What's the plan? - Movement-goal representations in the frontoparietal reach network

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- Important first step: Feature extraction!
- Motor-goal encoding and movement planning in the intact primate sensorimotor system
- Implications for BCI design?
Simultaneous multi-channel intracortical recordings in areas PMd and PRR
Space-context integration for reaching – Where, when and how?

- Parietal reach region (PRR)
- Dorsal premotor area (PMD)

Visual "where" 

Sensorimotor 

Motor 

Categorization 

Cognitive control
Cortical encoding of arm movement plans
Posterior parietal cortex

Parietal Reach Region
Dorsal Premotor Cortex

Single PRR neuron

visual cue → movement

spike rate / Hz

time / s
Cortical decoding of arm movement plans
Posterior parietal cortex

Parietal Reach Region

Population decode
(N = 131 neurons)

fixation
cue
planning

decoding performance

0 0.2 0.4 0.6 0.8 1
time from cue onset / s

chance level
Identifying movement plans
Step 1: Sustained activity during instructed delay

- fixation
- visual cue
- delay
- movement
- feedback

'visual' delay-activity

'motor' delay-activity

- visual memory?
- movement planning?
Goal-directed movement planning

- **spatial constraints**
  - localize potential target objects,
  - identify motor-goal options

- **behavioral context**
  - decide which action to perform
  - based on goal-selection criteria

= **goal-directed movement plan**
  - define motor-goal and specify
  - movement kinematics

→ **movement:**
  - not (only) spatial working memory
  - or spatial attention

→ **planning:**
  - not motor-control
Identifying movement plans
Step 2: Motor-goal selectivity

visual cue

PRO reach

ANTI reach

motor goal

visual vs. motor-goal encoding

visual tuning

motor-goal tuning
PRR encodes motor-goal location during the planning phase of an arm movement

Single neuron tuning

Population decoding:
→ train ‘pro’
→ predict ‘anti’

131 neurons

Gail & Andersen 2006 J Neurosci
Never trust any motor goal under 200\text{ms}?
Space-context integration – The partial pre-cuing experiment

- **Pre-cue**
- **Delay**
- **Fixation**
- **2nd cue (‘go’)**
- **Reach**
- **Feedback**

PRO reach - ANTl reach

Variable order of location and context cue
Congruent (PRO) motor goals are faster especially if context is known in advance

Westendorff et al. 2009 (in prep.)
Motor goals are earlier in PMd than in PRR but only for inferred (ANTI) reaches.

PRO reaches

ANTI reaches

Westendorff et al. 2009 (in prep.)
Context representation is more prevalent in PMd than PRR

Westendorff et al. 2009 (in prep.)
Motor goals are earlier in PMd than in PRR independent of the pre-cuing condition

Westendorf et al. 2009 (in prep.)
Motor goal latencies PRR and PMd

Westendorff et al. 2009 (in prep.)

- PRR
- PMd

- Visual context
- Pro-goal (context known)
- Pro-goal (else)
- Anti-goal

Mean latency / s

- PMd
- PRR

Graph showing latency differences for different conditions:
- Visual
- Context
- Pro-goal (context known)
- Pro-goal (else)
- Anti-goal

Graph bars indicate latency differences with labels 1, 2, and 3.
Limited generalization of motor-goal decoding

Population decoding:

→ train ‘pro’
→ predict ‘anti’

Drop from nearly 100% to ~70%
(compared to ‘pro’- or ‘anti’-only)

Gail & Andersen 2006 J Neurosci
All motor goals are equal?
Contextual gain modulations of motor-goal representations – examples

‘pure’ motor-goal tuning
monkey S, PMd

pro-preferring motor-goal tuning
monkey A, PRR

anti-preferring motor-goal tuning
monkey A, PRR

response relative to cue position

PRO reach
ANTI reach

Gail et al. 2009 JNeurosci (in press)
Contextual gain and selectivity modulations

similarity between model and neural data

Brozovic*, Gail* & Andersen 2007 J Neurosci
**Strength and bias of contextual motor-goal modulations**

PRR vs. PMd

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### Strength of modulations

- **Gain**
  - PRR: 2.5
  - PMd: 1

- **Spatial selectivity**
  - PRR: ***
  - PMd: ***

- **Direct modulation**
  - PRR: ***
  - PMd: ***

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### Bias (PRO-ANTI) of modulations

- **Gain**
  - Modulation index: 0.15
  - Modulation: PRO

- **Spatial selectivity**
  - Modulation index: 0.15
  - Modulation: PRO

- **Direct modulation**
  - Modulation index: 0.15
  - Modulation: PRO

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*Gail et al. 2009 J Neurosci (in press)*
**Conclusion**

**Motor-goal encoding in PRR and PMd**

- PRR & PMd reflect **ruled-based motor plans**
  - dynamic “sensory” to motor-goal transformation
  - some neurons visuomotor, most ‘motor-only’

- **latency** of motor-goal tuning
  - shorter in PMd than PRR (inferred goals, any pre-cuing condition)
  - shorter in SR congruent tasks (pro vs. anti)

- **gain-modulation** of motor goal tuning
  - motor plans are context-specific in PRR & PMd
  - PRR: bias for stimulus-driven motor goals (higher spatial selectivity)
  - PMd: bias for rule-guided motor goals (stronger gain)
Implications for BCI design

- dynamic visomotor transformation:
  - choose features ‘free’ of non-motor components
  - select features based on pro/anti test

- latency differences
  - conservative: wait for 200ms
  - progressive: use context information to decide

- gain-modulation
  - limited generalization to different behavioral context
  - decoder has to be context-specific (use PMd signals?)
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Selective memory encoding in the partial pre-cuing experiment

- **Pre-cue**
  - **Contextual & Spatial Pre-cue**
    - Contextual pre-cue
    - Spatial pre-cue
  - **No Pre-cue**

- **Memory Encoding**
  - Definite motor goal
  - Nothing
  - Task rule (context)
  - Cue location / Default motor goal / Pot. motor goal

- **Go-cue**
  - Nothing
  - Space-context integration
  - Apply rule to incoming spatial information
  - Cue re-mapping selecting among pot. motor goals

- **Movement Preparation**
Space-context integration
Hypothetical processing sequence

Pre-cuing condition

No pre-cue

Contextual pre-cue

Spatial pre-cue

Go-cue

Space-context integration

Context/rule

Cue location

Space/context integration
PMd–PRR differences in motor-goal latency are independent of the pre-cuing condition.

**Pre-cuing Condition**
- **No pre-cue**
  - 'go'-cue
- **Contextual pre-cue**
  - 'go'-cue
- **Spatial pre-cue**
  - 'go'-cue

**Motor-Goal Latencies**
- **PMd (N = 131)**
- **PRR (N = 197)**
  - Time from onset of go-cue / s
  - % motor tuned cells

Statistical results:
- **p = 0.0023**
- **p = 0.0039**
- **p = 0.011**

Westendorff et al. 2009 (in prep.)
Context representation is more prevalent in PMd than PRR.

Westendorff et al. 2009 (in prep.)
Conclusion
Space-context integration by gain-modulation