Manual control and direct matching

Matches and mismatches between predicted and actual sensory events in control of object manipulation

Principal sensorimotor control issues in object manipulation tasks

Planning and control of hand motion and motion of objects in hand

- transport of digits & hand for grasp
- selection of grasp sites
- object transport & tool handling

Control of finger forces

- Force coordination for grasp stability
- Adaptation to object’s physical properties: e.g., weight, mass distribution, shape, surface friction...

Predictive control policies

Critical sensory information: Vision

Vision predicts and monitors terminal states of action phase controllers

Analysis of gaze fixations expose what is captured by central vision, and when, during task progression:

- Gaze position predicts spatial goals of action phases
  - Help ‘online’ guidance of hand movements (eye position signals)
- Gaze predicts and monitors goal completion of action phases
  - Visual ‘control points’ for task progression at contact events, (actual and potential)
  - Performance errors can be assessed and corrective control actions applied, if required

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Tactile afferent neurons signal mechanical outcomes of action phases and critical object properties

**Contact responses**
- Contact timing
- Contact sites (digit)
- Contact force (direction, rate)
- Friction
- Local shape at contact sites

**Mechanical transients**
- Making and breaking contact between held and other objects
- Weight information (at lift-off)

**Release responses**
- Breaking contact between a fingertip and an object

**Tactile ‘control points’ for task progression**
- Actual and predicted sensory information can be compared at contact events
- Performance errors can be assessed and control actions launched, if required

**Contact sites re. digit**
- F1
- P1
- SA
- Ruffini

**Mismatches between predicted and actual tactile sensory events bring about control actions**
- Rapid corrective actions ("smart reflexes")
  - Specific for each controller (learned together with the controller)
  - Specific for nature of sensory mismatch
  - Fast detection of sensory mismatches
- Updating of internal object representations for improved future motor commands
  - Parametric adaptation of action phase controllers
  - ‘Single trial learning'

**Similar principles applies to adaptations to objects’...**
- Shape (curvature)
- Surface friction
- Mass (weight)
- Mass distribution

**Mismatches between predicted and actual weight triggers context-specific corrective actions ("smart reflexes")**
- Fumbling during finger numbness

**Fumbling during finger numbness**
- Normal sensibility (full vision)
- Strike a match
- Acute fingertip anesthesia (full vision)

- Frequent mismatches
- Multiple ‘reckless’ corrective actions

- http://www.youtube.com/watch?v=0LfJ3M3Kn80&feature=player_embedded
Firing rates in ensembles of tactile afferents code complex contact parameters, such as object shape.

- Normal force, N
- Displacement, mm
- Instantaneous impulses (3 trials)
- Envelope of neural signals

Preferred directions of normal axis
- Directional tuning of a single afferent

Puzzling issue re. use of tactile signals in object manipulation

How can tactile information be encoded (and decoded) rapidly enough to explain its use in object manipulation?

- Traditional codes based on firing rates in afferent neurons won’t work:
  - Tactile inputs shape fingertip actions when most afferents have had time to fire only one impulse!
  - Human tactile afferents typically fire at 10–50 imp/s → estimation of firing rates takes <20 – 100 ms)

Does the timing of ‘first’ impulses (spikes) in ensembles of afferents contain important information?

Firing rates in ensembles of tactile afferents also code contact forces, including force direction.

- Directions of force stimuli
- Normal axis
- Force
- Protraction
- Retraction

Preferred directions of tangential force component
- SA-I
- Ulnar
- Proximal
- SA-II
- Radial
- Dorsal


Relative timing of first spikes in ensembles of afferents permits fast encoding of complex contact parameters.
Relative timing of first spikes in ensembles of afferents permits fast encoding of complex contact parameters.

- Substantial divergence and convergence of primary afferents onto 2nd order neurons (e.g., Cuneate neurons).
- 2nd- and higher-order neurons function as ‘conjunction detectors’.
- Dispersion of conduction velocities provides parallel (additional) processing.

Conduction velocity varies amongst afferents (~35 – 75 m/s; ~14 – 28 ms conduction delay).


How can afferent tactile information be rapidly decoded? Hypothetical role of somatosensory pathways


Learning through spike timing dependent synaptic plasticity (e.g., Markram et al., 1997)

Sensory control of object manipulation: General Summary

- Sensory action plan (Definition of sensory subgoals)
- Implementation of Action-phase controllers
- Planned sensory events
- Mismatched drive control actions
- Learning novel object representations (and controllers)

- Triggering of corrective actions (‘smart reflexes’)
- Updating & upholding object representations for improvements of future motor commands