The compartmental tongue

EVIDENCE FOR INDEPENDENT NEUROMUSCULAR CONTROL OF SIX SECTORS OF THE OROPHARYNGEAL CAVITY.

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What's new here?

1. A detailed manual fibre-by fibre segmentation of the visible human female [7]
2. An expansive review of all sources of evidence to ascertain the arrangement of NeuroMuscular Compartments (NMCs)
3. Kinematic study of coupling between different tongue sectors.
4. Biomechanical modelling showing how NMCs co-operate to control function in sectors.

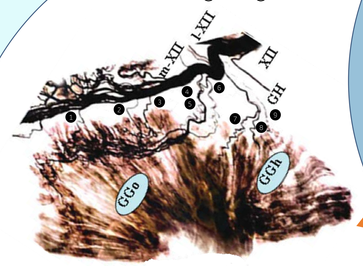
How can we determine the number of compartments?

The Partitioning Hypothesis (English, 1993)[6] holds that a neuromuscular compartment (NMC) is the smallest portion of a muscle that receives exclusive innervation by a group of motoneurons. An NMC can be contracted independently of other portions of the same muscle. There are several indicators of an NMC.

What are we saying?

Anatomical segmentation of genioglossus indicates 10 distinct fibre bundle origins arranged in pairs of medial/lateral NMCs located in 5 tongue body sectors. 7-9 primary nerves observed by Mu[1] in humans (10 in dogs) support this high number of NMCs. McClung identified distinct motoneuron clusters at different levels of the hypoglossal nucleus mapping to separate sectors. Histology, axon tracing and EMG experiments are often predicated on the assumption of 2 compartments and are not sensitive enough to detect more. Even so, evidence can be found of different strengths and timings of activation in more than two compartments. Kinematics show localised (mechanical) coupling but no correlation of distant sectors as previously reported[8] implying independent control. Biomechanical modelling shows width of groove can be controlled by a pair of genioglossus NMCs and Verticalis while the U-shaped course of Transversus fibres opposes them to stretch genioglossus and form a constriction in the oropharyngeal cavity.

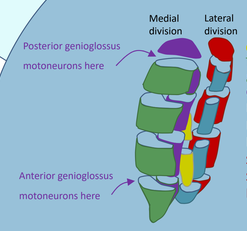
Innervation of human genioglossus



Image[1] shows 7-9 primary nerve twigs.

Each NMC requires a primary nerve twig

Hypoglossal motor nucleus (Monkey)



a) Verticalis, transversus and genioglossus motoneurons are proximate to each other in the medial division.

b) Motoneurons for posterior and anterior parts of genioglossus are grouped in separate levels of medial division[2].

Motoneurons of an NMC should be located proximately to each other and arranged musculotopically

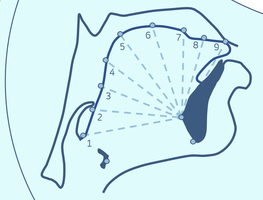
Histology

Differing percentage of slow muscle fibres in regions of adult human genioglossus[3]

Blade 46% Body 59% Base 64%

An NMC may have distinct proportion of fast and slow fibres

Kinematics

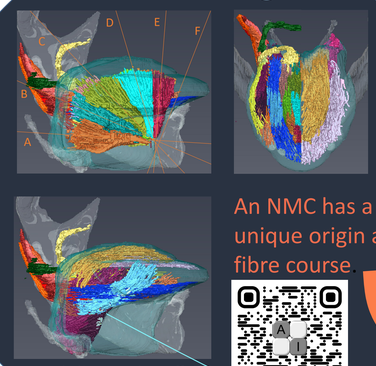


	1	2	3	4	5	6	7	8	9
1	1	0.9	0.7	0.5	0.3	0.1	0.1	0.1	0.1
2	0.9	1	0.9	0.6	0.3	0.1	-0	0	0.1
3	0.7	0.9	1	0.9	0.5	0.2	0	0	0
4	0.5	0.6	0.9	1	0.8	0.5	0.2	0.2	0
5	0.3	0.3	0.5	0.8	1	0.8	0.6	0.4	0.1
6	0.1	0.1	0.2	0.5	0.8	1	0.9	0.6	0.2
7	0.1	-0	0	0.2	0.6	0.9	1	0.9	0.5
8	0.1	0	0	0.2	0.4	0.6	0.9	1	0.8
9	0.1	0.1	0	0	0.1	0.2	0.5	0.8	1

Distant sectors e.g. 3-6-9 are uncorrelated

Correlation of distances to 9 points estimated by DeepLabCut from 20k frames of ultrasound from 34 sentences by 17 speakers

Anatomy

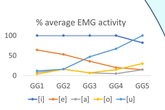


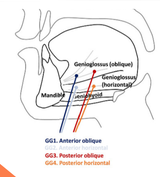
An NMC has a unique origin and fibre course.

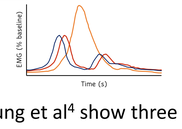
View in 3D

Electromyography

Miyawaki[5] observed EMG at 5 locations in genioglossus from posterior GG1 to anterior GG5 sectors and noted different average EMG values for the 5 Japanese vowels.







Yeung et al[4] show three differently timed excitations during a swallow.

NMCs may have different activation timing

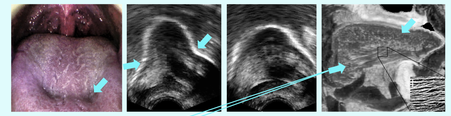
Why is this important?

This evidence suggests that groups of motoneurons control antagonistic teams (or synergies) of NMCs that control 5 sectors of the tongue body plus tip/blade. Vocal tract constrictions are made by relatively higher levels of activation of the transverse NMC compared with the genioglossus NMC for the same sector. Co-contraction leads to rostro-caudal expansion but the Oblique Longitudinalis (identified below) opposes this, enhancing and stiffening the constriction. This is very different from the idea that styloglossus and palatoglossus are primarily responsible for uvular and velar constrictions.

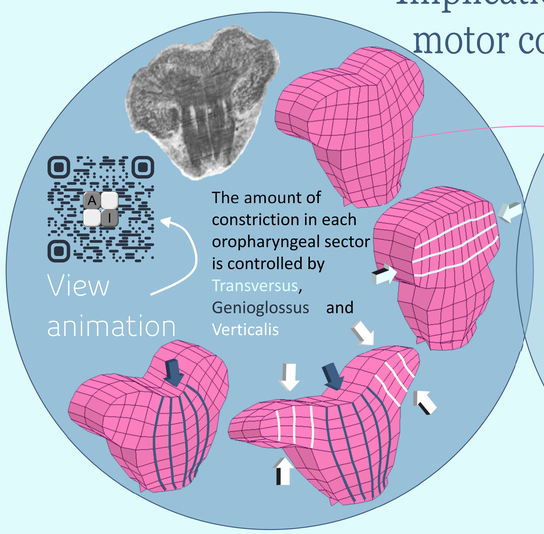
The most important muscle you didn't know about

The oblique inferior longitudinal compartment supports tongue body bunching by constraining rostro-caudal expansion of tongue body sectors.

Observed by Zaglas (1851), Von Kölliker (1852), Oikawa (1973), Mu & Sanders (2013)



Implications for motor control



NMCs control constriction along vocal tract

View in 3D

- The oblique NMC of Inferior longitudinal muscle constrains the rostro-caudal expansion of the tongue body
- The tongue body is controlled in 5 sectors by NMCs of Genioglossus, Verticalis & Transversus.
- The blade is controlled by Verticalis and Transversus and a set of longitudinal muscle compartments.

References

[1] Mu, L. and I. Sanders (2010). "Human tongue neuroanatomy: Nerve supply and motor endplates." Clinical anatomy (New York, N.Y.) **23**(7): 777-791.

[2] McClung, J. R. and S. J. Goldberg (2000). "Functional anatomy of the hypoglossal innervated muscles of the rat tongue: a model for elongation and protrusion of the mammalian tongue." The Anatomical Record 260(4): 378-386.

[3] Sanders, I., et al. (2013). "The human tongue slows down to speak: muscle fibers of the human tongue." The Anatomical Record 296(10): 1615-1627.

[4] Yeung, J., et al. (2022). "Task-dependent neural control of regions within human genioglossus." Journal of applied physiology **132**(2): 527-540.

[5] Miyawaki, K. (1975). "A preliminary report on the electromyographic study of the activity of lingual muscles." Annual Bulletin RILP 9: 91-106.

[6] English, A. W., et al. (1993). "Compartmentalization of muscles and their motor nuclei: the partitioning hypothesis." Physical Therapy 73(12): 857-867.

[7] Spitzer, V., et al. (1996). "The visible human male: a technical report." Journal of the American Medical Informatics Association 3(2): 118-130.

[8] Stone, M., et al. (2004). "Functional segments in tongue movement." Clinical linguistics & phonetics 18(6-8): 507-521.

Further reading and references

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