Workload Assessment using Speech-Related Neck Surface Electromyography

H-WORKLOAD 2018

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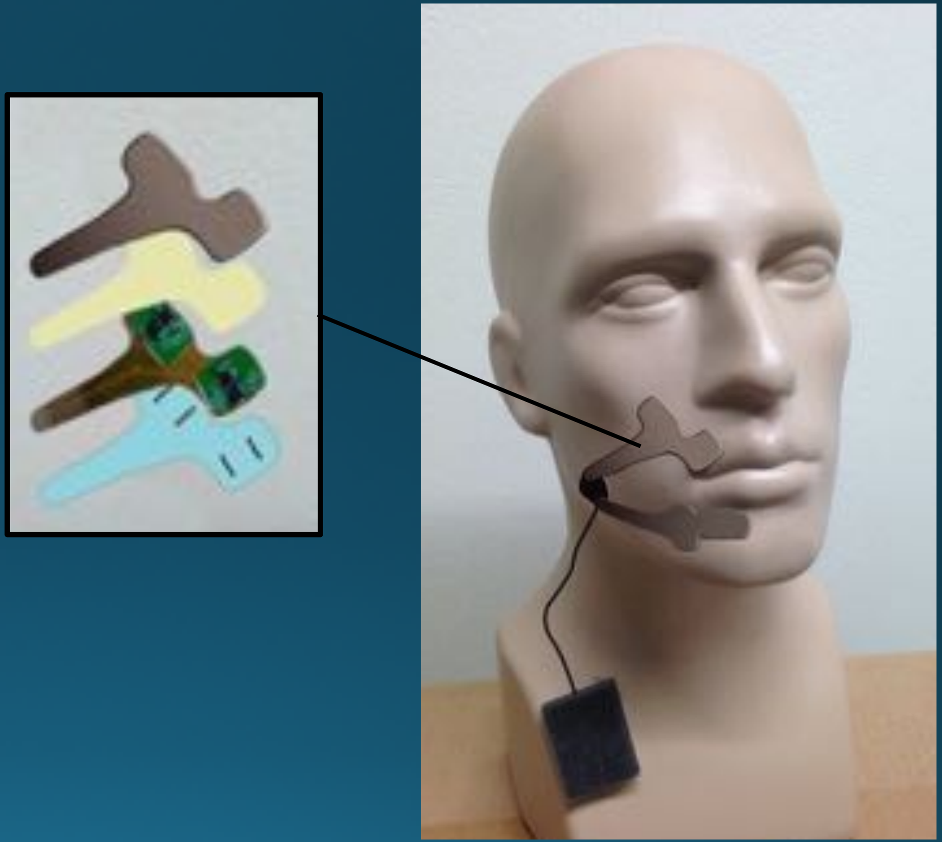
The Problem

- Robust real-time workload monitoring is difficult!
- Existing psychophysiological signals have limited utility:
  - Multiple measures are ***sensitive*** but ***divergent*** [Matthews et al., 2015]
  - Limited ***specificity***
  - Limited ***diagnosticity***

fnsEMG: A Solution?

Existing sEMG sensor designs



Notional sensor design

fnsEMG: A Solution?

- Face/neck surface electromyography (fnsEMG) can recognize and classify ***emotional responses***.
  [Van Boxtel, 2010; Cheng & Liu, 2008; Tassinary & Cacioppo, 1992; Van Boxtel et al., 1983]

fnsEMG: A Solution?

- Face/neck surface electromyography (fnsEMG) can recognize and classify ***emotional responses***.
  [Van Boxtel, 2010; Cheng & Liu, 2008; Tassinary & Cacioppo, 1992; Van Boxtel et al., 1983]

- It can also quantify neuromuscular activity related to the ***vocalization and articulation of speech***.
  [Meltzner et al., 2018; Meltzner et al., 2017; Denby et al., 2010; Jou et al., 2006]

Intermuscular Beta Coherence

- *Coherence* is a frequency domain measure of the *linear dependency* or *strength of coupling* between two signals/processes.

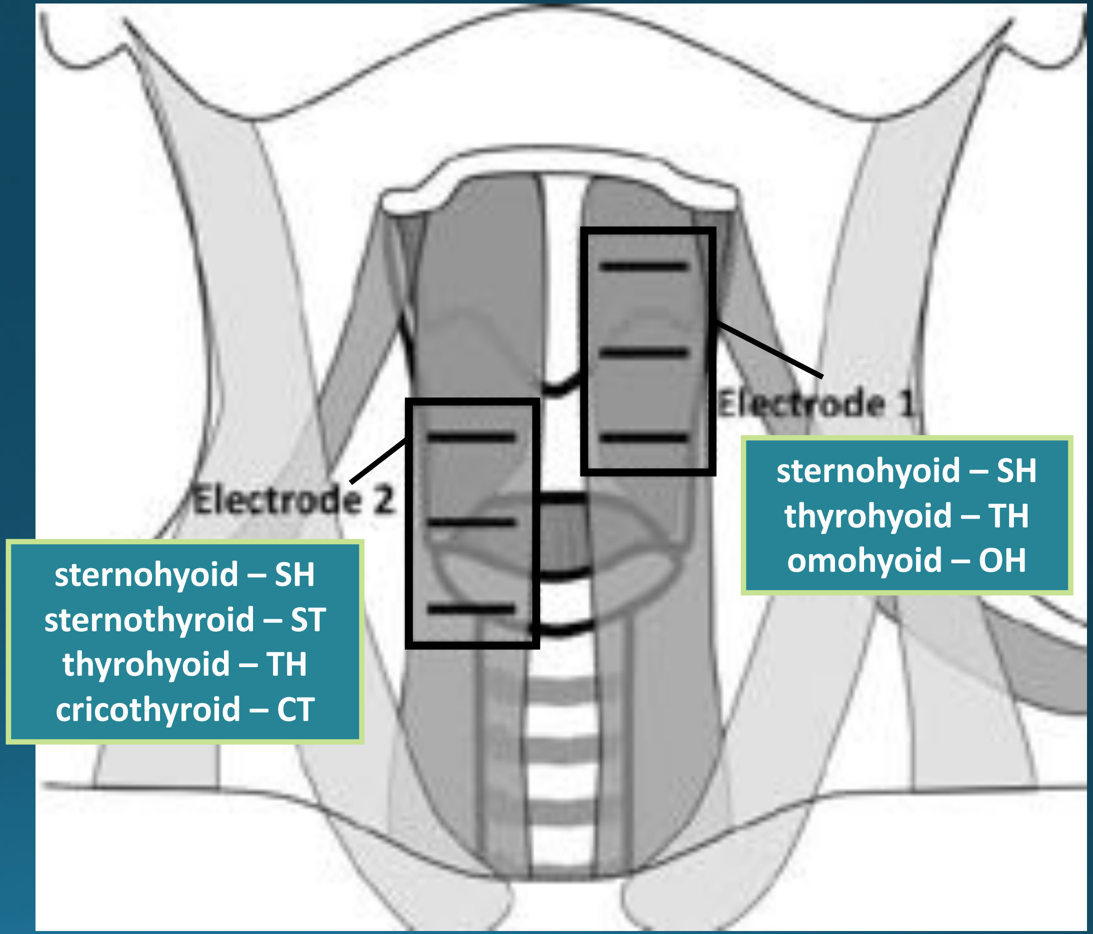
$$|R_{xy}(\lambda)|^2 = \frac{|f_{xy}(\lambda)|^2}{f_{xx}(\lambda) f_{yy}(\lambda)}$$

- *Intermuscular beta-band coherence* (15-35 Hz) is known to decrease during divided attention or reduced movement precision. [Kristeva-Feige et al., 2002]

Neck Intermuscular Beta Coherence

- ***NIBcoh*** can distinguish *healthy* vs. *strained* voice production.
  [Stepp, Hillman, & Heaton, 2010 & 2011]

- It has also been shown to *decrease* during speech when *attention is diverted* to a primary non-speech task.
  [Stepp, Hillman, & Heaton, 2011]

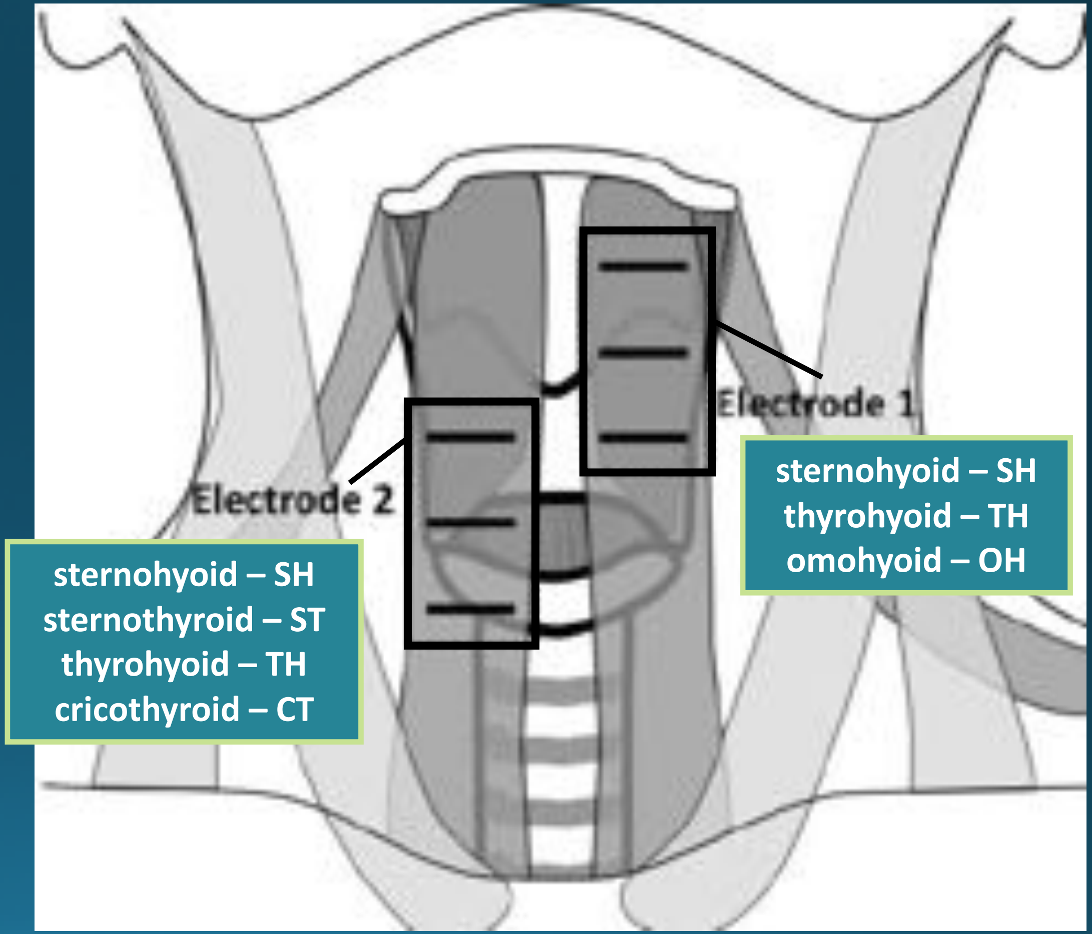


Hypotheses

- NIBcoh decreases under divided attention.
  - Confirm this finding of [Stepp et al., 2011], under a more conservative statistical model
  - Examine the impact of full-wave rectification on the EMG-EMG coherence analysis, responding to concerns raised by [Neto & Christou, 2010] regarding this common practice
- NIBcoh is correlated with task performance in a time-pressured mental arithmetic task with verbal responses.

NIBcoh Dataset

- Dataset from [Stepp et al., 2011]
- Neck surface electromyography (sEMG) was recorded over ventral neck strap muscles in 10 vocally healthy individuals during:
  - normal speech
  - static non-speech maneuvers
  - singing
  - "clear" speech (intentionally produced to maximize intelligibility)
  - hyperfunctional speech (mimicking a strained/stressed quality)
  - divided-attention speech (under **heightened cognitive load** by rapidly counting backwards from 100 by 7s)

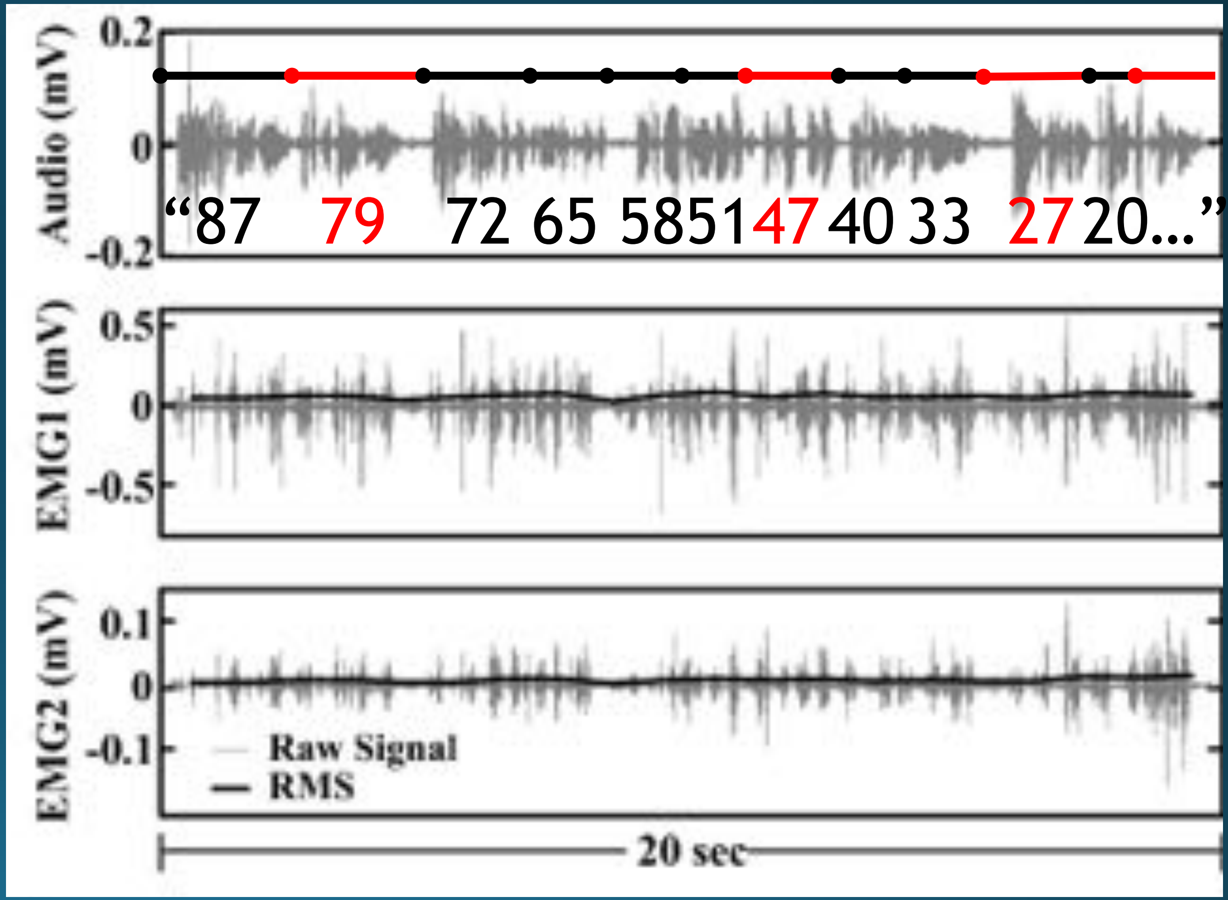


A "divided-attention" task

100, 93, 86, 78, 71, 64,
57, 50, 42, 35, 28, …

Data Analysis

- [Stepp et al., 2011] treated tasks as the unit of analysis (e.g., measuring coherence and sEMG RMS across entire recordings).
- We manually annotated the sEMG dataset for error commission (from speech recordings), and examined change in sEMG related to errors and response time.
  - Variables analyzed included NIBcoh, sEMG magnitude, and gradient, as well as acoustic features: average/peak amplitude, spectral roll-off, cepstral peak prominence, and sound intensity



Example of raw and RMS sEMG signals during 20 sec of reading from a participant with high beta coherence (0.63).

Replication Study

- Compared EMG-EMG coherence across 6 conditions from [Stepp et al., 2011] with repeated measures ANOVA
- Unrectified vs. Full-wave Rectified (see [Neto & Christou, 2010])
- Beta band (15–35 Hz) vs. 100–150 Hz band

Replication Study: Results

Coherence measure	Size of effect (generalized η^2)	p-value
Full-wave rectified		
Beta band	0.120	0.0715
100–150 Hz	0.0892	0.0905
Unrectified		
Beta band	0.176	**0.0194**†
100–150 Hz	0.0651	0.146

Do Signals Covary with Errors?

- Unit of analysis: individual response (e.g., “86”)
- Standardized EMG/acoustic variables
- Compared mean values for correct vs. incorrect responses
  - $H_0 : \mu_C = \mu_{\neg C}$

Do Signals Covary with Errors?

Measure	Estimated difference	t-statistic	p-value
NIBcoh	0.505	2.81	**< 0.006**
NIBcoh-rect	0.078	0.548	0.585
EMG magnitude (site 1)	0.432	-2.22	**0.028**
EMG magnitude (site 2)	0.532	-2.50	**0.014**
EMG gradient (site 1)	0.120	-0.772	0.44
EMG gradient (site2)	0.064	-0.414	0.68
mean acoustic amplitude	0.852	-2.35	**0.020**
peak acoustic amplitude	2.52	-2.96	**< 0.004**
sound intensity	0.345	-1.97	0.051
spectral roll-off	0.276	1.21	0.230
cepstral peak prominence	0.258	-1.67	0.097

Do Signals Covary with Response Time?

- Unit of analysis: individual response (e.g., “86”)
- Standardized EMG/acoustic variables
- Computed correlation with response time
    - $H_0 : \rho_{r,v} = 0$

Do Signals Covary with Response Time?

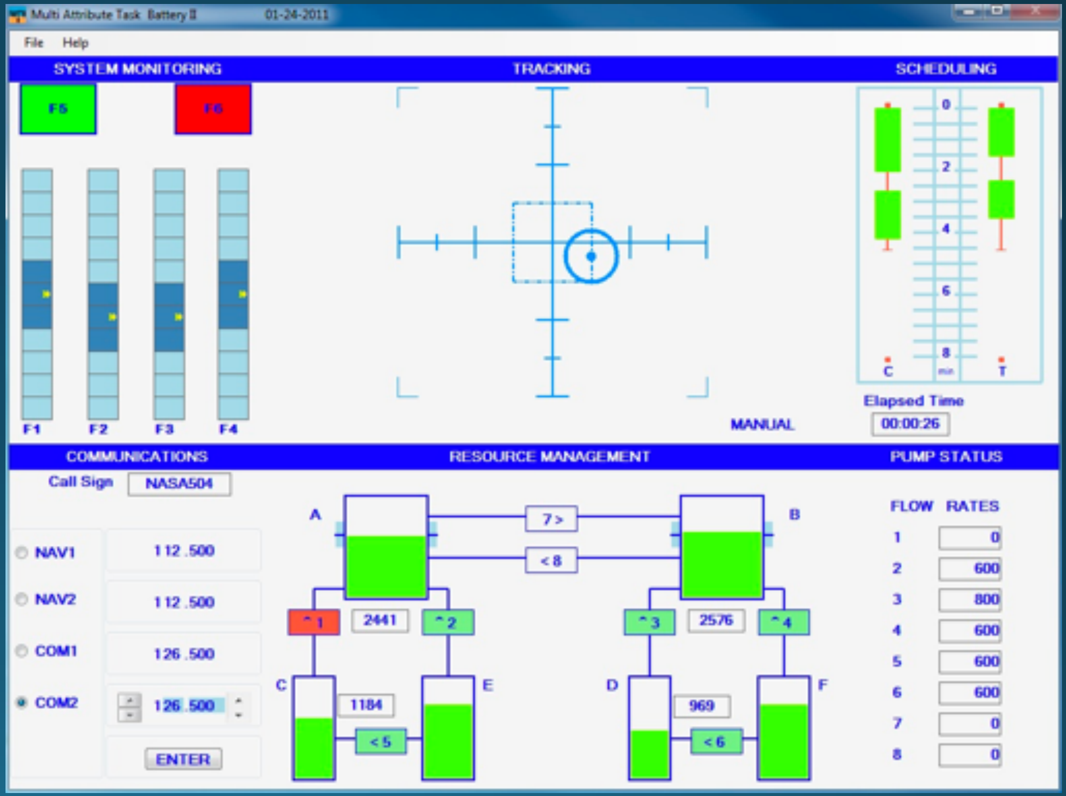
Measure	Pearson's r	t-statistic	p-value
NIBcoh	-0.196	-2.22	**0.028**
NIBcoh-rect	-0.078	-0.868	0.387
EMG magnitude (site 1)	-0.176	-1.98	0.050
EMG magnitude (site 2)	0.008	0.084	0.933
EMG gradient (site 1)	0.076	0.849	0.397
EMG gradient (site 2)	0.111	1.24	0.218
mean acoustic amplitude	-0.139	-1.56	0.122
peak acoustic amplitude	0.185	2.08	**0.040**
sound intensity	-0.223	-2.54	**0.012**
spectral roll-off	-0.005	-0.053	0.958
cepstral peak prominence	-0.219	-2.49	**0.014**

Caveats and Limitations

- Exploratory reanalysis of dataset *not* collected to assess sensitivity of NIBcoh to cognitive demands
  - Task demands were not experimentally manipulated
- Small sample size (n=10)
- Single task
- Sensitivity to outliers
- Unexplained correlations among variables

What Next?

- Collect EMG from multiple face/neck muscles
- Compare with conventional workload indicators
- Manipulate task complexity and “automation reliability” in Multi-Attribute Task Battery (MATB)
- Manipulate perceived risk



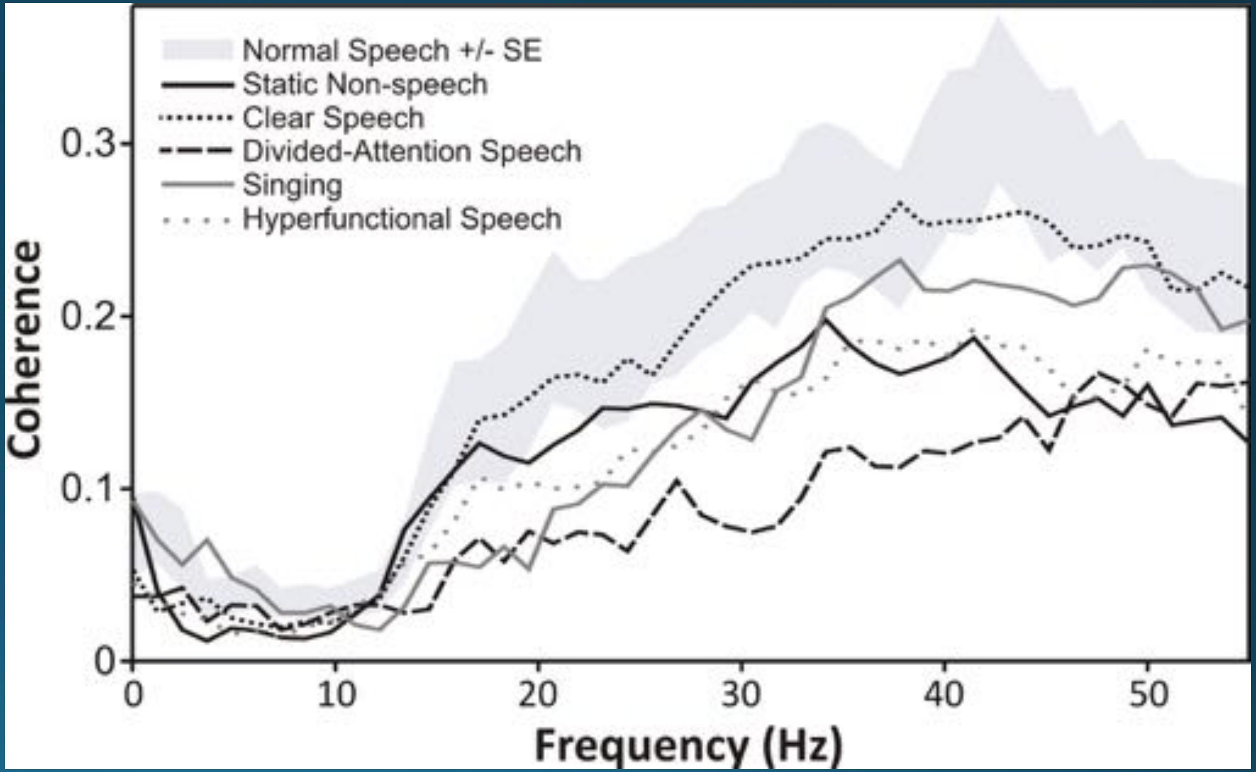
Discussion and Q&A

Thank You!

Phase I Dataset

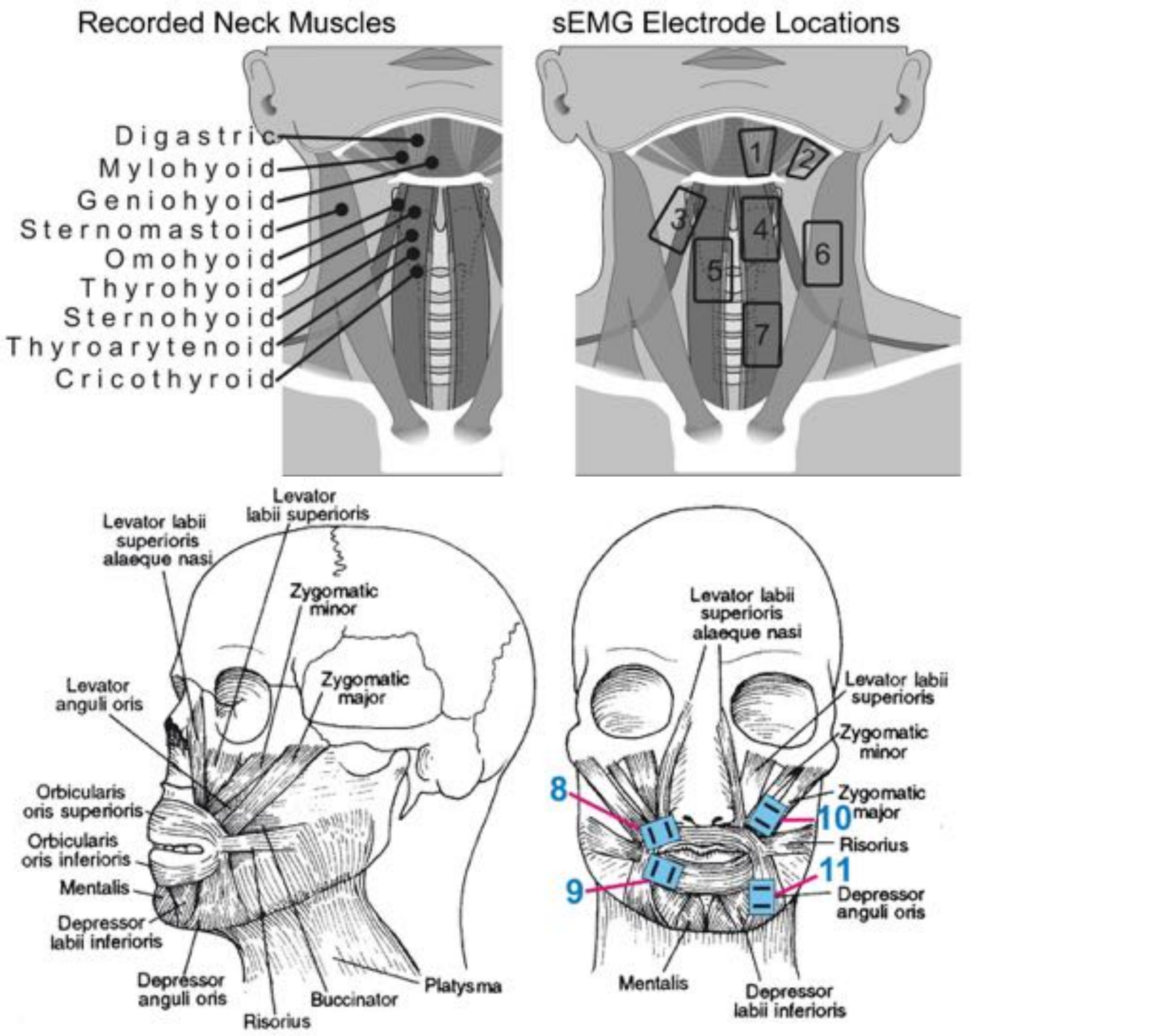
- Intermuscular sEMG beta-band coherence (15-35 Hz) is known to decrease during divided attention or reduced movement precision (Kristeva-Feige et al., 2002)
  - sEMG coherence was significantly reduced in the heightened cognitive load speaking task and hyperfunctional speech

$$|R_{xy}|^2 = \frac{|\mathrm{cov}_{xy}(f)|^2}{\mathrm{cov}_{xx}(f)\,\mathrm{cov}_{yy}(f)}$$



Neuromuscular anatomical/physiological foundation

- Muscles controlling speech articulation and facial expressions are relatively superficial and therefore accessible for non-invasive sEMG
  - We have used a set of up to 11 surface recording locations, providing robust speech-related signals
  - sEMG activity is similarly strong whether speech is spoken normally or only "mouthed" (e.g. no voice)



Adapted from Seikel, King & Drumright. *Anatomy & Physiology for Speech, Language and Hearing* 3rd Edition

Project Goal

Develop a *robust*, *reliable*, and *highly sensitive* model capable of *assessing the level of workload strain* and of *detecting/predicting overload* in real time in the context of human-automation interaction, enabling:

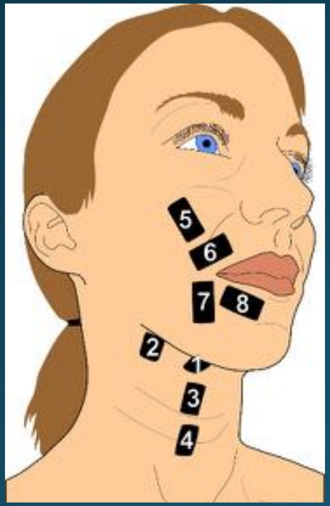
- Adaptive automation
- Cognitive countermeasures
- User interface affordances

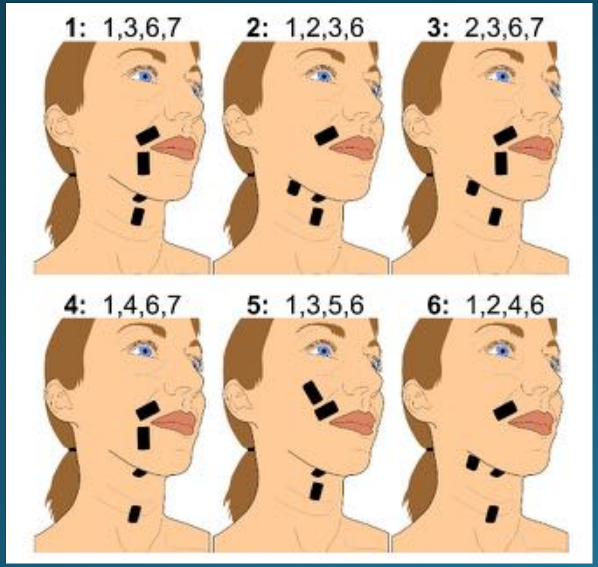
Planned Innovations

- Demonstrate utility of *face/neck sEMG* for workload assessment
- Show *improved specificity* of sEMG relative to alternate measures
- Develop a *minimally obtrusive* set of face/neck sEMG sensors and sensing locations for the workload assessment application
- Identify a *complement of unobtrusive sensors and measures* that, together with sEMG, allows for robust and reliable assessment of workload strain.

Neuromuscular anatomical/physiological foundation

- Our prior work has shown that sEMG information is sufficient for accurate automatic speech recognition using as few as 4 sensor locations
  - Information redundancy allows limited channel failure





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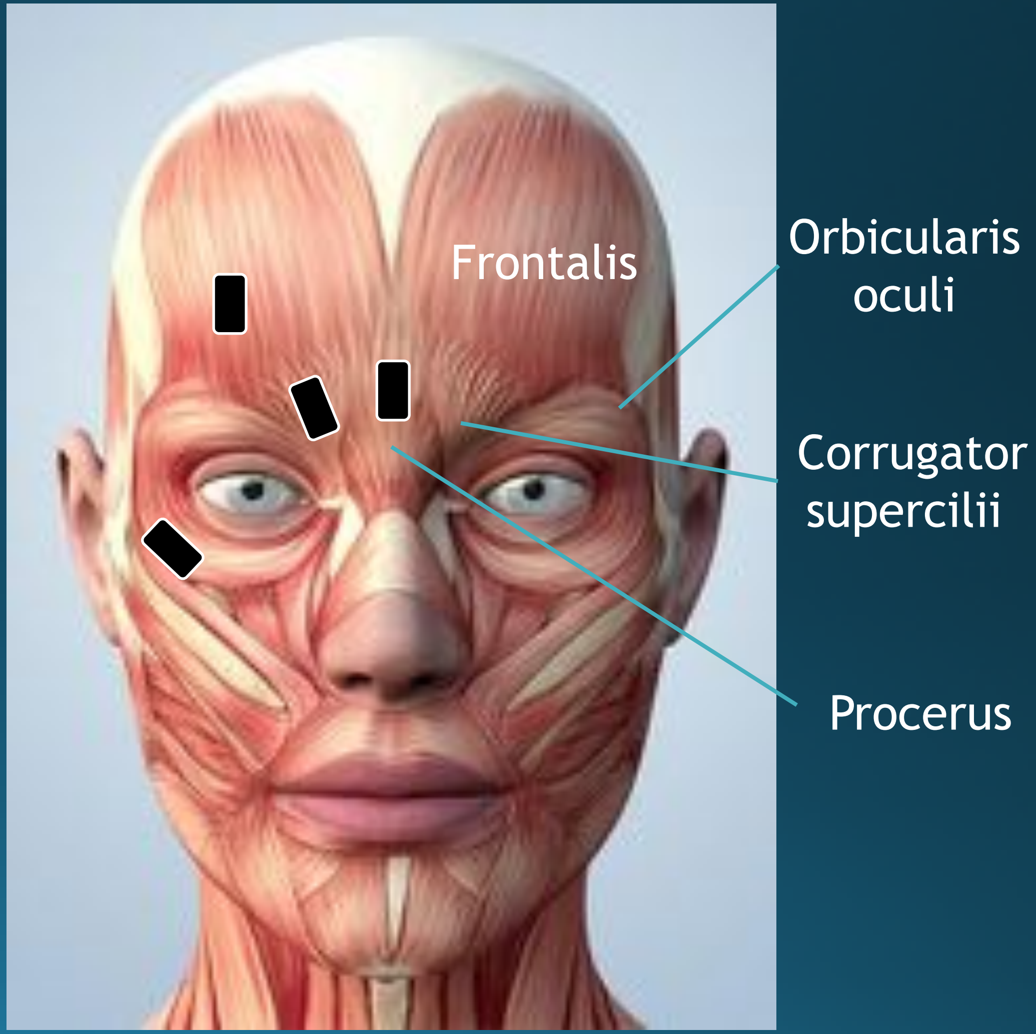
Neuromuscular anatomical/physiological foundation

We will add particular forehead and periocular sensor locations to capture eye blink and facial expressions

- Orbicularis oculi (orbital portion)
  - Eye closing muscles
    - Blink rate is correlated with stress/anxiety
- Frontalis, corrugator supercilii, and procerus
  - Surprise, scowling and frowning muscles
    - Active during negative emotional state
    - Active during surprise from unexpected outcomes
    - Amount of activity shown to relate to video game playing skill level (Weinreich, Strobach & Schubert, 2015)



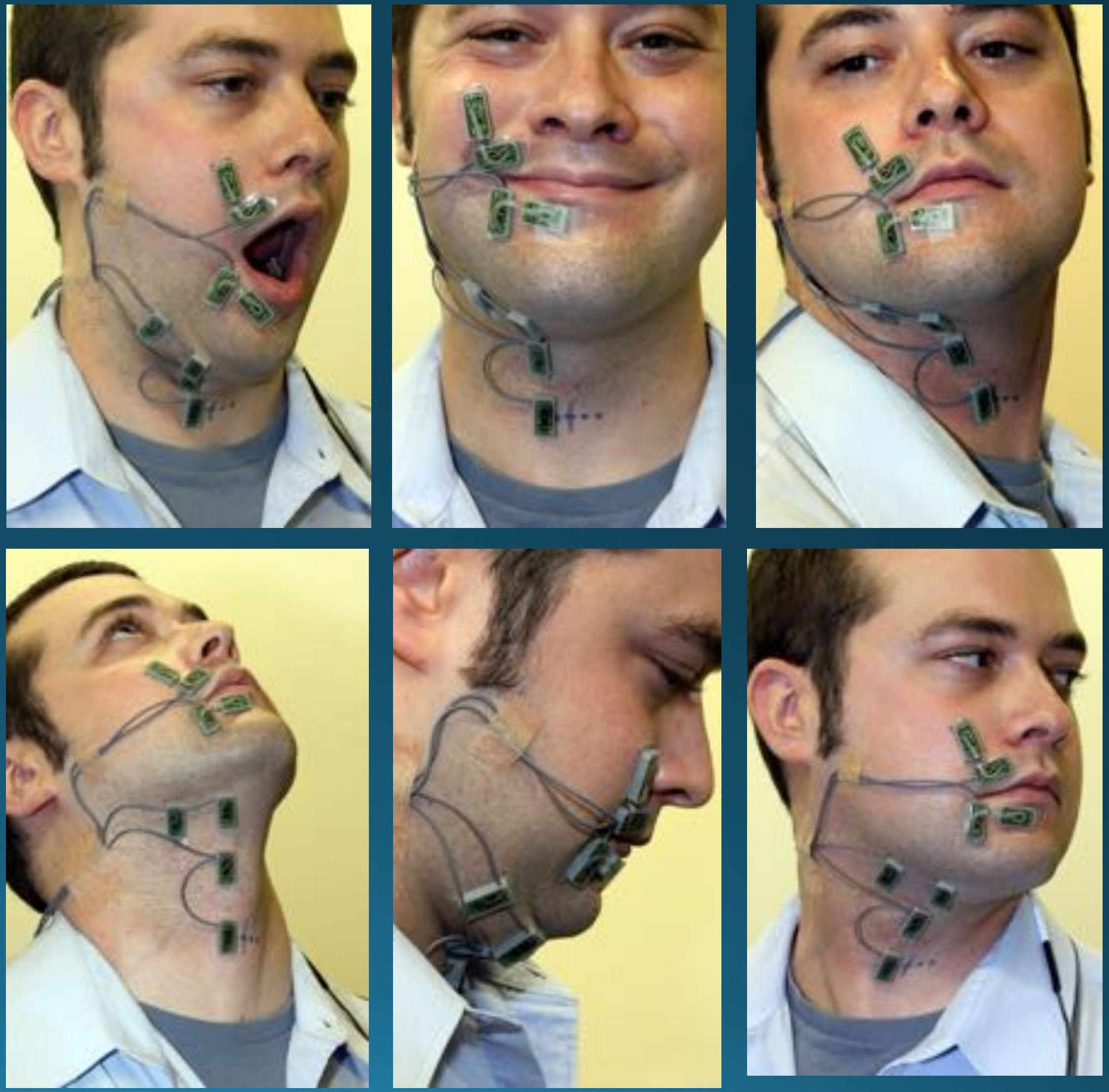
Muscular System of the Head by Roger Harris

Neuromuscular anatomical/physiological foundation

- Recording locations *can* be unilateral because head/neck muscle contraction are typically symmetrical (at least for speech)
- Some bilateral recording locations will allow us to measure intermuscular coherence
    - Coherence in the beta band (15-35 Hz) is known to decrease under stressed or divided-attention conditions (Stepp, Hillman & Heaton, 2011)
    - Beta coherence is believed to originate from the motor cortex, and is influenced by cognitive state

sEMG Sensor Technology

- Custom “mini” sensors were created by Delsys Inc. for our neck/face recording needs, which are now part of their product line
  - Designed to record from the relatively small muscles of articulation and facial expression
  - Light-weight and non-encumbering
  - Wireless communication to signal processing hardware



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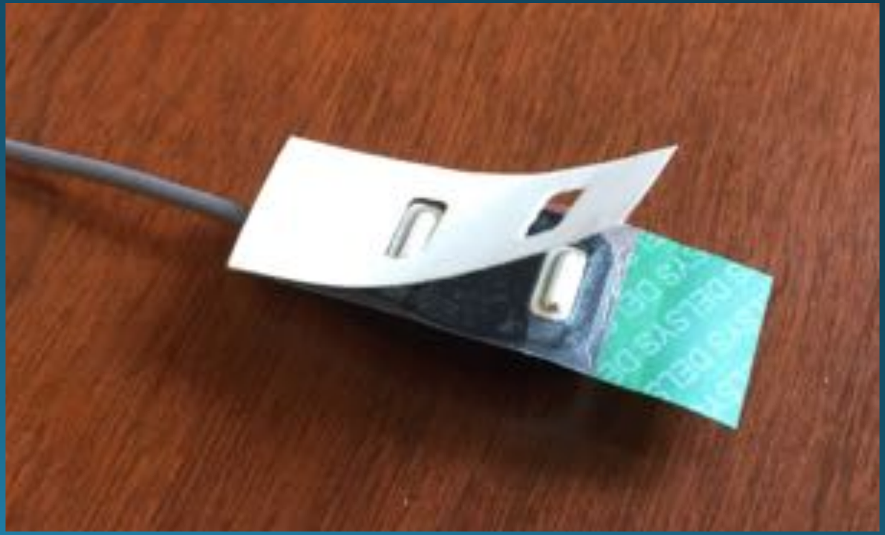
sEMG Sensor Application

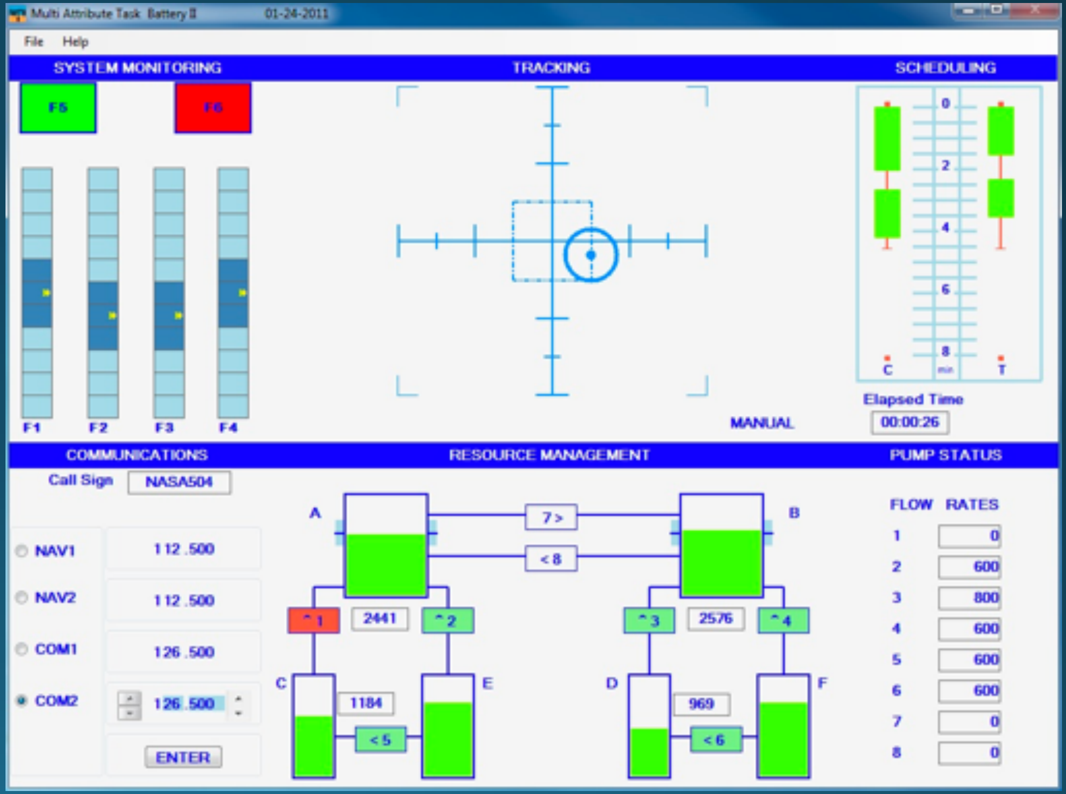
- Sensor placement is relatively easy and typically lasts for hours
  - Clean, shaven skin is ideal
    - Beards preclude perioral placement
  - Skin exfoliation through tape “peeling” provides strongest signals
    - Clear desk tape works well
  - Sensors attach through disposable double-stick interface strips
  - **No conductive gel or paste needed**



sEMG Recording

- sEMG sensors **communicate wirelessly** 40 meters
- Multi-function design embeds **Triaxial Accelerometry** in standard-size sensors
- Up to **16 EMG** channels and **48 accelerometer** channels
- **8 hours** of operation in full transmission mode (2 hour recharge time)
- **16-bit** resolution, **1926 Hz** EMG sampling rate
- **USB Connection** to PC (laptop or desktop)
- Real-time feedback of **signal strength & battery status**

Experimental Testbed / Tasks



Discussion

- Key challenges/opportunities from your perspective?
- Tasks / data sets
- Initial demonstration ideas and expectations
- Relationships to ongoing work
- Phase II proposal/award process