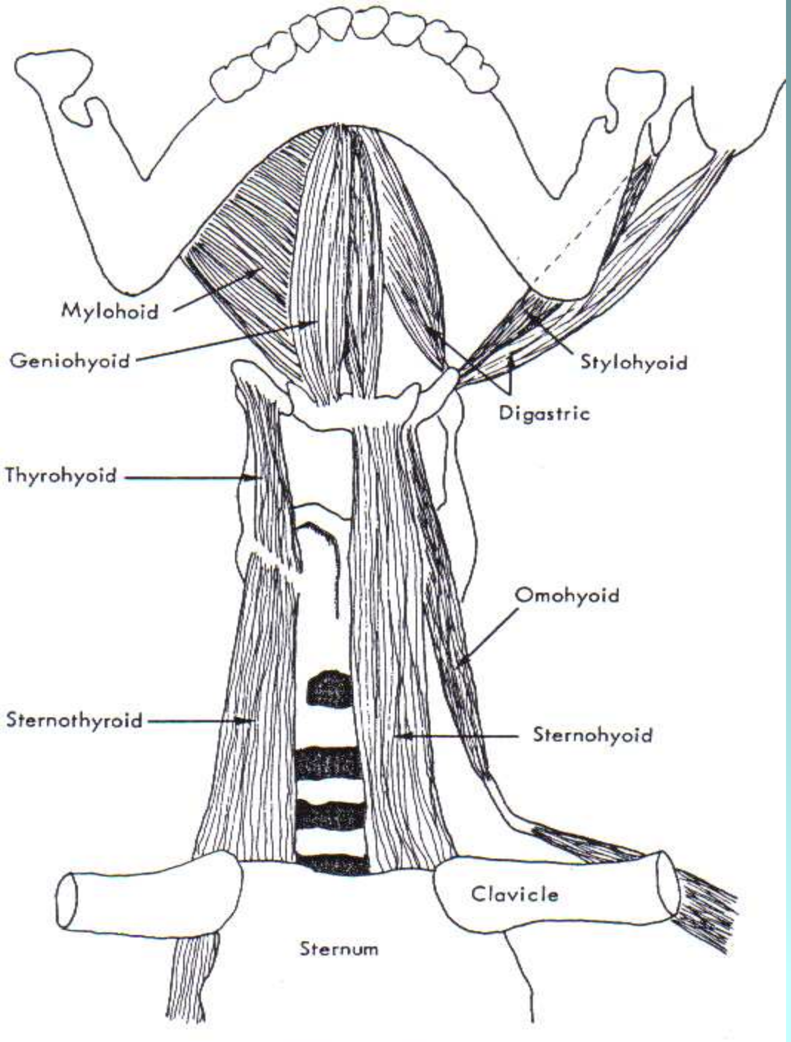
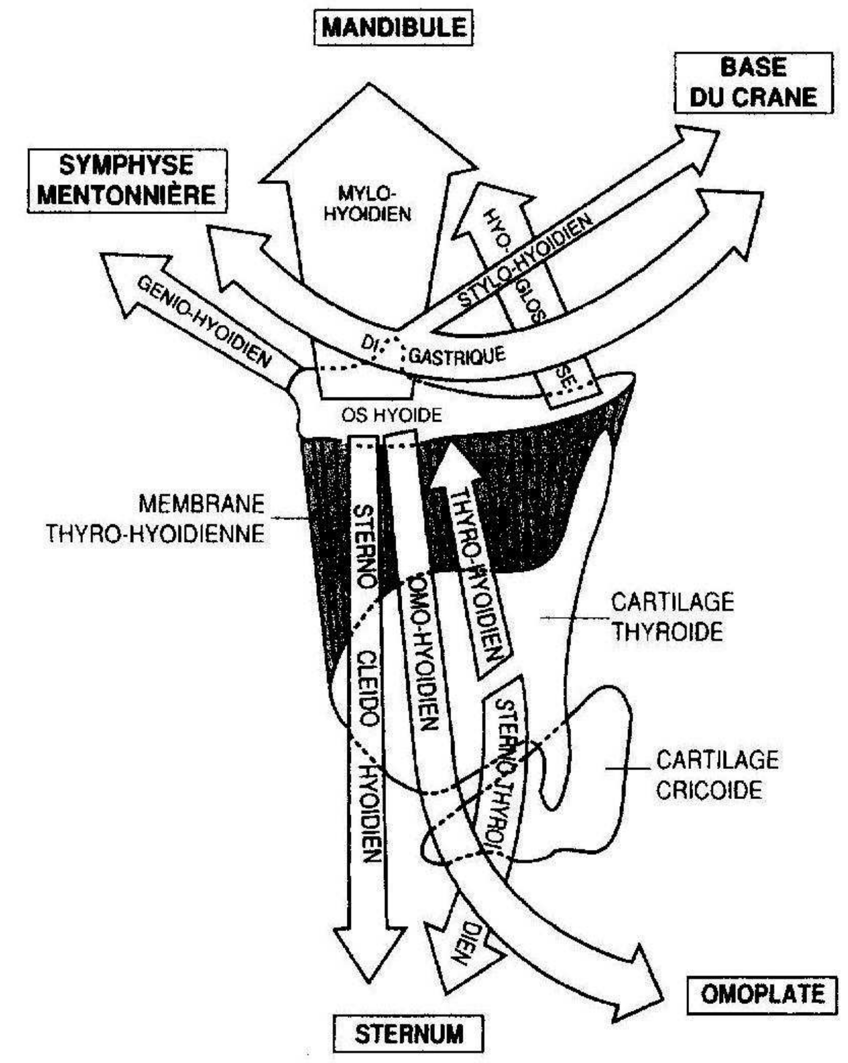


figure 6.24
The extrinsic laryngeal muscles.

Physiological parameters of the larynx

- **Upwards** : +Posterior Digastricus +Geniohyoid +Mylohyoid +Stylopharyngeus +Pharyngostaphyline ;Posterior Genioglossus ;Hyoglossus ;Stylohyoid ;Middle Pharyngeal Constrictor
-
- **Downwards** : +Sternocleidohyoid +Omohyoid +Sternothyroid ;Thyrohyoid



Physiologial parameters

Glottal aperture :

Abduction :

+Posterior Cricoarytenoid

Adduction :

+Lateral Cricoarytenoid

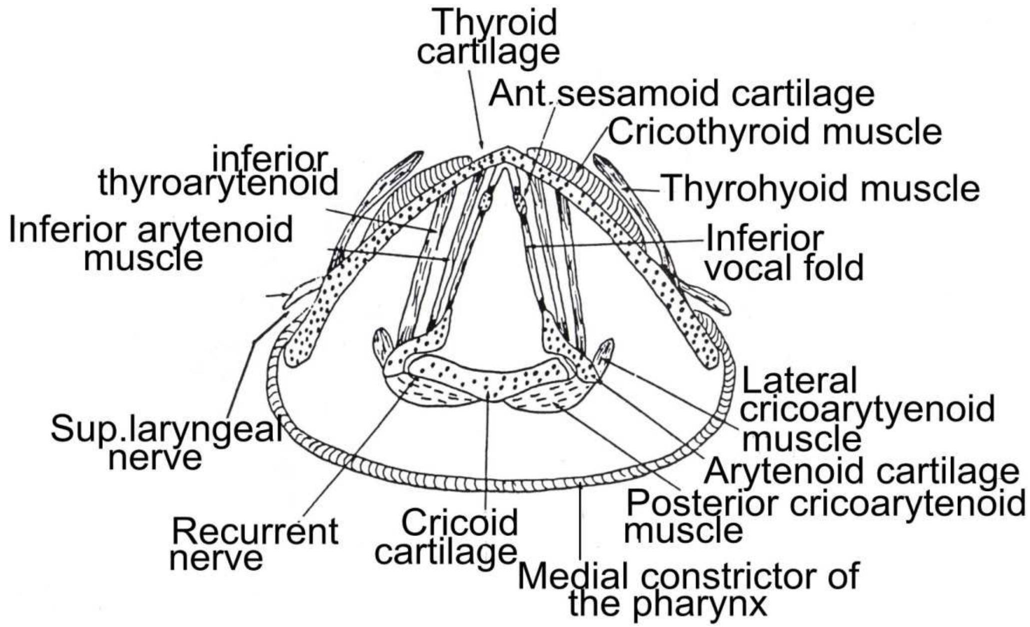
+Interarytenoids

;External Thyroarytenoid

;Aryepiglottic

;Thyroepiglottic

•



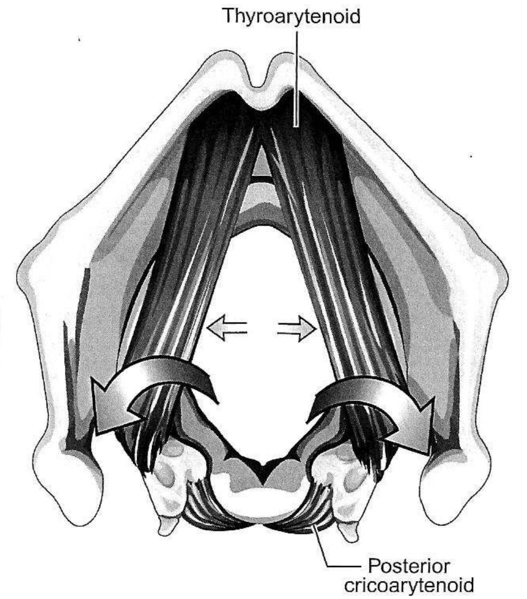


Figure 3-18. Rocking of the arytenoid cartilages away from the midline by contractions of the ***posterior cricoarytenoid*** muscles

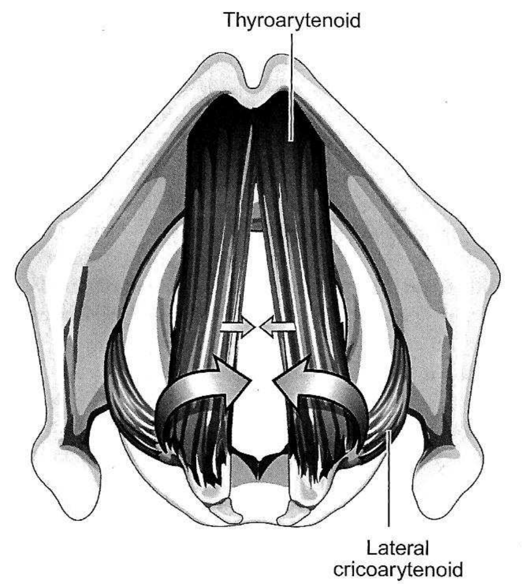
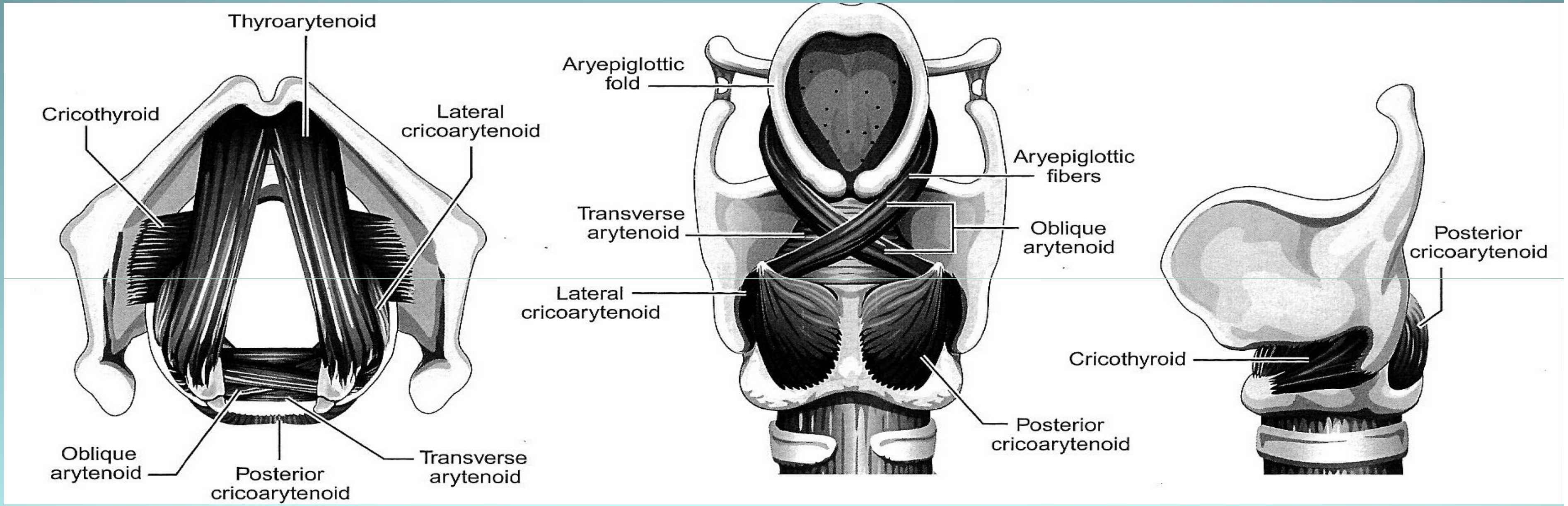


Figure 3-19. Rocking of the arytenoid cartilages toward the midline by contractions of the ***lateral cricoarytenoid*** muscles

Physiological parameters of the larynx

- **Vocal Folds :**
- **Lengthening** : +Posterior Cricoarytenoid
- **Shortening** : +Cricothyroid pars recta



- **Tension** :
- Tense : +Cricothyroid pars obliqua +Inferior Thyroarytenoid
- Lax : +Superior Thyroarytenoid

  Compression: +Lateral Cricoarytenoid + oblique Interarytenoids
-

EMG data in the literature

- **Voicing** control
  - Voicing:
    - Vocalis, Cricothyroid, Lateral Cricothyroid, Interarytenoids
  - Devoicing:
    - Posterior Cricoarytenoid, Sternohyoid
- **Nasalization**
  - Palatoglossus, Palatopharyngeus
- **Oral**
  - Levator palatini, Musculus Uvulae, Middle and Superior Constrictors of the Pharynx

EMG data in the literature

- **Vowels**
  - [u]: Styloglossus, Posterior Genioglossus, Posterior Digastricus, Internal and external Pterygoids, Mentalis, Platysma, Orbicularis Oris, -Buccinator, -Risorius
  - [o]: Styloglossus, Anterior Genioglossus, Superior Constrictor of the Pharynx, Internal and external Pterygoids
  - [a]: Styloglossus, Anterior Genioglossus, Inferior Lingual, Temporalis, Posterior Digastricus, Hyoglossus, Geniohyoid, Mylohyoid
  - [i]: Styloglossus, Posterior Genioglossus, Palatoglossus, Transverse, Verticalis, Depressor labii Inferioris, Buccinator, Zygomaticus Major

EMG – Elementatry Motor patterns

- [i]: Coactivation of the Anterior and Posterior parts of the Genioglossus
- [æ]: Coactivation of the Anterior Genioglossus and the Hyoglossus
- [u]: Coactivation of the Posterior Genioglossus and the Styloglossus
- [ɑ]: Coactivation of the Hyoglossus and the Styloglossus

Orthogonal organization of the muscles of the tongue

K. Honda

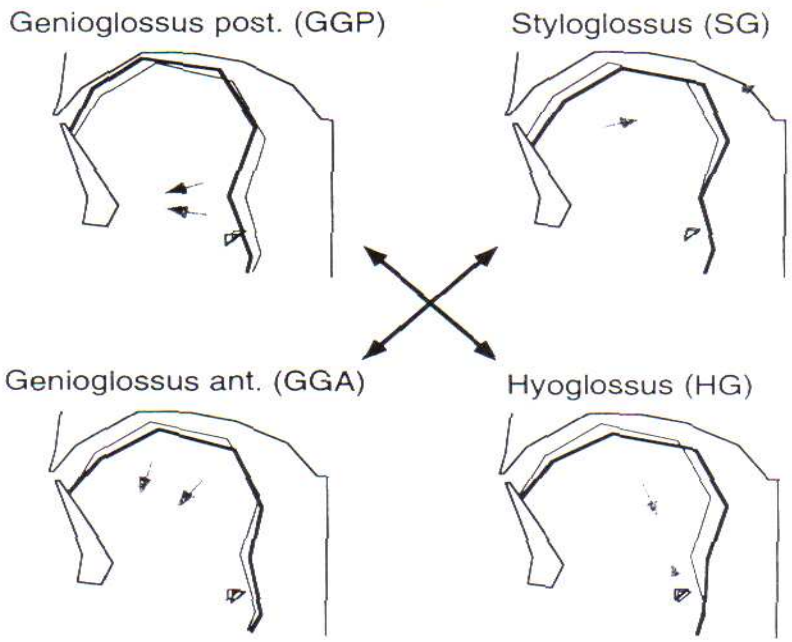
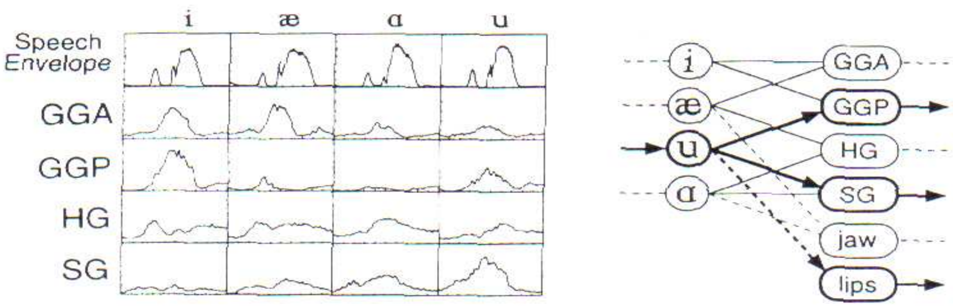


Figure 2. Effects of the extrinsic tongue muscles showing an orthogonal relationship among the antagonistic muscles. The genioglossus posterior (GGP) and the hyoglossus (HG) form a major antagonistic pair, and the styloglossus (SG) and the genioglossus anterior (GGA) form another pair. The triangles in the figure indicate the position of the hyoid bone.



(a) EMG from the extrinsic tongue muscles (b) Muscle group selection

Elementary motor patterns

- Maeda and Honda (1994) used the EMG signals from these muscles (SG, HG, PGG, AGG) as input parameters for Maeda's Model
- They derived vowel formants from them
- Obtained an acceptable correlation between the measured formants of vowels and those of the synthetic vowels thus obtained
- Gerard et al (2003) and Buchaillard (2007) relate local changes in the surface of the tongue to elementary motor patterns corresponding to a selection of two of the four extrinsic muscles
- Best use of physiological organization for contrasts ?

EMG data in the literature

- **Consonants**: Stops
  - Palatals:
    - Closure: Styloglossus, Palatoglossus
    - Release: Hyoglossus, Infrahyoid muscles
  - Alveolars:
    - Closure: Posterior genioglossus, Superior Lingual, Stylohyoid
    - Release: Anterior Genioglossus, Inferior Lingual
  - Bilabials:
    - Closure: Orbicularis, Masseter, Internal and external Pterygoid, Digastricus, Temporalis, Levator Anguli Oris, Mentalis, Zygomaticus Major
    - Release: Depressor Labii Inferioris, Platysma, Levator Labii Superioris Alaeque Nasi

EMG data in the literature

- **Fricatives**:
  - [f, v]: Internal and external Pterygoid, Zygomaticus Minor and Major, Buccinator, Temporalis, Orbicularis, Risorius
  - [s, z]: Anterior Genioglossus, External Pterygoid,

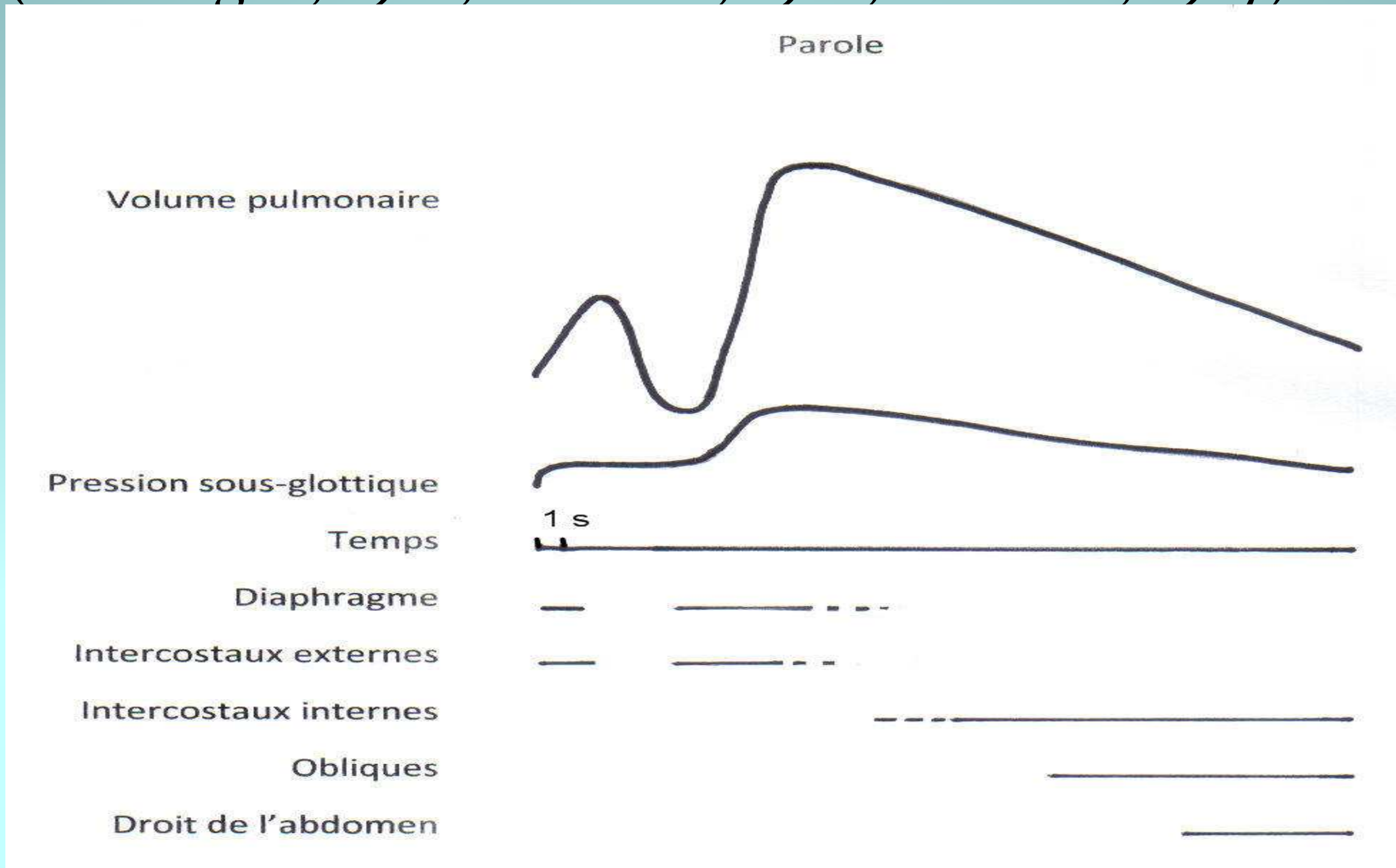
    -Inferior Lingual
  - [ʃ,ʒ]: Styloglossus, Palatoglossus, Transverse, temporalis, -Hyoglossus

The number of degrees of freedom!

- The individual muscles cannot be controlled individually:
  - excessive number of degrees of freedom
  - Heterogenity of neuromotor commands and influences
- Privileged relations between certain muscles to facilitate or to inhibit particular excitations
- The degree of freedom of each muscle is limited by belonging to a structure
- Functional groupings of muscles to promote the realization of classes of equivalent acts
- Essential property = to control and to coordinate
- Coordinative structures: functionnal embedding
- Commands address the coordinative structures rather than the individual muscles

The coordinative structures of speech

- Articulation just like any other skilled movement is the product of the activity of organizing coordinative structures
- **Respiration**:
  - Coordination of inhalation and exhalation muscles (Ladefoged, 1962; Hoshiko, 1962; Marchal, 1987)



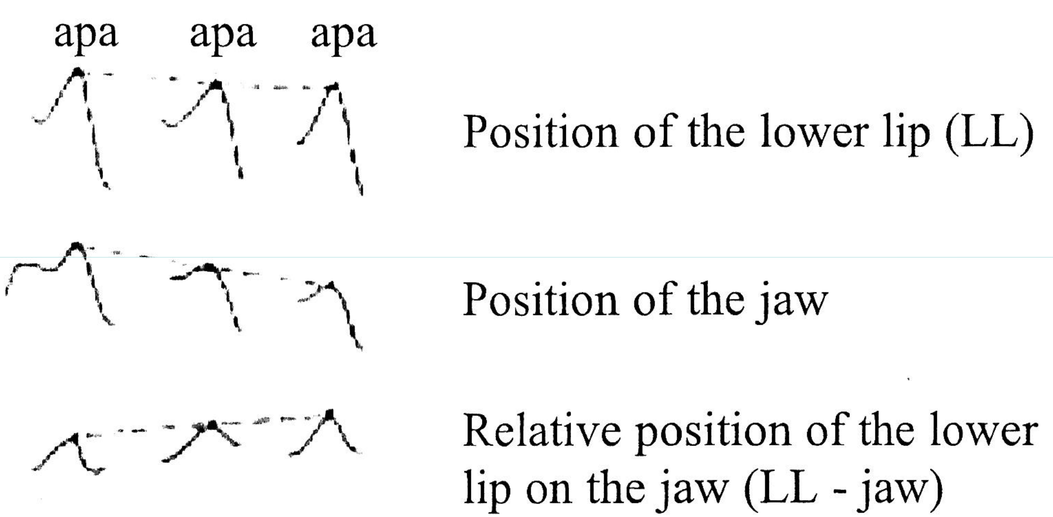
The coordinative structures of speech

- **Laryngeal adjustment**:
- 3 servo-systems:
  - receptors in the mucous membrane for subglottal pressure evaluation
  - mecano-receptors in the ligaments = tension of intrinsic muscles, length of the VF and movements of the cartilages
- **Vowel/ Consonant** distinction
- **Syllables** = ballistic chest pulses (?)

Coordinative structures of speech: coupling of systems

Labial configuration

- Jaw and Lips



When the jaw doesn't move as much, the lower lip compensates. The jaw and LL are coordinated for [p].

Coordinative structures of speech: coupling of systems

- **Vocal tract length**:
  - Lip-Jaw-Larynx
- **Aperture**
  - Jaw and Tongue
- **Larynx height**
  - Jaw, Tongue, larynx

Concluding remarks

- In order to deal with the concept of phonetic complexity, we have indicated that there is a definite need for a physiological theory of phonetics
- This theory should offer more adequate physiological correlations of basic articulatory parameters
- In terms of our present knowledge of the speech production mechanisms, it is already possible to correlate some basic articulatory categories with specific muscular activity:
  - The Consonant/Vowel distinction can be correlated with the specific functional activity of the intrinsic and extrinsic muscles of the tongue:

Conluding remarks

- Intrinsic and extrinsic lingual muscles can work relatively independently
- The two muscle groups can seemingly be correlated with the two most basic categories of Vowels and Consonants
  - Intrinsic muscles are located entirely within the body of the tongue; they alter the shape of the tongue in a fine-tuned manner
    - For consonants
  - Extrinsic muscles have their origin outside the tongue; they alter the gross position of the body of the tongue
    - For vowels
    - Orthogonal relationship of extrinsic antagonist muscles for aperture and anteriority contrast

Concluding remarks

- Stops vs Fricatives
  - Stops are produced with ballistic muscular contraction. « all or nothing maneuver », with saturation effect
  - Fricatives require a more delicate neural control: balance between the activities of protagonist and antagonist muscles groups
  - This distinction is reflected in the acquistion order of consonants by children
- Stops/Taps
  - Difference in the rate of muscular contraction
- Taps/Trill
  - Airstream mechanism

Concluding remarks

- We have discussed here a preliminary theoretical framework for the investigation of phonetic complexity
- Necessity to investigate more thorougly the underlying physiological aspects of speech production; i.e the means by which articulatory gestures are executed
- Future work:
  - To specify quantitative values to the articulatory parameters of a given articulator
  - To scale the physiological parameters: the individual contribution of the muscles
  - To identify the hierarchically embedded coordinative structures
  - To model motor equivalence = production functions
  - To build models for the activity of the different articulators
  - To specify the way in which the time functions of the various parameters are interpreted as phonetic elements

Concluding remarks

- To investigate the coordination between systems and subsystems
- To assess the compensatory mechanisms at the peripheral level
- To make explicit the control mechanisms
- To test the models: EMG studies combined with EPG, Ultrasound, articulography...., systematic more documented experimental investigation of speech defects and of their consequences
- and finally cross-language comparisons to distinguish pure bio-mechanical constraints from language specific phonological constraints

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