

World Haptics, Delft
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The complexity of touch encoding in humans and applying it in tactile sensors

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Importance of touch

‘Touch is a language we understand instinctively’



Isaac Asimov’s Robot:
“Robbie’s metal skin, kept at a constant temperature of 70°F by the high resistance coils within, felt nice and comfortable”.

Mechanoreception
Thermoreception
Chemoreception

Duration

Pressure

Edges

Rough

Wet

Texture

Softness

Warm

Cool

Cold

Sticky

Hot

Calming

Exciting

Pleasant

Soothing

Unpleasant

Painful

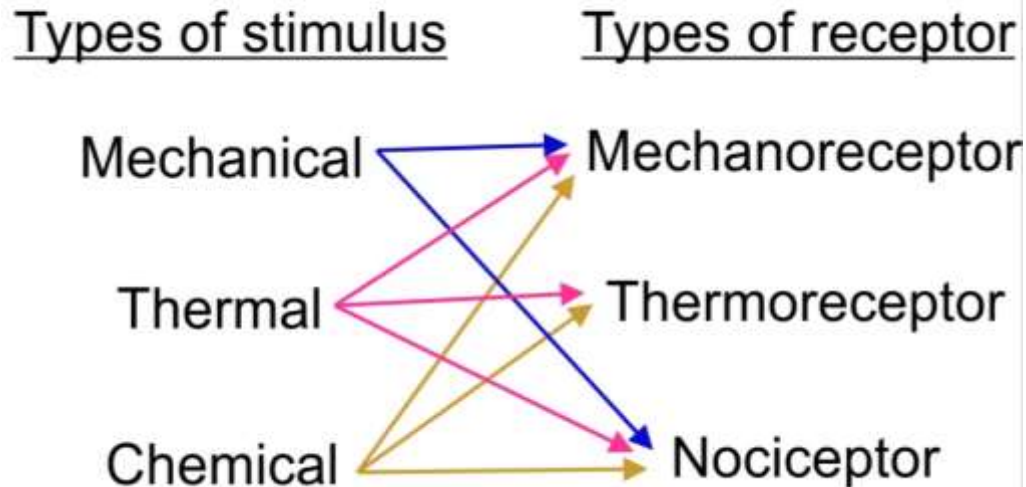
Itchy

Link between afferents and feelings

Encoding of somatosensory signals

Does not matter if it is solid, liquid or gas...

Mechanoreception Thermoreception Chemoreception



Artificial touch

How *real* can artificial touch be?

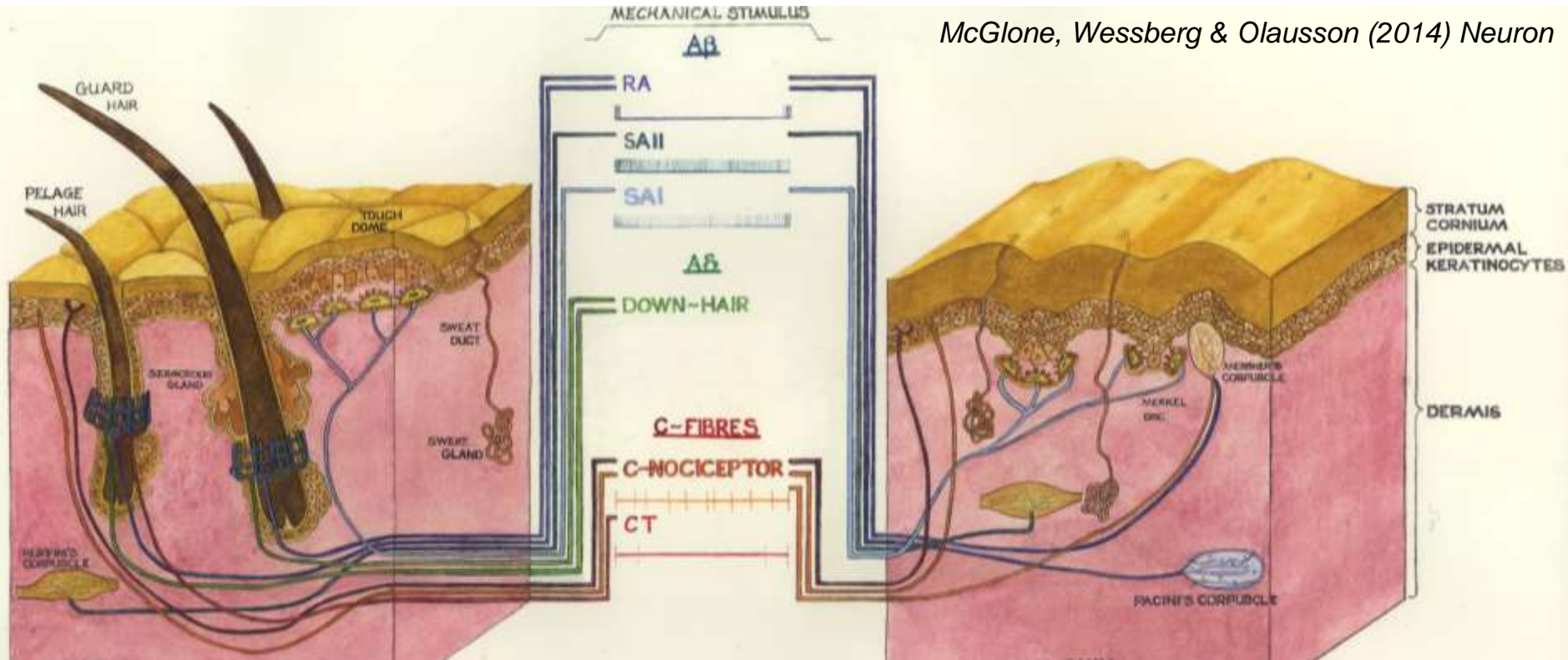
How *closely* does it need to resemble the biology to be useful or convey complex messages?

Realistic artificial feedback:

- **Mechanical signals**
- **Thermal signals**
- Nociceptive signals

Mechanoreceptors in the skin

McGlone, Wessberg & Olausson (2014) Neuron


















Hairy skin

Glabrous skin



Low-threshold mechanoreceptive afferents

Response to long-lasting indentation	Unit type	Receptive field in:		Characteristics
		Glabrous skin	Hairy skin	
	FA1		(Not present)	Small, sharp receptive field Density highest in finger tips
	FA2			Large receptive field Sensitive to vibration
	SA1			Small, sharp receptive field Irregular firing to indentation
	SA2			Often spontaneous firing Regular firing to indentation
	Hair	(Not present)		One unit consists of ~20 hairs Sensitive to movement of hairs
	Field	(Not present)		Large, irregular receptive field with high-sensitivity spots

+ C-tactile (CT)
unmyelinated
afferents


Innocuous touch + temperature

- ▶ With touch comes temperature
 - ▶ **Neutral** – little sense of temperature, as similar to skin temperature (28-34°C)
 - ▶ **Increase** – warm, hot, painful
burning, hairy, dry, cosy, rough, scratchy, dirty, sticky
 - ▶ **Decrease** – cool, cold, painful
wet, slippery, smooth, numb, fresh, clean
- ▶ Temperature can:
 - ▶ Modify touch
 - ▶ Add an affective component to touch



Thermoreceptors in human skin

Class	Type	Preferred stimulus
Thermoreceptor	A δ cool	Touch and cooling
Thermoreceptor	C-cold	Cold $\sim 20^{\circ}\text{C}$; spontaneous from $\sim 30^{\circ}\text{C}$, respond down to 0°C Changes in temperature
Thermoreceptor	C-warm (?)	Low threshold $\sim 30\text{-}40^{\circ}\text{C}$ High threshold $>38^{\circ}\text{C}$
Nociceptor	A δ hot	Noxious touch/temperature
Nociceptor	C-mechano-heat	Touch with heat ($\sim 40^{\circ}\text{C}$)
Nociceptor	C-mechano-heat-cold	Touch with heat ($\sim 40^{\circ}\text{C}$) or cold ($<20^{\circ}\text{C}$)

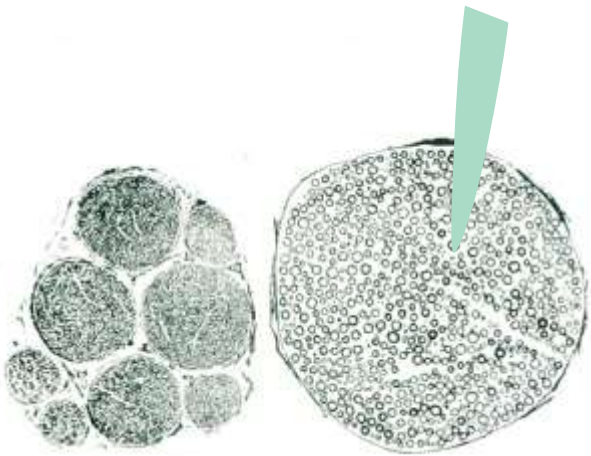
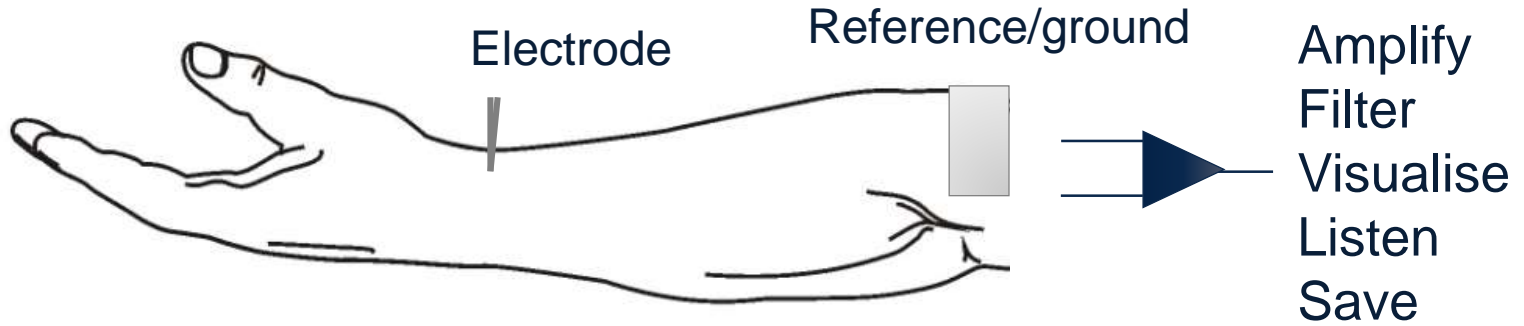
Adriaensen et al (1983) J Neurophysiol
Ackerley & Watkins (2018) J Neurophysiol



Microneurography :
Recording from
single afferents in humans



Microneurography

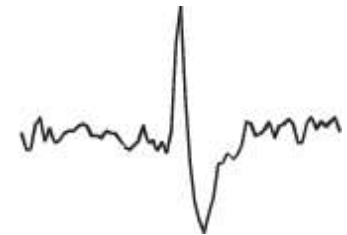


Myelinated SA1 afferent



Touch

Nerve spike



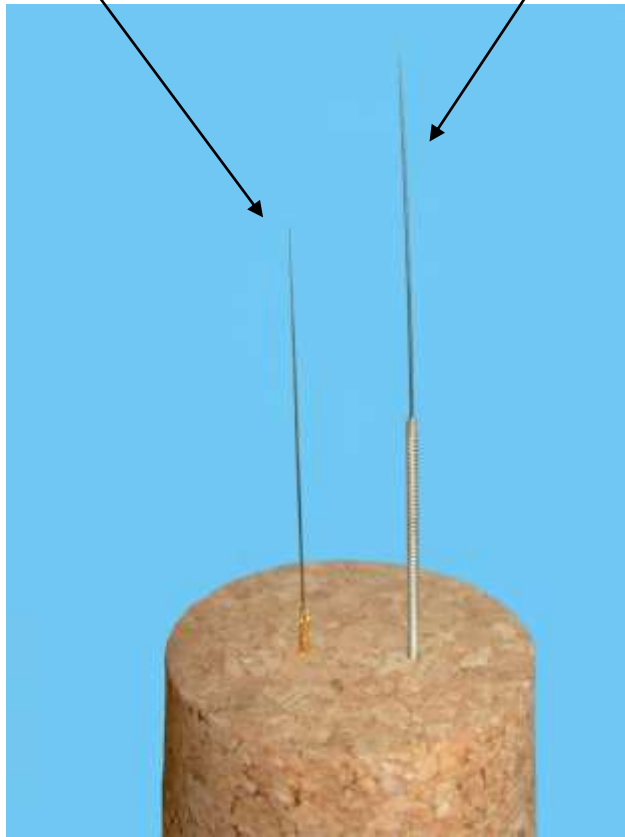
1 ms



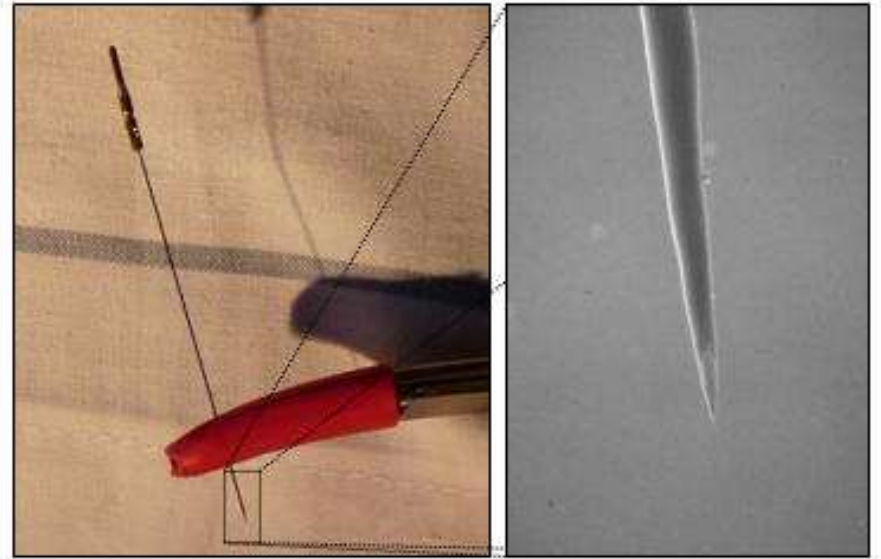
Electrodes

Microneurography

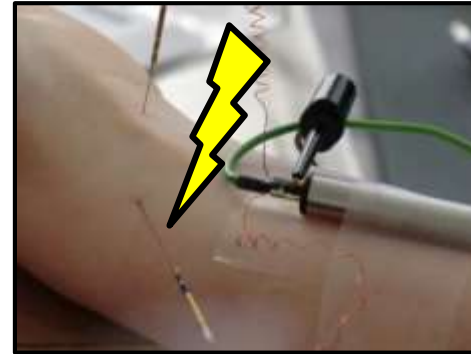
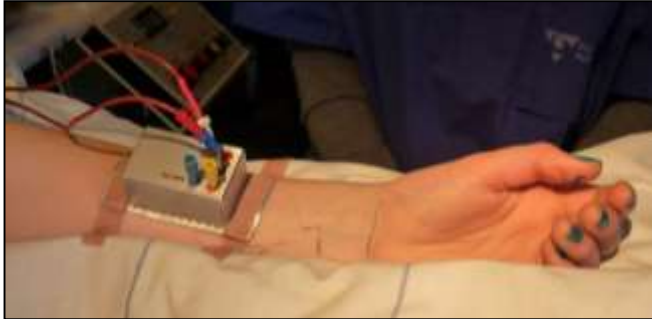
Acupuncture



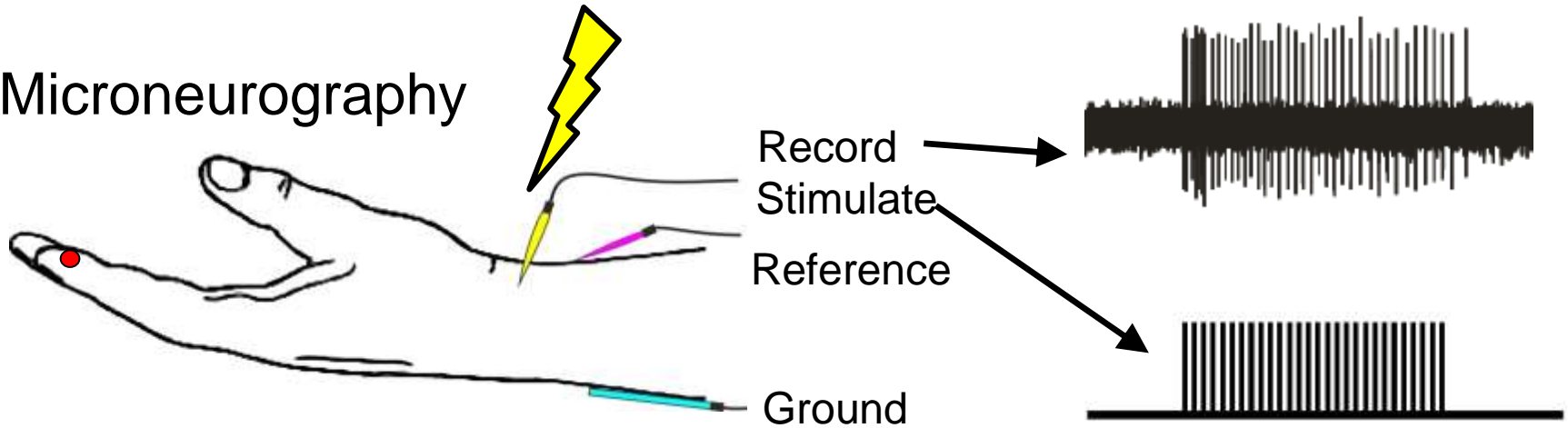
Coated tungsten
0.2 mm diameter
Electrode tip $\sim 5 \mu\text{m}$
 $\sim 300\text{-}500 \text{ k}\Omega$ impedance



Microstimulation



Microneurography



Does the projected sensory field match the receptive field?

Touch

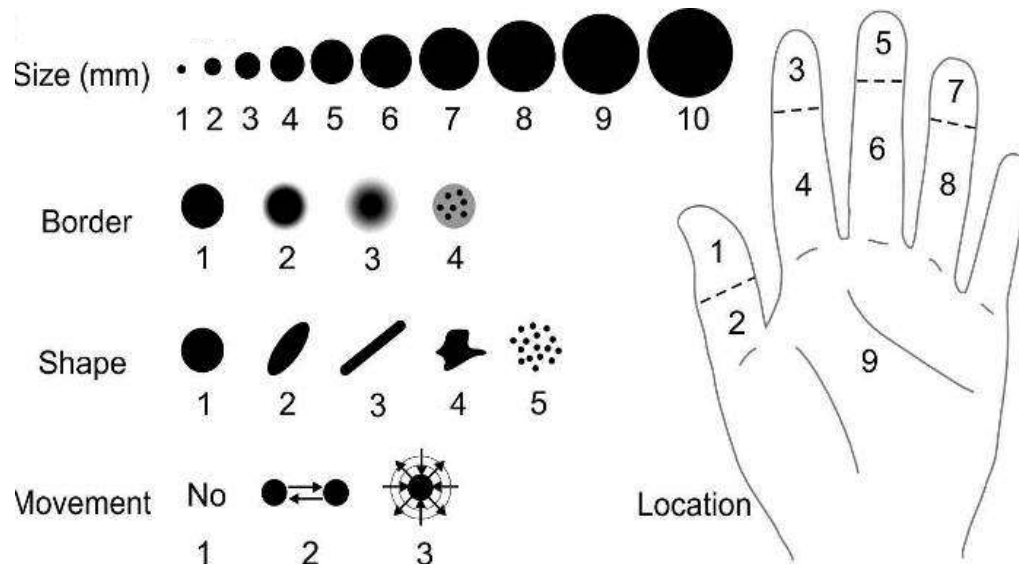


- Glabrous skin (e.g. hands) suited to convey **discriminative** touch *Ackerley et al. (2014a) Front Neurosci*
- Hand contains ~17 000 mechanoreceptors
- Mechanoreceptors are most dense at the fingertip
- Humans use more **sensory** language for touch on glabrous skin e.g. hard, rough, smooth, cold
Ackerley et al. (2014b) Front Neurosci
- Of interest to investigate discriminative touch input
- how we sense **shape, texture, stickiness**
- **Investigate “quantal touch”**
– ***stimulate single mechanoreceptive afferents...***

Microstimulation

Does activity in a single afferent reach consciousness?

~handful of research papers on single unit microstimulation



Stimulate electrically
(~3 μ A, 60 Hz, 1s)
note sensations

Vallbo et al (1984) Brain

Sensations generated from microstimulation

Quantify artificial projected sensations

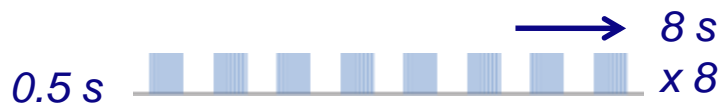
Type	N	Size	Shape	Border	Sensations felt
FA1 Meissner	125	2 mm	Oval	Slightly sharp	Small point of vibration, pricking, tingle
SA1 Merkel	90	2 mm	Round	Slightly sharp	Pulling, small point of pressure
FA2 Pacini	14	6 mm	Oval	Slightly diffuse	Larger area of touch sensation, intense vibration
SA2 Ruffini	21	8 mm	Oval	Slightly diffuse	Natural pushing sensation*

Total n = 250 units

*Sanchez-Panchuelo, Ackerley et al (2016) eLife, O'Neill et al (2019) NeuroImage, *Watkins et al (2022) J Physiol, Ackerley et al (in prep)*

Microstimulation at 7T fMRI

- Characterise afferent
- Test sensation
- Into 7T scanner
- Electrical stimulation
- Vibrotactile stimulation

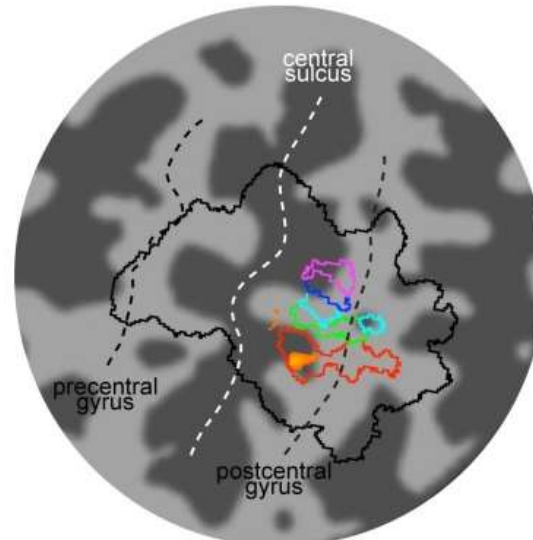
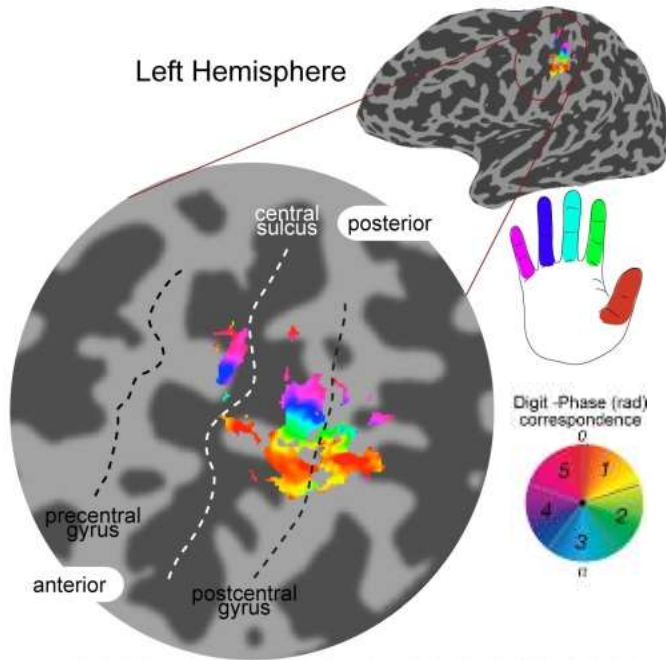


Link events at the periphery
with central interpretation

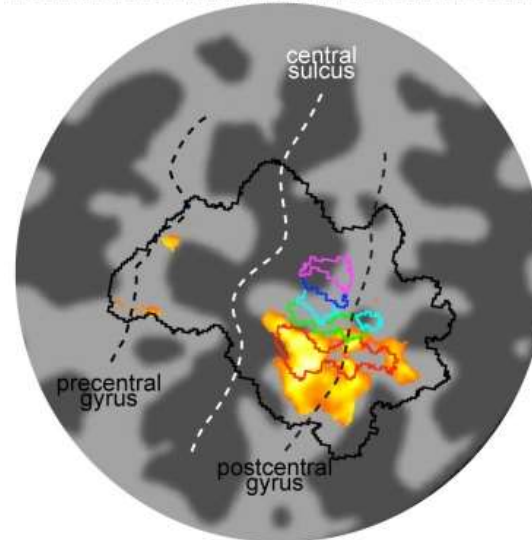
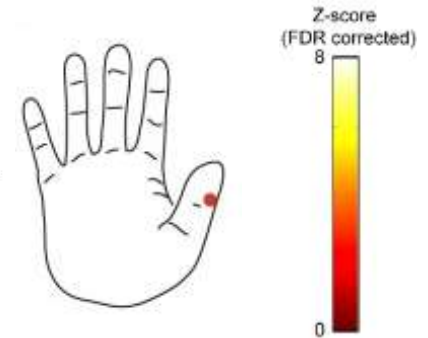
Equipment: Glover et al (2017) *J Neurosci Meth*

Microstimulation S1

Point-vibration over finger tips



Microstimulation of unit

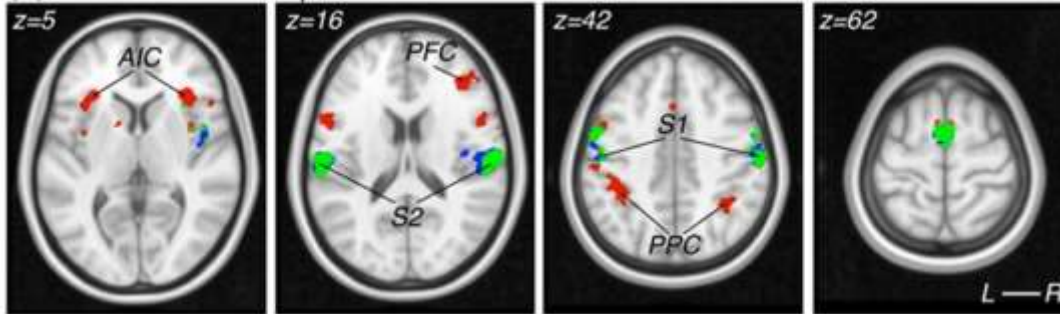


Point-vibration at site of unit

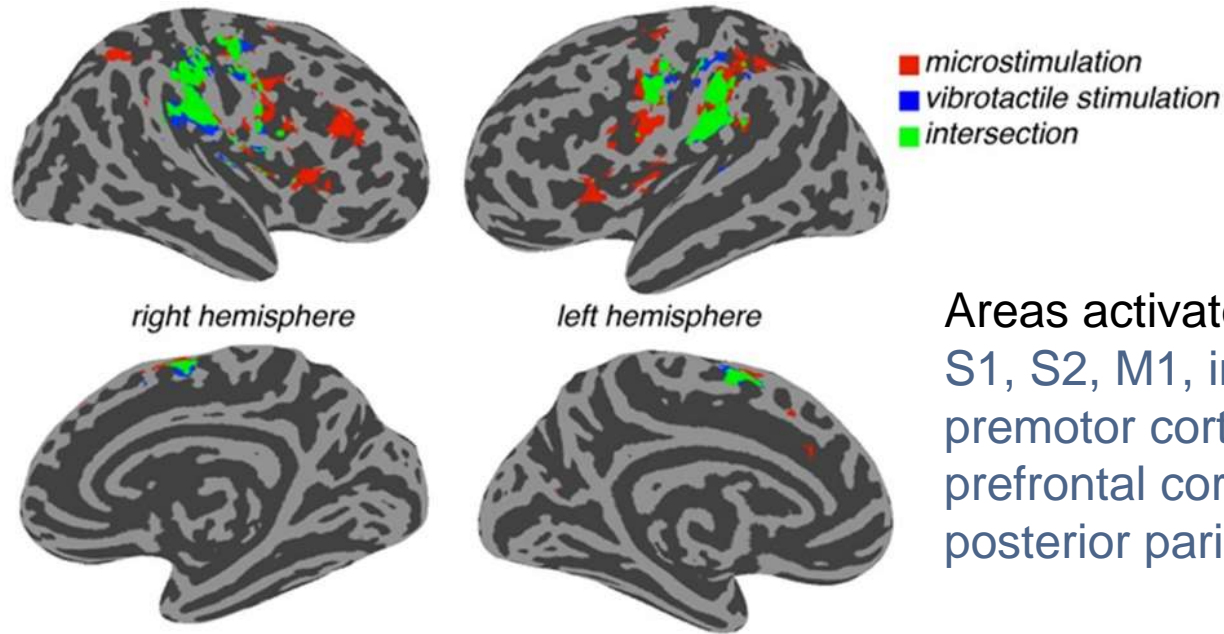
Sanchez-Panchuelo, Ackerley et al. (2016) eLife

Regions activated in touch and microstimulation

(a) Activations in MNI space

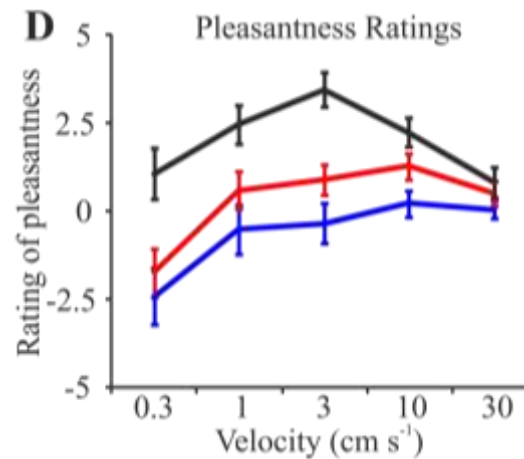
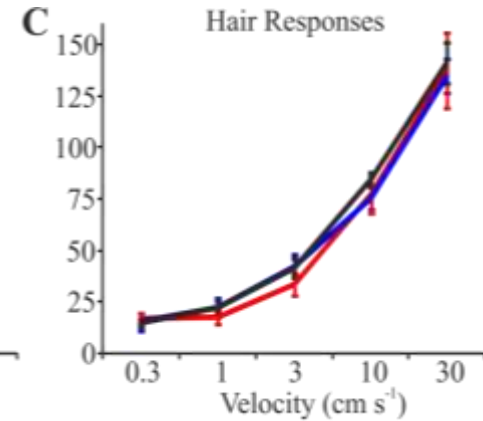
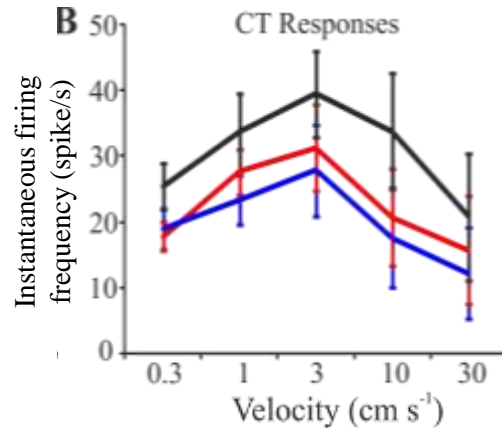
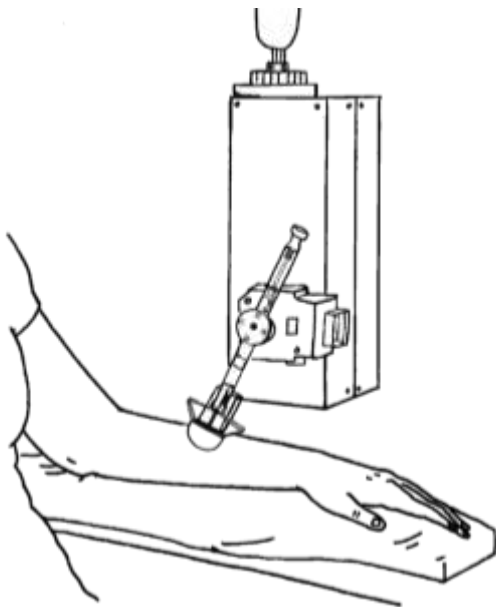


FA1 responses, $n = 8$



Sanchez-Panchuelo, Ackerley et al. (2016) eLife

C-tactile (CT) optimal responses



Stroking temperature

● Cool 18°C

● Neutral 32°C

● Warm 42°C

Preferential responses to the **speed** and **temperature** of touch

Ackerley et al. (2014) J Neurosci

Conclusions



▶ Single afferent microstimulation

- ▶ You can **feel** a single mechanoreceptor
- ▶ Inherent differences between mechanoreceptor types
- ▶ Network of brain areas involved in the most basic touch

▶ Facilitate artificial dexterous manipulation

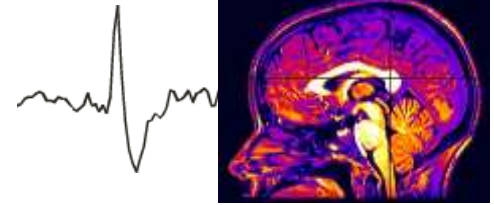
- ▶ Subtle signals are important (e.g. slip) – large force encoding range
- ▶ **Thermal signals** – much smaller thermal encoding range
- ▶ Congruence with multisensory signals (e.g. audition)

▶ Considerations

- ▶ Need to consider firing from different types of afferent
- ▶ A lack of firing is also important (absence of signal)
- ▶ How real does artificial touch **need** to be?



Thank you



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Dept of Physics & Astronomy, University of Nottingham, UK


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