PART 1—BASIC ELEMENTS

1.1 The lingual Center of mass (barycenter)

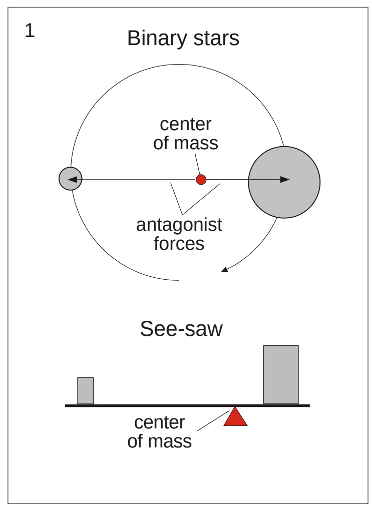
In examining phoneme production the gross movement and shaping of the tongue offers little significant information on the internal workings of the tongue. Successful analysis of lingual articulatory behavior can be gained only when its internally operating physical **forces** are investigated. This is not out of our reach since we have sufficient sensitivity to perceive minute actions of the tongue and we can easily locate the muscles active in shaping it.

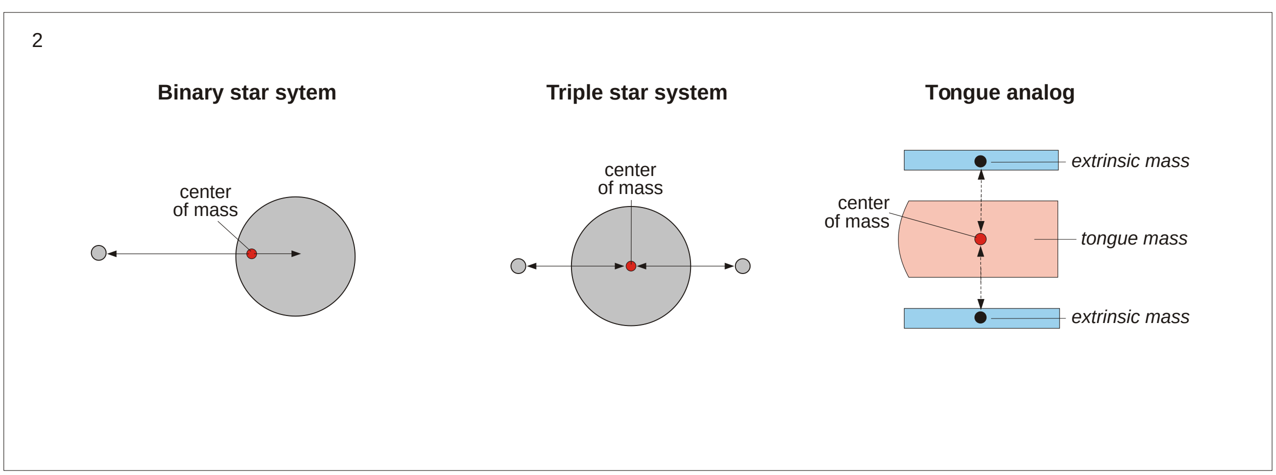
The notion of **centers of mass** is essential in the analysis of forces in physical and engineering studies and the same methodology is applicable to investigating speech mechanics since that too is a system of force interactions. In tracing lines of muscular forces we can locate the **center of mass** (also called **barycenter**), or the **central anchoring node** of any muscular setting. Mapping the positions of such **nodes** and their behaviors can readily lead us to understanding the physiological mechanics of the phoneme production.

1.2 Center(s) of mass of the tongue

The classic example of a center of mass is in binary stars where it is the point where the gravitational forces of each body meet at a distance determined by the proportion of their relative masses or in a balance or see-saw, where the center of mass is the pivot that sets the opposing masses are equilibrium, fig. 1.

In case one star is much larger than the other one the center of mass lies in the larger star. This is the case in a triple system as well if one star is sufficiently large and this configuration provides a good analog of the muscular system of the tongue, where the upper and lower extrinsics take on the role of the smaller stars and the tongue acts as the large one. Thus, the barycenter of the tongue is a point where the resultants of externally entering forces concur, fig. 2.

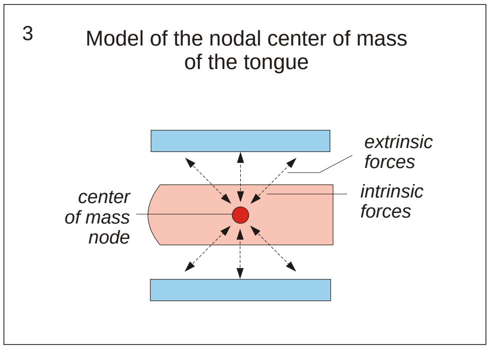




1.3 The source of lingual nodes

The tongue behaves as mass of muscles which tenses when stimulated by forces impacting it. The extrinsic lingual muscles penetrate and extend within the tongue mass and the intrinsic muscles tense as they sense and oppose distorting forces, and in response to external forces the tongue as a whole, and more precisely, regionally generates center(s) of mass, or **nodes**.

The lingual framework of **forces** and **nodes** and their behavior discussed here are manifested and become perceptible at or near tonic levels of the orolingual complex resting at **equilibrium**. To fully **isolate** such nodes all extrinsics lingual and phonatory forces must be reduced to a minimum, leaving only the intrinsically energized lingual node under focus. The nodes function as **centers of mass**. The general **center of mass** of the tongue is a point or region within the **intrinsic** lingual muscle mass where the resultants of incoming **extrinsic** forces converge and are **antagonistically** balanced by the intrinsic mass. I.e., the node is a centrally located region of highest tension (or highest mass) of intrinsic musculature which counterbalances the surrounding extrinsically forces impacting the tongue, fig. 3.

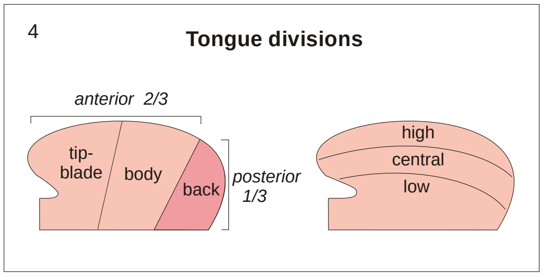


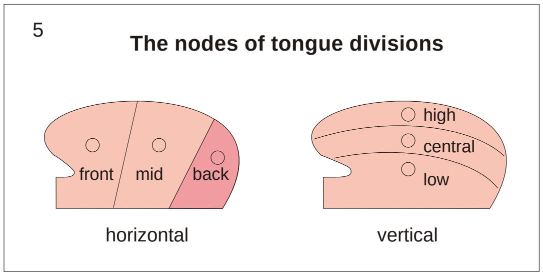
Note: see page 10 for some factors in correctly perceiving and observing lingual nodes.

1.4 Tongue divisions

The tongue is **divisible** both horizontally: tip-blade, body and base (or root), (or front, center and back) as well as vertically: the upper (dorsal), central and low levels. Anatomically and developmentally, the tip-blade and body occupy the oral 2/3 tongue and the base comprises the pharyngeal 1/3. The vertical divisions consist chiefly of the superior longitudinal, the mid-central vertical-transverse mass, and the inferior longitudinals, fig. 4.
The divisions are distinctly perceptible when appropriately directed forces separate and isolate them from the rest of the tongue, and thus can be felt as a well defined regions. Each division is maintained by its particular **center of mass** (barycentric) nodes. Thus, there are six divisional **nodes**, although in perfectly balanced state of the tongue the mid and central nodes coalesce into a single merged node, fig. 5.

The coactive behaviors of the **tongue divisions** are essential features of articulation mechanics. The relative independence of regional demarcations and their activities greatly increase the resolution in controlling tongue action.





PART 2— PRIMAL NODES

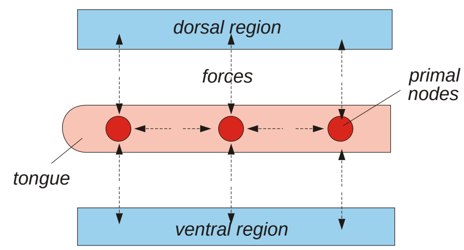
2.1 The primal nodes of the lingual frame

At this point focus will be directed on the **horizontal** line of lingual nodes. The muscular architecture of the lingual system employs **three intrinsic muscle nodes** to generate various configurations in order to maintain equilibrium during various subsequent behaviors. Without such service there would be no initial system setting.

Each of these nodes is located in one of the tongue divisions. The **triad** of the fundamental primary areas or nodes can at this point be called the **front** (anterior), **central** and **back** (posterior) nodes, fig. 6.

This structural organization is **axiomatic**: building stepwise from such nodal force configuration of the tongue the mechanics of phoneme production can be systematically described. It is the functionality of these nodes in all oro-lingual behaviors that gives unity to these functions: respiration, feeding and vocalization are all variations in the activity of a **single** mechanism. Based on their importance it is useful to designate these three nodes as **primal nodes**.

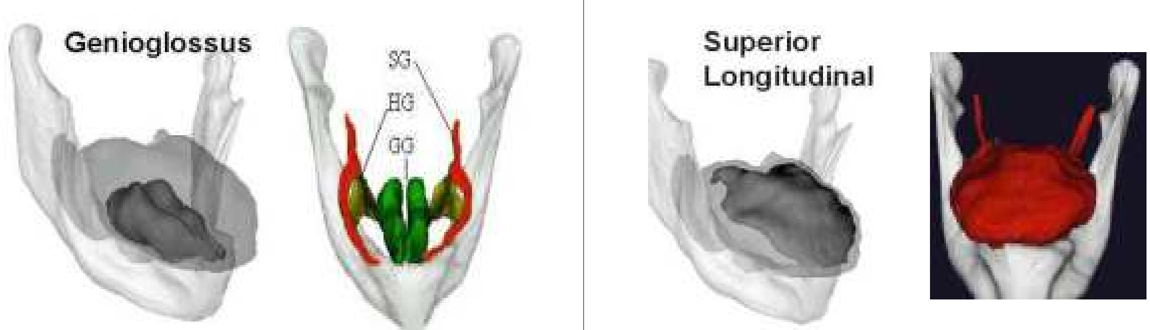
6 **The three primal lingual anchor nodes**



2.2 The three nodes - physical evidence of nodal masses

Physical evidence appears to supports the existence of such triple nodal configurations. Images from figs. 2, 3 and 4 in **The Human Tongue Atlas** patently show a wave-shaped rippling pattern on the upper surfaces of the superior longitudinal and the genioglossus muscles. The bulges visible in the four examples exhibit thickened regions of muscle mass along the axial line. The presence of these signify concentrations of regional force in the muscle masses, fig. 7.

7



from figs. 2, 3, and 4 in "The Human Tongue Atlas".

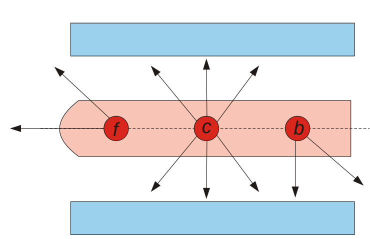
Source: Ira Sanders and Liancai Mu, “A 3-Dimensional Atlas of Human Tongue Muscles” https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3687025/

2.3 Directions of primal node actions — the Rule

Each primal node, during the coaction of its agonist and antagonist forces exhibits a particular **characteristic movement** behavior. The front node protracts and partly elevates the tongue blade, the central node centralizes the tongue body and the back node depresses and retracts the tongue back. Fig. 8. illustrates the muscular forces generating the nodes.

The locations and inherent movements of the nodes reflect the basic organization of masticatory-swallowing actions: the front, central and

8 **Rule of primal node action**

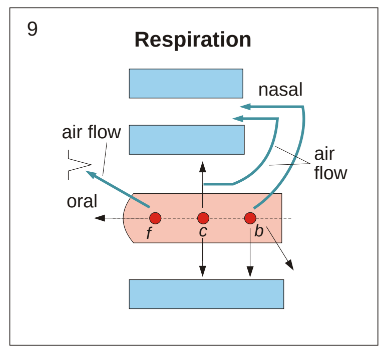


Each primal node, during the coaction of its agonist and antagonist forces exhibits a particular **characteristic movement** behavior. The front node protracts and partly elevates the tongue blade, the central node centralizes the tongue body and the back node depresses and retracts the tongue back, fig.8.

The locations and inherent movements of the nodes reflect the basic organization of masticatory-swallowing actions: the front, central and back regions of the tongue must be activated in a coordinated way to cycle and transfer the food in an well-ordered anterior or posterior direction both during mastication movements and in moving the bolus into the swallowing position. The action of suckling offer an example of this mechanism. The front region grips the nipple, the central one pumps and the back swallows the milk. Cf., J. F. Boma et. al., *Ultrasound demonstration of tongue motions during suckle feeding*, Dev Med Child Neurol. 1990 Mar; 32(3):223-9, and Michael W. Woolridge, *The anatomy of infant suckling*, Midwifery, 1986 Dec; 2(4): 164-71, where it is stated that suckling is a peristaltic action.

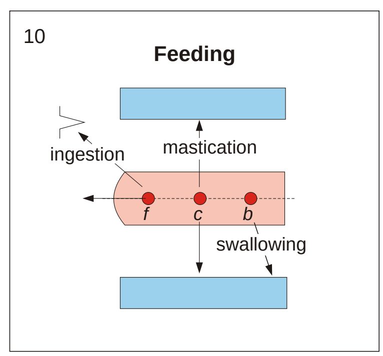
2.4 The primary functions of the oral tract

2.4.1 Respiration



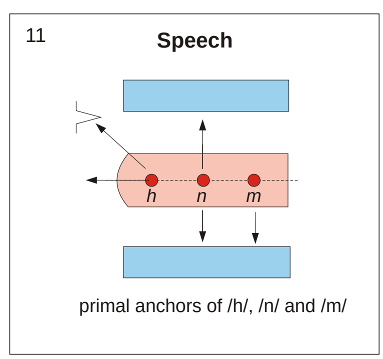
The three primary functions of the oral tract are respiration, feeding and vocalization. Breathing, working at the lowest energy level among the three is the most fundamental one. Both feeding and vocalization are **secondary** functions **superimposed** on the primary respiratory framework since breathing must proceed continuously. Without going into details it can be said that in respiration each primal node performs according to the **PR** rule: the front node by its action initiates open mouth breathing. The central node, sets up moderately closed nasal breathing with mouth open or closed. The back node generates full nasal breathing with mouth closed, fig. 9 .

2.4.2 Feeding



In feeding the primal nodes function as the centers of lingual agency in ingestion, mastication and deglutition. The **front** node protracts the tongue and biases for jaw opening, creating space for reception of food. Note that the involvement of **jaw** movement sets up an oro-lingual-mandibular framework where lingual actions are altered by the mandibular contribution: in the frontal node action phase the tongue is depressed toward the oral floor. The central node action palatally or ventrally compresses the tongue in manipulating the bolus. The back node function initiates the swallowing phase, fig. 10.

2.4.3 Speech - the h, n, and m nodes



In speech articulation the primal nodes move and shape the tongue to specifically initiate articulation of the **phonemes** /**h**/, /**n**/ and /**m**/. It may be emphasized that primal node behavior implies activity only within the tongue, and excludes all other actions such as antagonist action exerted by extrinsic lingual muscles or those of phonation, etc.

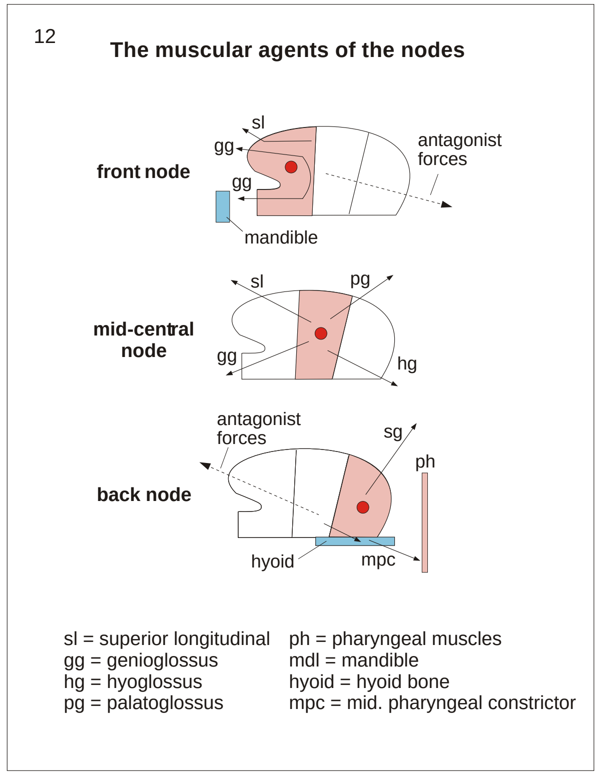
It is important at this point to note that based on their inherent association with the above listed phonemes it is convenient to **designate** the **primal nodes**, in any functional setting whatsoever, as the **h**, **n** and **m** nodes or anchors. This practice will be followed throughout this discussion, fig. 11.

2.4.4 Anatomic factors of node generation

The musculature generating each of the three primal nodes is shown in fig. 12. Their roles are as follows:

Front node: the genioglossus and superior longitudinal pull forward and elevate the tongue tip.
Mid-central node: the superior longitudinal and the palatoglossus above draw the central division dorsally and they also stabilize it horizontally by simultaneously protacting and retracting it. Below, the genioglossus and hyoglossus act similarly while pulling the tongue ventrally. The two pairs of forces balance the tongue and keep it in equilibrium centered in oral space.
Back node: The styloglossus and middle pharyngeal constrictor draws the tongue back.

Except for the mid-central node the **antagonists** of the primary agents are only depicted as general directions of force because their energy levels are relatively low compared to the primary ones and they chiefly serve only to balance the agonists. In the case of the **mid-central** node both the agonists and antagonists are indicated since both sets are of equal power in maintaining the centrality of the node.

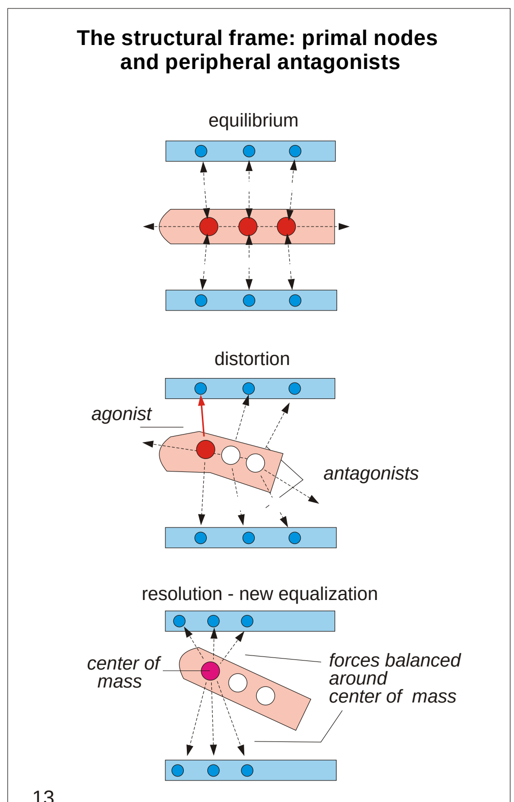


2.5 Equilibrium, distortion and hierarchy of node frames

2.5.1 Hierarchy of states of mergers - distortion/equilibrium

The fundamental equilibrium of **intrinsic** lingual muscle is maintained by the three **primary** nodes. Any action of forces impacting a setting in equilibrium distorts that framework and a new setting is superimposed to balance distortion and thus to create a secondary superimposed equilibrium, fig. 13.

Additional settings can be **superimposed** and these superimposed frames line up in a series of levels of decreasing rank and degrees of equilibrium. Superimposition of a secondary or tertiary, etc. frame requires increasing force in order to both maintain the preceding frames which remain embedded in the global structure and to balance them as they are antagonists to the superimposition. This increases the energy needed for each added superimposition which follow a series of **hierarchical** ordering: each higher energy state decays to the lower one, and eventually to the primal setting. When a new equilibrium is achieved the new node becomes the central node (or center of mass) in the newly created balanced framework.

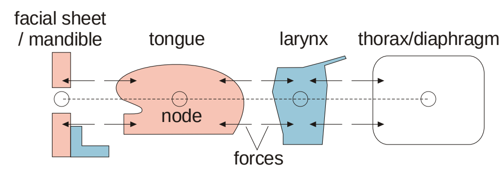


Forces active between nodes are not shown.

2.5.2 The lingual trinode

The linear sequence of constrictive elements of the **entire** oral-respiratory tract extending from the lips to the diaphragm represent an inseparable and continuous series of valves that are interconnected by the action of mutual agents and antagonists of one another, fig. 14.

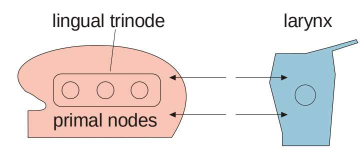
14 **Muscular valve series of the oral-espiratory tract**



As an example: while articulation is the function of the **tongue**, and phonation is the function of the **larynx** these two activities are mechanically unified. Vocalization or articulation of any sort elevates the larynx creating laryngeal frame distortion which then increases glottal tension resulting in phonation. The **facial** sheet coacts both with lingual movements and with balancing laryngeal action both as a co-agent and antagonist.

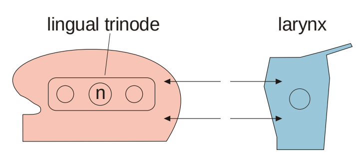
To serve in this series as the single node representing the entire tongue the primal nodes **unite** in a merger. This unit can be called the **lingual trinode**. Figure 15 shows the h-n-m **trinode** and the larynx in an agent-antagonist relationship. At the same time, the trinode also modulates tongue shape and position in its coactivity with phonation forces.

15



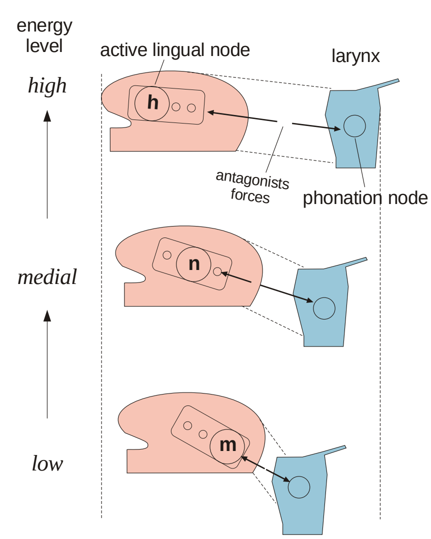
However, according to its **internal** configuration the trinode itself varies as to which node within it serves as the **primary agent** of the unit at a particular time. In the neutral speech setting the primary node is **n**, which occupies a **central** position in the lingual framework, fig. 16.

16 **Speech mode**



In the **respiratory** mode the choice of the primary node agency depends on the energy level in the system at any time. Thus, at the highest tension level the h node is the principal lingual antagonist of the phonation anchor. The n and m nodes act as primary agents, respectively, at medial and low energy levels. The identity of active node determines both the distance between the tongue and larynx, and the axial tilt of the trinode, fig. 17 .

17 **Respiratory mode**

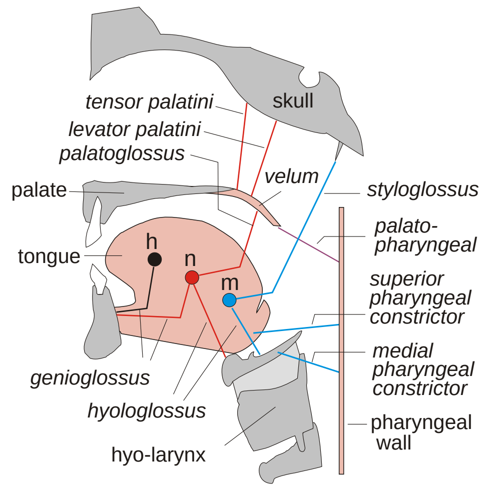


The changes in the position and tilt of tongue are not shown in the diagram

2.5.3 The extrinsic connections of the lingual trinode

The trinode is active in all oro-lingual functions. Besides managing its own internal frame configurations the tongue as a **whole** also acts as the antagonist of extrinsic lingual forces. In doing so each primal node is inherently associated with a particular extrinsic structure, fig. 18:

18 **Extrinsic connections of the primal nodes**



(1) the **h** node, in protracting the tongue and activating the mandible connects to facial muscles through the oral sphincter, since the frontal part the genioglossus attaches to the jaw which in turn attaches to the facial sheet. (Frontal tongue elevation is done by the superior longitudinal, which is an intrinsic muscle).

(2) the **n** node, mobile within the middle oral region is coactive above with the palatoglossus and velar muscles, and below with the medial genioglossus and the hyoglossus (or more precisely with the chondroglossus). Through its velar attachment by way of the the palatoglossus the n node also connects with nasal and oro-pharyngeal muscles, which fact accounts for the high degree of nasality of the /n/ phoneme.
`

(3) the **m** node is linked to the hyolarynx by the hyoglossus and through the tongue and hyoid bone to the superior and medial pharyngeal constrictors, as well as to the cranium by the styloglossus, all of which are muscles that retract the tongue.
In the speech frame the trinode is ready to form lingual configurations associated with the above extrinsic regions.

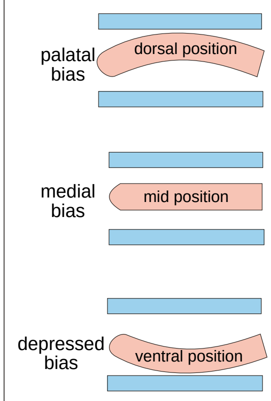
PART 3— PRIMAL PRESETTINGS

3.1Primal presetting positions

While the tongue is a mobile organ it can also remain temporarily held or **locked** in various **semi-stable positions** in the vertical dimension, both at rest and during respiration, mastication and speech. Horizontal tongue displacements, except for the central one, are less stable. The potential for this semi-stable vertical position setting is a **fundamenta**l faculty in tongue behavior.

The most stable of these positions are: (a) vertically **medial** in oral space, (b) **dorsally proximated** against the palate, or (c) **ventrally proximated** against the mouth floor. Intermediate settings between these are maintainable for only shorter periods as they noticeably impede respiration to various degrees, fig 19.

19
Dorsal, medial
and ventral presettings



The tongue also takes on three discrete and easily perceived horizontal positional settings during its **three chief functions**, as well. It is forwarded in mastication, medial in respiration and backed in speech.
In **speech** the posteriorly targeted pressure of the **retracted** lingual presetting increases tension in the oro-pharyngeal frame which reaches the larynx as well. This force causes the laryngeal frame to react as an antagonist, increasing its own tension, resulting in a controlled measure of glottal stricture that is appropriate for **phonation**.
In **mastication** the **protracted** lingual presetting positions the tongue for posteriorly transfering food. The **medial** presetting of the tongue in **respiration** allows maximal respiratory tract equilibrium.

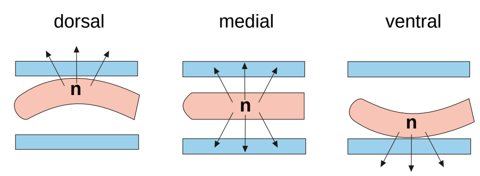
It should be remembered that the three lingual presettings are clearly **observable** only in a state of **lowest** energy level. Once the active frame emerges the tongue becomes centered through a **secondary** action. This superimposed setting sets up an equilibrium, but at a higher energy level, from which release of tension returns the frame to the initial presetting.

3.2 The mechanical roles of the primal nodes in primal presettings

3.2.1 The n nodal functions - agent of presetting

1. The initializing agent which sets up the dorsal, medial and ventral primal presettings of the tongue is the n node. The dorsal, medial and ventral presettings are the basis in distinguishing vowel and consonant articulations, fig. 20. (See Part 2).

20 The chief agent of primal settings



The initializing agent of primal settings is the n node. Once set it remains as the anchor of the setting until appropriate changes occur in that structure.

2. The n node, which is oro-spatially centered can elevate or depress the tongue by the action of the vertical symmetry of its muscular frame. When upper and lower force components are **balanced** and centered on the n node the **medial** primal presetting is attained. In the **other** two primal presettings either the upper of lower forces of the n node predominate.

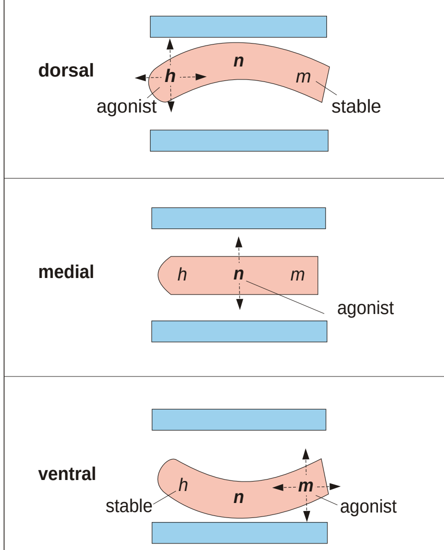
2a. The tongue lacks **vertically** directed muscles, and so pure vertical movement is accomplished by the joining of the **oblique** forces to form a vertical resultant. That is, to vertically elevate the tongue the anterior superior longitudinal and the palatoglossal work together, while vertical depression is accompished by the combination of the genioglossus and hyoglossus muscles.

3. When the initializing action of the n node takes place it distorts lingual equilibrium and a re-balancing is required to equalize the unbalanced forces. Once the n node has generated a primal presetting it stays stable and embedded while the h and m nodes respond to equalize the distortion due to the n displacement. The aggregate action of the three nodes appears as a superimposed frame over that of the previous one. (More in Part 2).

3.2.2 The h-m nodal functions - stable vs. active

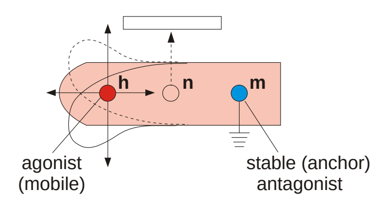
To equalize the distortion generated by initialization of a presetting the h and m nodes each take on certain behaviors: one stabilizes the trinode and the other, as the antagonist, modulates the tongue shape to balance the first one. As will be seen, this faculty is basic in phoneme production and it is easily perceivable.
While in the **speech mode**, holding the dorsal presetting in full **palatal** contact and then focusing observation only on the h and m nodes, we easily ascertain that the **anterior** node h is **stable,** rigidly maintained in its place in the tongue, while the posterior node m is **mobil**e and can reposition and reshape its part of the tongue. On the other hand, the ventral presetting shows **contrary** symmetry: here it is the m node that anchors the back of the tongue, while anteriorly the h node moves freely. This is a fundamental geometrical difference between the articulation of vowels and consonants, figs. 21 and 22.

21 **The roles of the primal nodes in primal presettings**



This difference is observable by comparing the dorsal and ventral presettings. In the dorsal one it is consonants, not vowels that can be articulated, and the converse is true in the case of the ventral one. The medial presetting enables the production of the three primal phonemes h, n and m. (More in Part2).

22 **Model of h-m mechanics**
(in the dorsal presetting)

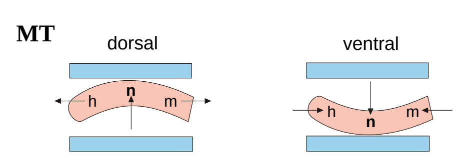


Note: the ⏚ symbol attached to the m node to indicating stabilizing, or anchoring function is taken from electronics where it stands for electrical grounding.

In the presettings the h and m nodes constitute a single mechanical unit, an agonist-antagonist couple, which cannot be separated without losing its function. As opposed to the role of the n node in initializing the presetting, the h and m nodes are responsible for fully completing the frame generation of dorsal and ventral presettings.
At the same time, in holding one another in balance, the merged h and m nodes also serve together as antagonists of the n node. This trinodic balancing function is basic to shaping the tongue.

Thus, all **three nodes** are functional in the primal presetting frame. The dominant agent in the presettings is the **n node**: as seen by the Rule it is **n** that **elevates** or **depresses** the mid-tongue. The resulting distortion is equalized by the **h** and **m** nodes, but the action differs in each of the two presettings. In the dorsal one the **h** and **m** nodes pull away from the center, while in the ventral one they pull centrally. In simplest terms the dorsal presetting longitudinally **extends** while the ventral one longitudinally **contracts** the tongue, fig. 23.

Directional biases of primal nodes in presettings



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3.2.3 Masking of the primary presettings

The behavior of the nodes in primal presettings, and of the n node in particular, is largely **masked** in full articulation mode especially since the involvement of extrinsic muscles complicates the global framework. Observing the behavior can be done by freezing the presetting framework and then gradually allowing it to **decay**. As the system returns to its resting state the various nodes become inactive in order of hierarchy until the fundamental anchoring n node appears in isolation.

3.2.4 The role of primary presettings in oral tract functions

The primal presettings are semi-stable nodal framework configurations that the tongue specifically sets up to perform distinct mechanical functions. For instance, dorsal, medial and ventral settings generate the lingual frameworks, respectively, of (a) respiration, (b) vocalization, and (c) mastication. Once an initial primal presetting is established secondarily superimposed primal presettings are applied in the performance the three main oro-lingual functions:

Mastication: (a) dorsal pressure of the tongue forces food forward and backward (as well as sideways) between the tongue and the palate; (b) in ventral pressure the tongue is upward concave somewhat like a ladle and serves to collect the food, (c) the medial presetting, being intermediary between the dorsal and ventral positions serves as the common anchoring between those two.

Respiration: (a) the medial setting is modal; (b) the dorsal setting occurs in thoracic breathing; (c) the ventral position appears abdominal breathing.

Speech: (a) dorsal presetting initiates consonant articulation, (b) the ventral one serves vowels; (c) medial setting produces the respiratory phonemes h, n and m. (This topic is covered in Part 4.1, ff.).

Note: **Jaw** behavior is the coactive with the tongue in generating presettings. Jaw closure generates the dorsal setting, a neutral jaw produces the medial setting and an open jaw causes the ventral setting.

3.2.5 Notes on observing nodes

3.2.5a Nodes: isolated vs. engaged (pre-articulative)

An important point should be noted. All discrete individual nodes are normally **masked** by the complex interactions present in the global framework; therefore they are apparent only when **isolated** in a tonic or low energy state of the system. This subject is more fully covered in section *Phase Relations*.

3.2.5b Intrinsic (or anchor) vs. extrinsic (or manifold)

There are **two** subsets of forces in a nodal frame. One is the **intrinsic** lingual frame of the central anchor node while other one is that of the surrounding **manifold** of **extrinsic** lingual forces. Normally the two sets of forces appear combined, engaged in mutually antagonistic traction, and so neither one is observable as a discrete entity. Therefore, the **anchor** node must be **isolated** by causing it to exert centripetal pull toward itself. The **manifold**, in turn, becomes observable when it is isolated, and the extrinsic muscles pull the anchor centrifugally.

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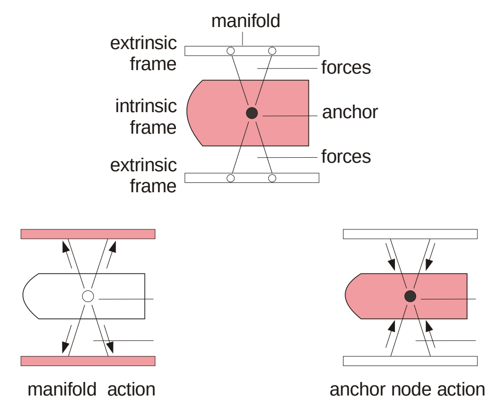
Anchor vs. manifold



3.2.5c Positional variants

Another point to consider is that just as articulated phonemes do, each node possesses positional variants within the tongue, such as front, high central or low versions. These are all assigned particular secondary subframes imposed over the mid-central node of a particular phoneme. It is important to distinguish the positional variants from the mid-central one, as the latter is usually the one to be observed.

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Positional variants