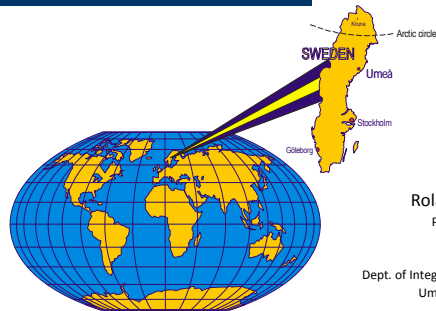


Manual control and direct matching

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



Roland S Johansson
Professor of Physiology

Dept. of Integrative Medical Biology
Umeå University, Sweden
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Principal sensorimotor control issues in object manipulation tasks

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

Control of finger forces

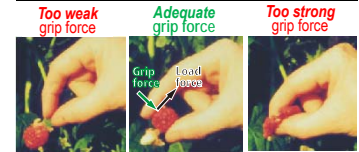
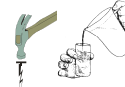
- transport of digits & hand for grasp



- selection of grasp sites



- object transport & tool handling



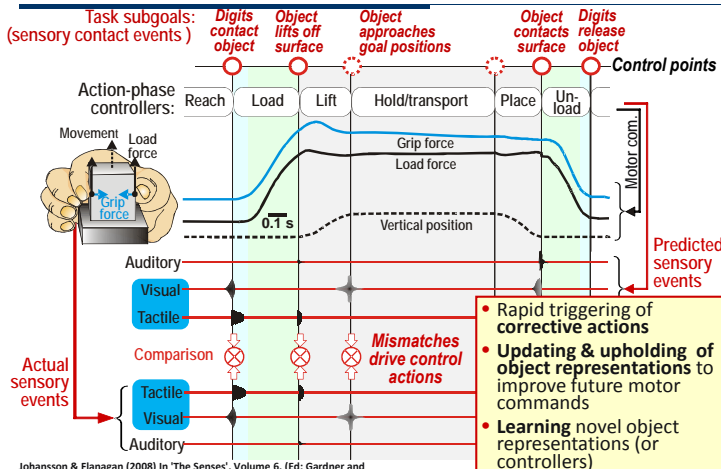
- Force coordination for grasp stability
- Adaptation to object's physical properties: e.g., weight, mass distribution, shape, surface friction ...

Predictive control policies

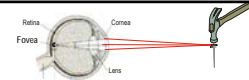
Critical sensory information:

Critical sensory information:

Manipulation is organized around sequential action phases delimited by contact events representing task subgoals

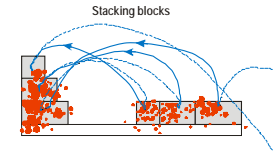


Vision predicts and monitors terminal states of action phase controllers



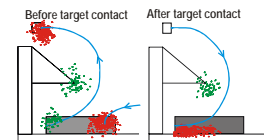
Analysis of gaze fixations expose **what** is captured by central vision, and **when**, during task progression:

- 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)

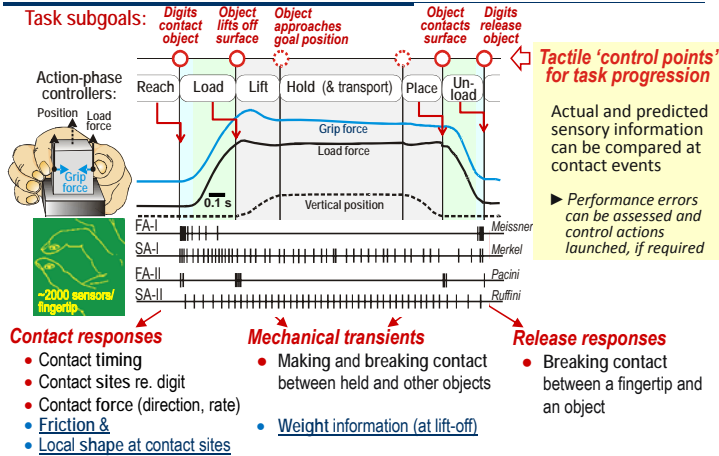
- ▶ Performance errors can be assessed and corrective control actions applied, if required



Johansson & Flanagan (2008) in 'The Senses', Volume 6, (Ed: Gardner and Kaas) Academic Press, pp 67-86.

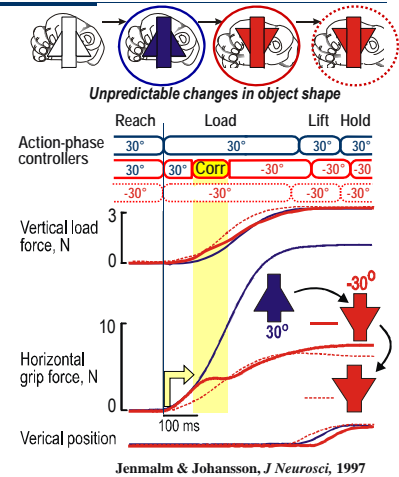
Johansson et al., *J Neurosci.* 2001; Flanagan & Johansson, *Nature*, 2003

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

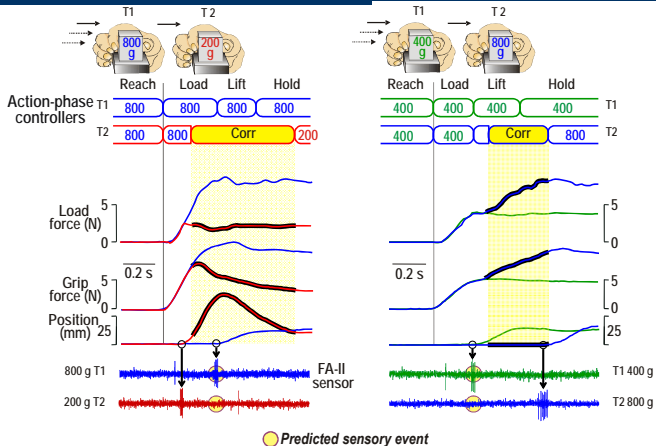


Mismatches between predicted and actual tactile sensory events bring about control actions

- 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

Strike a match

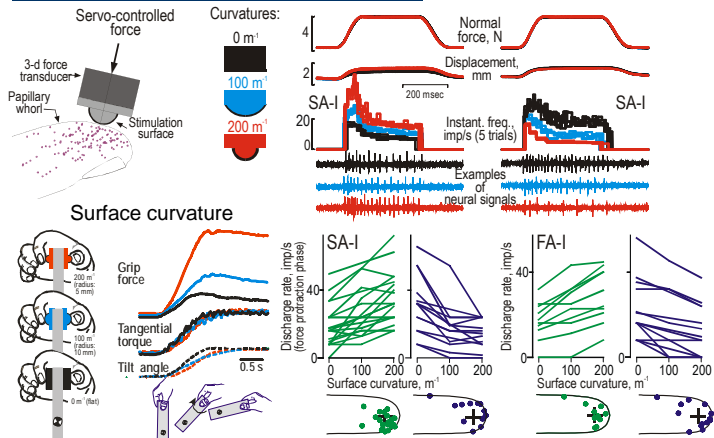
Normal sensibility (full vision) 7.5s

Acute fingertip anesthesia (full vision) 29s

Frequent mismatches
 → Multiple 'reckless' corrective actions

http://www.youtube.com/watch?v=0LfJ3M3Kn80&feature=player_embedded

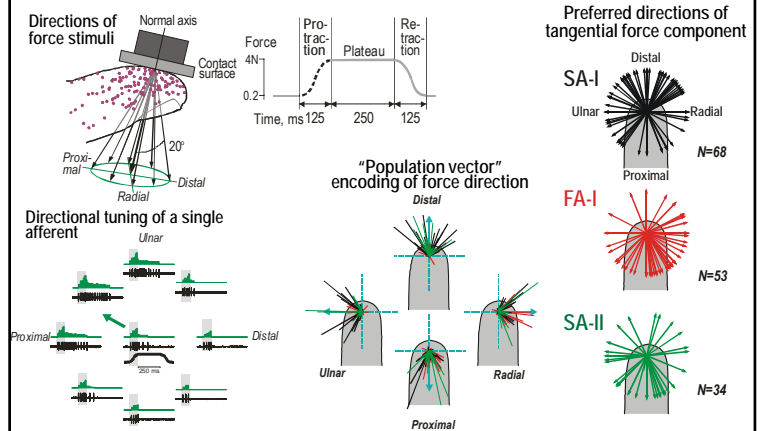
Firing rates in ensembles of tactile afferents code complex contact parameters, such as *object shape*



Goodwin et al., *J Neurosci* 1998;
Jennalm et al., *J Neurophysiol* 2000

Jennalm et al. *Europ J Neurosci* (2003)

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



Birznieks, Jennalm, Goodwin & Johansson, *J Neurosci*, 2001
Birznieks, Macefield, Westling & Johansson, *J Neurosci*, 2009

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?

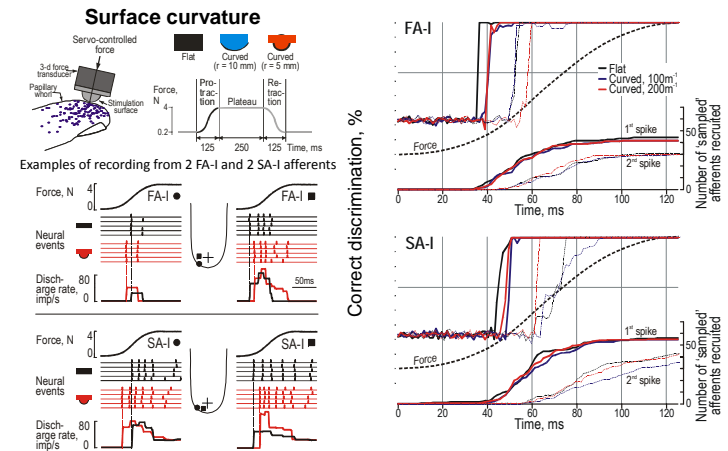
Traditional codes based on firing rates in afferent neurons won't work:

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)

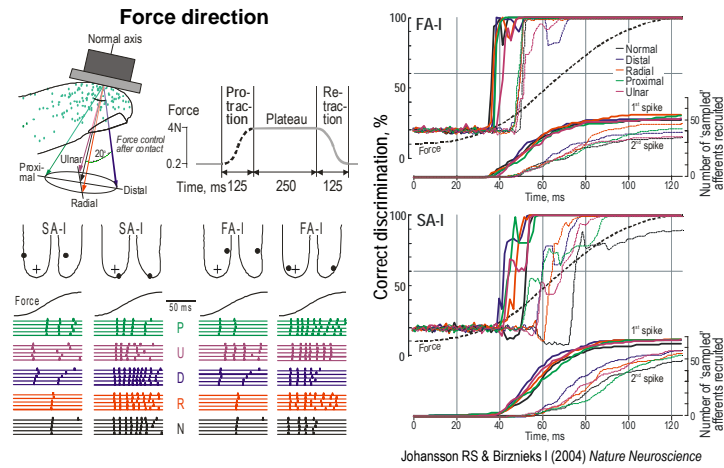
Does the **timing** of 'first' impulses (spikes) in **ensembles of afferents** contain important information?

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



Johansson & Birznieks (2004) *Nature Neuroscience*

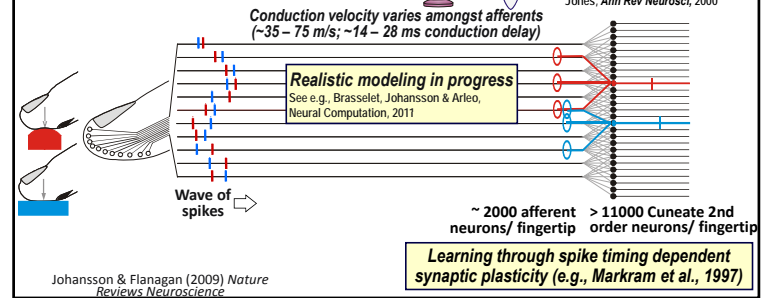
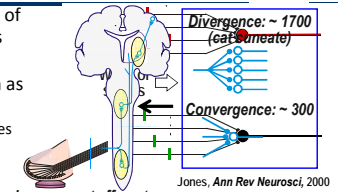
Relative timing of first spikes in ensembles of afferents permits fast encoding of complex contact parameters



How can afferent tactile information be rapidly decoded?

Hypothetical role of somatosensory pathways

- 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



Sensory control of object manipulation: General Summary

