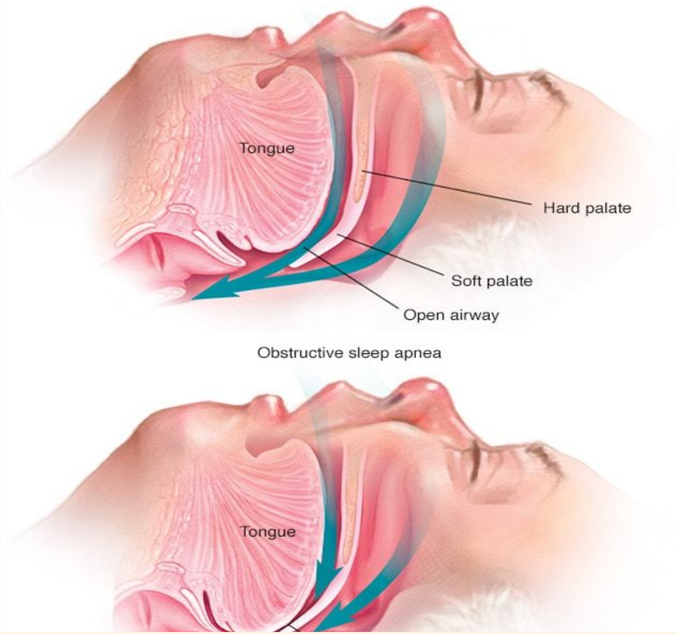
Obstructive Sleep Apnea

My understanding of the related anatomy, current solutions, and niche ways of stimulation

Introduction

Obstructive sleep apnea (OSA) is a sleep disorder where the throat muscles repeatedly **relax and block the airway during sleep** [1].

One main way of obstruction is through the tongue, which slides backward to block the airway. To rid of this obstruction, we aim to **push the tongue forward during sleep**, which can be done through different means. This requires a good understanding of the tongue's anatomy and innervation.



[1] https://www.mayoclinic.org/diseases-conditions/obstructive-sleep-apnea/symptoms-causes/syc-20352090

01

Physiology

The Makeup of the Tongue

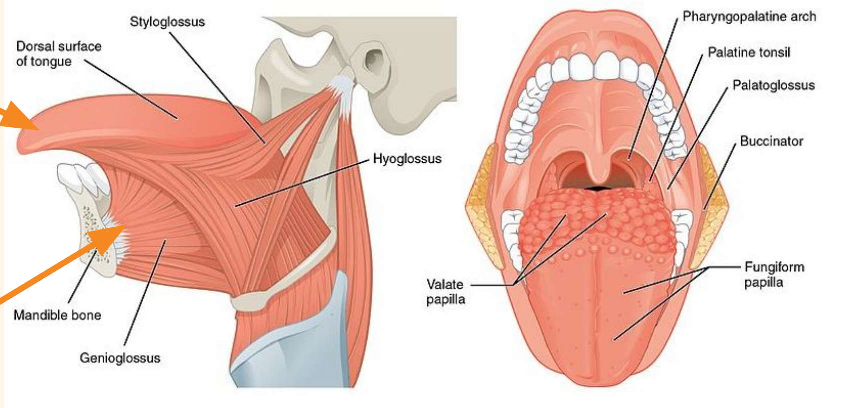
The **tongue** is a muscular hydrostat, meaning it's made of muscles and no bones (e.g. elephant trunk or octopus tentacle). It is comprised solely of:

1. Intrinsic Muscle

All the muscle inside of the tongue, causing changes in shape (e.g. flatten, curl) but cause no external movement.

2. Extrinsic Muscle

Attach to bones (e.g. jaw or skull) and move the tongue around.



(a) Extrinsic tongue muscles (b) Palatoglossus and surface of tongue

We will focus on the **extrinsic muscle**, as that will cause the tongue to move forward and out of the airway.

[1] https://3d4medical.com/blog/intrinsic-and-extrinsic-muscles-of-the-tongue

Four Main Groups of Extrinsic Muscles

These muscles collectively control the movement of the tongue: [1]

1. Genioglossus

Large, fan-shaped; makes up the bulk of the tongue. Attaches to the mandible and pulls the tongue forward. **Primary target for implantable OSA devices.**

2. Hyoglossus & Styloglossus

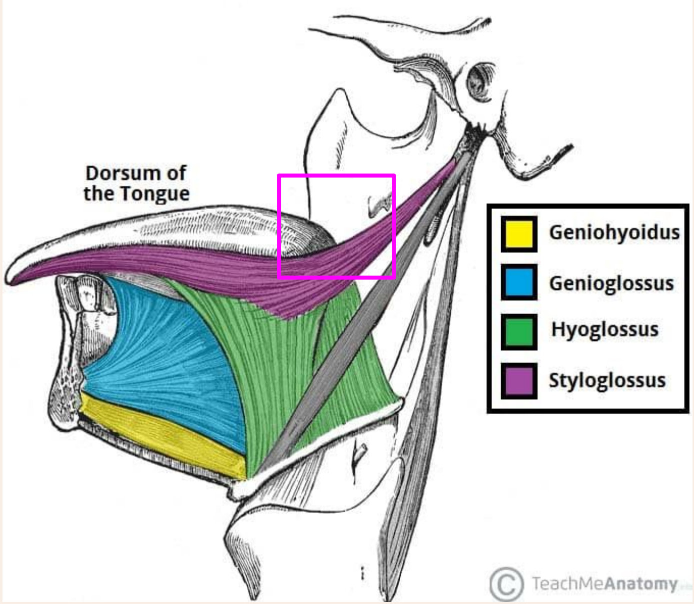
Aim to retract the tongue (pull back and up/down). **AVOID stimulating these** during therapy.

3. Palatoglossus

Responsible for elevating the back of the tongue.

4. Geniohyoid

Forms the floor of the oral cavity. Aids in swallowing, vocalizing, and respiratory functions.



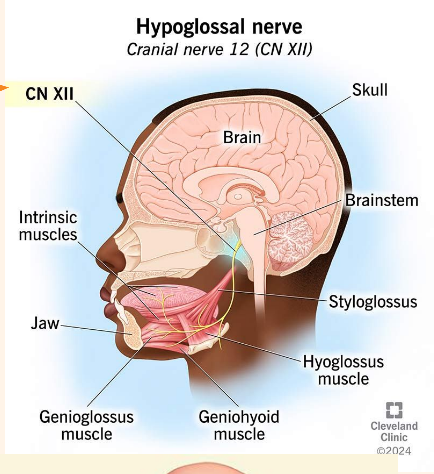
[1] https://teachmeanatomy.info/head/muscles/tongue/

Wiring of the Tongue

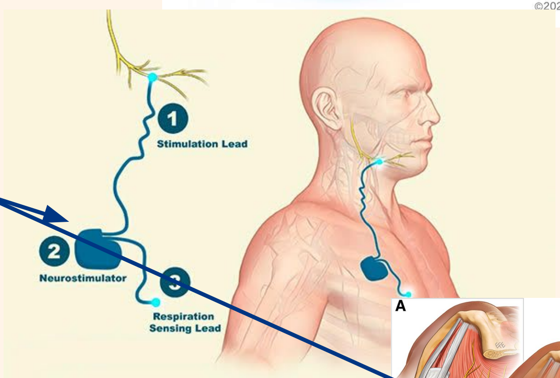
The **hypoglossal nerve** (AKA Cranial XII) controls almost all tongue muscles [1].

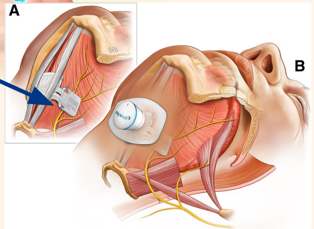
- Works for both genioglossal and retractor muscle

To move forward, have to selectively stimulate medial branch for genioglossus and avoid lateral branch (which goes to hyoglossus).



For patients with moderate to severe OSA who cannot tolerate CPAP, **Hypoglossal Nerve Stimulation (HGNS)**, (implanting a neurostimulator to CNXII to stimulate the genioglossus) is the leading surgical alternative [2].





[1] https://my.clevelandclinic.org/health/body/21592-hypoglossal-nerve
[2] https://pmc.ncbi.nlm.nih.gov/articles/PMC7914469/

02

Ways to Move the Tongue Forward

NMES Therapy

Neuromuscular Electrical Stimulation (NMES)

A physical therapy technique using safe electrical impulses (mimics brain activity) to force targeted muscles to contract [1]. Can trigger w/ EMG.

Safely exercises and strengthens the tongue and upper airway muscles during the day [2].

Tweetable abstract

In this randomised controlled trial, patients with mild obstructive sleep apnoea (OSA) were noted to adhere to daytime neuromuscular electrical stimulation, which led to improvements in OSA severity indexes and daytime sleepiness https://bit.ly/3s4gKx2

exciteOSA Technology

- Daytime jaw training
- Non-invasive stimulation
- Targets genioglossus

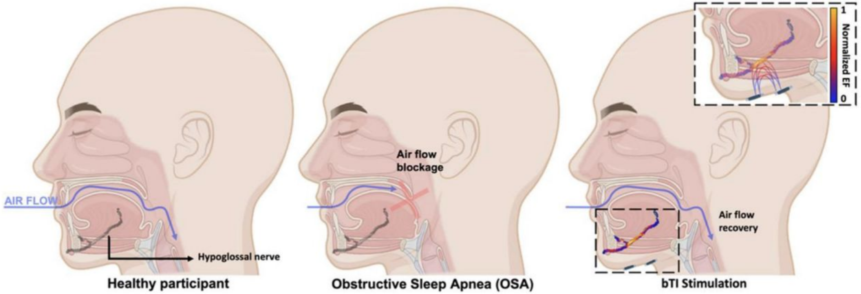
[1] pmc.ncbi.nlm.nih.gov/articles/PMC10616008/
[2] pmc.ncbi.nlm.nih.gov/articles/PMC10752290/

Interferential Current (IFC)

Interferential Current (IFC)

Non-invasive physical therapy and chiropractic treatment that uses two slightly different medium (to high) frequency electrical signals to penetrate into tissue, intersect to make it low frequency [1].

[2] did a variant of this called **Temporal Interference (TI)** for bilateral hypoglossal nerve stimulation. Found that traditional transcutaneous stimulation evokes no response with equivalent amplitudes of stimulation. **No wearable exists for this yet.**

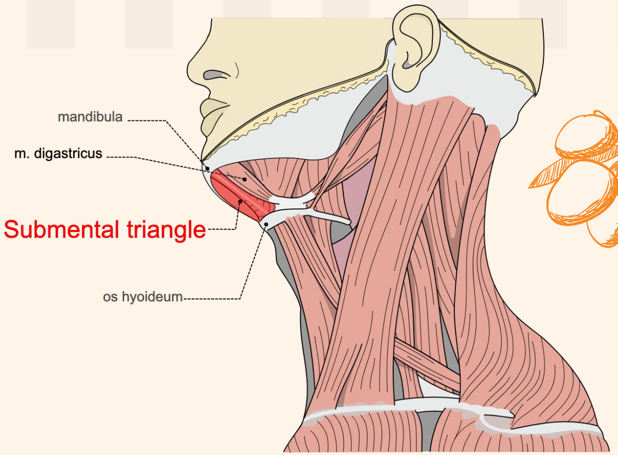


[1] https://www.pthealth.ca/services/physiotherapy/treatment-modalities/electrical-stimulation/interferential-current-therapy/
[2] https://pubmed.ncbi.nlm.nih.gov/37553702/

Mechanical Stimulation

Low frequency mechanical vibrations to the **submental region** (area under the chin) -> can cause/trigger the **tonic vibration reflex**, meaning involuntary contractions.

- Happens when high-frequency mechanical vibrations (30-150 Hz) send messages to spinal cord through CN XII [1].



Used in swallowing therapy for the suprahyoid for hyolaryngeal elevation. Used to increase tone in hypotonic muscles and cause relaxation.

[2] demonstrated that **GG muscle responses can be evoked with mechanical vibrations** applied to the lower jaw or the submandibular muscles in healthy subjects during wakefulness.

applications for improving the patency of airways during sleep. The presence of these GG reflexes may also explain a mechanism by which the vibrations produced during snoring can help the airways stay open in individuals who may otherwise have obstructed airways in sleep.

Implications that this naturally helps with OSA, but no tech that has done this.

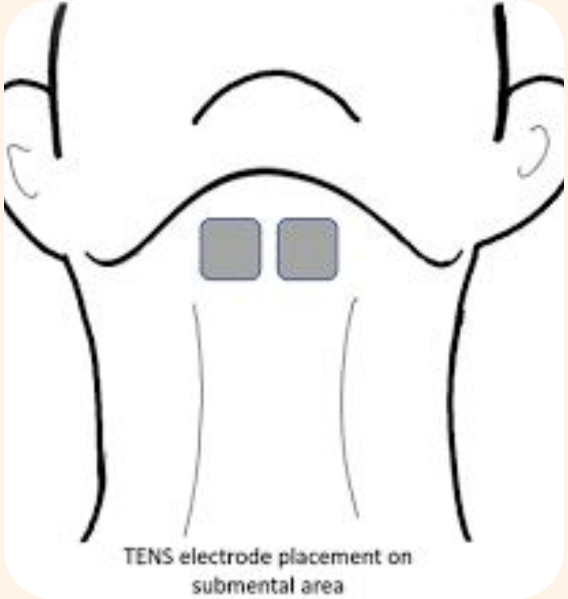
[1] https://en.wikipedia.org/wiki/Tonic_vibration_reflex
[2] https://pubmed.ncbi.nlm.nih.gov/31018744/

Submental Transcutaneous Electrical Stimulation (TES)

Transcutaneous Electrical Stimulation (TES): Sending electrical pulses through the skin under the chin to target the hypoglossal nerve and tongue muscles during sleep.

[1] evaluated domiciliary TES for patients with OSA struggling with CPAP adherence. Associated with reduced SP, DP, and MAP.

Not yet widely implemented; larger comparative studies against CPAP (gold standard) are required.



[1] The Lancet: Domiciliary TES for Obstructive Sleep Apnea

Transcutaneous Vagus Nerve Stimulation (tVNS)

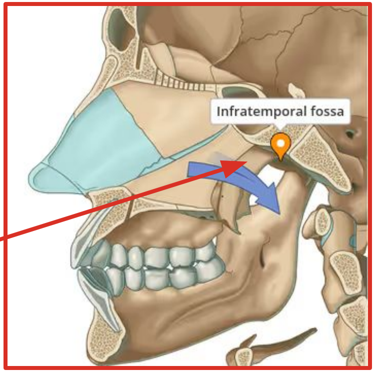
Transcutaneous Vagus Nerve Stimulation (tVNS): involves triggering the vagus nerve via the ear, traditionally used for epilepsy. It has been implemented with earbuds, but can also work in headbands.

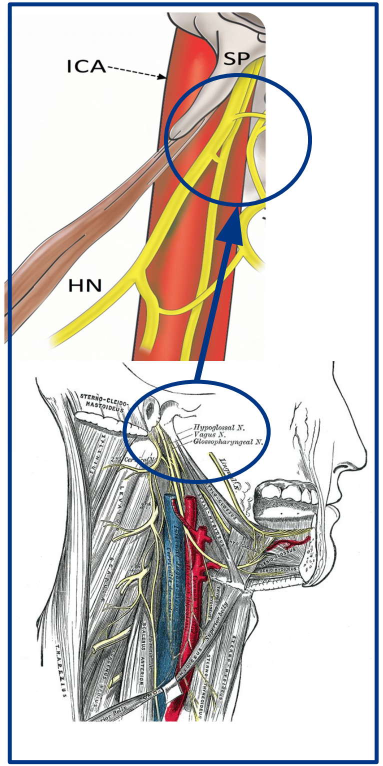
Neural Pathways

Vagus Nerve → Nucleus tractus solitarius (NTS) → CNXII Connection

Sensory information transmission flow

[2] found that CNXII can be accessed through the **infratemporal fossa**, near the ear and jaw. This suggests a headband approach may be superior for stimulation.





[1] https://www.frontiersin.org/journals/neurology/articles/10.3389/fneur.2025.1694455/full
[2] https://pubmed.ncbi.nlm.nih.gov/15475798/

Trigeminal Nerve Stimulation

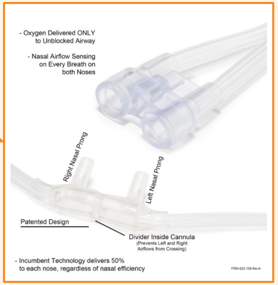
Trigeminal Nerve Stimulation: contracts face and affects respiration. The motor division controls the muscles of mastication, helping maintain upper airway stability and patency.

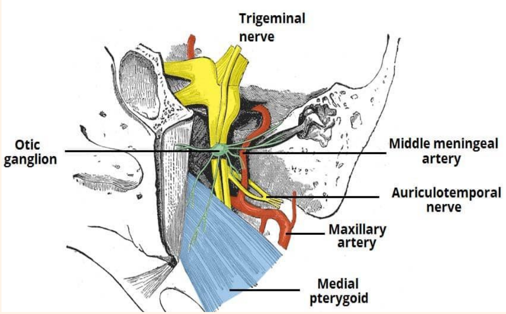
Trigeminocardiac Reflex (TCR): During sleep, airway obstruction can trigger the TCR, causing protective but disruptive physiological responses (double-edged sword) like reduced heart rate, sudden micro-arousals, and apnea.

The TCR, as the most powerful autonomic reflex, is known to cause bradycardia and apnea. The resulting decrease in heart rate and apnea are the mechanisms through which the TCR can be implicated in causing various sleep disorders (Figure 1). In this regard, the role of

interneurons that modulate the trigeminal motor system. Alteration in the excitability of this group of interneurons could increase the firing probability in trigeminal motor neurons during sleep arousals leading to excessive jaw muscle contractions, as seen in SB (44).

Trigeminal Thermal Neuromodulation (TTN): Targets cold receptors in the nasal mucosa or face via micro-dosed cooling (delivering cold oxygen). Uses the diving reflex to trigger localized parasympathetic response that shrinks swollen nasal turbinates, reducing airway resistance without full TCR event risks [5].





Implementation Strategies:

Sleep masks with low-frequency electrical or thermal [5] stimulation to trigger respiratory reflexes.

Heart rate and breathing monitoring to trigger mechanical vibration (on chest [2] or wrist [3,4]) for **subcortical microarousal**, pulling the tongue forward without waking.

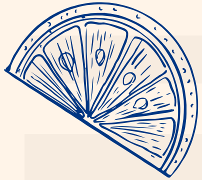
[1] https://pmc.ncbi.nlm.nih.gov/articles/PMC5326750/ [2] https://pmc.ncbi.nlm.nih.gov/articles/PMC3850014/ [3] https://pmc.ncbi.nlm.nih.gov/articles/PMC7783873/ [4] https://pmc.ncbi.nlm.nih.gov/articles/PMC6613561/ [5] https://www.sleepandbrain.com/trigeminal-thermal-neuromodulation

03

Future Steps

Comparison

	Mechanism	Wearable	Pros
Pathway 1: Direct submental collar	Directly activate the **hypoglossal** nerve to pull tongue forward.	Use conductive intarsia knitting (metallic threads) to give **TES** or **IFC**.	Directly targeting genioglossus, gets rid of need for hydrogel patches.
Pathway 2: Kinesthetic neckband	Triggering the **tonic vibration reflex** to induce involuntary muscle contraction.	Embedding miniaturized haptic coin motors (**actuators**) into a soft, targeted compression band worn under the chin.	Completely avoids the electrical risks of skin irritation or accidental nerve overstimulation.
Pathway 3: Cranial modulator (mask or headband)	Using the brainstem reflexes (**Trigeminal or Vagus**) to calm the nervous system and indirectly open the airway.	A sleep mask or headband equipped with micro-thermal **cooling** elements (for Trigeminal Thermal Neuromodulation) or conductive nodes near the ear (for tVNS).	Highly comfortable form factor with minimal disruption to the neck/throat area.



Thank you!

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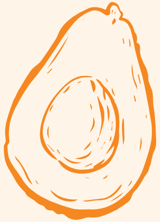


Obstructive Sleep Apnea

Iterations on the different techniques seen last time.

1. Interferential Current (IFC)

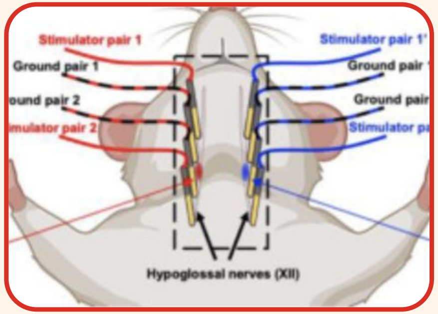
RECALL IFC (AKA TI): bypasses pain, using 2 medium/high frequency waves intersecting to make low frequency envelope for stimulation.

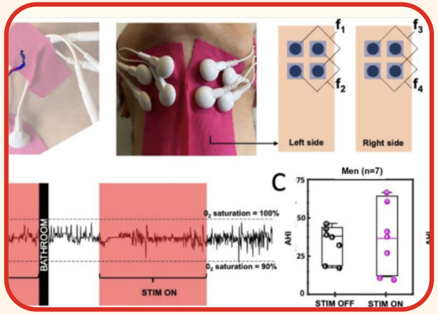
[2] conducted a study on bilateral TI, where **4 pin heads** were placed on each side of throat above CN12. Metrics were AHI, force recordings (physical force of tongue movement) and tongue EMG.

Stimulation Profile: 5 Hz offset (3000Hz, then 3005 Hz)

Current: 1mA per pair, ramped up by 0.5mA

Success Metric: tongue twitch at offset





STEPS TO RECREATE

1. 2 pairs surface electrodes under submental triangle, aligned bilaterally parallel to CN12 for max depolarization efficiency
2. Drive synchronized waveform generators at 2000Hz & 2020Hz for 20Hz envelope
3. Ultrasound submentally to confirm and submental EMG to quantify

Note: Method uncommon due to interlapping facial nerves and skin sensitivity. **Somnial Inc. [3]** is private; market status unknown.

[1] https://www.pthealth.ca/services/physiotherapy/treatment-modalities/electrical-stimulation/interferential-current-therapy/
[2] https://pubmed.ncbi.nlm.nih.gov/37553702/ | [3] https://somnialbio.com/

2. Mechanical Stimulation & TVR

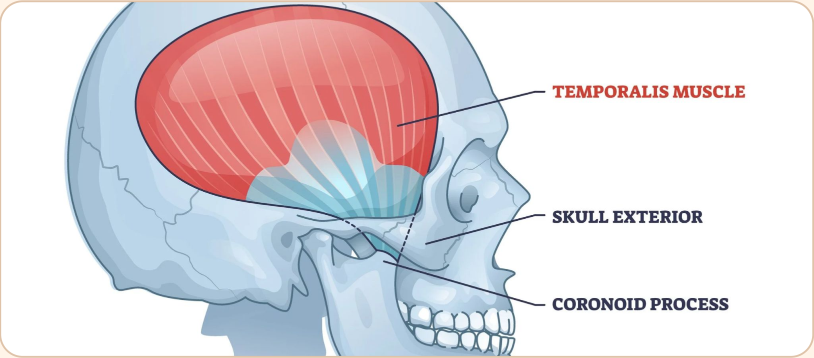
Recall: mechanical vibrations at lower jaw and submandibular muscles cause TVR. 30-150 Hz usually gives involuntary contraction of GG, even without electricity [1]

Mechanoreceptors

[2] found in upper airway; used 3s long, 5mm vibrations at 8 & 12 Hz (12 Hz had larger response).

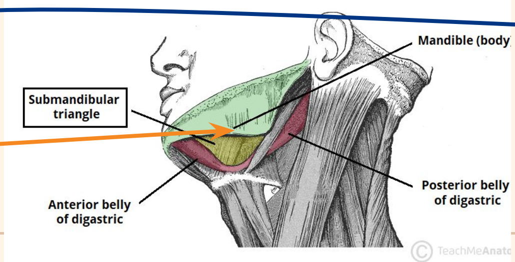
Jaw-Tongue Reflex (JTR):

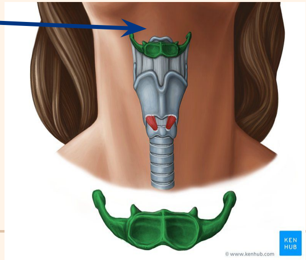
- Observed in cats, monkeys, humans.
- Opening mandible correlated with higher GG activity.



Maximizing signal pickups from muscle:

1. Middle submandibular triangle | **2.** ~2cm away from hyoid bone



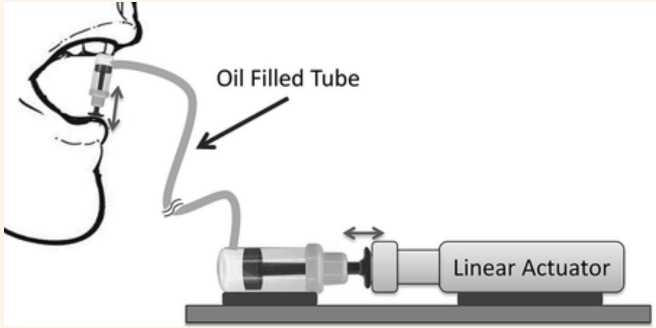


** Would need to test tightness of wearable, if any, because skin thickness did matter.

[1] https://en.wikipedia.org/wiki/Tonic_vibration_reflex
[2] https://pubmed.ncbi.nlm.nih.gov/31018744/

2. Mechanical Stimulation & TVR

Linear movements (vertical) on mandible with oil-filled tubing with plastic syringe; have subject bite down. Very early prototyping, don't need.

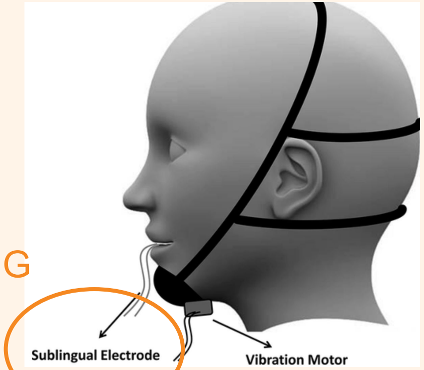


Look for: gradual and sustained increased basal muscle activity (tonic) rather than spike. Map to see which has higher tone for lower power.

Setup

1. Variable frequency on vibrator, submental EMG
2. Vibrator to lower jaw/submental triangle with strap
3. Sweep 30-150 Hz
4. Activate vibrator in 5 second bursts, measure submental EMG.

for EMG



[1] https://pubmed.ncbi.nlm.nih.gov/31018744/

3. Microarousals & Vibrations

[1] Mechanoreceptor Stimulation (Abdomen)

Clinical trial targeting high-density Pacinian corpuscles to evoke a "stable reflex" and increase chin tone (80-100Hz).

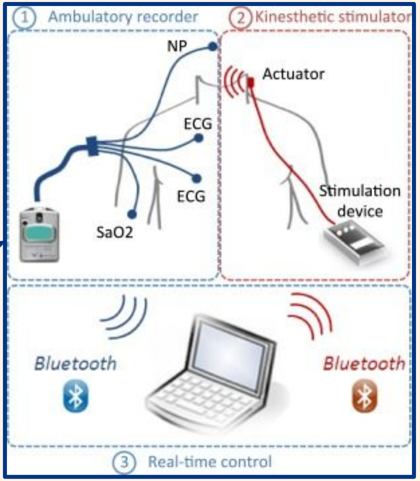
Goal: Sub-cortical engagement to lower arousal.

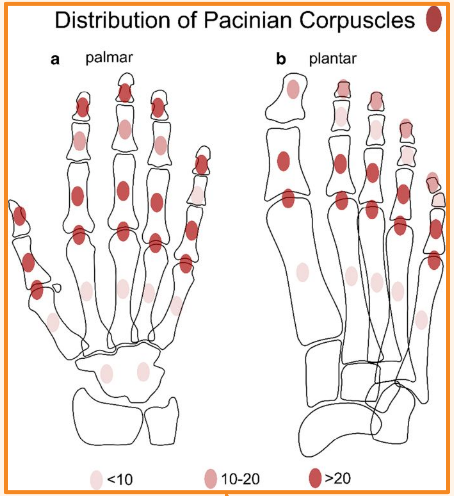
[2] Kinesthetic Simulation (Adults, 2016)

Used kinesthetic simulation:

1. Cardiorespiratory ambulatory recorder (Holter)
2. Stimulation system
3. Control Device

Result: Successful first clinical evaluation.





Experimental Setup

1. Tools: LRA, PSG, and RIP monitoring.

2. Placement: LRA to lower abdomen/chest via elastic band.

3. Frequency: LRA @ 200-300 Hz (SENSITACT-based).

4. Protocol: 0.5-1s bursts in sleep; PSG EEG used to identify abrupt changes (3-15s).

Pacinian corpuscles located most in **hairless skin regions**, which in adults means the subcutaneous tissues of the hands and feet, with the absolute peak concentration found in the fingertips and the soles of the feet [3]

[1] https://clinicaltrials.gov/study/NCT03651648
[2] https://www.sciencedirect.com/science/article/abs/pii/S1959031816000312
[3] https://pmc.ncbi.nlm.nih.gov/articles/PMC8035111/

4. Transcutaneous Vagus Nerve Stimulation (tVNS)

Transcutaneous Vagus Nerve Stimulation (tVNS): involves triggering the vagus nerve via the ear, by stimulating local branch.

Neural Pathways

Vagus Nerve → Nucleus tractus solitarius (NTS) → **CNXII Connection**

Sensory information transmission flow

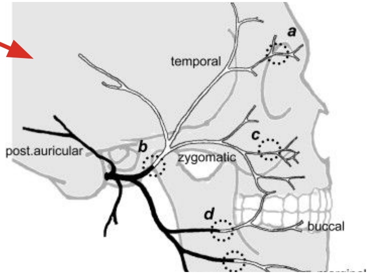
Setup:

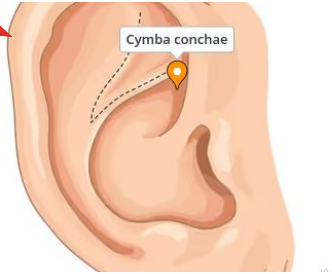
1. sEMG, constant current neurostimulator
2. Apply dry electrodes below zygomatic arch, anterior to earlobe, can access CN5
3. Output biphasic pulse current (e.g. 30-40 Hz frequency and 100-200 microsecond pulse)
4. Sweep from 1mA upward, use ultrasound submentally to see GG. Use sEMG to check other muscles.

Trigeminal Nerve Stimulation: contracts face and affects respiration. The motor division controls the muscles of mastication, helping maintain upper airway stability and patency.

Trigeminocardiac Reflex (TCR): During sleep, airway obstruction can trigger the TCR, causing protective but disruptive physiological responses (double-edged sword) like reduced heart rate, sudden micro-arousals, and apnea.

NOTE: You can artificially boost respiratory drive [3] by telling CNXII to increase GG tone. Therefore, tVNS to **cymba conchae** can activate the vagus → NTS brainstem pathway.





[1] https://www.frontiersin.org/journals/neurology/articles/10.3389/fneur.2025.1694455/full | [2] https://pubmed.ncbi.nlm.nih.gov/31751088/ [3] https://www.hopkinsmedicine.org/health/conditions-and-diseases/obstructive-sleep-apnea/hypoglossal-nerve-stimulation

New Consideration: Microarousal through Sound [1]

Well-known that genioglossus activity increases after arousal.

1. Higher activity of GG motor units
2. Increased firing of inspiratory and non-respiratory motor units.

Increased genioglossus activity is independent of conventional respiratory control.

[1] applied 1000 Hz, 0.5-2s, 45-100 db through headphones. Found 208 Motor units + 31 during arousal

NOTE: this approach takes a "increase arousals to decrease arousals" approach.

Microarousal:

1. Within 5s of tone
2. 3-15s long
3. followed by >1 min NREM loop
4. None of prev 60s or 30s after.

Genioglossus stimulation by hypoglossal nerve happens through 2 paths:

1. Inspiratory: modifies overall activity to compensate for respiratory load. NEED THIS
2. tonic: optimize airway shape in response to local demands. Only happened as respiratory drive returned to baseline.

[1] https://academic.oup.com/sleep/article/47/1/zsad202/7233015#:~:text=Thirty-four%20healthy%20participants%20were,3-15s)%20AASM%20arousals.

Obstructive Sleep Apnea

Amplification of 2 different motions and where to apply this.

1. *Gripping* AKA power grip or cylindrical grip

Physiology/anatomy: relies on extrinsic forearm muscles that pull on long tendons in fingers (as opposed to *just* finger muscles). Two things must happen at once: [2]

1. **Primary flexors:** curl fingers
2. **Wrist stabilizers:** lock wrist in 20-30° backward tilt for leverage*

Detect intent → Process (run EMG data and smoothen) → Threshold for max voluntary contraction → 20-50 Hz stimulation for smooth tetanus [1]

Process of amplifying

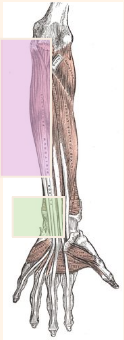
ELECTRODE PLACEMENT:

Ch 1 (Flexion): Volar forearm, proximal-middle third, ulnar side. Targets FDS, FDP.

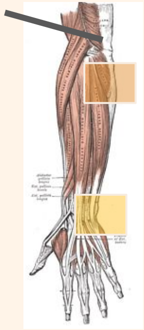
Ref: Distally, closer to wrist

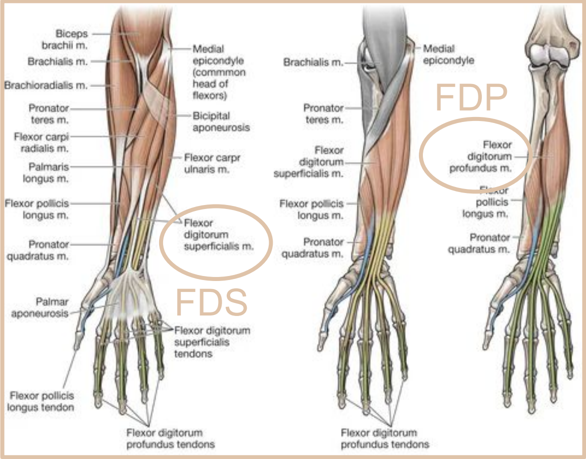
Ch 2 (Wrist): Dorsal forearm, ~2" below lateral epicondyle. Targets ECRL, ECRB.

Ref: Distally, to back of wrist

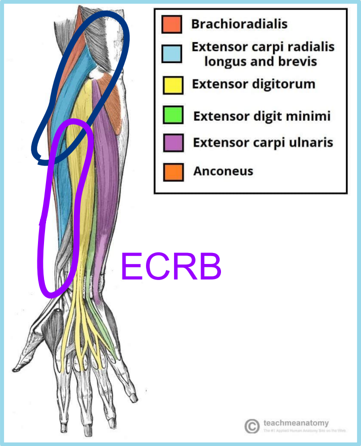


lateral epicondyle





ECRL



*If wrist bends forward while fingers curl, flexors lose tension -> weak grip.

[1] https://pmc.ncbi.nlm.nih.gov/articles/PMC3375668/ | [2] https://gripgenie.com/blogs/grip-zone/the-anatomy-of-grip-strength

1. Gripping AKA power grip or cylindrical grip

[1]: Functional Electrical Stimulation (FES)

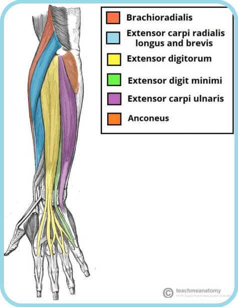
Targets 'motor points' where nerve enters muscle, giving strong contraction at low intensities.

- Small electrodes better for selectivity
- Distance of ~3cm keeps current density homogenous
- Different fingers require different intensities

[2]: Electrode Placement

Keep sEMG and electrodes directly on extensor side of forearm, over **extensor carpi radialis.**

- Pulse width: 30-50 µs (noted)
- FES start: 120-170 µs
- FES max: 250-300 µs



[3]: Stimulation Frequency

Upper limb range: 20-40 Hz.

- Forearm target: ~**40 Hz**
- Max current for upper limb: **100 mA**

[4]: Amplitude & Intensity

Usually starts at 1mA; increase by 1mA increments until muscle activation is observed.

- Forearm aim range: **1mA - 50mA**

[1] https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0190936 | [2] https://www.frontiersin.org/journals/neuroscience/articles/10.3389/fnins.2022.909602/full | [3] https://pmc.ncbi.nlm.nih.gov/articles/PMC9309284/ | [4] https://pmc.ncbi.nlm.nih.gov/articles/PMC11236753/

2. Pinch AKA pincer

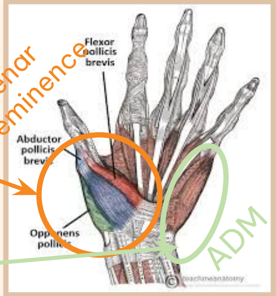
pulse width: 150 microseconds-250 microseconds (don't penetrate hand too deep) [4]
amp: start at 1mA, increase 1mA [3]

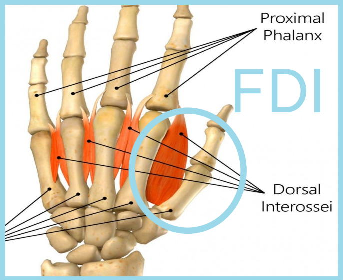
Process of amplifying

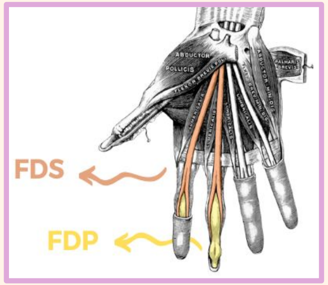
Detect intent → Process (run EMG data and smoothen) → Threshold for max voluntary contraction → Fire both channels at 20-50 Hz (smooth tetanus) [2]

Physiology/anatomy: Pad of thumb and index finger. Not much forearm involvement (mostly intrinsic).

1. **Thumb (opposer):** thenar muscles, fleshy base of the thumb, called **the thenar eminence**. Has 3 muscles:
   a. Opponens Pollicis
   b. Abductor Pollicis Brevis
   c. Flexor Pollicis Brevis
2. **1st Dorsal Interosseus (index stabilizer):** AKA FDI, a teardrop-shaped muscle in the web space in the hand, between thumb and index. Abducts index, giving lateral stability to pinch.
3. **FDS (index flexor):** tendon for curling tip of index down.
4. **FDP (radial and ulnar divisions)**
5. **Abductis digiti minimi (ADM):** On pinkie







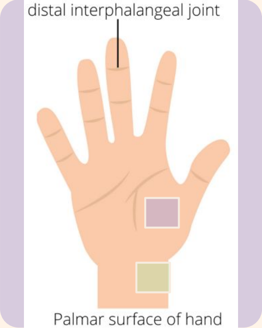
ELECTRODE PLACEMENT: intrinsic muscles in hands are small and densely placed so use small electrodes (1.5-2cm)

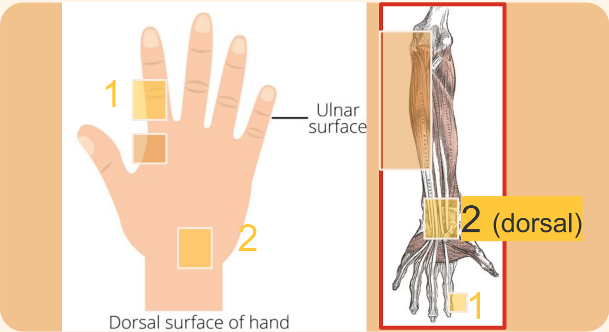
Ch 1 (thumb opposition): on palm of hand, centre of thenar eminence (APB) to target motor branch of median nerve of those muscles. [1]

Ref: ~proximally, just below wrist crease on thumb (radial side)

Ch 2 (Index finger stabilize and flex): dorsal side of hand, on belly of FDI (web space) [1] OR (preferred) on forearm for radial FDS [5]

Ref: Side of index OR ~ proximal on back of hand.

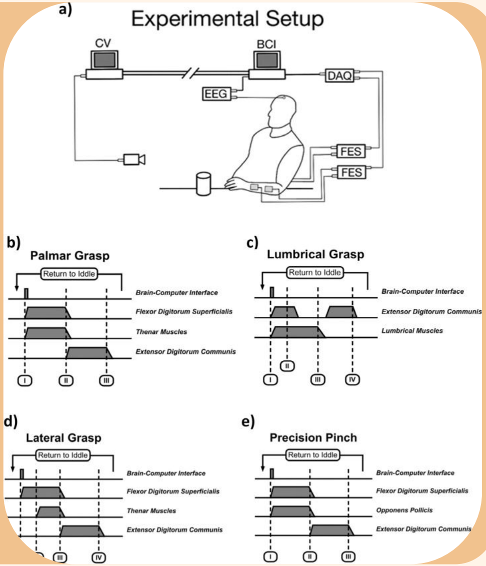




[1] https://doi.org/10.1016/j.clinph.2010.07.025 | [2] https://pmc.ncbi.nlm.nih.gov/articles/PMC3375668/ | [3] https://pubmed.ncbi.nlm.nih.gov/29997429/ |
[4] https://pdfs.semanticscholar.org/6fc3/25399ed615f89799124fc2b5f0a018564927.pdf | [5] https://pmc.ncbi.nlm.nih.gov/articles/PMC6037320

2. Pinch AKA pincer

See next slide



[1] EEG-Controlled Pinch and Grasp

Successful pinch and grasp were achieved using FES. The system utilized EEGs as the primary control point for intent detection.

[2] Pulse Width and Muscle Selectivity

Pulse duration dictates penetration depth and fibre recruitment selectivity.

- Short widths (10-50 µs) target localized fibres to generate high torque.
- Wide pulses (300-600 µs) are used for large dynamic movements like quadriceps cycling.
- To prevent fatigue, use **VFTs/DFTs**. An initial "doublet" followed by a low-frequency train leverages the "catchlike property" for sustained force.

[3] Anatomical and Neural Tethering

FES can cause unintended movement in adjacent fingers due to "enslavement."

- **Juncturae tendinum** link extensor tendons across the hand.
- Single neurons often innervate multiple motoneuron pools.
- Effect is stronger during extension than flexion; adjacent fingers interfere more.

[1] https://pmc.ncbi.nlm.nih.gov/articles/PMC6037320 | [2] https://pdfs.semanticscholar.org/6fc3/25399ed615f89799124fc2b5f0a018564927.pdf |
[3] https://pmc.ncbi.nlm.nih.gov/articles/PMC11380997/

2. Pinch AKA pincer

[1]

Precision Pinch Coordination

A multi-channel stimulator coordinates key muscle groups for functional precision:

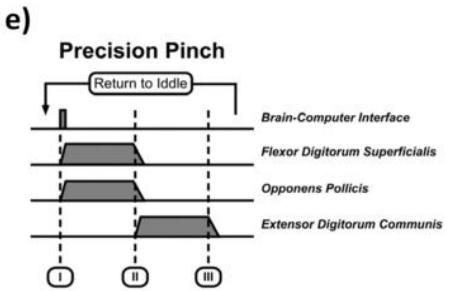
- **FDS (Flexor Digitorum Superficialis):** Provides the primary flexion force.
- **OP (Opponens Pollicis):** Rotates the thumb into opposition with the fingers.
- **EDC (Extensor Digitorum Communis):** Stabilization and release. (don't need)

Note: Lateral grasp programmed for general thenar muscles vs isolating OP.

Dynamic Sequence Programming

Mimicking natural human movement through programmed stimulation cycles:

1. **Grasp Cycle:** System sustains grasp for exactly 8 seconds before returning to idle.
2. **Ramping Protocol:** Gradual intensity adjustments at initiation and deactivation ensure smooth, non-jerky movement.



[1] https://pmc.ncbi.nlm.nih.gov/articles/PMC6037320