G. S. Tong (2008)

THE MECHANICS OF MASTICATION

Contents

A. Trisegmentals in frameworks

Terms used by Hiiemae and Palmer (2003) are used in this paper. Cycling the food during mastication is **processing**. **Transport 1** refers to the posterior movement of the newly ingested food, and moving food posteriorly toward the deglutition region is called **transport 2.**

General note: it is important to keep in mind that unless otherwise indicated all tongue motions and shaping described occur in an isolated settings. That is, these behaviors take place when the only active agent is tongue, while all other associated parts of the speech mechanism remain neutral.

1. **Trisegmental** horizontal and vertical structure forms the 3x3 anchor matrix. Trisegmental **cyclic** action provides the mechanism for both cyclic tongue and jaw movement and tongue shaping in mastication described in Hiiemae and Palmer (2003), as well as the generation of the features of systematic infant babble and syllabic structuring documented by MacNeilage and Davis 1995. This identity underlies the similarity between masticatory and articulative tongue behavior noted by these and other authors. fig. a.

1a. The active tongue anchor here is in the anterior 2/3 part of the tongue (oral part). Its movements are anchored by the posterior 1/2 (pharyngeal) part.

2. The trisegmental structure in   and **speech** is essentially the same but performs different functions for reasons including the fact that the jaw is differently anchored in these functions, according to its own particular trisegmental format i.e., placement of its hinge apparatus, (for more on this see Ontology of speech). The jaw is the largest, heaviest and most powerful part of the upper visceral architecture and therefore its particular temporomandibular matrix setting plays a decisive role in framework formation.

3. In the **process** phase of mastication, as termed by Hiiemae and Palmer, lingual anchors generate the various tongue shapes and placements (heaps and valleys) which, in relation to the palate and oral walls and floor, posit and move the food to be repeatedly chewed. These tongue positioning are also the source which generate, when arising in the speech frame, the phonemes d/t, g/k, n, a, i, etc. Fig. a.2. During processing the active central tongue segment is stabilized by the pharyngeal (or posterior 1/3 part of the) tongue.

a.1

tongue segments

3x3 tongue anchor matrix

a.2 process

a.3 transport 2
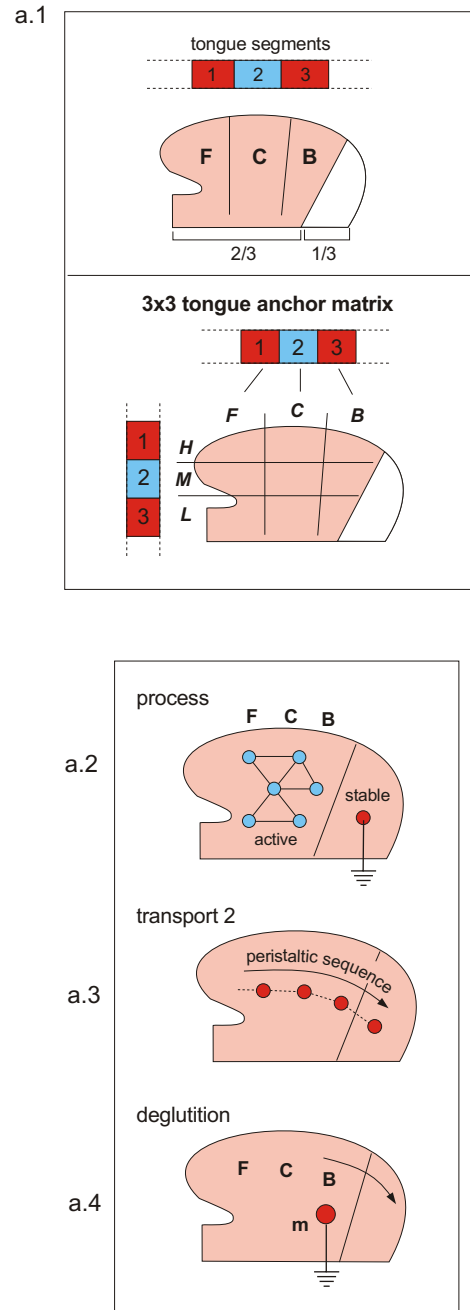
a.4 deglutition

4. In the **transport 2** phase of mastication the masticated bolus is moved peristaltically posteriorly through the fauces to the tract region of deglutition. fig. a.3.

The anchoring is shared or merged, in sequentially changing proportions, by the front, central and back segment anchors of the oral 2/3 tongue. Entering the **deglutition** phase the stable anchoring passes to the anterior oral 2/3 part and the posterior pharyngeal 1/3 becomes active.   fig. a.4.

5. Musculature of tongue segment action

The main muscles of the mastication processing phase are shown in Diagram 1. The intrinsic lingual muscles are indicated only in the central segment action in figure 1.b.

Fig. 1a. In the initial action the **front** segment of the active tongue region creates a **heap** which anteriorly seals of the mastication space and pushes the food inwards. The genioglossus frontally pulls the tongue against the mandible and tenses it, thus heaping it against the palate in coactivity with the superior longitudinal.
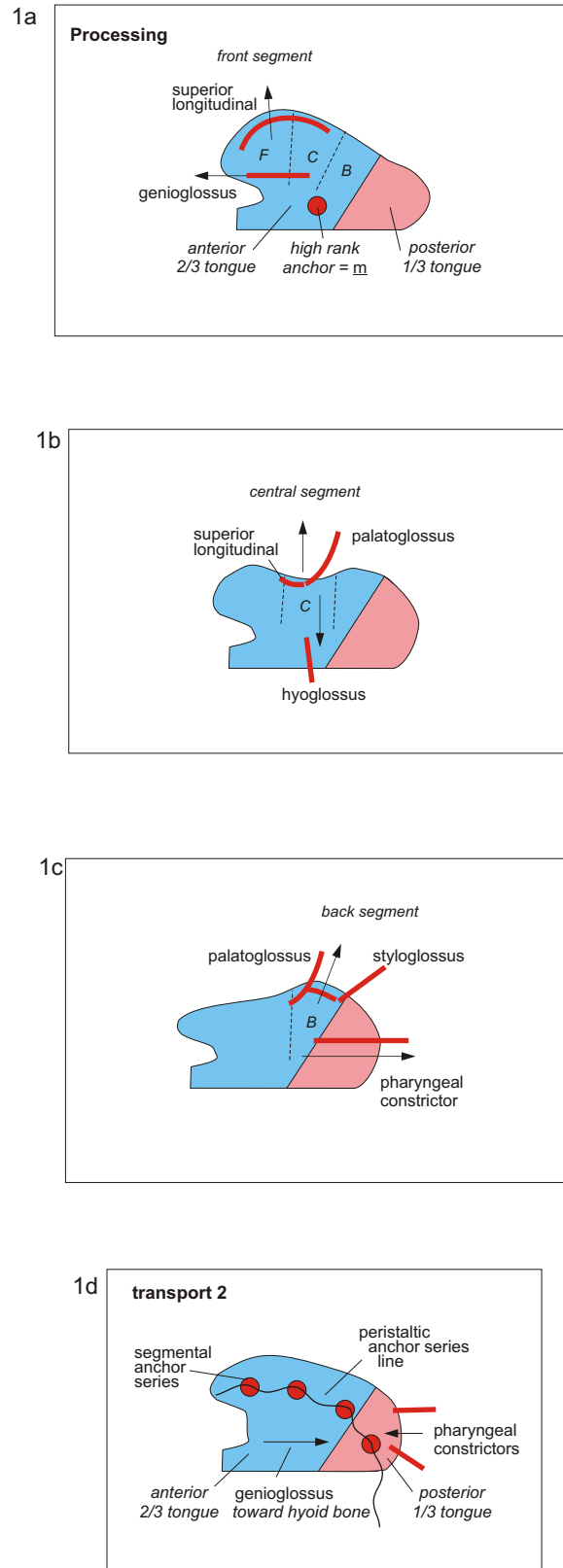
Fig. 1b. The action of the **central** segment **constricts** the tongue and allows the bolus to pass through dorsal and lateral channels. Lingual inward/medial constriction is produced by the intrinsic vertical and transverse muscles which narrow the tongue vertically and laterally.

Fig. 1c. The **third** segment forms a **heap** to block passage and then presses the bolus forward to prepare for the next cycle.

Seen as a sequential trisegmental series of closing, opening and again closing the tract, we can interpret it as **peristaltic** action, which has been recognized as the pumping mechanism of suckling (cit.) However, in mastication processing the behavior is not linear, but cyclical and is an example of modified peristalsis, or **metaperistalsis.**

Fig. 1d. shows the muscular map of the **transport 2** phase, where the anchor sequence begins a linear peristaltic action with a frontal segment heap, followed by a central segment valley, and a back segment heap. As food leaves the oral space and enters the deglutition phase, the peristaltic transport continues with serial closure and expansion between the pharyngeal tongue part and the pharyngeal constrictors.

Diagram 1. Musculature of trimeric action in mastication

1a — Processing. front segment. superior longitudinal. genioglossus. F C B. anterior 2/3 tongue. high rank anchor = m. posterior 1/3 tongue.

1b — central segment. superior longitudinal. palatoglossus. C. hyoglossus.

1c — back segment. palatoglossus. styloglossus. B. pharyngeal constrictor.

1d — transport 2. segmental anchor series. peristaltic anchor series line. pharyngeal constrictors. anterior 2/3 tongue. genioglossus toward hyoid bone. posterior 1/3 tongue.

B. The interpretation of lingual aspect of mastication as an anchor-matrix function

We have looked at the AMS structural mechanics of speech ontology and have established it to be an interaction of complimentary antagonist anchoral trisegments working in monadic coactivity with the mandible. At this point we can interpret the mastication process described by Hiiemae and Palmer as an alternate function of the same structure.

This description is necessarily general because to analyze the complex action of mastication as anchor-matrix behavior requires us to reduce this behavior to a single variable by eliminating all but lingual activity. The coaction of the organs of mastication, the mandible, tongue, velum, etc., creates merged upper visceral frame action which distorts and so masks the anchoral mechanics of the tongue. Tongue action must be isolated by keeping the mandible tonically immobile, and executing only the lingual action of mastication without the presence of food material. Similarly, investigating the effect of jaw action on the tongue the latter must be in a tonic state.

C. The masking factors:

Such isolation is important because the independent shaping and movement of the tongue is controlled by at least three external agencies:

(a) jaw rotation (because the jaw is the most powerful force in the system, and so takes the primary role in coactive and antagonist relations), by

(b) the presence of food material on the surface of thea tongue—bolus on the dorsal tongue causes dorsal arching and bolus on the ventral blade and tip causes ventral arching, while bolus on the sides of the tongue causes axial and transverse constriction on the tongue. fig. c.1.

(c) because of laterally asymmetrical twisting movements of the tongue. fig. c.2.

d) various other factors appear when isolation of tongue action is absent, including head and body tilt.

Still another difficulty in full framework masticatory action is the fact that mastication processing contains no discrete components such as are the phonemes in speech, and is a gliding action, rather than syllabic clutch-type anchor change sequence, as is speech.

Therefore, describing only the isolated tongue behavior we can analyze tongue shaping and movement as a mapping of lingual masticatory anchors and their envelopes.

c.1

Necessary isolation of the tongue
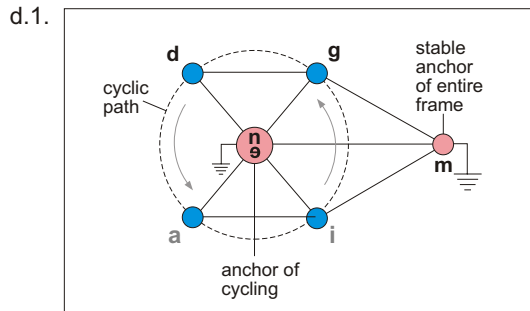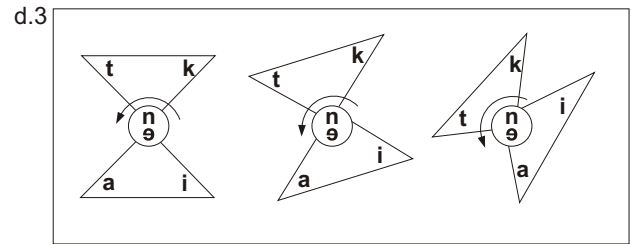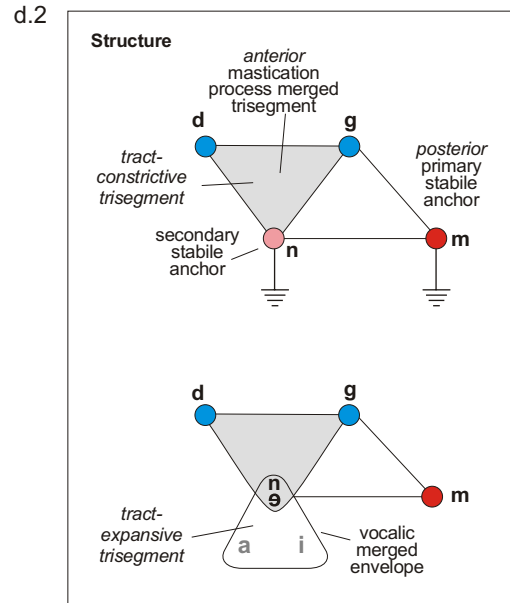
c.2

Effect of bolus on tongue
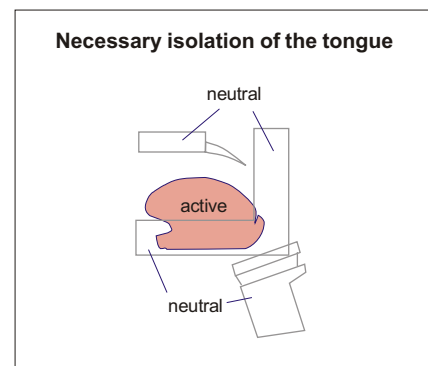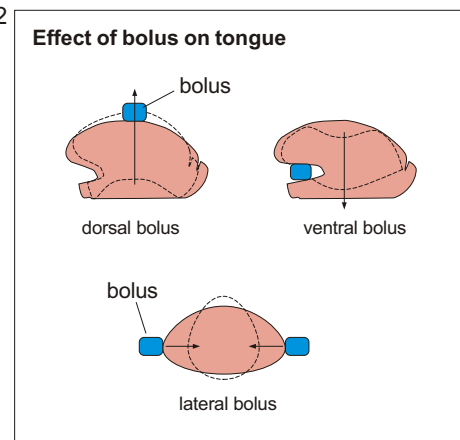
D. Structure

1. The lingual masticatory anchor structure is geometrically composed of four trisegments formed by anchors and lines of forces connecting them. Fig. d.1.

All the units are coactive, and are mutual antagonists or (co-agonists) of one another. The posterior two units are the lingual stabilizing structure for the entire mechanism anchored on m. The two anterior units are a composite dual trisegment performing the cyclic movement of food processing, anchored on n–ə. Fig. d.2.

2. In mastication (as in suckling, and unlike in speech), the trisegments a-ə-i and t-n-k of the cycling mechanism are not discrete units, but are merged through their combined n+ə«central anchor. This composite movement envelope rotates as a single unit. Fig. d.3.
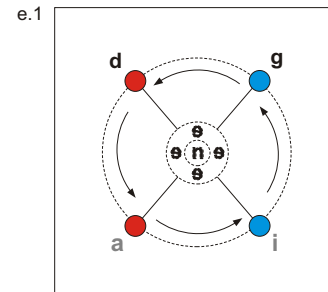
Anchor matrix of mastication process

d.2

Structure

anterior mastication process merged trisegment

tract-constrictive trisegment

posterior primary stabile anchor

secondary stabile anchor

tract-expansive trisegment

vocalic merged envelope

d.1.

cyclic path

stable anchor of entire frame

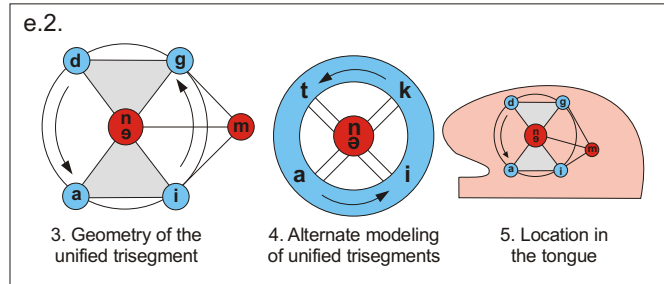anchor of cycling

d.3

E. Action
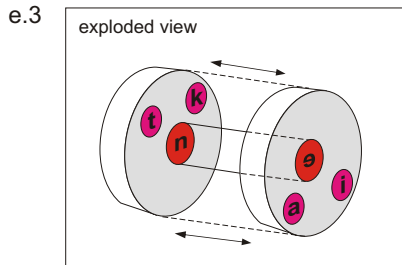
The central anchor of mastication process

The consonantal and vocalic trisegments form a single mechanical unit composed of two merged anchor centered envelopes. The two rotate around a common central merged anchor, which is, in turn a merger of the mid-central anchor of each. The n/« merged anchor operates in a unit formed by two concentric envelopes. fig. e.1.

In terms of tract cross section the n constricts and the ə expands. Thus, the rotation cycle of the anterior trisegment is anchored not only on its mid-central anchor n, but also on its the compensatory antagonist anchor-envelope, which is centered on ə and includes a and i. These two, respectively, germinally consonantal and vocalic envelopes are an antagonist unit pair, each in turn serving to balance or compensate/equalize the tract distortion produced by the other. figs. e.2., e.3., e.4.

e.1

Trisegments united

e.2.

3. Geometry of the unified trisegment

4. Alternate modeling of unified trisegments

5. Location in the tongue

e.3 exploded view

e.4

Exploded views of cyclic action

cyclic anchor motion

merger

1. 3-D exploded view of the two-trisegment structure

2. 2-D exploded view of the two-trisegment structure

e. This diagram shows the constrictive and expanding antagonist relationship between n, m and their surrounding coactive tract correcting germinal vowels. The anchor a is coactive with m, while n is coactive with ǝ. This structure produces the universal /ma/ of early infant speech. fig. e.5.

Cycling in mastication is generated by the coactive antagonist trisegmental pairs already described.
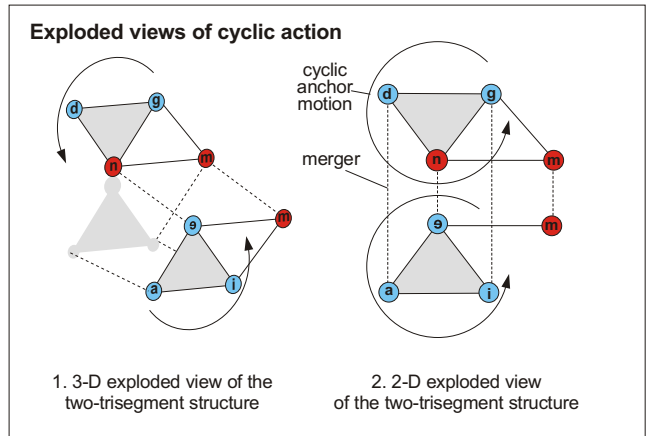
The direction of the cycling is posterior to anterior in general, if starting from the posterior dorsal heap of the tongue, as described by Hiiemae and Palmer. It can be noted that the opposite direction in cycling occurs in suckling and drinking.

The movements of food on the dorsal surface of the tongue serves to transfer material to the dental biting surfaces and to move the chewed material forward. The dorsal trisegment is tract constrictive (or germinal consonantal), activated by the germinal anchors t, n, and k. The ventral trisegment, which moves the food backward, is activated by the a-ǝ, and i anchors and it is tract expansive (or germinal vocalic).

The cycling of food is achieved through sequential alternation between the upper dorsal and the lower ventral trisegments, the anchors of which move in a glide manner, respectively, anteriorly and posteriorly. It is the bolus of food that actually follows a cyclic path.
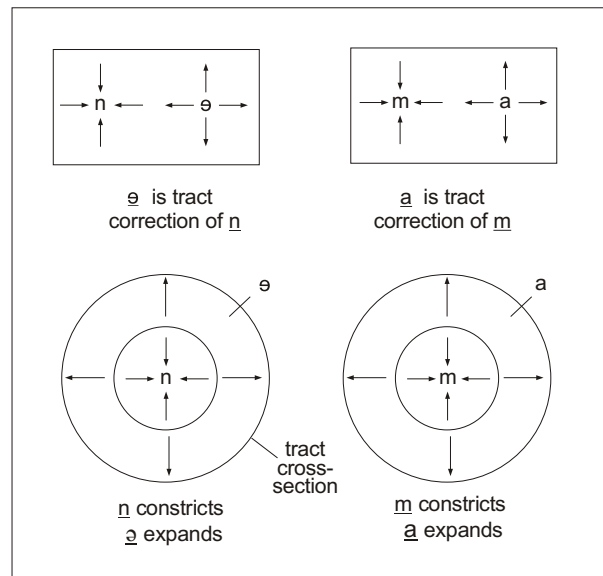
In the initial dorsal phase the active k anchor is transferred to t, then occurs a phase of transition from the dorsal to the ventral trisegmental envelope. Next, the ventral phase consisting of a to i anchor travel transports food backwards until the end of the ventral envelope is reached and then the action primacy is transferred once more to the dorsal envelope phase. fig. e.6.

m and n anchor tract corrective vowel associations

e.5

ǝ is tract correction of n

a is tract correction of m

ǝ

a

tract cross-section

n constricts ǝ expands

m constricts a expands

Pattern of cyclic anchor movement

e.6

1st half cycle

t ← k

n ǝ

1st anchor glide transition

t — k

n ǝ

a

2nd half cycle

n ǝ

a — i

2nd anchor glide transition

k

n ǝ

i
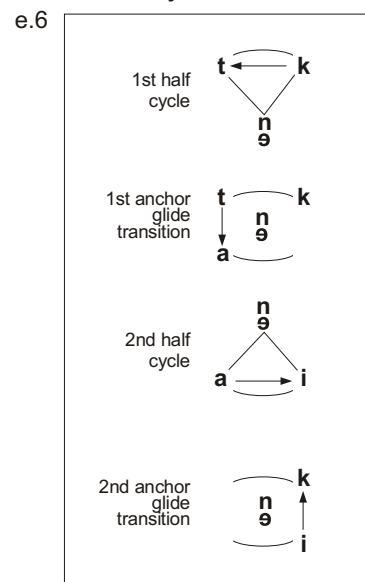
F. Deglutition initiation

As Hiiemae and Palmer reported (cit.), in the mastication process food that is being chewed is repeatedly cycled moving posteriorly in the oral space before once again being re-transported it to the front. The n anchor centering of the action is maintained. But as the food is liquefied the intensity of mandibular and lingual work of chewing action is reduced and at one point the action that gradually moves food posteriorly no longer returns it to the front, but rather, continues moving it posteriorly. fig. f.1.

At such times the action of the cycling trisegment gives way to pre-deglutition transport 2, there is an exchange of roles between the n-centered cycle envelope and the m anchor which formerly stabilized it and the former becomes the stabilizing anchor for the m anchor envelope that now becomes active passing the bolus into the pharynx.

Demo:

If chewing is continuously performed without any food in the mouth, a point in time is reached when swallowing is triggered.
The mechanism behind this is in part metaperistaltic, and in part **glottoregulative.** The latter is not covered here. (*See G. S. Tong, Foundation of Speech mechanics...*)
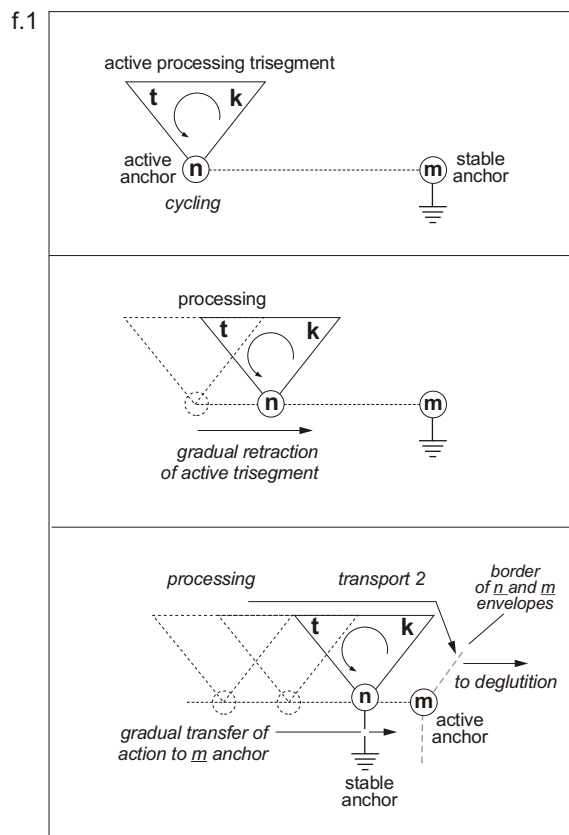
G. Mandible-tongue coactivity

Taking into consideration the mechanics of monadic jaw-tongue unified interaction, it is important to note two facts:
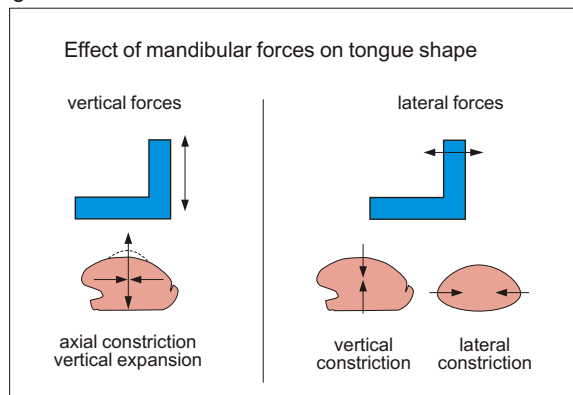a) when the cranio-mandibular musculature is active, in a non-tonic, dynamically varying energized state, the tongue transversely and vertically contracts in direct proportion to mandibular energy level. fig. g.1.
b) jaw rotation, as has been discussed earlier causes certain tongue relocations and shape changes. (Jaw down—tongue back and k heap; jaw up—tongue forward and t heap.) fig. g.2.
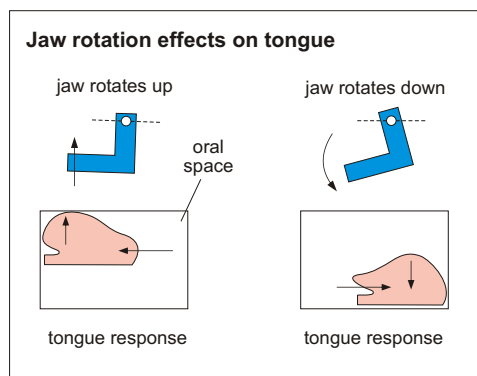
Taking into account these points, we can sketch the mapping of the anchor envelopes of the masticatory processing cycle.

f.1

active processing trisegment

t   k

active anchor (n) --------- (m) stable anchor

cycling

processing

t   k

(n) --------- (m)

gradual retraction of active trisegment

processing   *transport 2*   border of n and m envelopes

t   k

to deglutition

(n) (m)

gradual transfer of action to m anchor   active anchor

stable anchor

g.1

Effect of mandibular forces on tongue shape

vertical forces   lateral forces

axial constriction vertical expansion   vertical constriction   lateral constriction

g.2

Jaw rotation effects on tongue

jaw rotates up   jaw rotates down

oral space

tongue response   tongue response

H. The elision:

The shape if the tongue anchor matrix changes with the function and energy applied. The modal (lowest energy) state of the UV system is in quiet diaphragmatic respiration. Here the lingual anchor of respiration is active; the 3x3 matrix is passive. In speech, suckling and mastication the 3x3 matrix becomes active and produces characteristic distortions. This is partly from the enlargement of mandibular forces.

In mastication an important distortion appears during the latter part of the ventral half phase of processing: the low back region of the oral space and tongue is compressed toward the center of the matrix, and this effectively cuts out the phase of the i anchor action. An **abbreviation,** or **elision** of the path occurs in anchor movement between a and k, (steps 5 to 1 in Chart MC). fig. h.1.

This can be observed through an experiment. If one stops at the appropriate point in the masticating cycle, the various concurrently active germinals, t, k, n, a, and ə can be produced, but i cannot. If the i anchor is generated in this context, there arises a strong bias for triggering **deglutition**.

This back-low truncated shape in the diagram from Hiiemae, et. al., *Hyoid and tongue surface movements in speaking and eating* (2002), which indicates all positions occupied by anterior and posterior tongue markers during a processing cycle apparently **supports** the presence of such **elision**. fig. h.2 .

h.1

h.2

Source: Karen M. Hiiemae, et. al. (2002)

I. Notes to chart MC: The isolated lingual anchor mechanics of the masticatory process cycle
(on p. 9)

This diagram depicts the lingual anchor mechanism of the masticatory process as a framework of trisegmental anchor envelopes. It is a map **strictly** of **isolated** tongue behavior with the rest of the framework in a neutral state, so that their influences affecting the tongue and the entire framework are minimized. The positions of the jaw, which are also shown serve only as reference.
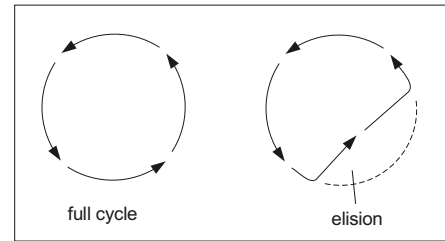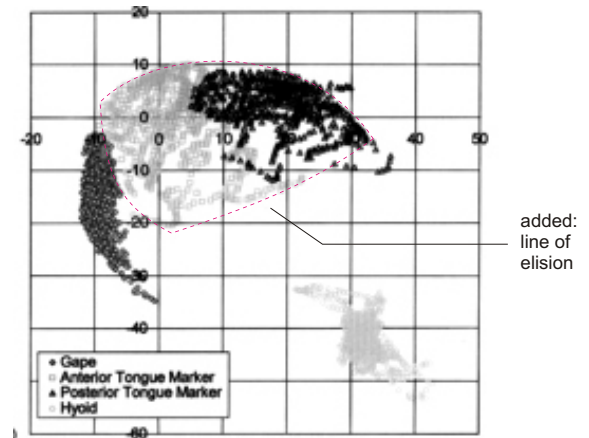
1. The dorsal t-n-k and ventral a-ə-i trisegments function as a single merged unit, each centered first on its on mid-central anchor and secondarily, as the merged antagonist pair n/ə. An analogue of such hierarchical bistate anchoring occurs in the way a planetary moon orbits around its planet, which in turn orbits its star.

The interchange of dorsal and ventral actions proceeds as a fluid glide.

2. The cyclic motion is generated by alternating exchange of primary agent roles in the antagonist pair. The dorsal tract constrictive phase and the ventral expansive one alternate.

3. Jaw-tongue action is not considered in this isolated tongue map, nevertheless, the positions of the jaw are indicated at the appropriate points in diagram MC. In an actual, non-isolated setting of framework components these mandibular positions are associated with the particular cycle phases.

CHART MC — The steps in the masticatory processing cycle

1. The k̲-heap in dorsal trisegment primacy starts forward dorsal transport of bolus, which is in the dorsal space.

2. Midway point in dorsal transport.

3. Anterior t̲ heap gates (blocks) the bolus movement.

4. Transferring of anchor/envelope primacy between the two trisegments. The bolus is about to enter the ventral space.

5. Ventral trisegment primacy (tract compensation) opens the channels inferior and lateral to the tongue. A germinal a̲ heap posteriorly moves the bolus in the ventral space.

6. The envelope space of the germinal _ is elided, see above 8. Elision.

7. Transfer of primacy once again, from ventral to dorsal, returning to the k̲ heap position. The new cycle begins.

Chart MC (the masticatory cycle)

The lingual anchor mechanics of the masticatory process cycle
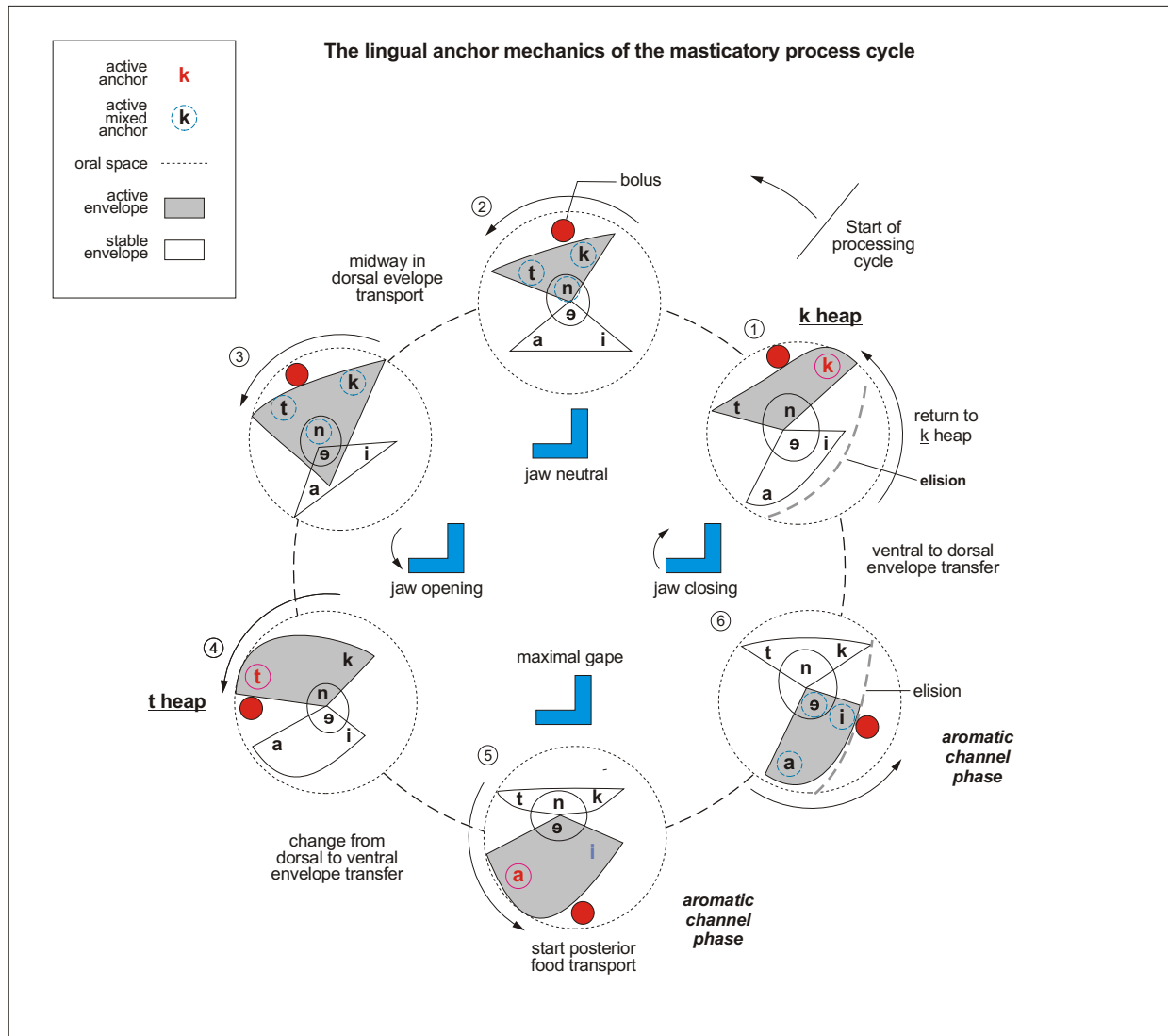
J. Retronasal aroma perception

Olfactory perception of food **aroma** is an essential part of food processing and it is enabled through the specific phases of the cyclic movement of the n/ə envelope. The germinal stops that generate the front and back gate heaps of the tongue are constrictive, and since constriction in one valve of the UV causes the constriction of the remaining valves, the envelopes of these germinals will also close the velar and nasal air channels. However, the a-ə-i envelope, which is the tract expanding respiratory compensatory antagonist envelope of the t-n-k trisegment, enlarges the tract, including that of the velar and nasal regions, and thus allows the passage aromatic air. This occurs during the phases when the ventral trisegment is primary agent and air is expired. figs. j.1. and j.2.

During **deglutition** the valves are once more closed, but immediately after the bolus enter the esophagus the m/a envelope expands the velo-nasal tract to receive the residual air that has filled the pharynx during deglutitional compression. At that time deglutition is followed by expiration and the aroma of that particular swallowing is sensed once more for a final time. Inspiration never occurs on completion of deglutition. This is the moment when people approving of food typically generate the /m/ sound.

Thus, it is during the backward cycling and transport of the processed food that the aromatic components of food are perceived.

Demonstration: in the masticatory mode, but with no food in mouth, slowly and carefully expire nasally. Note that the tongue and oral space takes on the a-ə-i configuration.

j.1

j.2