Scaling up Cognitive Efficacy with Operational Neuroscience

Santosh Mathan

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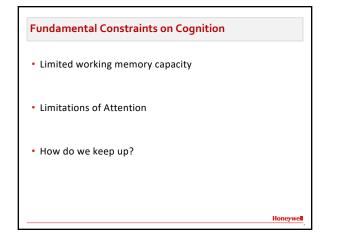

"It keeps me from looking at my phone every two seconds."

Fundamental Constraints on Cognition

- Limited working memory capacity

- Limitations of Attention

- How do we keep up?

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Scaling Up Human Performance

- Systems that are sensitive to cognitive state

- Novel means of interacting with computer systems
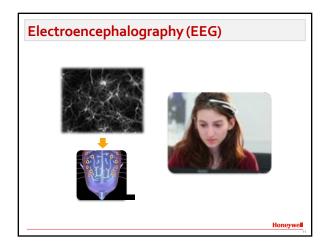
- Enhancing cognitive capacity

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Neural Measures: Objective and Fine-Grained

Differences related to task difficulty

Differences related to proficiency

Practicality?
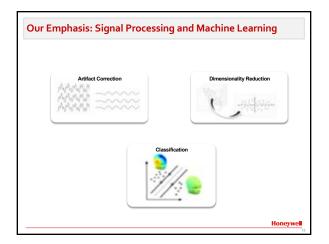
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EEG

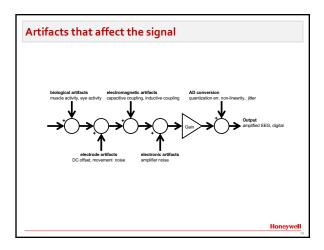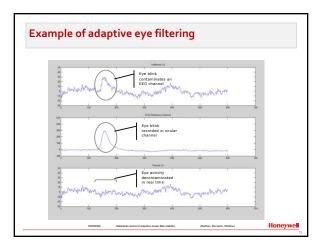- Excellent temporal resolution

- Relatively inexpensive

- Portable

- Insight into a broad range of cognitive activity

- Limited spatial resolution
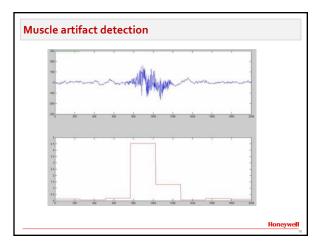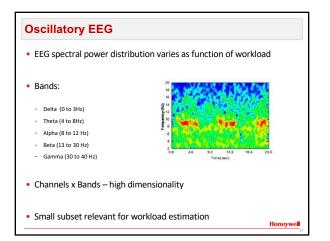
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Electroencephalography (EEG)

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EEG sensors

High Density Laboratory System (BioSemi)

Low Density Wireless EEG System (ABM)

Dry Electrode System (QUASAR)

Consumer Systems (Emotiv)

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Our Emphasis: Signal Processing and Machine Learning

Artifact Correction

Dimensionality Reduction

Classification

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Artifacts that affect the signal

biological artifacts
muscle activity, eye activity

electromagnetic artifacts
capacitive coupling, inductive coupling

AD conversion
quantization err, non-linearity, jitter

Gain

Output
amplified EEG, digital

electrode artifacts
DC offset, movement noise

electronic artifacts
amplifier noise

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Example of adaptive eye filtering

Eye blink contaminates an EEG channel

Eye blink recorded in ocular channel

Eye activity decontaminated in real time

H0009368   Statistical control of adaptive ocular filter stability.   (Mathan, Dornsich, Whitlow)

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Muscle artifact detection

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Oscillatory EEG

- EEG spectral power distribution varies as function of workload

- Bands:

  - Delta (0 to 3Hz)
  - Theta (4 to 8Hz)
  - Alpha (8 to 12 Hz)
  - Beta (13 to 30 Hz)
  - Gamma (30 to 40 Hz)

- Channels x Bands – high dimensionality

- Small subset relevant for workload estimation

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Logistic Regression

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Augmented Cognition: Cognitive State Sensing

- Cognitive state sensing in harsh operational contexts
- Detect: cognitive capacity < information processing demands
- Dynamic assistance to manage workload
- Classification accuracy: > 0.80 AUC

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Comparison to other indices of cognitive effort

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Helicopter Study – DARPA Sandblaster

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Attention Estimation

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Scaling Up Human Performance

- Systems that are sensitive to cognitive state

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High-Throughput Image Analysis

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Access to imagery

- Broad number of sources, low cost of acquisition and storage

Relative strengths of humans and automation

- Automated techniques not as accurate as human analysis
- Manual analysis is slow

Robust split-second perceptual judgements

- People can make reliable perceptual judgments

Perceptually-driven High-Speed Triage

- Decompose large high-resolution images into chps
- Present chips in high-speed bursts to users using RSVP

Target Identification

- Model distribution of ERP peaks and click latency to pinpoint targets

The Event Related Potential

Target Onset

100 ms

200 ms

300 ms

< 150 ms	Occipital	Feature Extraction & Encoding
~ 300 ms	Frontal	Attention & Decision Making
~ 450 ms	Parietal	Memory & Decision Making
~ 500 ms	Motor	Response Selection and Execution

Neurally-Tagged Hotspots

Confirming Targets

Multi-fold improvements in performance

SAM Sites

Effects demonstrated with broad range of target types among professional image analysts

Crucial Human Performance Related Factors

- Presentation parameters

- Target eccentricity

- User attention

BCI

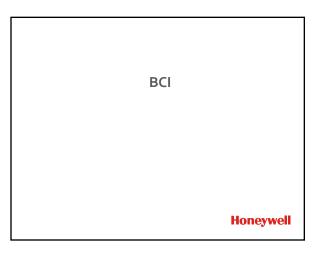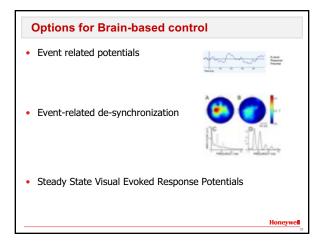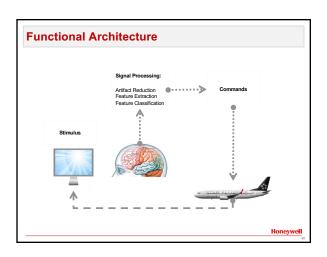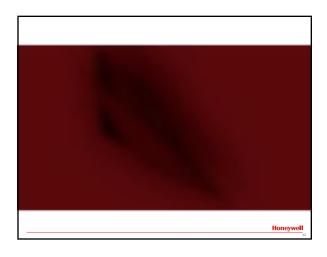## The need for new interaction modalities

Options for Hands-Free Control

- Speech: Challenging in noisy and comm heavy settings

- Gestures: Limited utility without the use of hands

- Gaze: instant, random access to objects. Midas touch

- Brain-based control

Options for Brain-based control

- Event related potentials

- Event-related de-synchronization

- Steady State Visual Evoked Response Potentials

Functional Architecture

Signal Processing:
Artifact Reduction
Feature Extraction
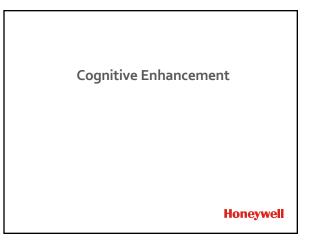Feature Classification

Commands

Stimulus

Scaling Up Human Performance

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Cognitive Enhancement
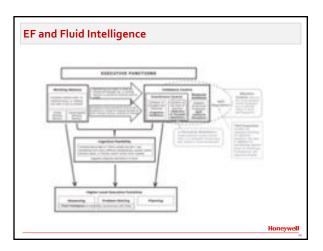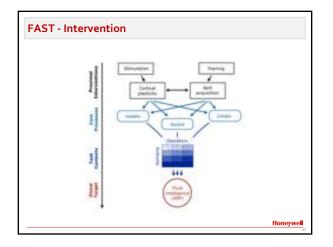
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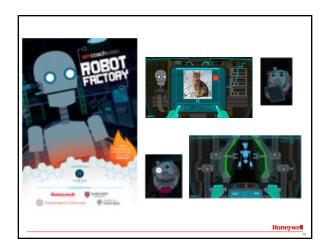
Objective
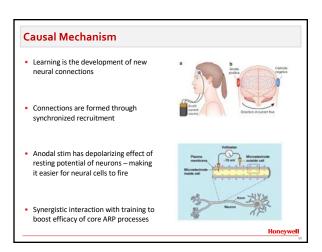
- Enhance reasoning and problem solving

- Related to Fluid Intelligence
  - Solving novel problems
  - Modifying behaviors in light of new information
  - Generating strategies
  - Sequencing complex actions

- Recent results suggesting Fluid Intelligence can be enhanced

- Methodological weaknesses with prior work

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EF and Fluid Intelligence

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FAST - Intervention

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Collaborators

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Slide 1

ROBOT FACTORY

Causal Mechanism

- Learning is the development of new neural connections

- Connections are formed through synchronized recruitment

- Anodal stim has depolarizing effect of resting potential of neurons – making it easier for neural cells to fire

- Synergistic interaction with training to boost efficacy of core ARP processes
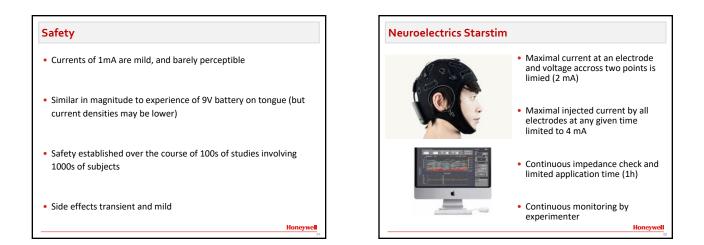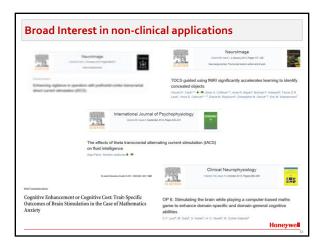
Safety

- Currents of 1mA are mild, and barely perceptible

- Similar in magnitude to experience of 9V battery on tongue (but current densities may be lower)

- Safety established over the course of 100s of studies involving 1000s of subjects

- Side effects transient and mild

Neuroelectrics Starstim

- Maximal current at an electrode and voltage accross two points is limied (2 mA)

- Maximal injected current by all electrodes at any given time limited to 4 mA

- Continuous impedance check and limited application time (1h)

- Continuous monitoring by experimenter

Broad Interest in non-clinical applications

Context

- Lets rewind to December 2014

Emerging Consensus in Late 2014 / Early 2015

- Meta review from Jaeggi Lab: cognitive training produces 0.24 effect size improvement relative to control

- Other meta reviews critical – gains largely seen with passive control

- Emerging consensus: No convincing evidence that WM training influences Gf

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Participants

- Age: 18-65; Healthy; English Proficiency

- Exclusion:
  - History of neurological or psychological problems
  - Skin problems
  - Medical devices
  - Any unstable medical condition

- Recruitment via fliers and email

- Compensation: $20 / per session (14) + $120 completion bonus
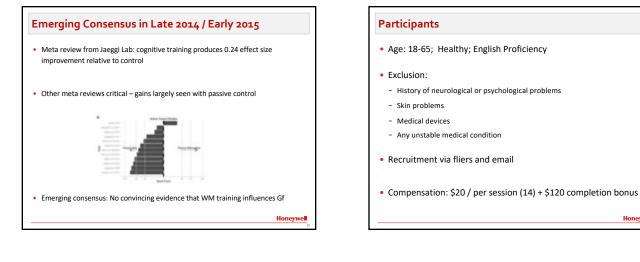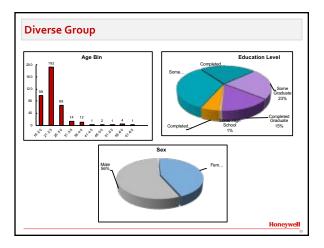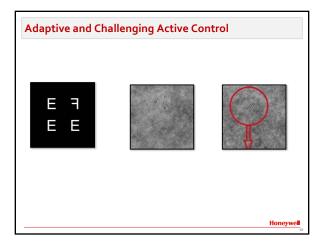
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Details of Current Study

- 4 conditions:
  - tDCS + game, tRNS + training, sham + training, sham + active control

- 440 subjects; 110 per group;

- 11 days of training, 9 with stimulation, stimulation limited to 30 m

- Measures:
  - Test of fluid intelligence
  - Resting state EEG
  - EF tasks (tests of Update, Inhibit, Switch)

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Diverse Group

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Adaptive and Challenging Active Control

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MITRE Results

- Statistically significant outcomes associated with interventions in 3 out of 6 tests

- Marginally significant gains relative to active control on 1 test

- Statistically significant gain relative to AC on SEM latent variable

- Effect sizes ranging from 0.20 to 0.36

- Do these results matter?

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These Results Matter

- Address numerous methodological weaknesses

  - Well designed active control task
  - Sensitive and reliable tests
  - Large and diverse sample
  - Control for baseline differences

- Short duration and practical intervention

- Effect sizes match levels previous studies were only seeing with passive control

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Scaling Up Human Performance

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Thanks

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