# AppetiteCheck: Feasibility of Momentary Vagus Nerve Stimulation as an Implicit Intervention for Eating Behavior

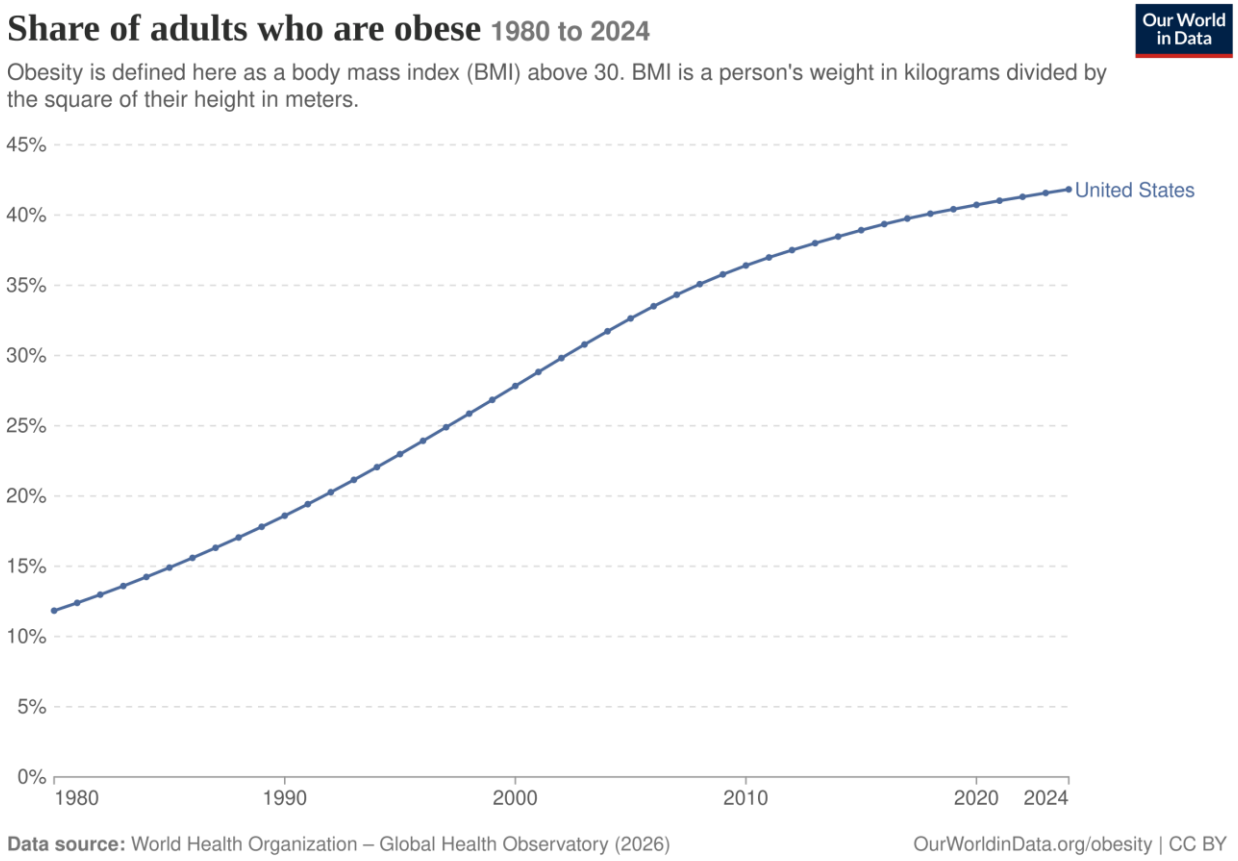
**Tan Gemicioglu**, Jas Brooks, Pedro Lopes, Tanzeem Choudhury



CORNELL TECH

THE UNIVERSITY OF CHICAGO

# Overeating is a widespread problem




- **40.3%** of US adults had obesity in 2023 (CDC)
- Overeating and emotional eating raise risk of heart disease, stroke, and Type II diabetes
- Many people overeat at a subclinical level

# We often eat while distracted



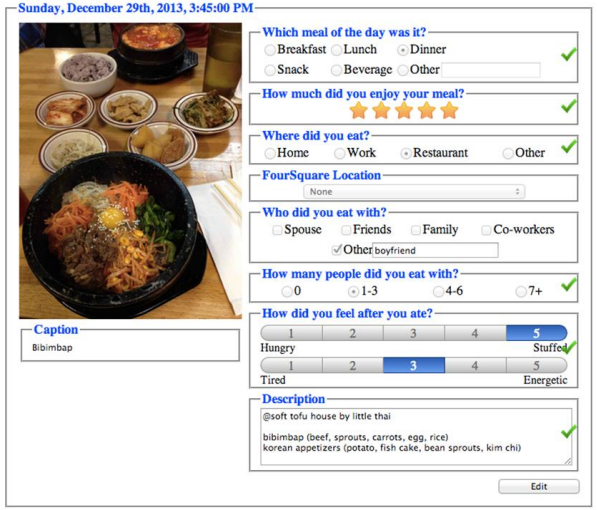
**70%**

of US employees eat while working at least once a week

**Distracted, habitual eating is where mindful strategies are hardest to apply**

# From tracking eating to intervention

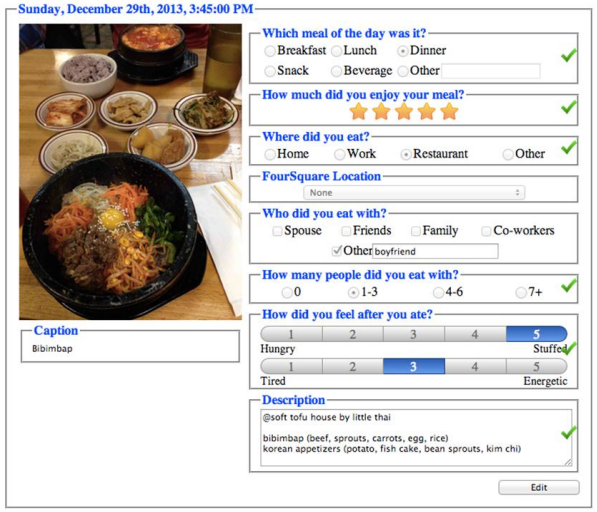
## Tracking




Cordeiro et al., 2015

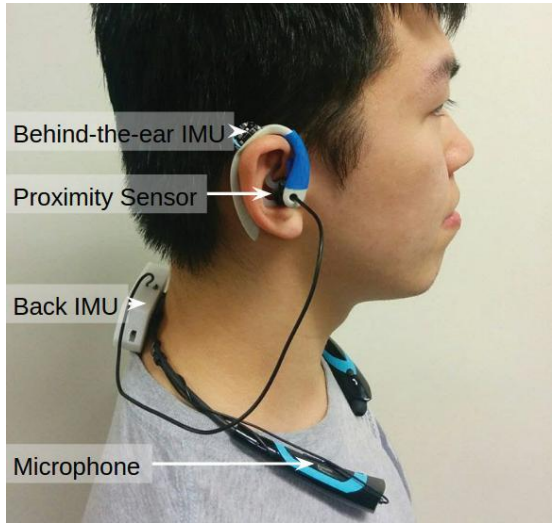
# From tracking eating to intervention

## Tracking




Cordeiro et al., 2015

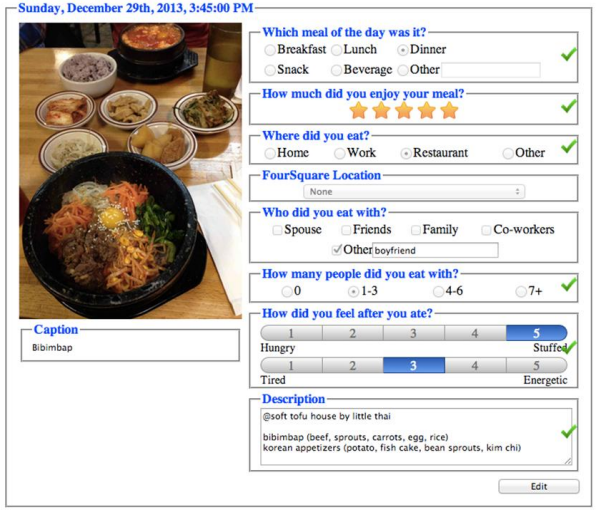
## Sensing




Bedri et al., 2017

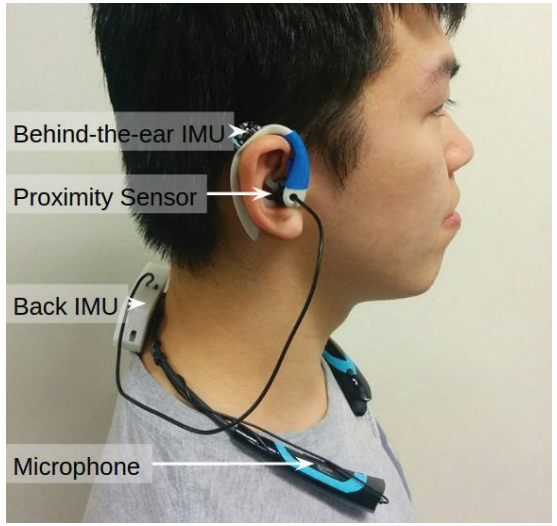
# From tracking eating to intervention

## Tracking




Cordeiro et al., 2015

## Sensing




Bedri et al., 2017

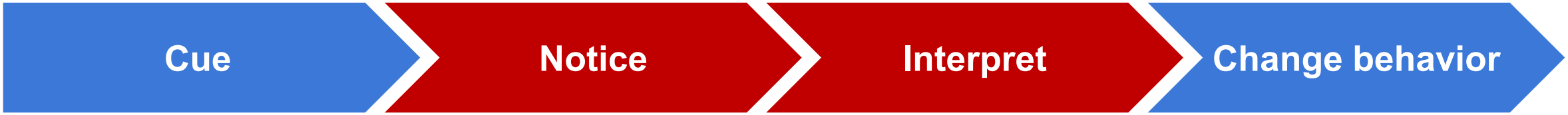
## Intervention



Nakamura et al., 2023

# Can we intervene without asking for attention?

**Perceptual cues (e.g., peripheral interaction)**



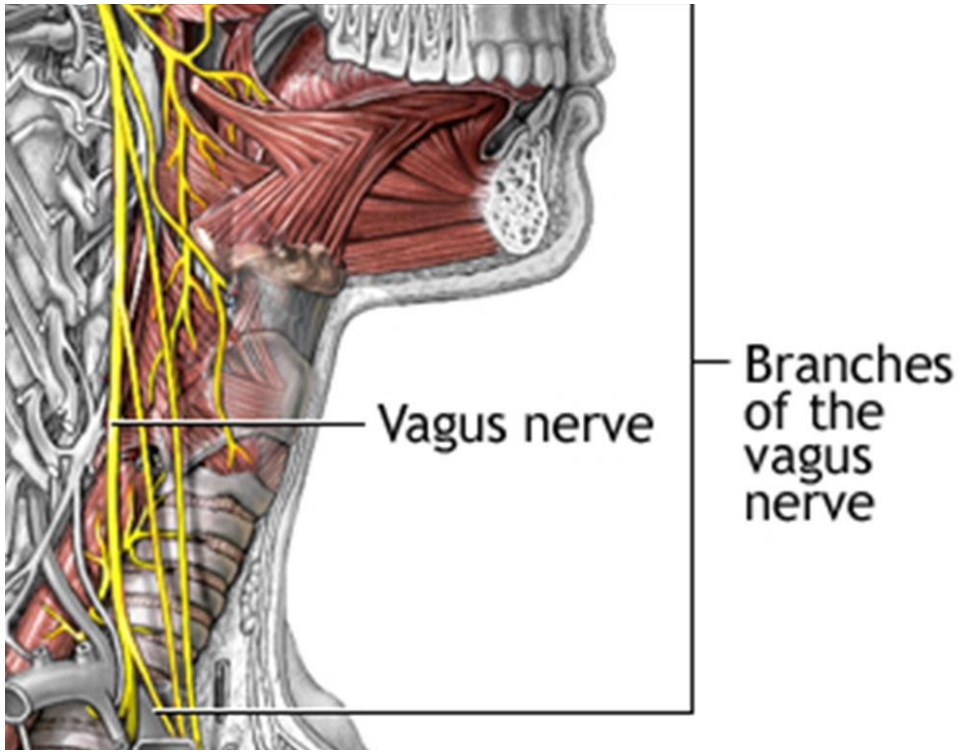

*requires attention*

**Physiological modulation (AppetiteCheck)**




*no cue to notice or follow*

# The vagus nerve links gut and brain




- Primary bidirectional pathway of the gut–brain axis
- Carries satiety signals and regulates autonomic balance
- Implanted VNS reduced food intake and weight in animals and humans
  - Pardo et al. 2007; Gil et al. 2011; Yao et al. 2018
- **...but implants require surgery**

# Non-invasive vagus nerve stimulation



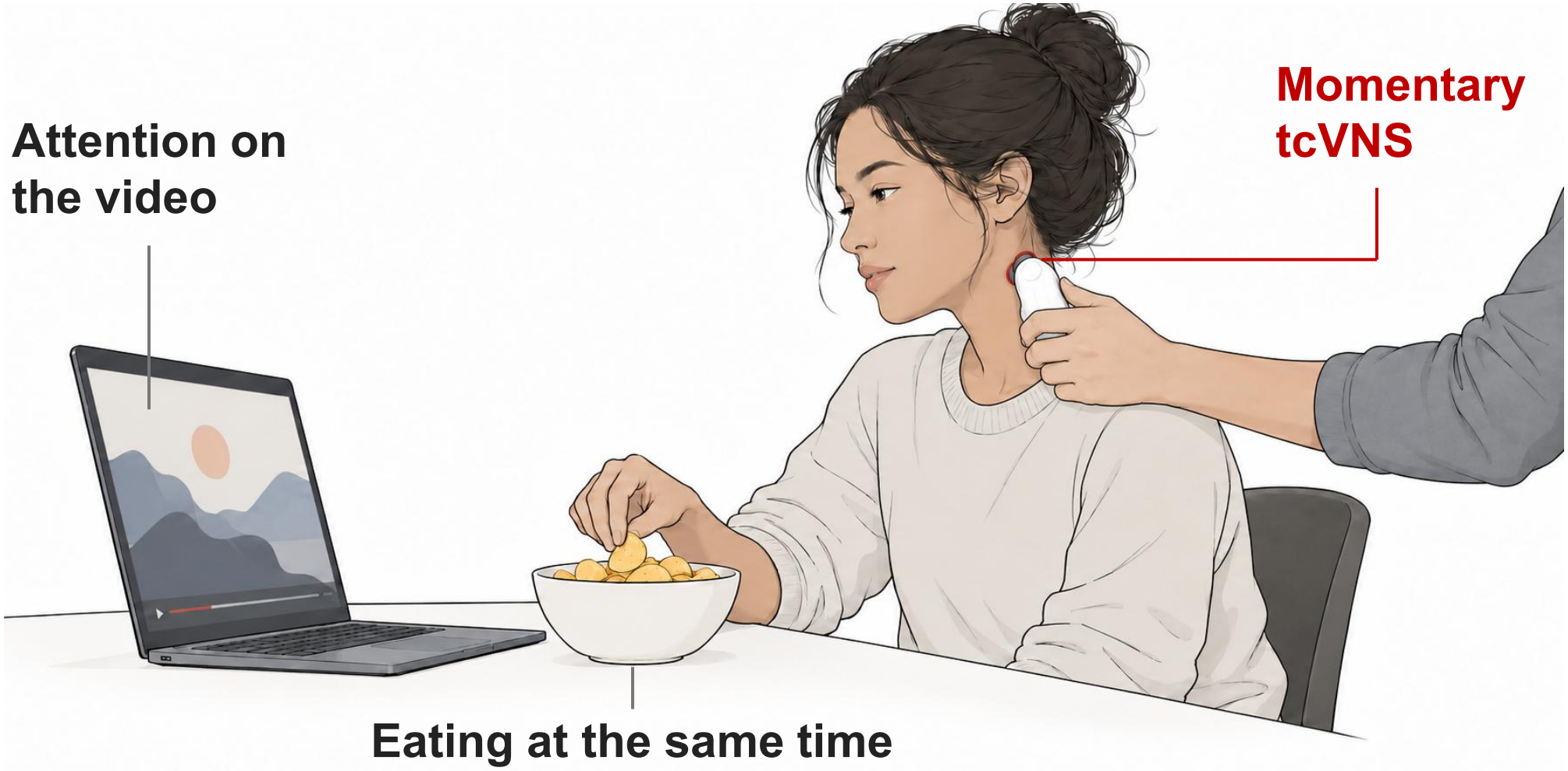

Implanted VNS




Non-invasive VNS

- **Transcutaneous cervical VNS (tcVNS)**: a mild current on the side of the neck
- Increases stomach–brain coupling
  - Müller et al. 2022
- Effects can begin rapidly
  - Rodenkirch et al. 2022; Li et al. 2023
- **→ suited to a momentary intervention during eating**

# AppetiteCheck: tcVNS during eating



# Research questions

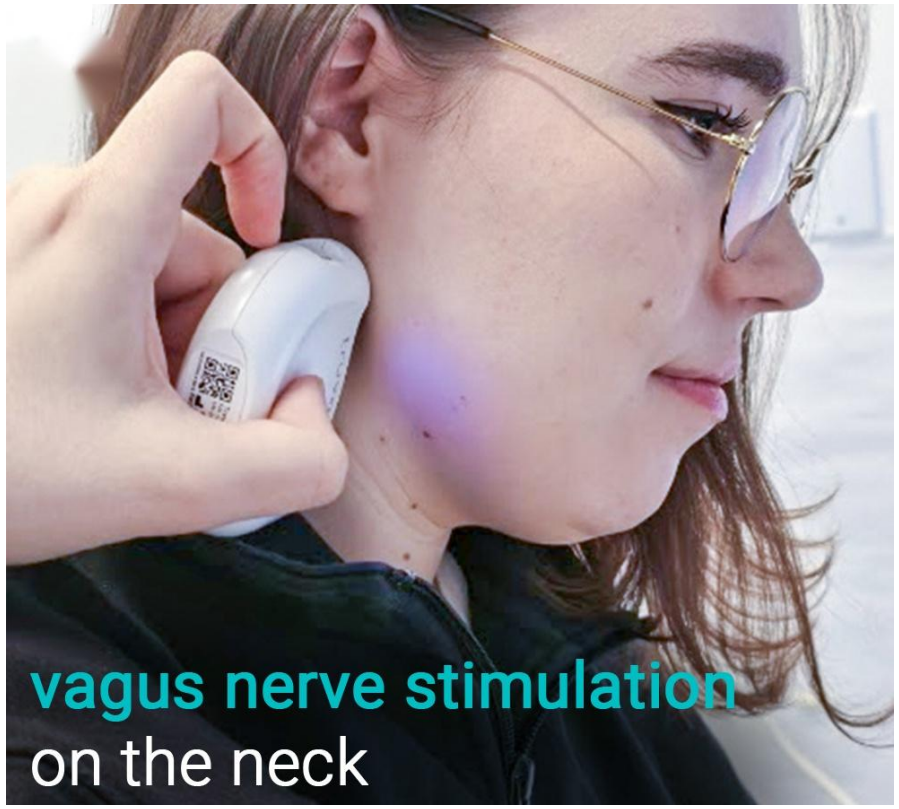
- **RQ1:** How does momentary tcVNS affect the amount of food eaten and eating rate in a single eating episode?
- **RQ2:** How is satiety after an eating episode affected by momentary tcVNS?
- **RQ3:** What is the effect of momentary tcVNS on physiological activity?

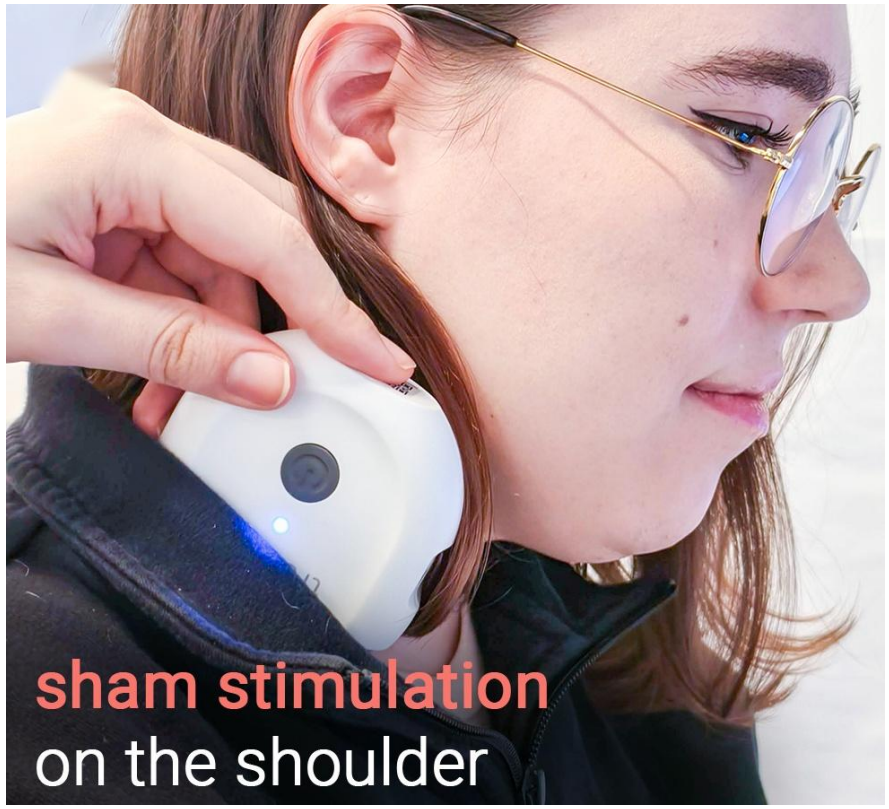
# The stimulator



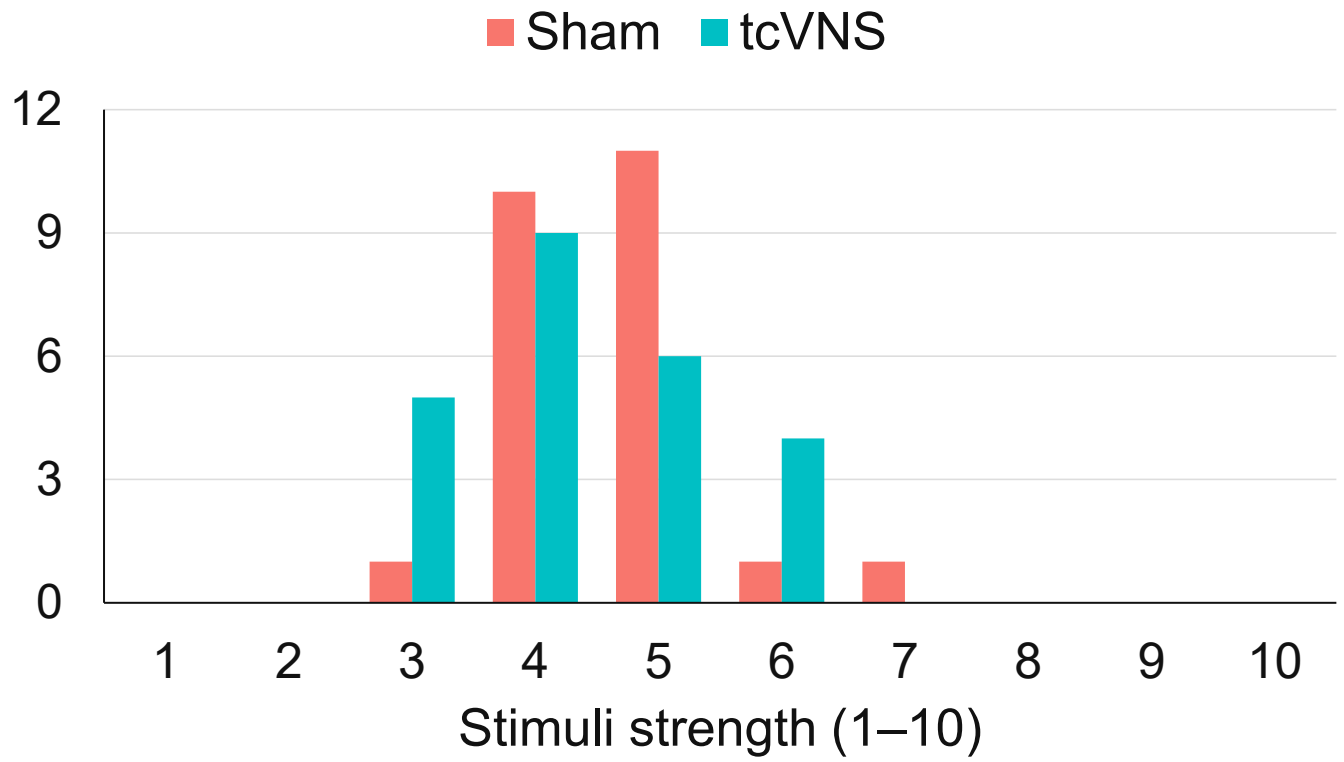

- Truvaga Plus: same hardware as the clinically used gammaCore
- 5 kHz biphasic sinusoidal bursts at 25 Hz, 1 ms pulse width
- Pilot tests were done with an open-source, pocket-sized alternative

# VNS on the neck vs. sham on the shoulder



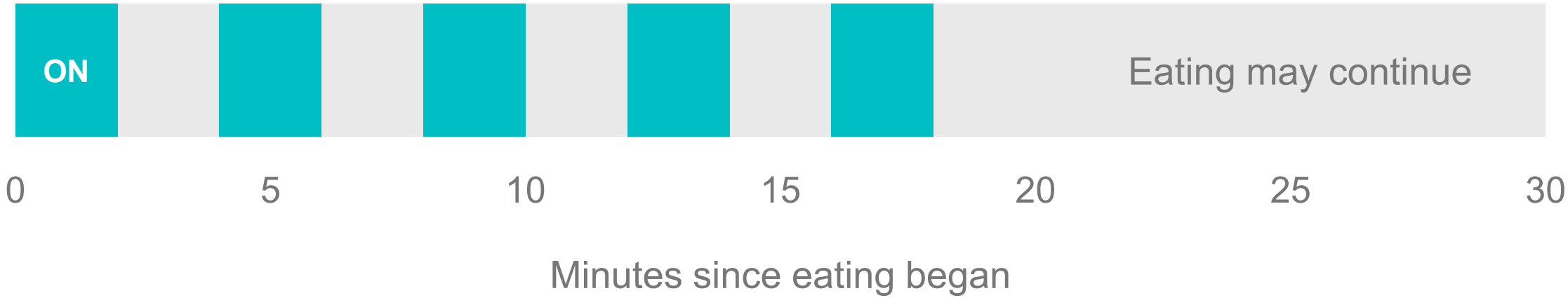
# Personalized to be just barely perceivable




- Minimize sensation so the system can stay in the background
- Calibrated on the stimulation site before each session

# Momentary stimulation

**Distracted eating (up to 30 min)**



# A distracted snacking task

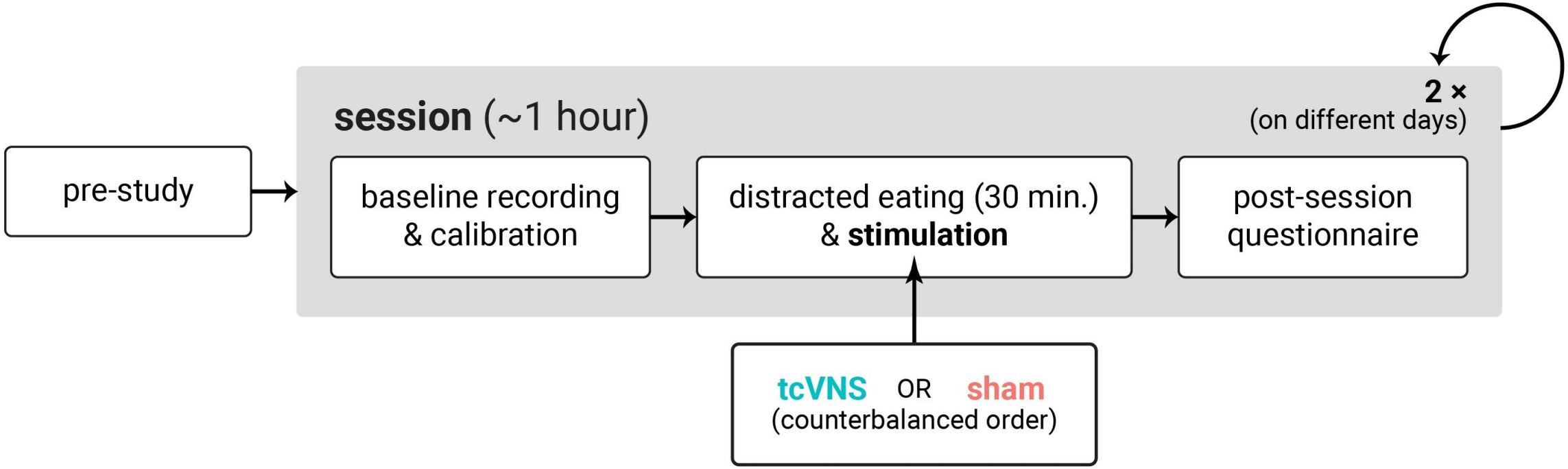





- Watched a self-selected video (YouTube, Netflix, Bilibili, ...)
- Chose one snack, kept same across sessions:
  - chips, candy (M&Ms), cookies (Oreos), or raisins
- No food or coffee for 3 hours before the session
- Ate as much as desired from standard food portion
- Up to 30 minutes

# Study design

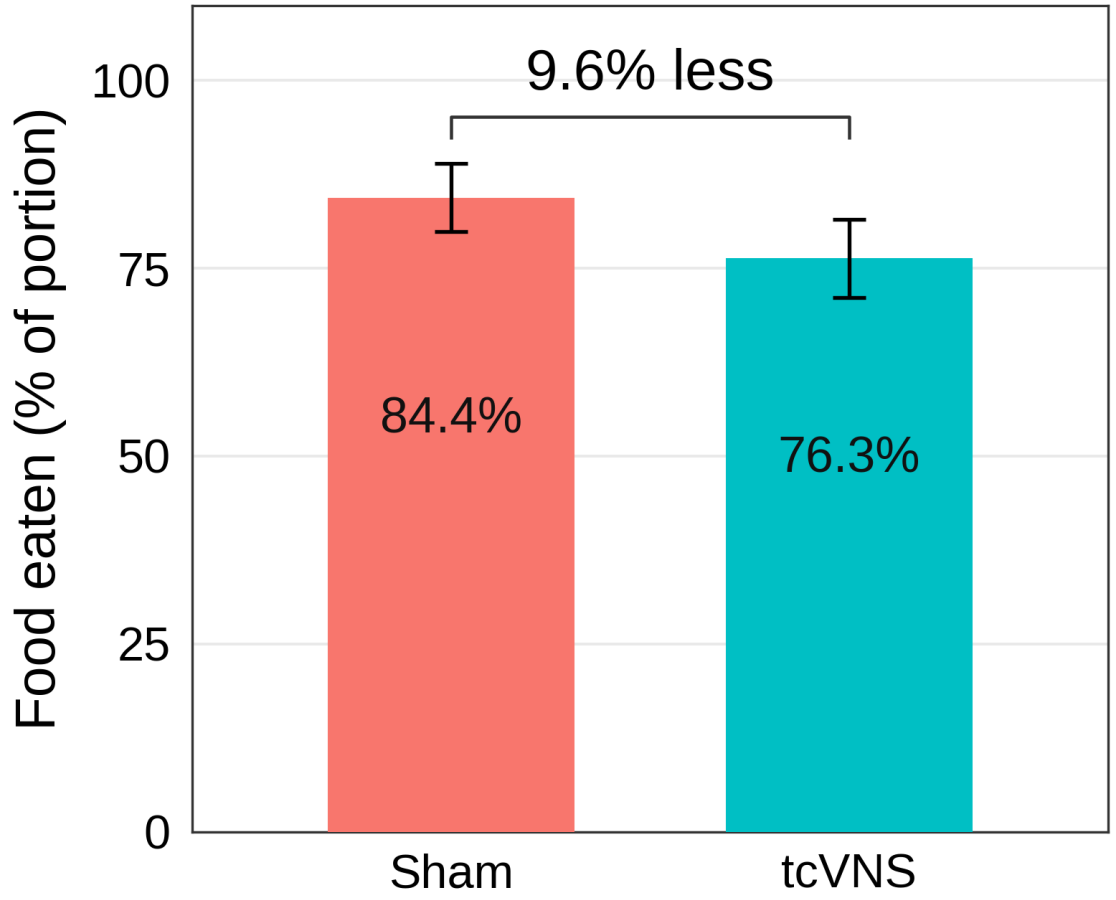
- **24 participants** (aged 22–53; 12 men, 10 women, 2 non-binary)
- **Within-subject**, counterbalanced, single-blind; two ~1-hour sessions on different days



# Measures

| Behavioral | Physiological | Self-report | Qualitative |
|---|---|---|---|
| Food eaten<br>(% of portion) | Heart rate<br>(Polar H10 ECG) | Satiety<br>(Flint et al.) | Sensation |
| Eating duration | RMSSD (HRV) | Eating impulsivity | Form factor |
| Eating rate<br>(g/min) | HF (HRV) | Stimulus perception; agency & embodiment | Adoption in daily life |

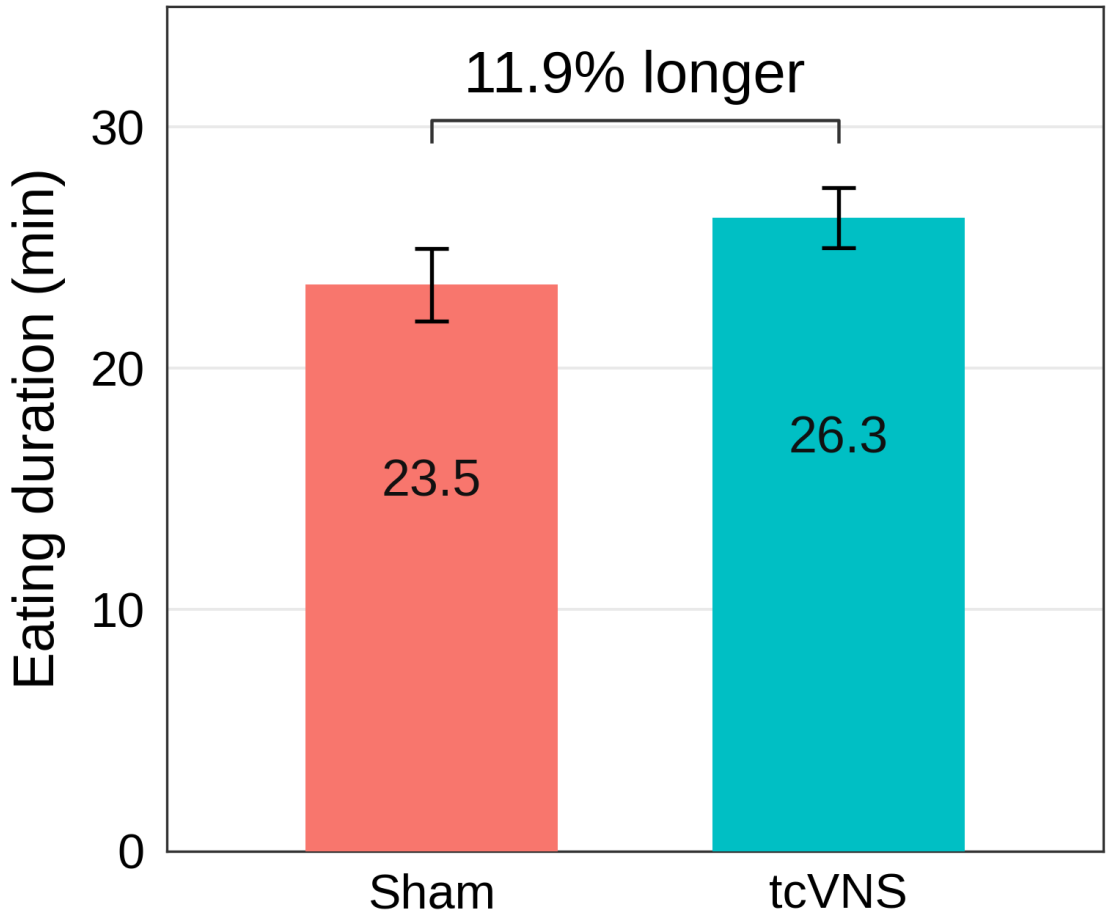
# Participants ate less under tcVNS




**9.6% less food**

eaten under tcVNS than sham

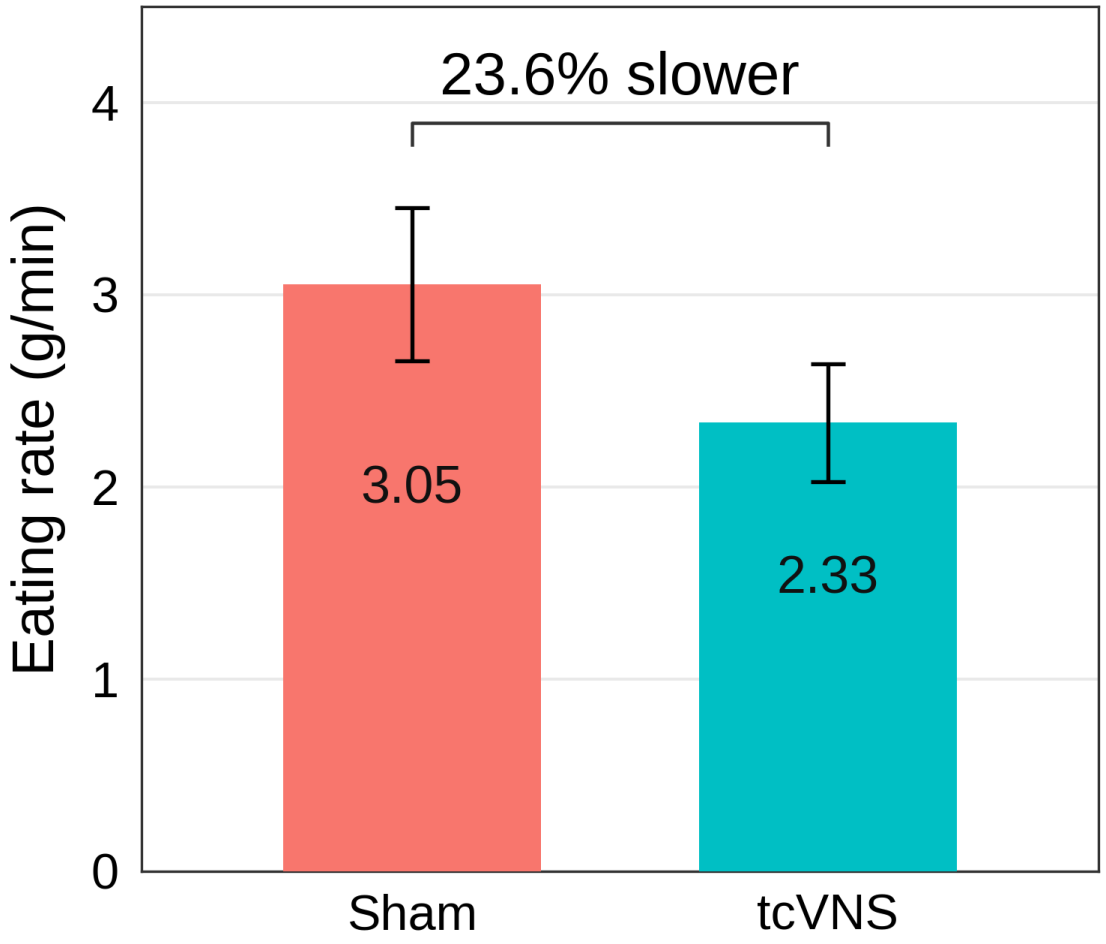
# Eating episodes lasted longer under tcVNS




**+2.8 minutes**

of eating under tcVNS (11.9% longer)

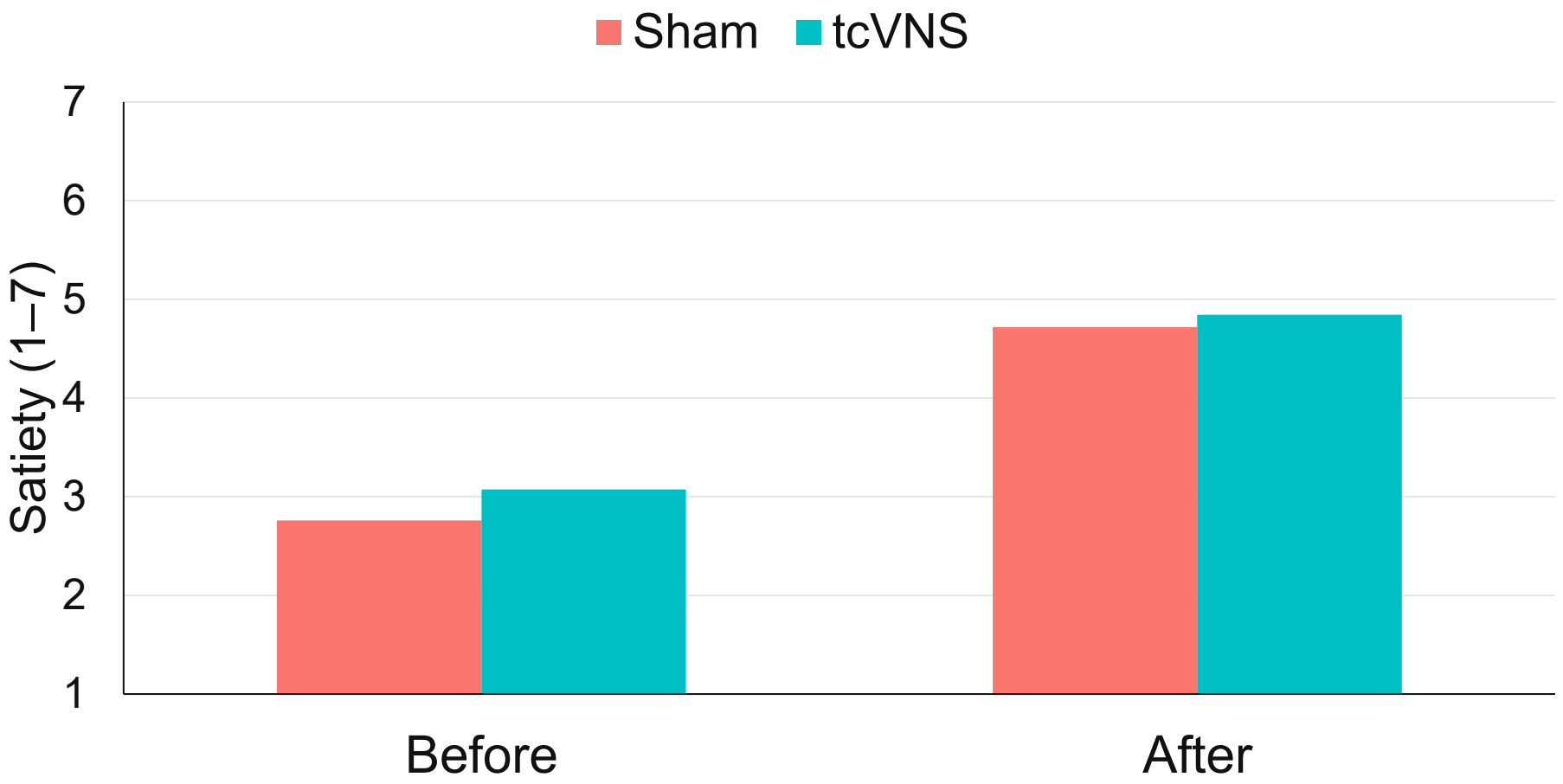
# Eating was 23.6% slower under tcVNS




**23.6% slower**

eating rate under tcVNS (−0.72 g/min)

# Satiety was the same despite eating less




**Satiety rose**

after snacking in both conditions ($p < .001$)

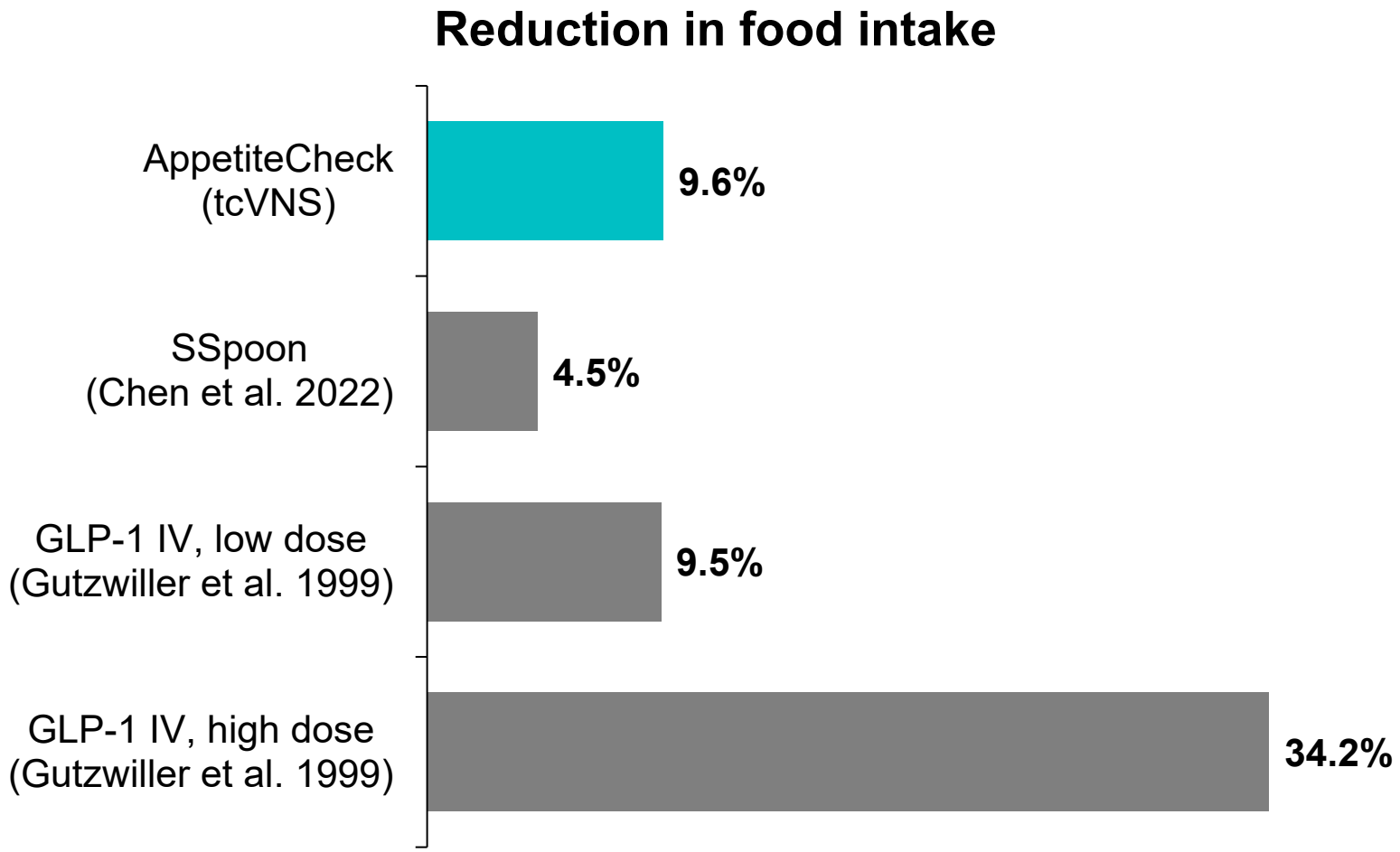
**No difference**

between tcVNS and sham ($p = .44$)

# Lower heart rate, but no HRV difference

| | |
|---|---|
| Heart rate | **5.2 bpm lower** |
| RMSSD | No significant difference |
| HF power | No significant difference |

# How does the effect compare?



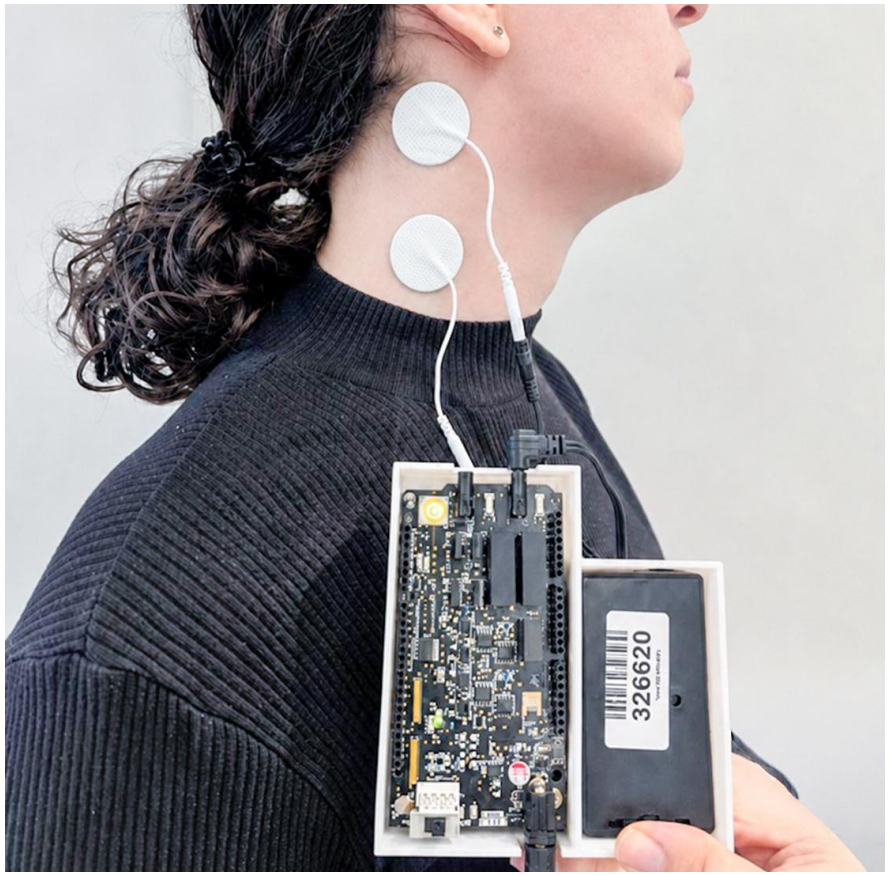

**Eating rate:**

**23.6% slower** (AppetiteCheck)

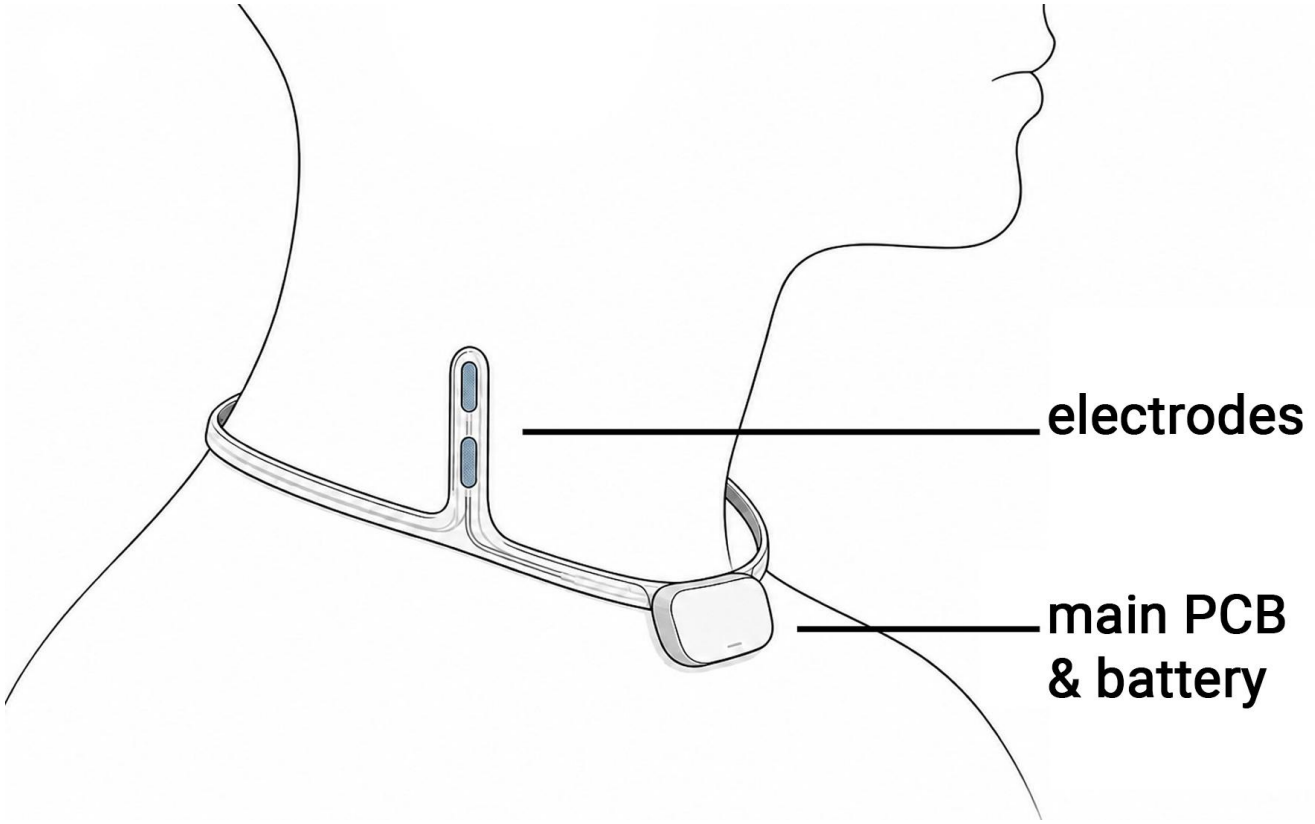
18% slower (Earinter)

14.9% slower (SSpoon)

# Towards a wearable AppetiteCheck




Early pocket-sized prototype




Envisioned necklace (future work)

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**Paper:**

Supported by NSF
#2212351 & #2212352

# Sensing is the power bottleneck

**tcVNS draws only ~3.8 mW** during stimulation; 24 × 2-min sessions/day

| Configuration | Battery | Lifetime |
|---|---|---|
| On-demand tcVNS | 110 mAh | **~13 days** |
| + IMU/PPG eating detection | 110 mAh | **~4.1 days** |
| + Active acoustic sensing (MunchSonic) | 110 mAh | **~4.2 hours** |
| + Active acoustic sensing (MunchSonic) | 350 mAh | **~13.4 hours** |

# Friction in the handheld setup

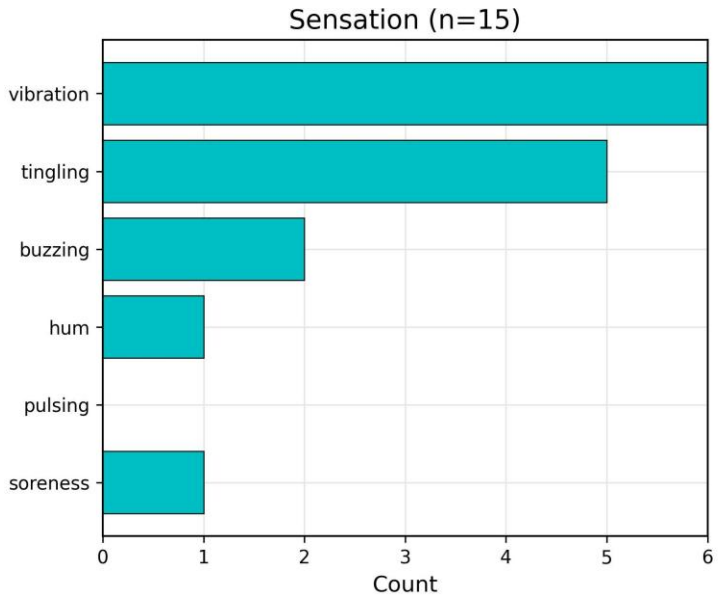
“It was okay, just made it difficult to move as I was eating”

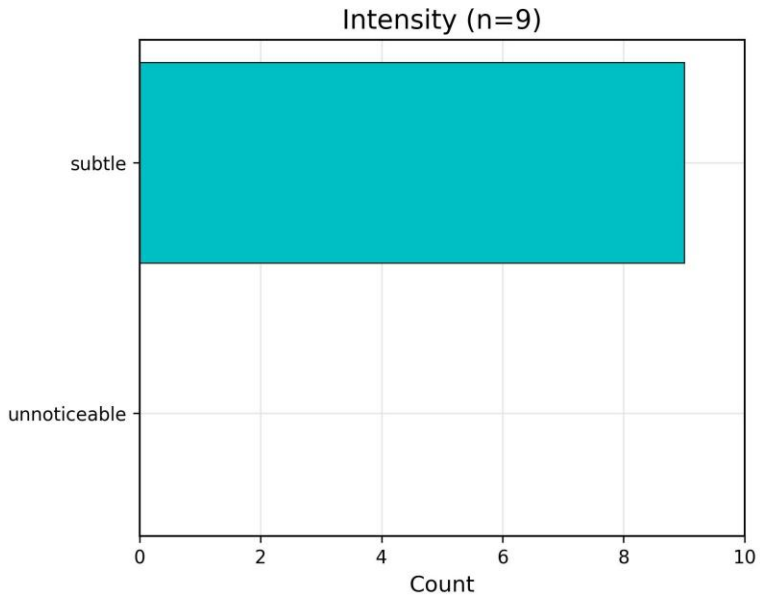
P3

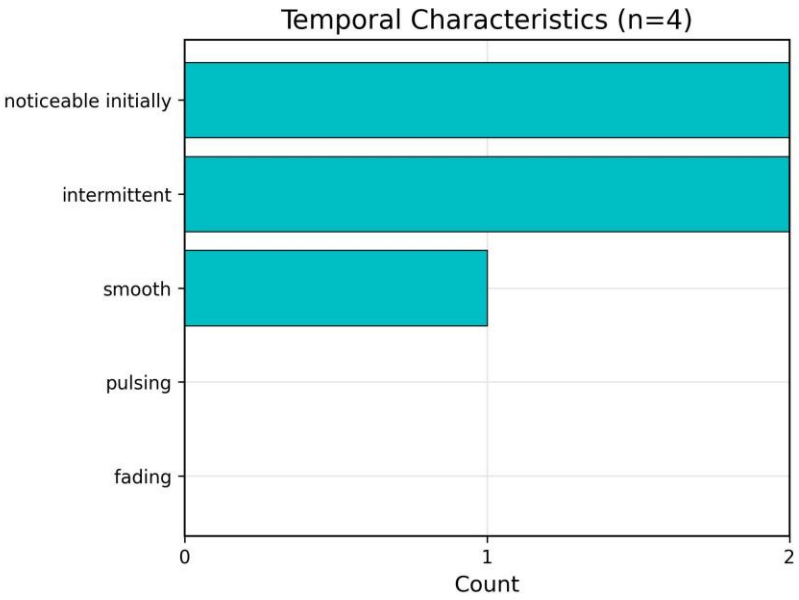
“I felt it could have been something attached rather than the person holding it.”

P24

# tcVNS felt like a subtle vibration




- **Sensation:** vibration, tingling
- **Intensity:** subtle
- **Over time:** noticeable initially, then fading
- Likened to a massage gun (P8, P17, P21) or car vibration (P7)

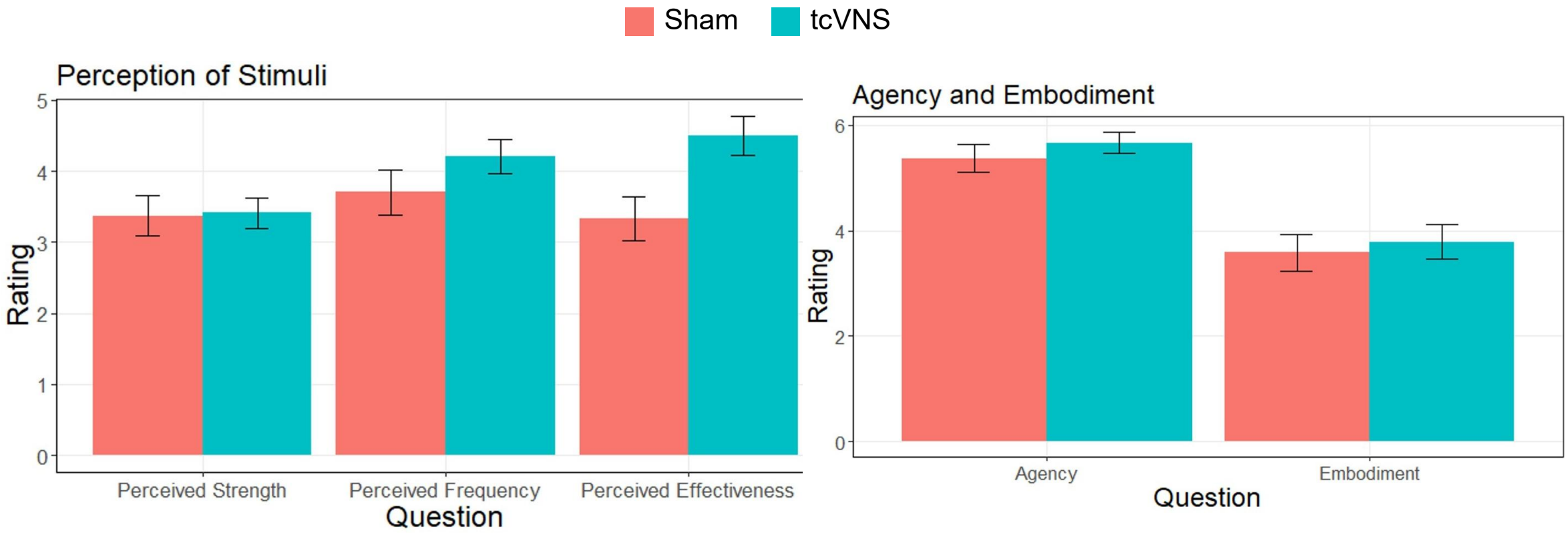
# Limitations

- A single, distracted snacking episode in a lab setting
- Experimenter-held device added pressure on the neck
- Sham could not perfectly match the tcVNS sensation; expectation effects cannot be fully ruled out
- Half of sessions ended with an empty plate (ceiling on intake)
- Healthy participants; no evidence yet of clinical or long-term efficacy

# Participants and analysis

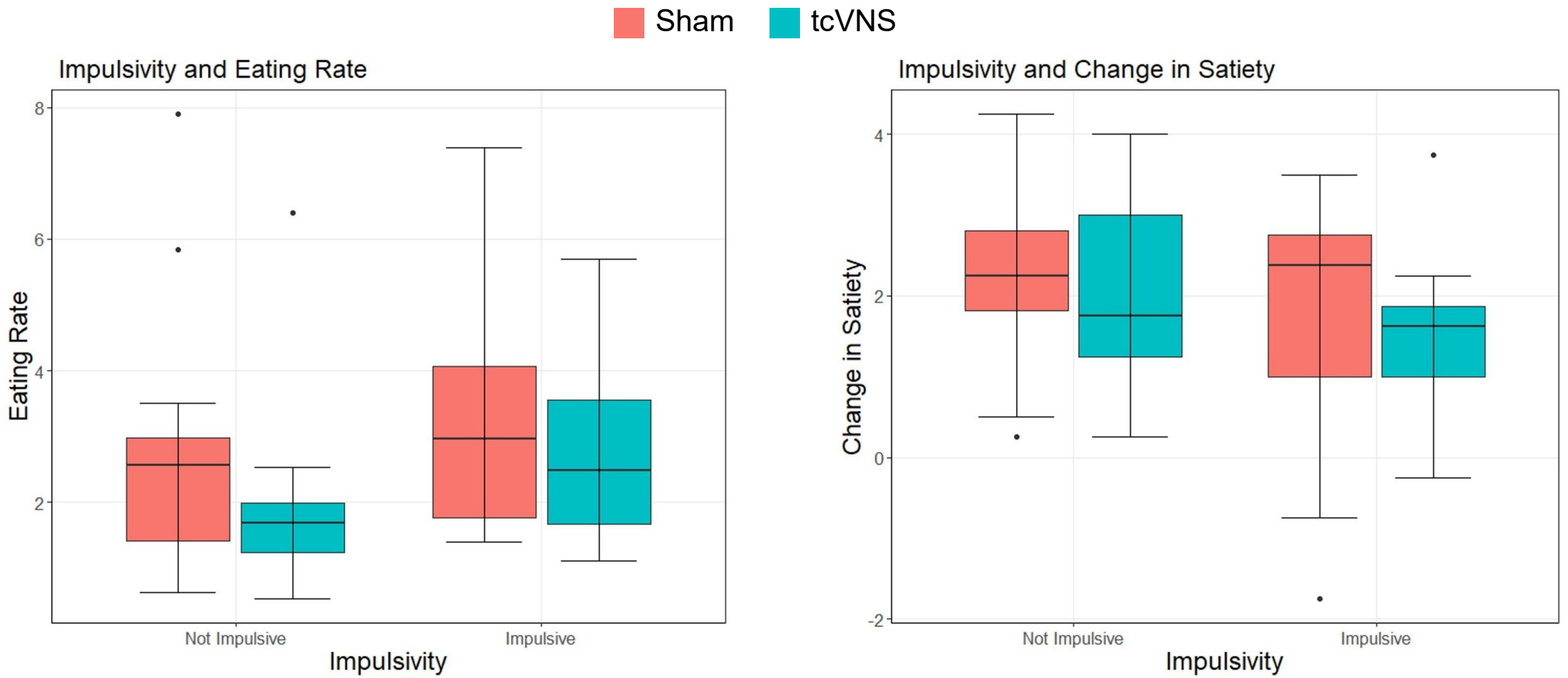
- 27 recruited; 24 completed both sessions (2 could not reschedule, 1 did not eat)
- A priori power analysis: N = 21 for f = 0.25 at 80% power
- Linear mixed-effects models (lme4) with participant as random intercept
- Snack type, video type, and impulsivity treated as exploratory; nested models compared by AIC
- Post-hoc comparisons with Bonferroni correction (emmeans)
- Cornell IRB0148698

# Stimulation felt mild; agency stayed high



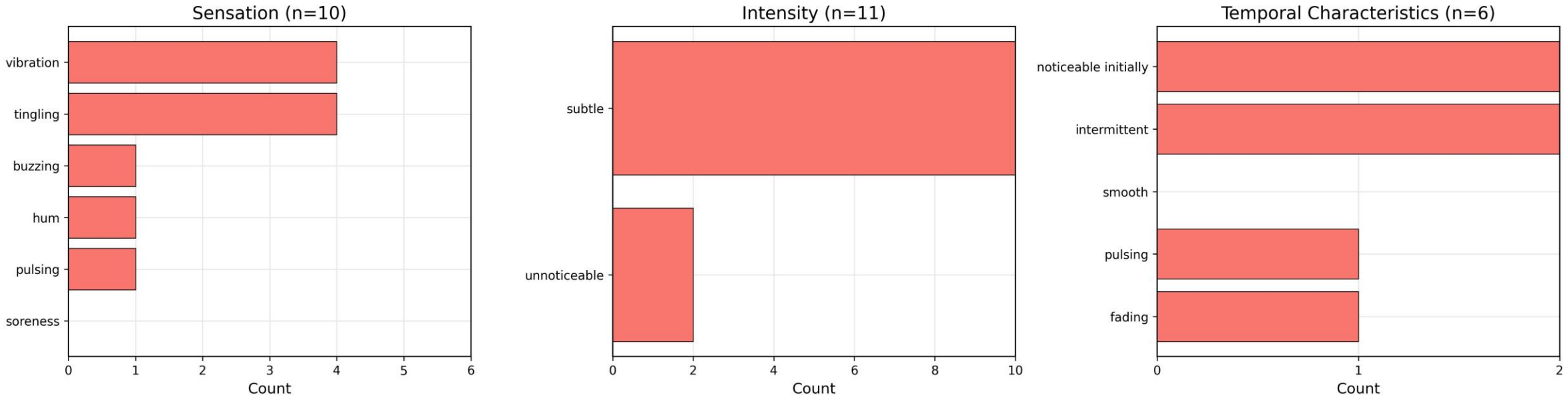

- Strength rated low (3.4/7) in both conditions; tcVNS rated as affecting eating more ($p < .001$)
- Agency stayed high (5.5/7); embodiment was low (3.7/7) with a handheld device

# Impulsivity did not moderate the effect




12 impulsive / 12 not impulsive; no main effects or interactions with condition

# Sham felt similar, but narrower




- Vibration and tingling, mostly subtle; 2 participants found sham unnoticeable
- Fewer secondary impacts than tcVNS (n = 6 vs. 11)