Sensorimotor Neuroscience, Psychophysics and Our work

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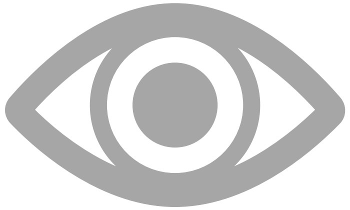
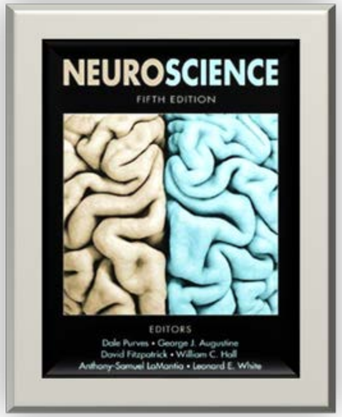
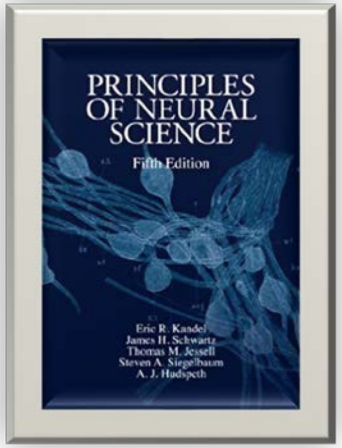


Neuroscience
(just the touch sensory part)

Psychophysics
(just the tactile perception)





Neuroscience

(just the touch sensory part)

What is touch ?

Active touching, or haptics, involves the interpretation of complex spaciotemporal patterns of stimuli that are likely to activate many classes of mechanoreceptors.

Neuroscience – 5th Edition

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Neuroscience – 5th Edition

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Active touching, or haptics, involves the interpretation of complex spaciotemporal patterns of stimuli that are likely to activate many classes of **mechanoreceptors**.

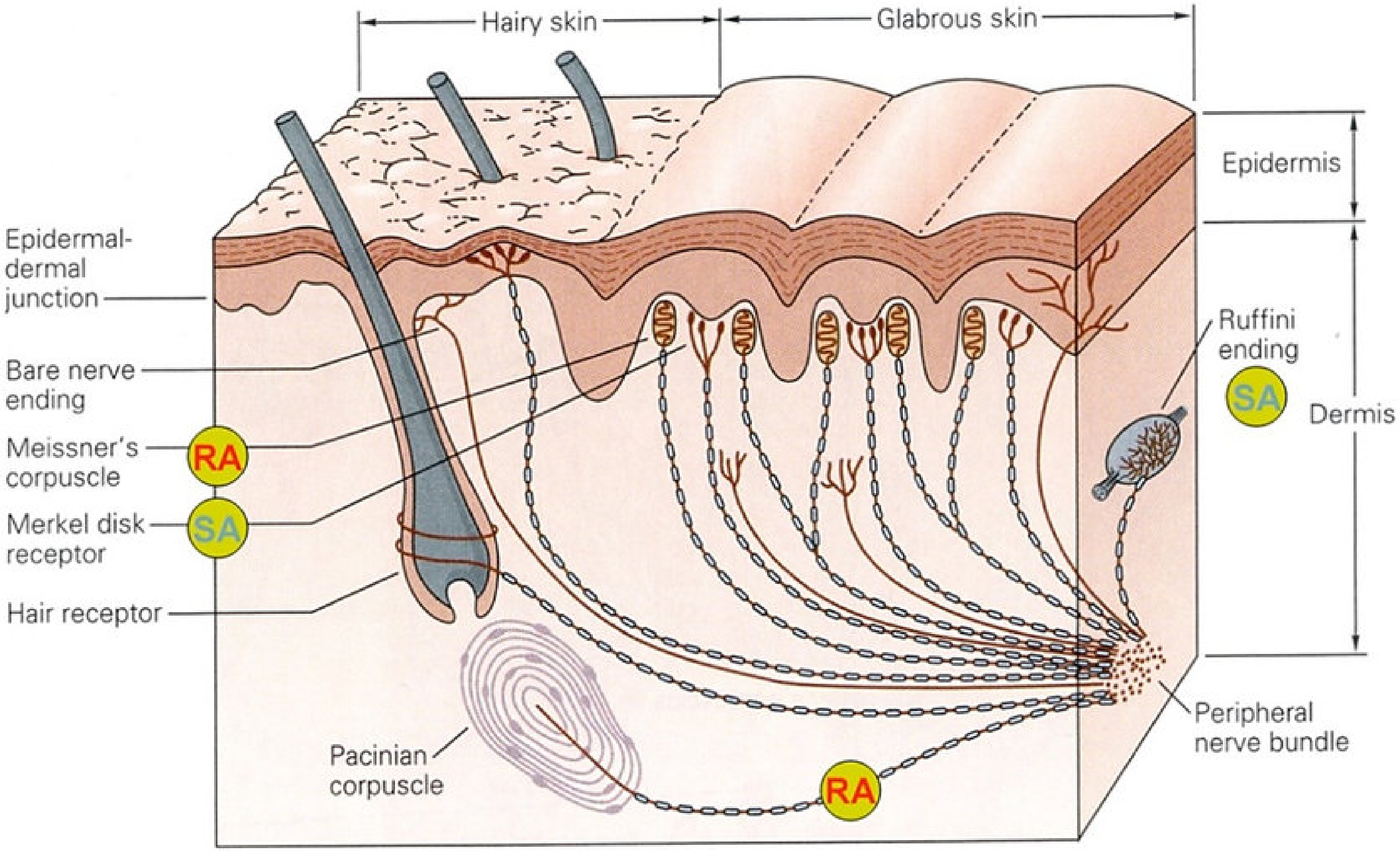
Neuroscience – 5th Edition

Understanding Touch

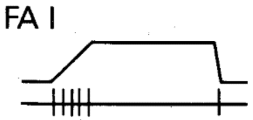
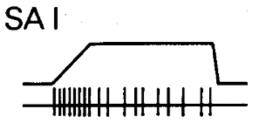
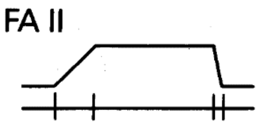
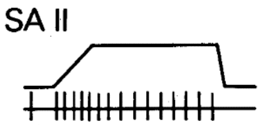
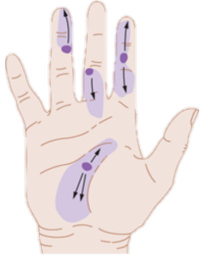
- Many (classes of mechanoreceptors)
- Activate (Activation characteristics)
- Spacious (how are they distributed)
- Temporal (their adaption speed)

What are mechanoreceptors ?

A **mechanoreceptor** is a sensory receptor that responds to mechanical pressure or distortion. Normally there are four main types in glabrous mammalian skin

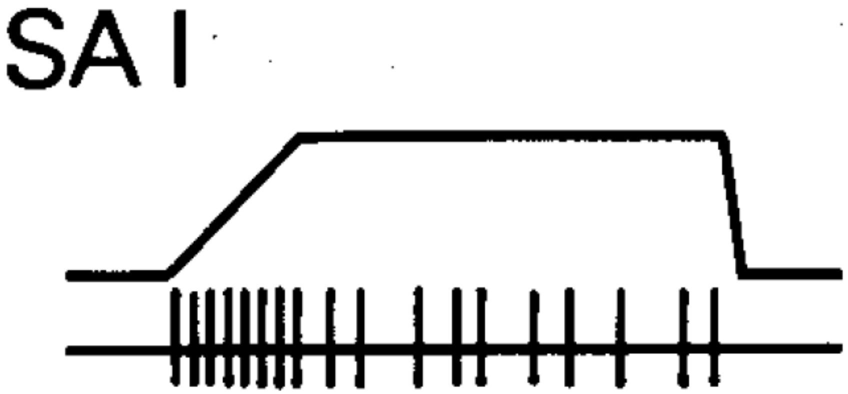

Hairy skin
Glabrous skin
Epidermis
Dermis
Epidermal-
dermal
junction
Bare nerve
ending
Meissner's
corpuscle
RA
Merkel disk
receptor
SA
Hair receptor
Ruffini
ending
SA
Pacinian
corpuscle
RA
Peripheral
nerve bundle

Classes of Mechanoreceptors

		ADAPTATION			
		FAST No static response	SLOW With static response		
RECEPTIVE FIELDS	Small, sharp borders 	FAI – Meissner (43%)  Edge sensitive	SAI – Merkel (25%)  Edge sensitive		INNERVATION DENSITY
	Large, Obscure borders 	FAII – Pacinian (13%) 	SAII – Ruffini (19%)  Sensitive to lateral skin stretch		

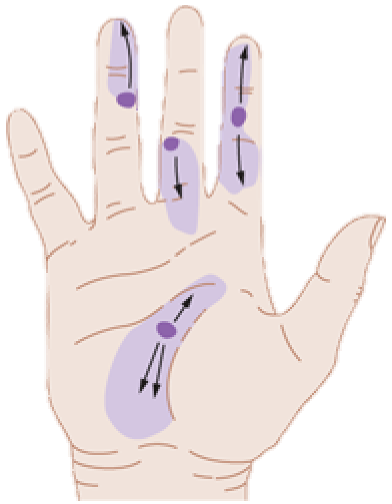
Slow Adapting I – Merkel Cells

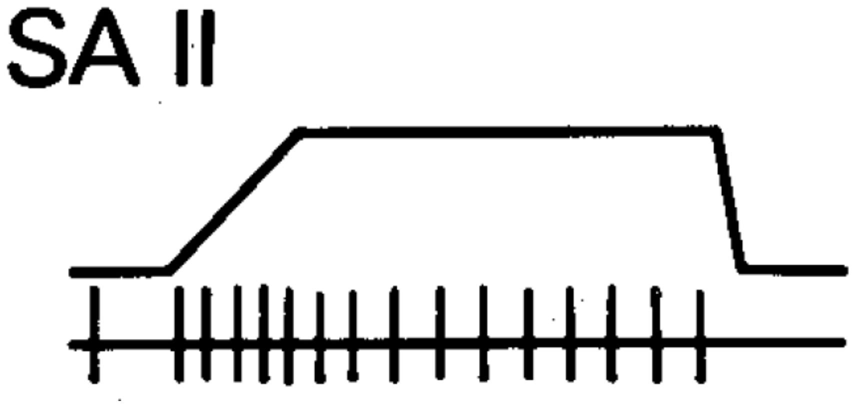
- Irregular discharge when stimulated.
- Highly sensitive to edges and curvature.
- Moderately low threshold (30 µm)



Slow Adapting II – Ruffini Endings

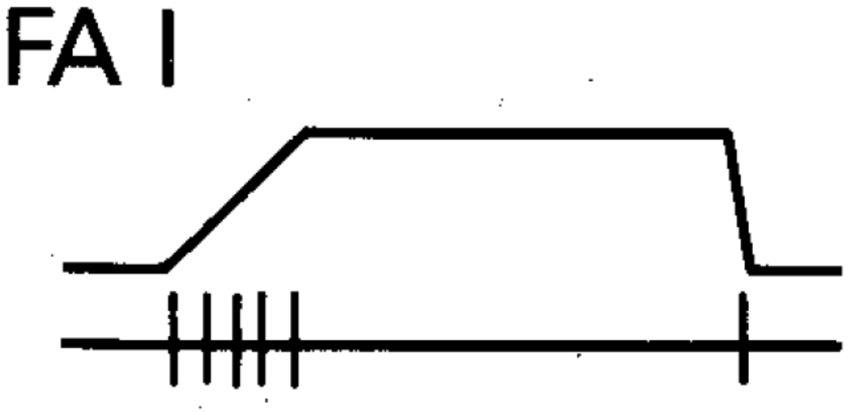
- Regular discharge when stimulated.
- Very sensitive to lateral skin stretch.
- High threshold to indentation (300 μm).
- *Not in non-human primates.





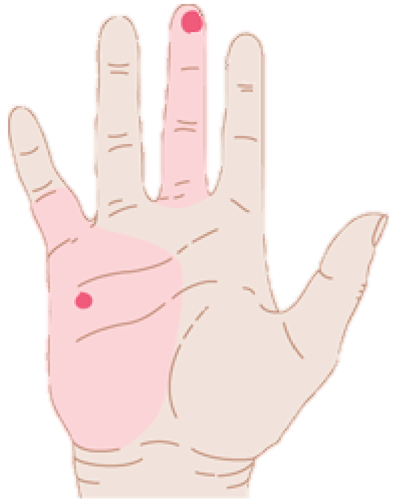
Fast Adapting I – Meissner Corpuscles

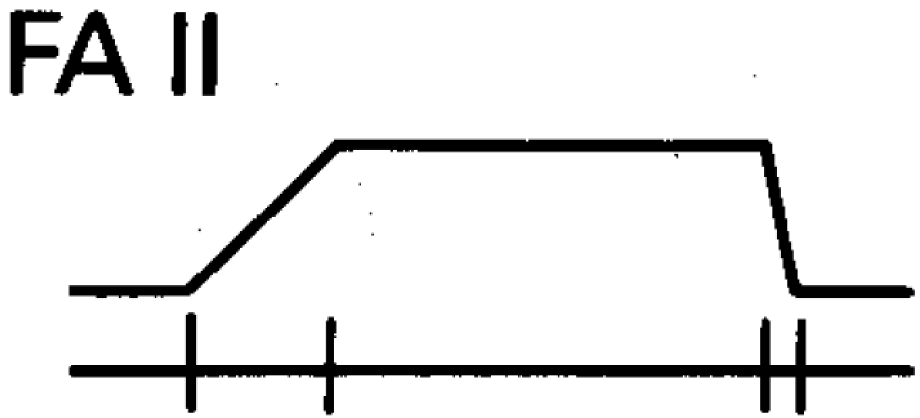
- Codes for velocity of skin indentation and motion across the skin.
- About 40% of innervation in the hand.
- Sensitive to low frequency vibration (~ 40-50 Hz).
- Low threshold (6 µm).



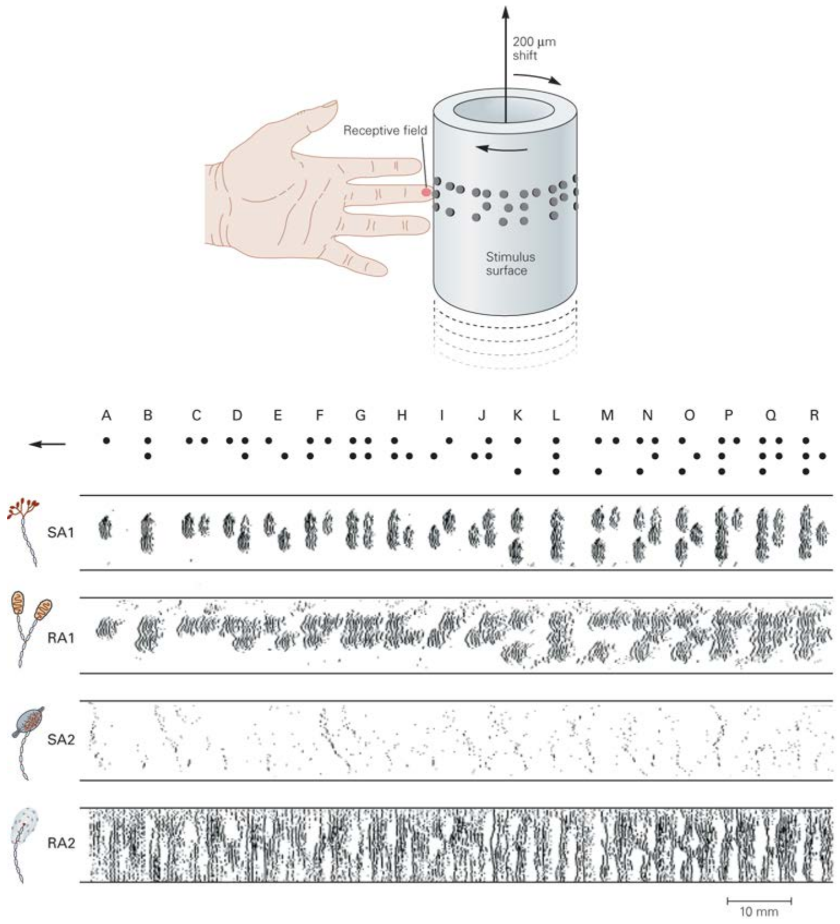
Fast Adapting II – Pacinian Corpuscles

- Codes for acceleration - change in indentation rate.
- Picks up high frequencies (300-400 Hz).
- Extremely low threshold (0.08 μm!!)



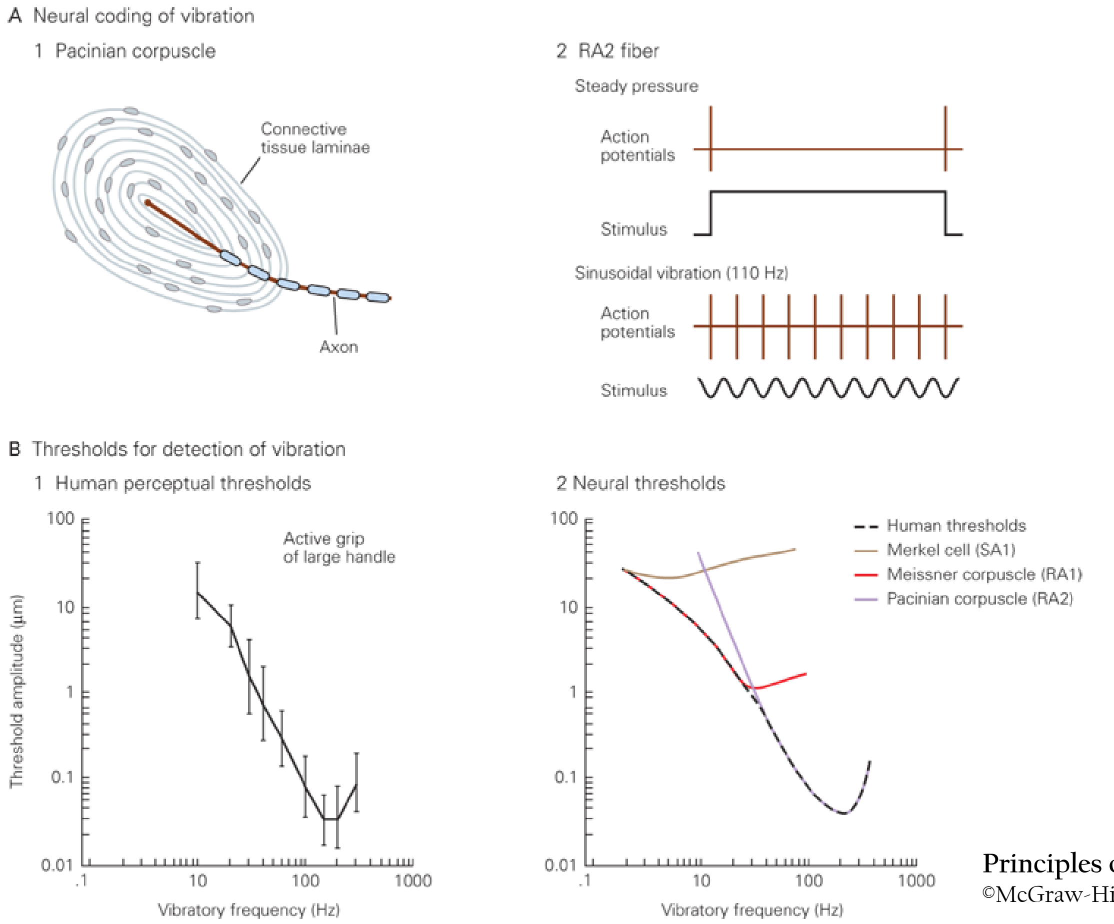


Combined Activation



Principles of Neural Science 5e, Chapter 23 Figure 6

Activation: Frequency Response



Principles of Neural Science 5e, Chapter 23 Figure 8

Receptive Field

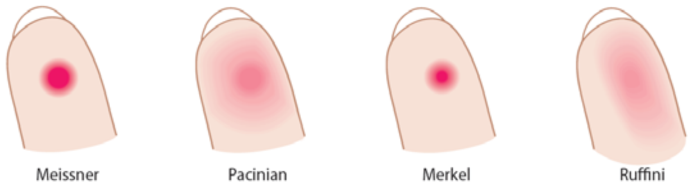


Fig. 1. The receptive field of different class of mechanoreceptors, this image shows the relative area in which the mechanoreceptor gets activated[4]

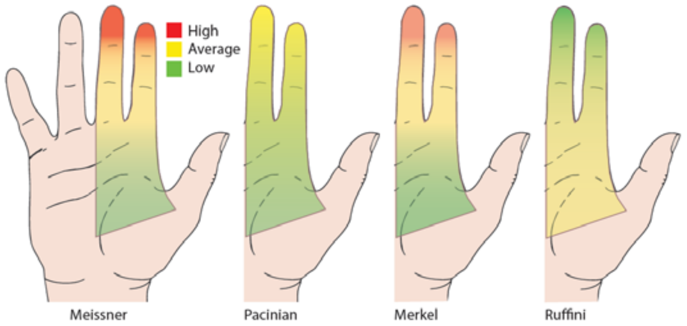


Fig. 2. A representative heatmap[5] showing the distribution of relative densities of the different types of mechanoreceptors within the volar region of the hand[6].

A Neuroscience-based Classification of Wearable Haptic Systems for the Fingertip and the Hand
World Haptics 2019 (Submission)

Functional Roles of Different Receptors

SA1 Merkel

Edges, curvature, & texture

FA1 Meissner

Motion detection & grip control

SA2 Ruffini

Skin stretch

FA2 Pacinian

Feeling through objects, perception of fine texture

Summary

TABLE 9.2 ■ Afferent Systems and Their Properties

	Small receptive field		Large receptive field	
	Merkel	**Meissner**	**Pacinian**	**Ruffini**
Location	Tip of epidermal sweat ridges	Dermal papillae (close to skin surface)	Dermis and deeper tissues	Dermis
Axon diameter	7–11 μm	6–12 μm	6–12 μm	6–12 μm
Conduction velocity	40–65 m/s	35–70 m/s	35–70 m/s	35–70 m/s
Sensory function	Shape and texture perception	Motion detection; grip control	Perception of distant events through transmitted vibrations; tool use	Tangential force; hand shape; motion direction
Effective stimuli	Edges, points, corners, curvature	Skin motion	Vibration	Skin stretch
Receptive field area[a]	9 mm^2	22 mm^2	Entire finger or hand	60 mm^2
Innervation density (finger pad)	100/cm^2	150/cm^2	20/cm^2	10/cm^2
Spatial acuity	0.5 mm	3 mm	10+ mm	7+ mm
Response to sustained indentation	Sustained (slow adaptation)	None (rapid adaptation)	None (rapid adaptation)	Sustained (slow adaptation)
Frequency range	0–100 Hz	1–300 Hz	5–1000 Hz	0–? Hz
Peak sensitivity	5 Hz	50 Hz	200 Hz	0.5 Hz
Threshold for rapid indentation or vibration:				
Best	8 μm	2 μm	0.01μm	40 μm
Mean	30 μm	6 μm	0.08 μm	300 μm

[a]Receptive field areas as measured with rapid 0.5-mm indentation.

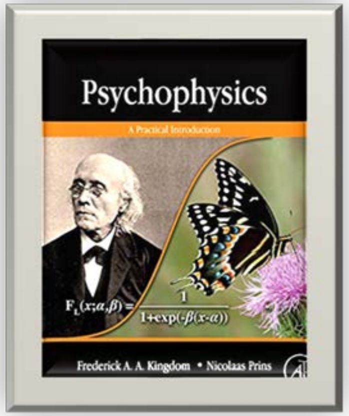
(After K. O. Johnson, 2002.)

NEUROSCIENCE 6e, Table 9.2

VWF Syndrome (Scary Slide)

- Another way ***peripheral neuropathy*** can occur is through exposure to <u>high levels of vibration for extended periods of time</u> (e.g., jack-hammer operator, etc.), a syndrome called **Vibration White Finger**.

Psychophysics



What is Psychophysics

A subdiscipline of psychology dealing with the relationship between physical stimuli and their subjective correlates, or percepts

History and Why

"psychophysics" was coined by Gustav Theodor Fechner in 1860

made to connect physical stimuli to the different components of consciousness, particularly **sensation**.

Human senses, nearly all, work in a manner and obey Weber–Fetcher law, that response of the sense machinery is logarithm of an input.

Psychophysics is a framework or methodology to develop **objective** measures of any sensory (human) system

Okamoto, Shogo, Hikaru Nagano, and Yoji Yamada. "**Psychophysical dimensions of tactile perception of textures.**" IEEE Transactions on Haptics 6.1 (2013): 81-93.

Reference Table of Studies on Perceptual Dimensions of Tactile Textures

Author	Year	Texture	Dimension 1	Dimension 2	Dimension 3	Dimension 4	Modality
Yoshida [8]	1968	25 materials	Hard/soft, Cold/warm, Rough/smooth	Moist/dry, Smooth/rough	Hard/soft		Visuo-hapt.
Lyne [18]	1984	8 tissues & paper towels	Hard/soft	Embossed (Roughness)			Visuo-hapt.
Hollins [20]	1993	17 materials	Rough/smooth, Warm/cold, Sticky/slippery,	Hard/soft	Not specified (Stiff)		Haptic
Hollins [19]	2000	17 materials	Rough/smooth	Hard/soft	Sticky/slippery		Haptic
Tamura [13]	2000	15 materials	Rough/smooth Hard/soft	Warm/cold	Moist/dry		Unknown
Picard [21]	2003	24 car seats	Hard/soft, Rough (Fine roughness)	Relief (Macro roughness)	Hard/soft		Haptic
Picard [25]	2004	40 fabrics	Hard/soft	Rough/smooth			Haptic
Soufflet [27]	2004	26 fabrics	Rough/smooth Hard/soft	Warm/cold			Haptic
Ballesteros [22], [24]	2005	20 materials	Rough/smooth	Hard/soft	Slippery/sticky		Haptic
Shirado [12]	2005	20 materials	Rough/smooth	Cold/warm	Moist/dry	Hard/soft	Haptic
Gescheider [28]	2005	7 raised dots	Macro roughness	Rough/smooth	Fine roughness		Unknown
Bergmann Tiest [23]	2006	124 materials	Hard/soft	Smooth/rough	Not named	Not named	Haptic
Tanaka [11]	2006	13 fabrics	Moist/dry, Rough/smooth	Hard/soft, Cold/warm			Haptic
Yoshioka [15]	2007	16 materials	Hard/soft	Rough/smooth	Sticky/slippery		Haptic
Summers [29]	2008	10 papers	Rough/smooth				Haptic
Guest [30]	2011	15 fluids	Slippery/sticky	Rough/smooth	Oily		Haptic
Guest [26]	2011	5 fabrics	Rough/smooth	Moist/dry	Hard/soft		Haptic

Okamoto et.al’s

Five Dimensions

HARDNESS (HARD / SOFT)

WARMNESS (WARM / COLD)

FRICTION (MOIST/DRY, STICKY SLIPPERY)

FINE ROUGHNESS (ROUGH/SMOOTH)

MACRO ROUGHNESS (UNEVEN, RELIEF)

ROUGHNESS

Our Work





George, S.Z., Khosravi, H., Peters, R., Oehlberg, L., & Chan, S. (2019). **Improving Texture Discrimination in Virtual Tasks by using Stochastic Resonance.** *CHI'19 Extended Abstracts* https://doi.org/10.1145/3290607.3312839

Stochastic Resonance

Stochastic Resonance is a phenomenon in sensory systems, where adding the right amount of noise to a signal can enhance the signal-to-noise ratio, such that a weak signal becomes detectable

Premise

It's been found that SR works for real-world texture discrimination, so it should potentially work for enhancing virtual texture discrimination.

Step 1

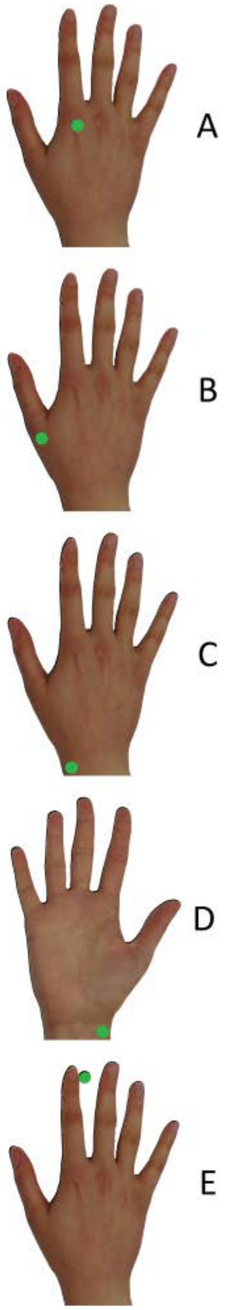


Figure 2: Hand mount points for five SR actuators, adapted from Enders et al. [5]

Step 2

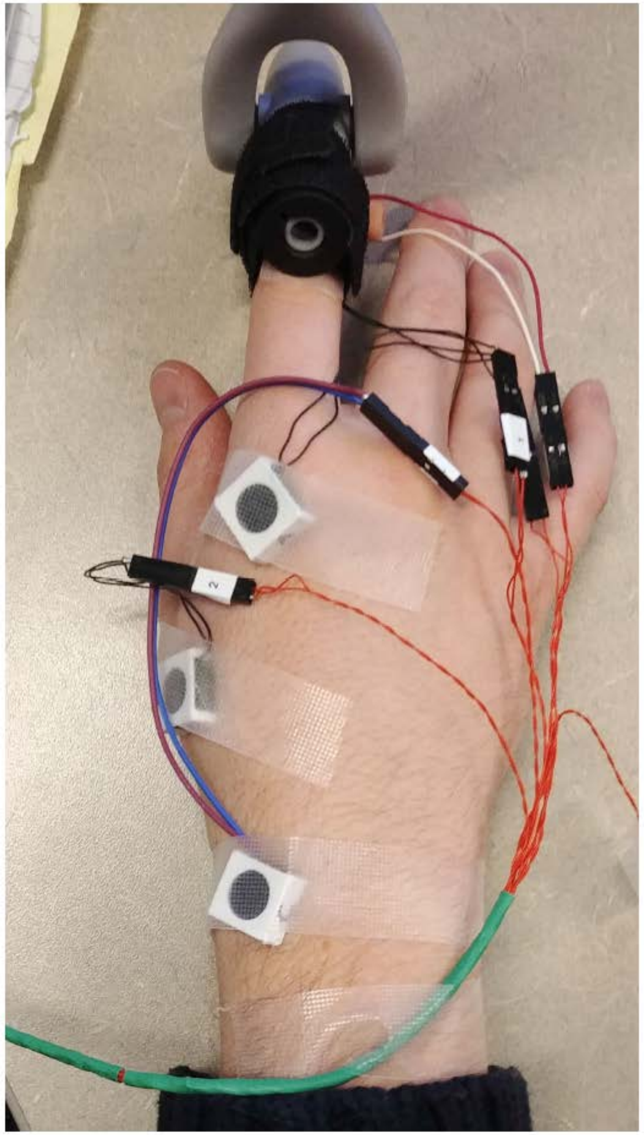


Figure 1: SR actuators are mounted on five points on a participant's dominant hand.

Step 3

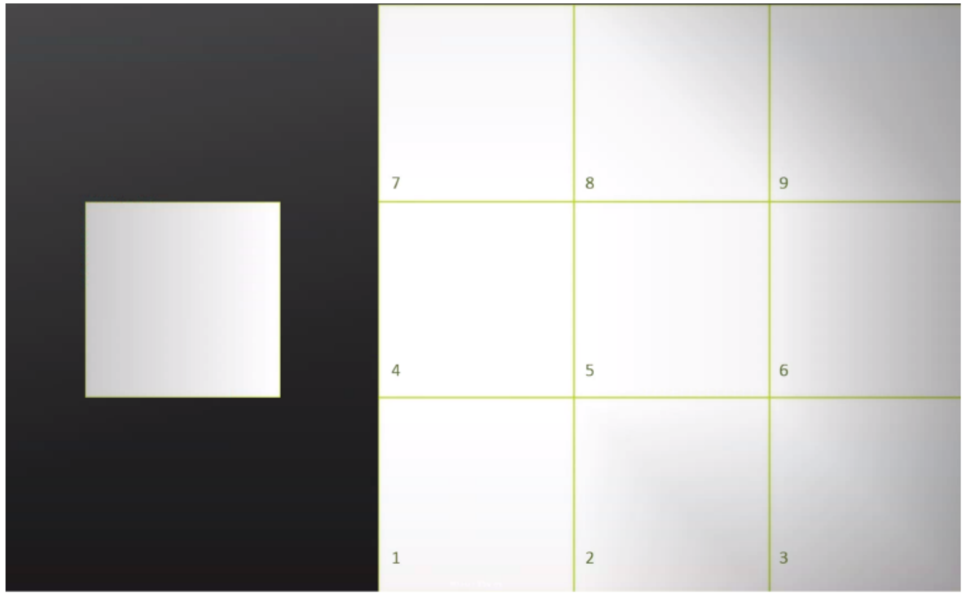


Figure 3: The texture discrimination task interface, which shows a $3x3$ layout of textures (right) ordered from bottom-up / left-right order from $P40$ to $P320$ along with the test surface (left).

Step 4

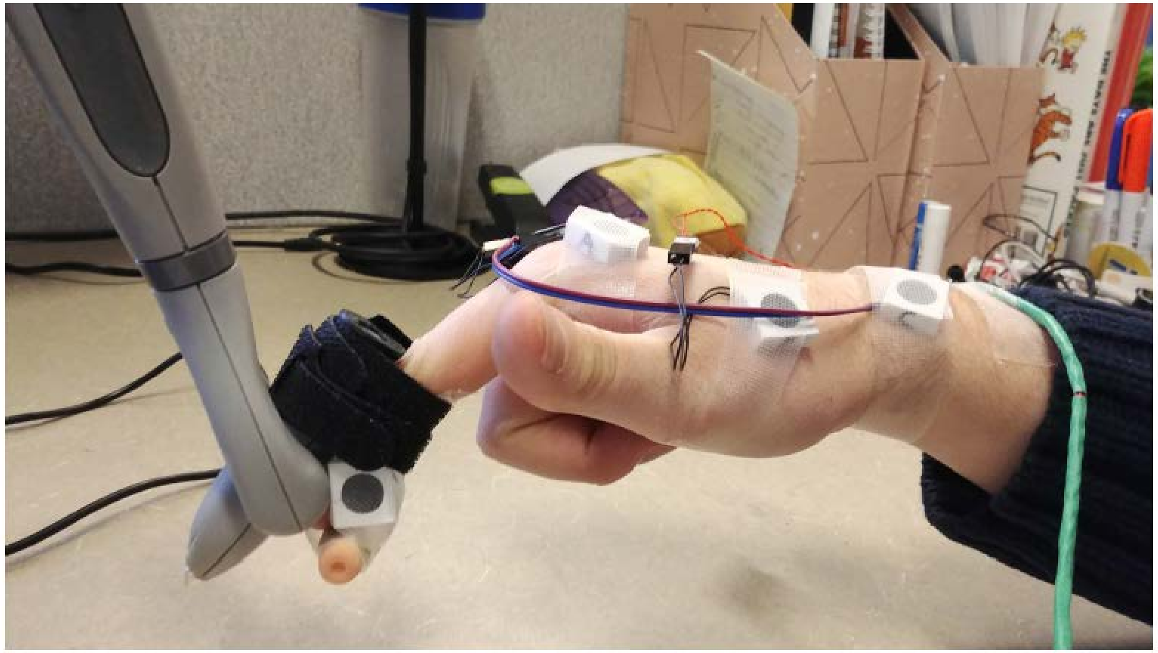


Figure 4: The *MM3C* is mounted on the fingertip along with SR actuators on the hand.

Step 5

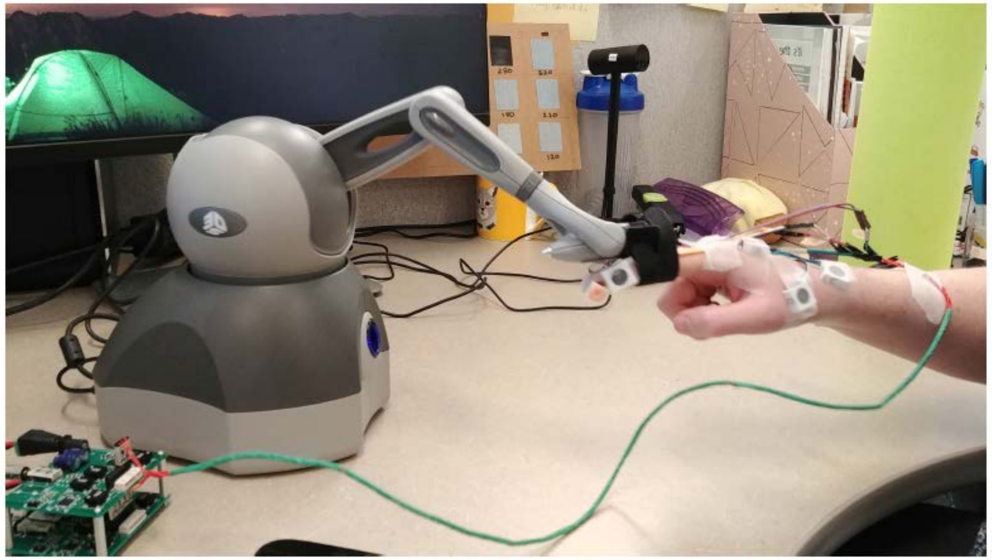


Figure 5: A participant interacts with the virtual textured sandpaper surface. The attached *Phantom Omni* provides kinesthetic feedback while the finger-mounted LRA provides cutaneous feedback.

Step 6

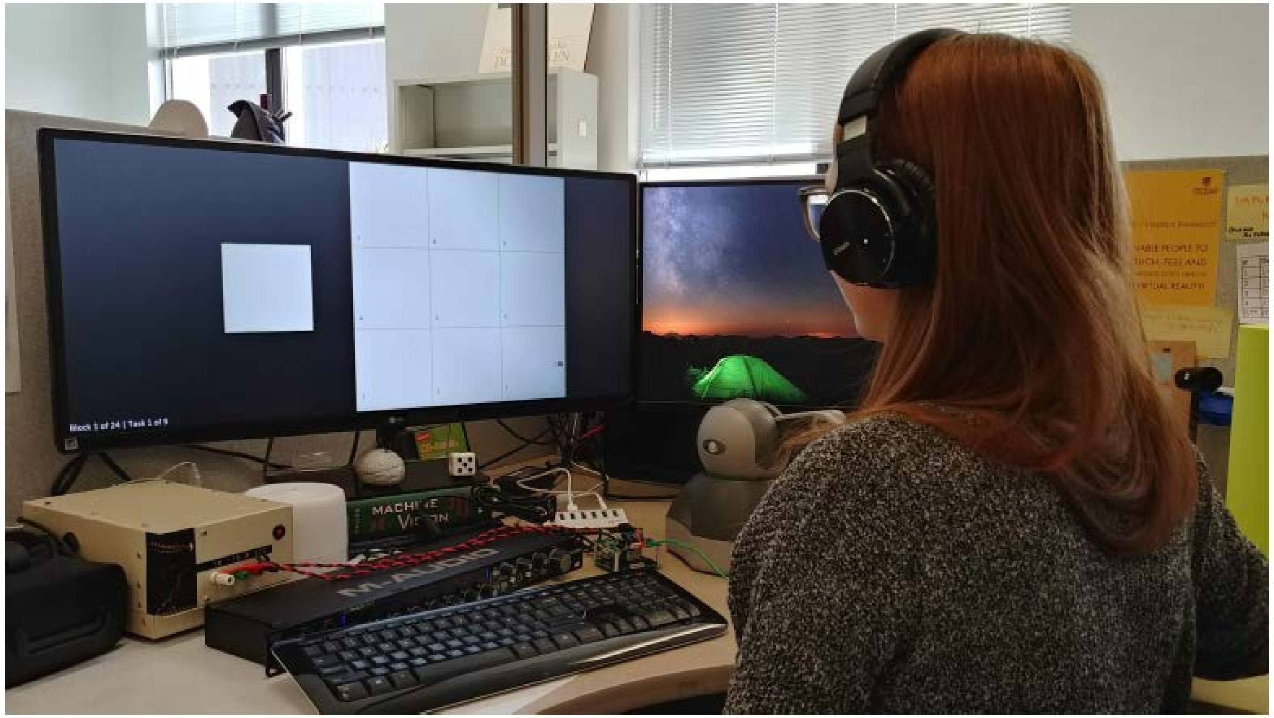


Figure 6: A pilot participant performing a texture discrimination task.

Step 7

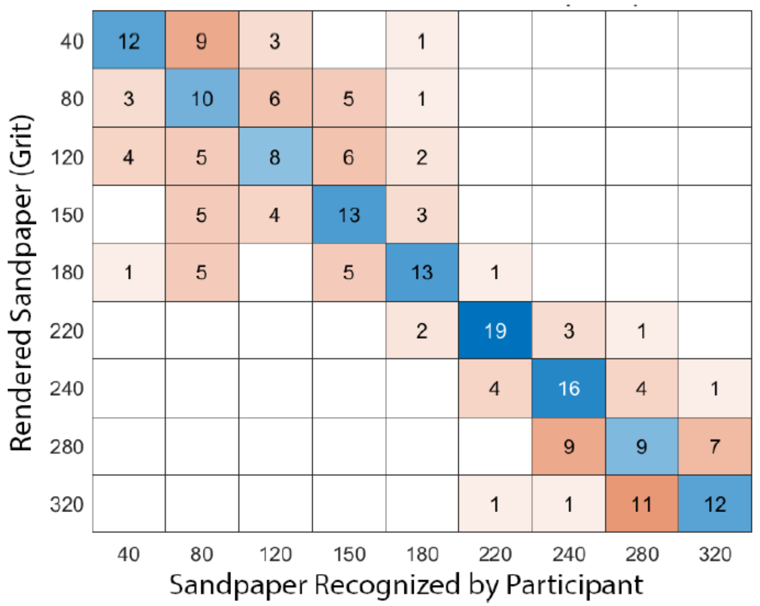


Figure 7: Preliminary confusion matrix results showing participant perception of grit size (x-axis) compared to the rendered sandpaper grit size (y-axis). Cells report number of trials resulting in each perception-rendered pair; diagonal cells reflect accurate perceptions of rendering.

Result(s)

Next Steps

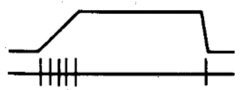
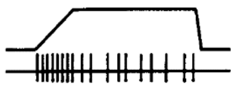
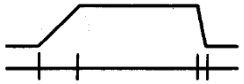
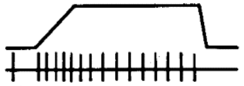
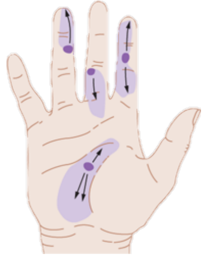
- Actuators are not good enough to perform at sub-threshold levels
- Should try electrical SR for a stable setup

George, S.Z., Oehlberg, L., Peters, R., & Chan, S. (2019). **Improving Texture Discrimination in Virtual Tasks by using Stochastic Resonance.** *(Submitted to World Haptics Conference 2019)*

Premise

Wearable Haptic Devices needs to be more Neuroscience aware and we can create a classification based on the perception aspect of touch

Recollect …

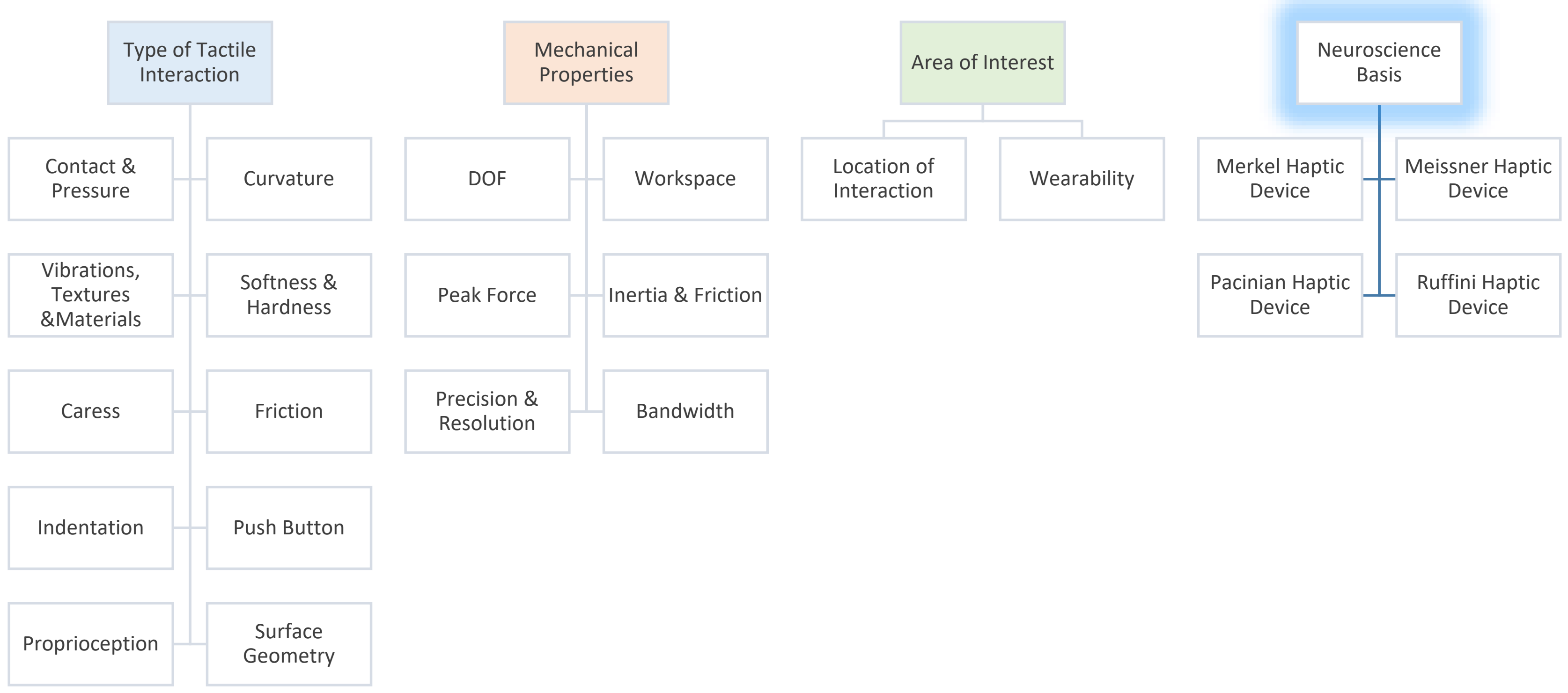
		ADAPTATION			
		FAST No static response	SLOW With static response		
RECEPTIVE FIELDS	Small, sharp borders 	FAI – Meissner (43%) FA I  Edge sensitive	SAI – Merkel (25%) SA I  Edge sensitive		INNERVATION DENSITY
	Large, Obscure borders 	FAII – Pacinian (13%) FA II 	SAII – Ruffini (19%) SA II  Sensitive to lateral skin stretch		

And …

- Type of Tactile Interaction
  - Contact & Pressure
  - Curvature
  - Vibrations, Textures &Materials
  - Softness & Hardness
  - Caress
  - Friction
  - Indentation
  - Push Button
  - Proprioception
  - Surface Geometry
- Mechanical Properties
  - DOF
  - Workspace
  - Peak Force
  - Inertia & Friction
  - Precision & Resolution
  - Bandwidth
- Area of Interest
  - Location of Interaction
  - Wearability

Pacchierotti, C., Sinclair, S., Solazzi, M., Frisoli, A., Hayward, V., & Prattichizzo, D. (2017). **Wearable Haptic Systems for the Fingertip and the Hand: Taxonomy, Review, and Perspectives.** *IEEE Transactions on Haptics*, *10*(4), 1–1. https://doi.org/10.1109/TOH.2017.2689006

Now


Type of Tactile Interaction
Contact & Pressure
Curvature
Vibrations, Textures &Materials
Softness & Hardness
Caress
Friction
Indentation
Push Button
Proprioception
Surface Geometry
Mechanical Properties
DOF
Workspace
Peak Force
Inertia & Friction
Precision & Resolution
Bandwidth
Area of Interest
Location of Interaction
Wearability
Neuroscience Basis
Merkel Haptic Device
Meissner Haptic Device
Pacinian Haptic Device
Ruffini Haptic Device

Examples

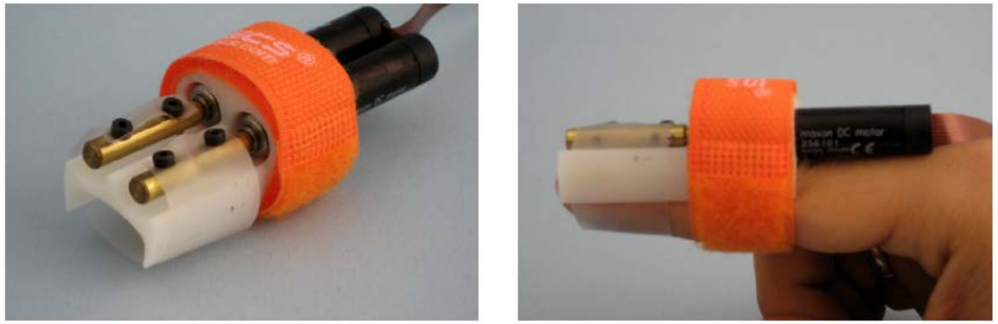


Fig. 3. Gravity Grabber [19], an example of a Meissner Haptic Device

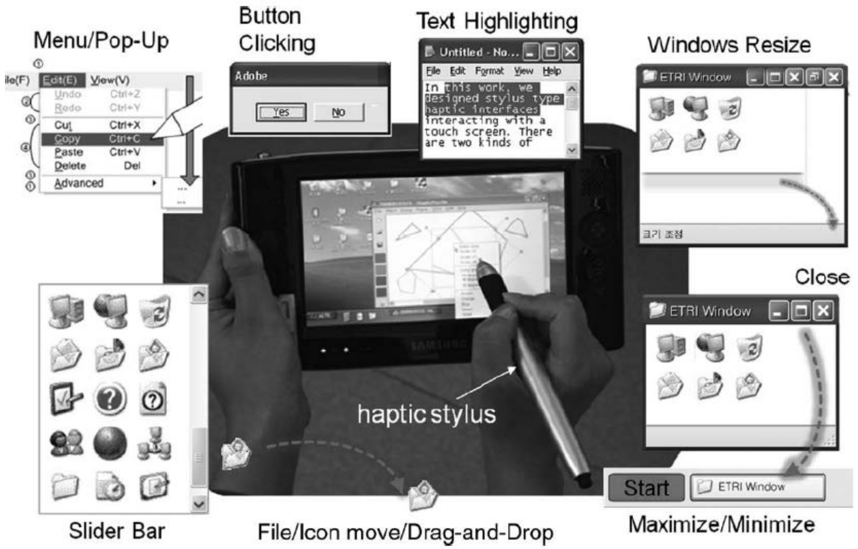


Fig. 4. Wubi Pen [25], an example of Pacinian Haptic Devices

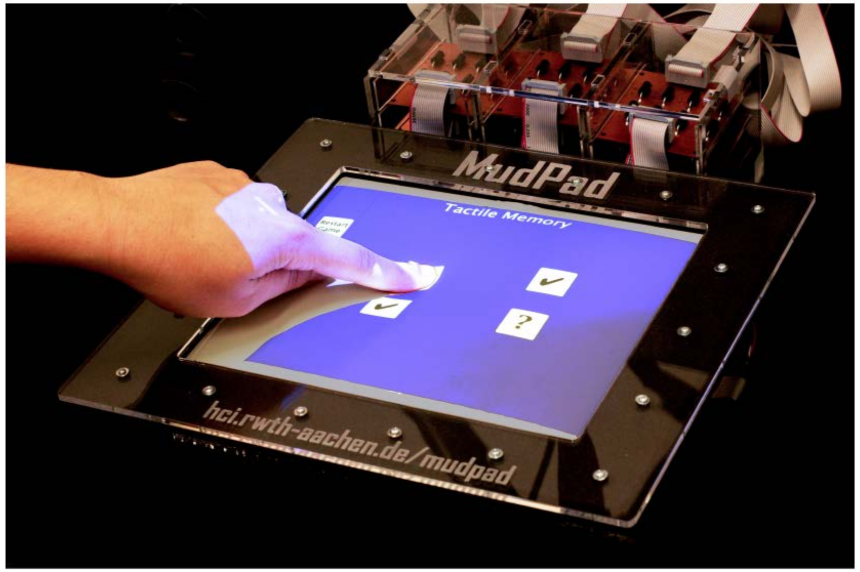


Fig. 5. The Mudpad System [31], is an example of a Merkel Haptic Device

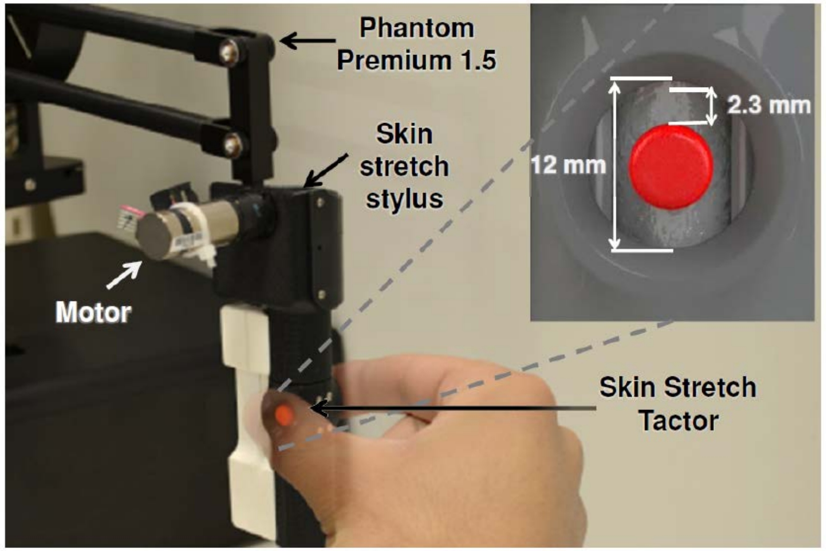


Fig. 6. Fingerpad skin stretch device [36], is an example of a Ruffini Haptic Device

Don’t Forget …

SA1 Merkel

Edges, curvature, & texture

FA1 Meissner

Motion detection & grip control

SA2 Ruffini

Skin stretch

FA2 Pacinian

Feeling through objects, perception of fine texture

Dr. Ryan Peters (Lecture Notes)

Discussion

IS NEUROSCIENCE BASED CLASSIFICATION USEFUL?

DO YOU THINK STOCHASTIC RESONANCE (ENHANCEMENT) CAN BE APPLIED ELSEWHERE?

PSYCHOPHYSICS FRAMEWORK USEFUL OR NOT?

SHOULD WE CARE ABOUT THE BIOLOGY WHILE DESIGNING HAPTIC DEVICES?