



Intro to Haptics

CMSC730 | Huaishu Peng | Fall 2022

5 SENSES



SIGHT



HEAR



SMELL



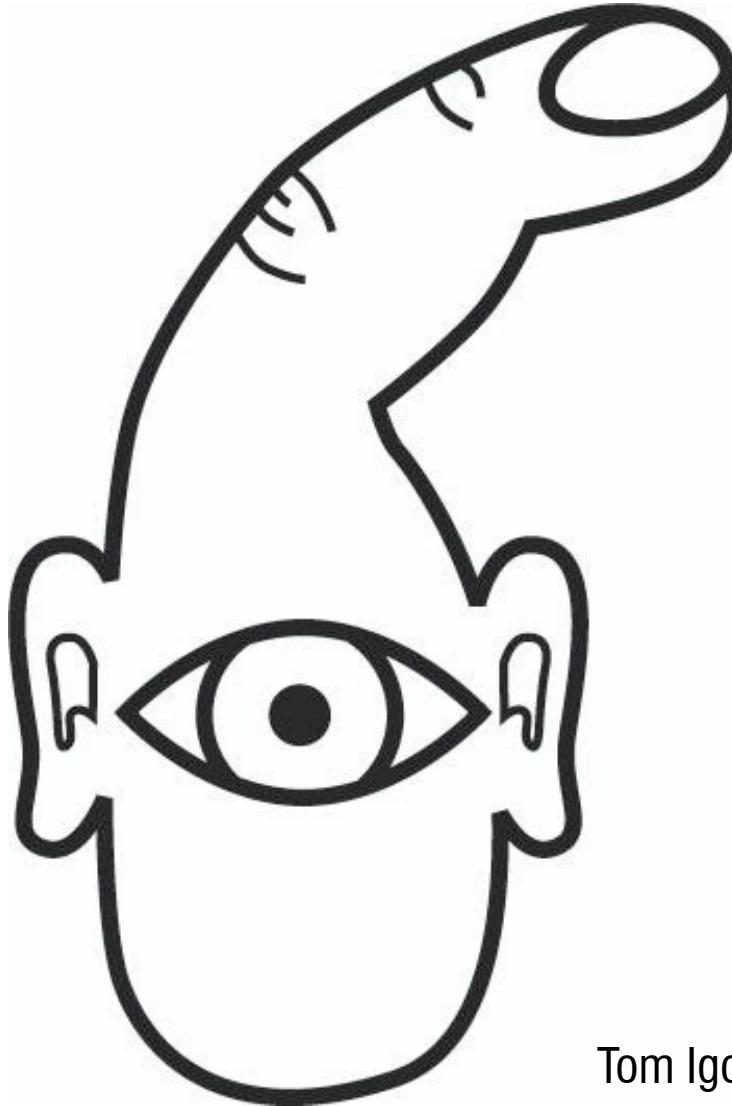
TASTE



TOUCH

Sight vs Touch

Sight
centralized
broad
passive
cognitive



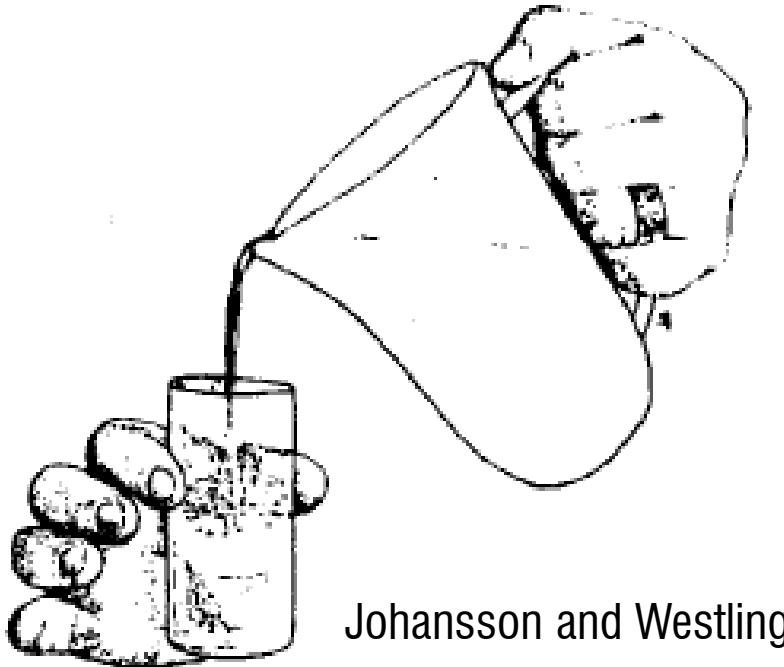
Tom Igoe

Touch

distributed
narrow
active
physical

What is haptic

Cutaneous
Temperature
Texture
Slip
Vibration
Force



Johansson and Westling

Kinesthesia

Location/configuration
Motion
Force
Compliance

- The haptic senses work together with the motor control system to:
- Coordinate movement
 - Enable perception



Cutaneous

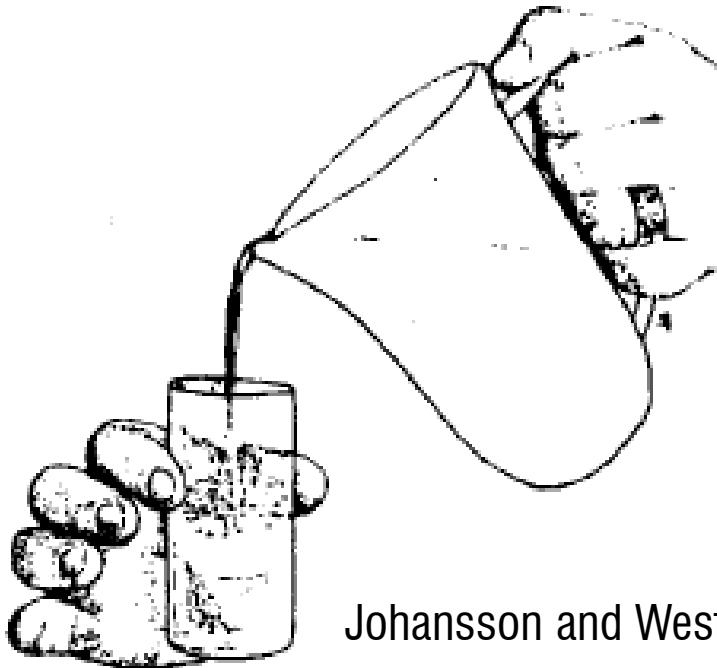
**Normal,
Pre-anesthetization
Performance**

**From the laboratory of
Dr. Roland Johansson
Dept. of Physiology
University of Umeå, Sweden**

<https://www.youtube.com/watch?v=0LfJ3M3Kn80>

What is haptic

Cutaneous
Temperature
Texture
Slip
Vibration
Force

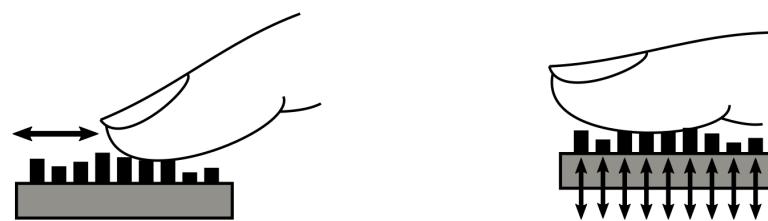


Johansson and Westling

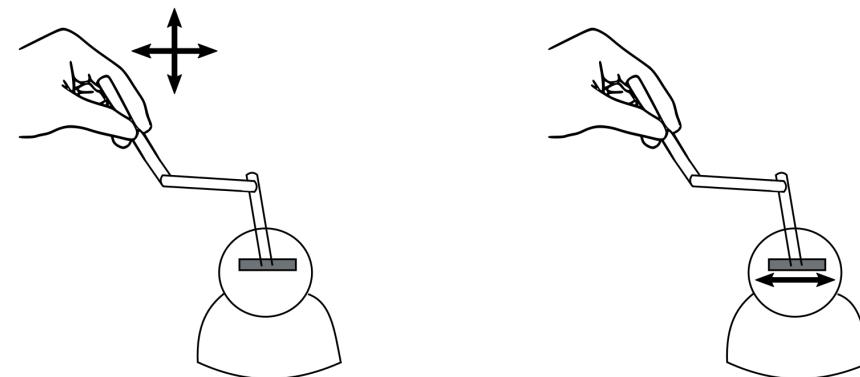
Kinesthesia
Location/configuration
Motion Force
Compliance

kinesthetic vs. tactile devices

Cutaneous
Tactile haptic devices
stimulate the skin



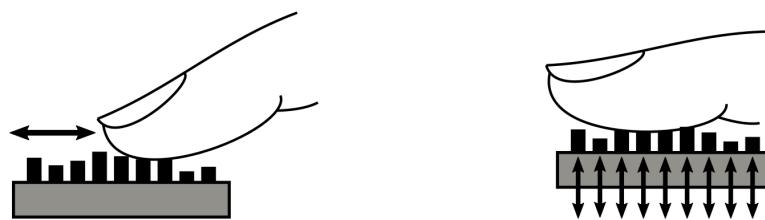
Kinesthetic
Kinesthetic haptic devices
display forces or motions
through a tool



Active Passive

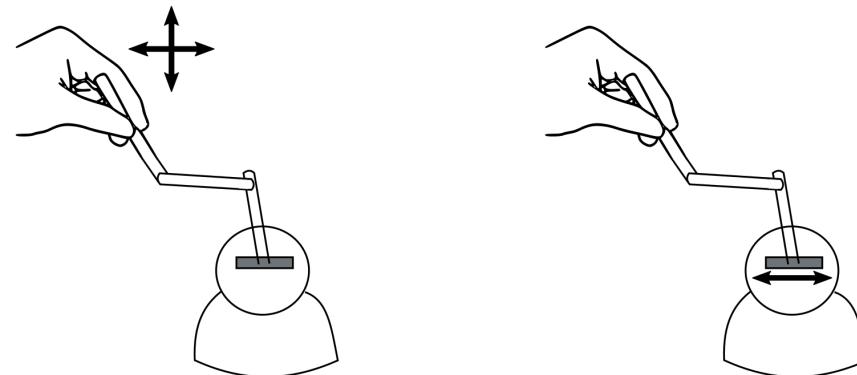
kinesthetic vs. tactile devices

Cutaneous
Tactile haptic devices stimulate the skin



Tactile haptic devices can more easily be wearable

Kinesthetic
Kinesthetic haptic devices display forces or motions through a tool



Kinesthetic haptic devices are usually grounded

Tactile (cutaneous) device basics



Tactile feedback

goal is to stimulate the **skin** in a programmable manner to create a desired set of sensations

sometimes **distributed** tactile feedback is provided

tactile feedback is generated by a **tactile device**, sometimes called a **tactile display**

not usually called a **tactile interface**

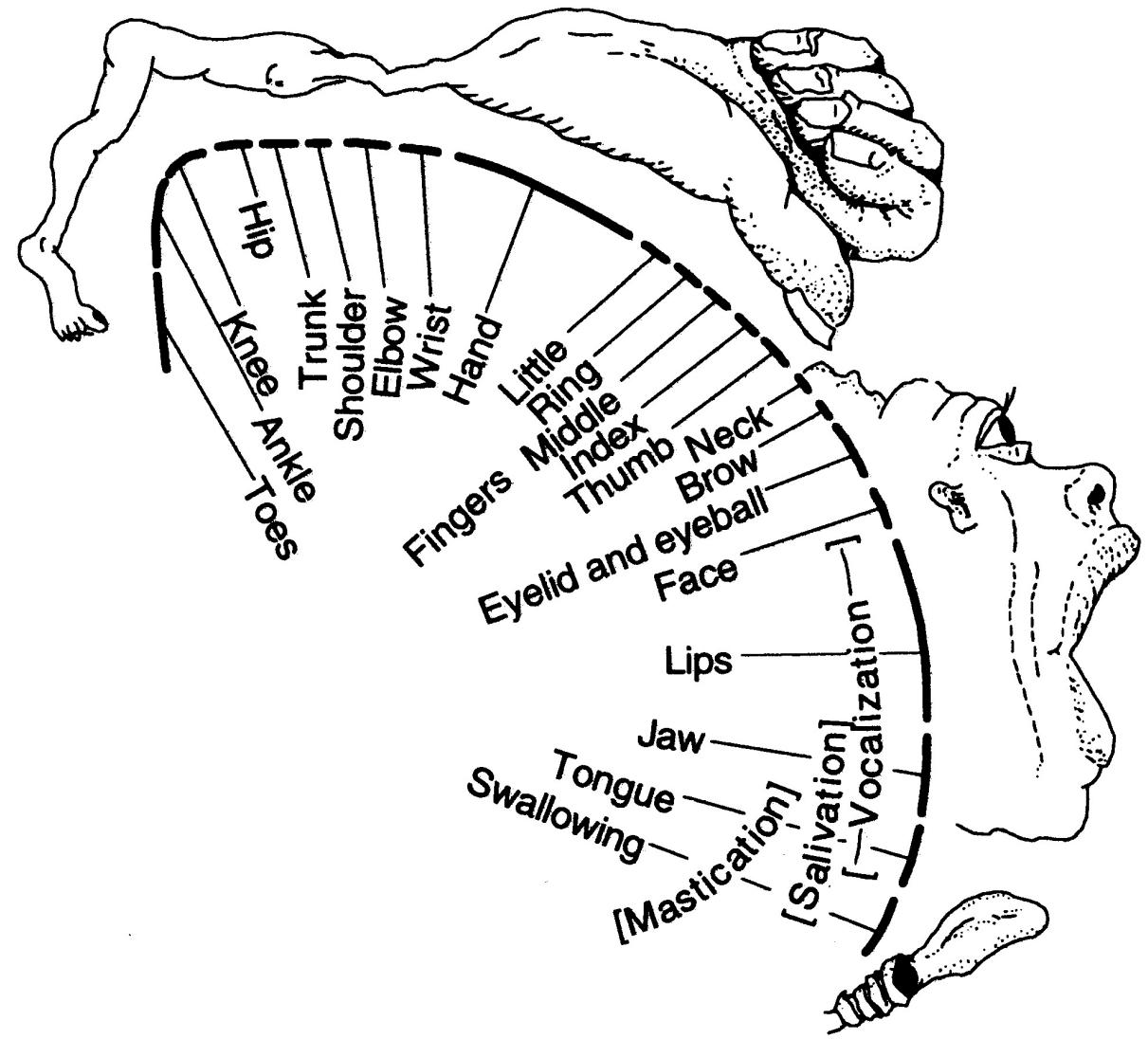
(why not?)

can aim to recreate real sensations, create novel ones, or communicate information

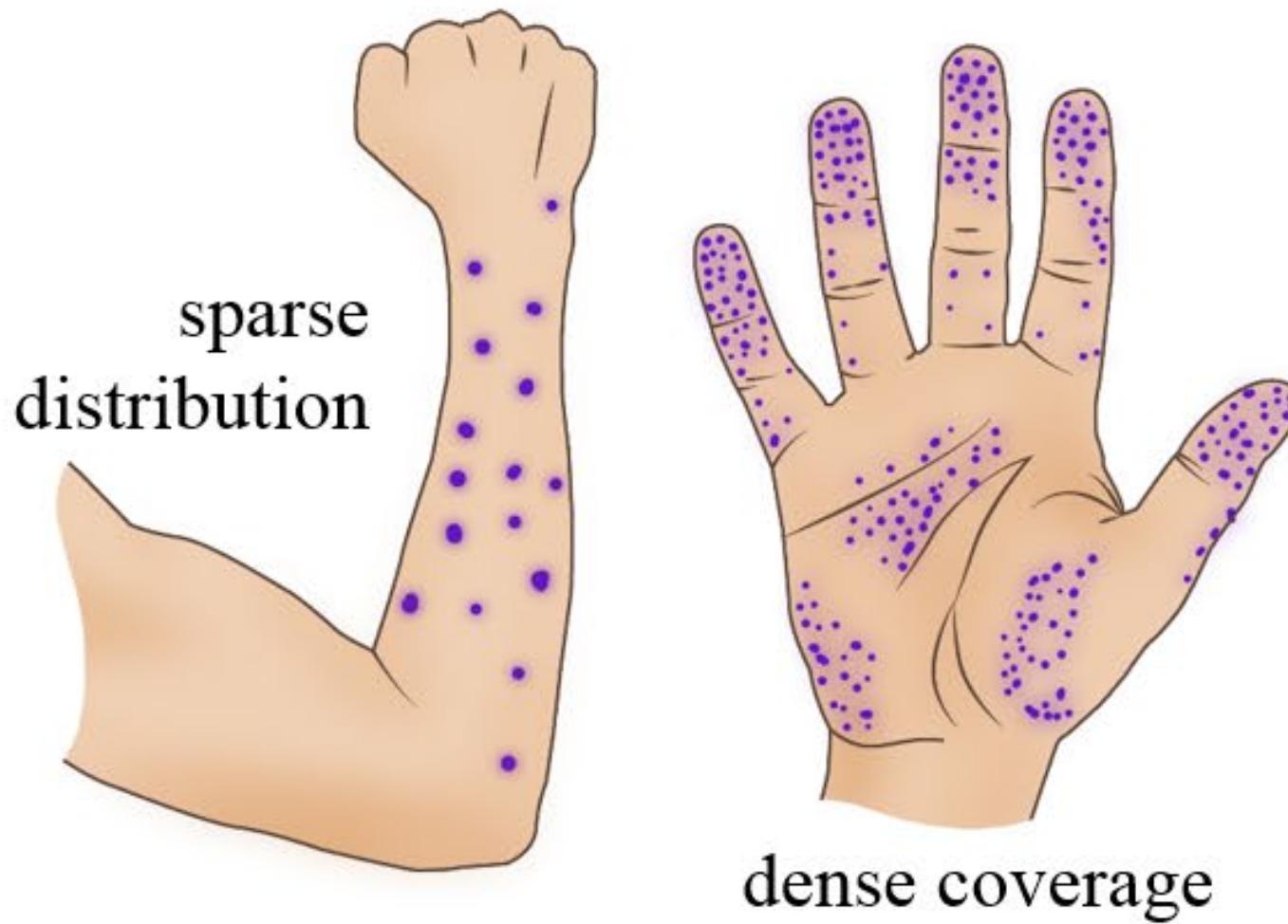
Sensory homunculus



mapping the human somatosensory cortex



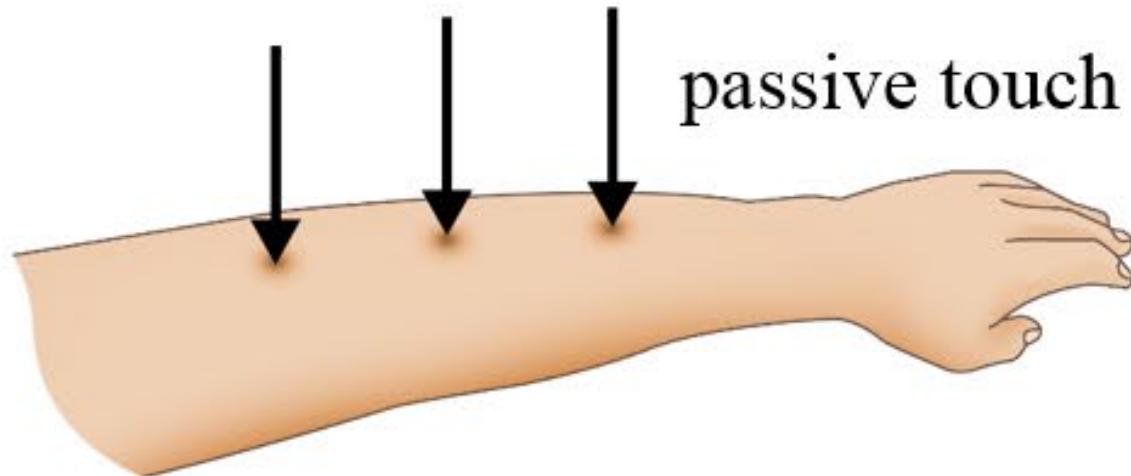
Arms vs fingertips



Active vs. passive touch

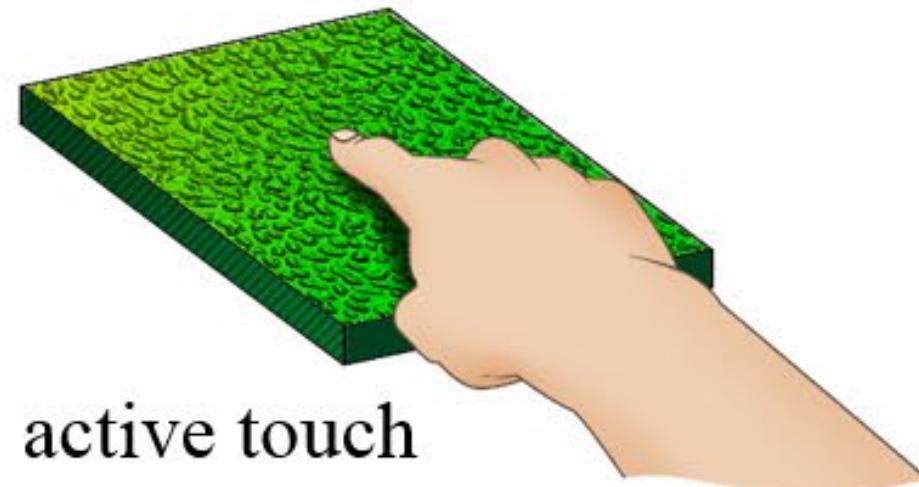
Passive touch

Focus on the sensation experienced

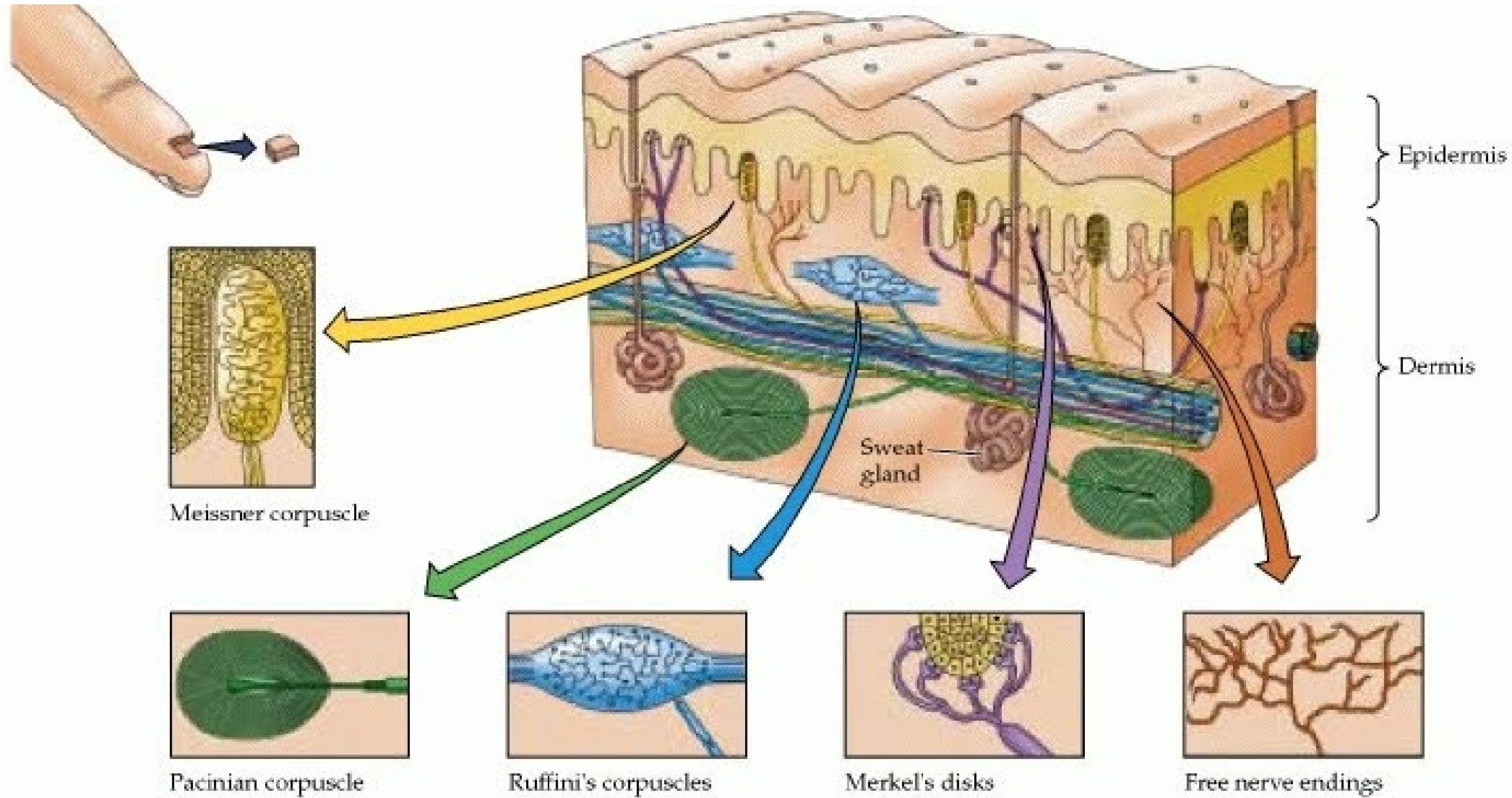


Active touch

Focus on the object



Mechanoreception



Mechanoreceptive afferents

classified by depth:

I: closer to skin surface

II: deeper beneath surface response

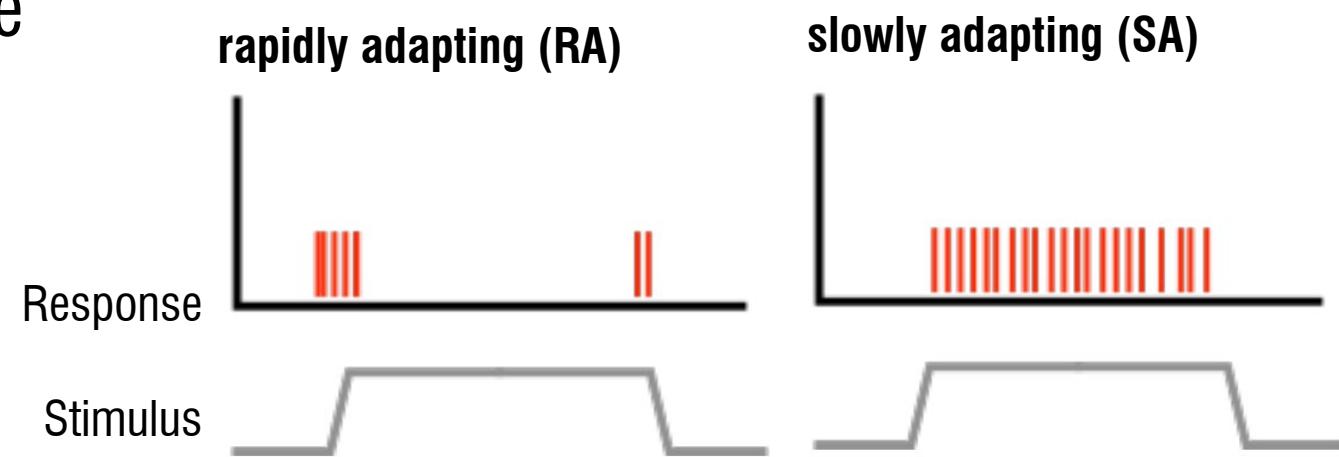
classified by rate of adaptation:

rapidly adapting = phasic

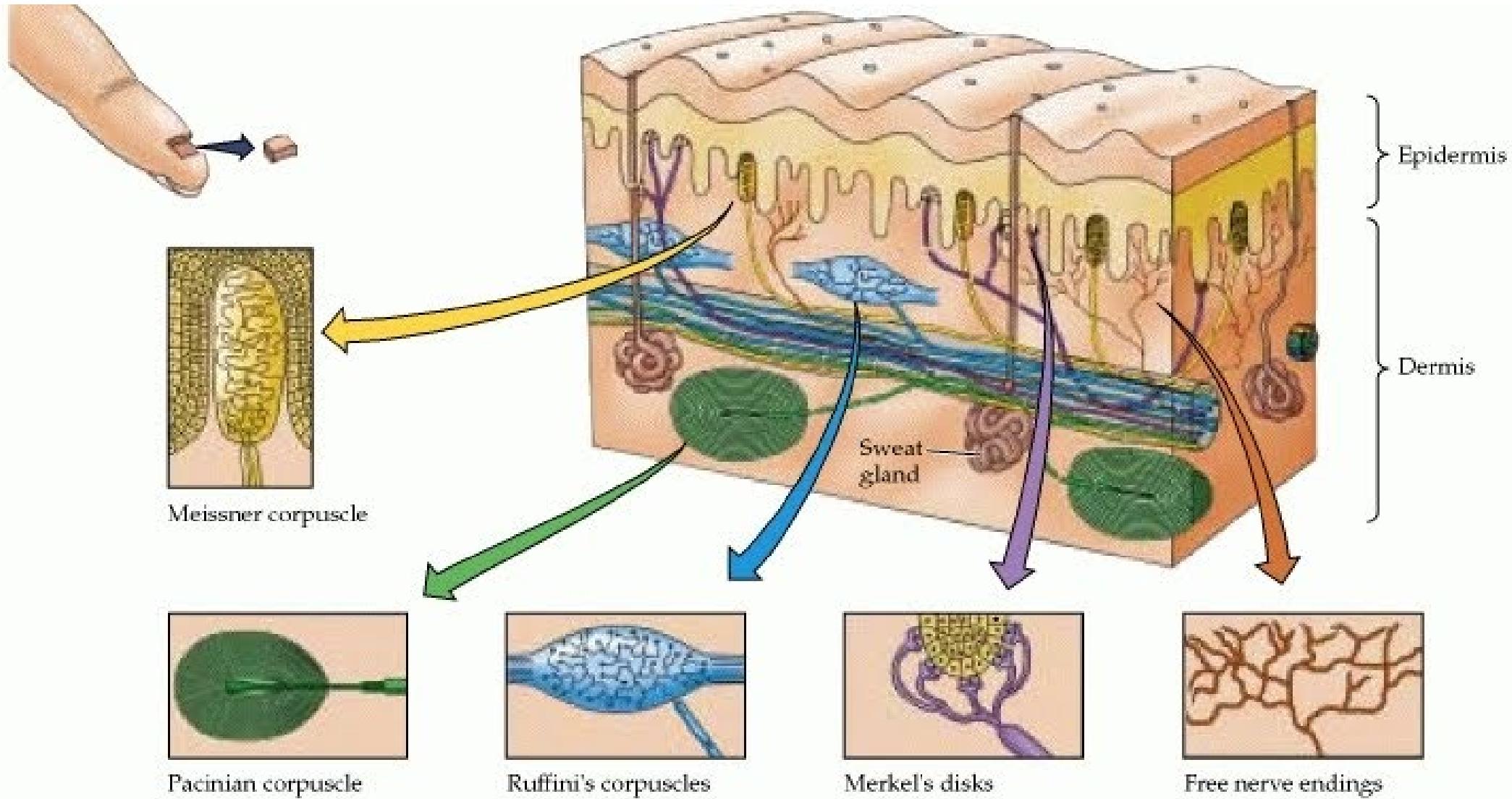
slowly adapting = tonic

classified by sensing modality:

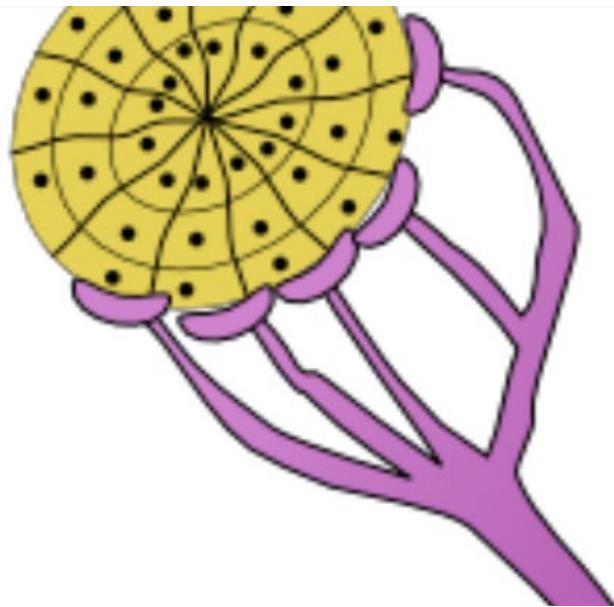
e.g., receptor structure



Cross section of glabrous skin



Merkel (SA I)



form and texture
perception

low-frequency
vibrations

Shape: disk

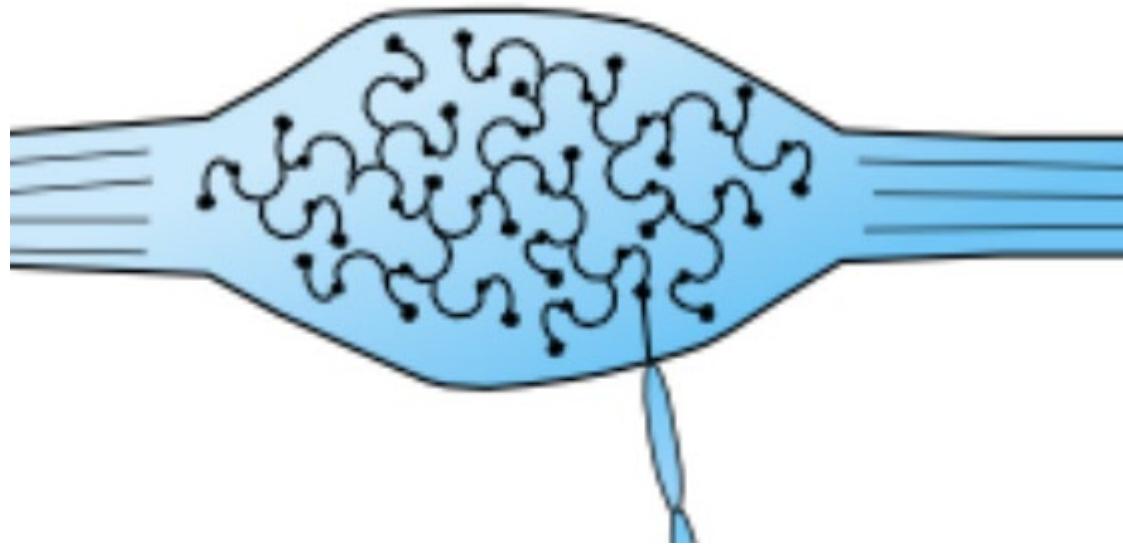
Location: near border between epidermis & dermis

Type: SA I

Best Frequencies: 0.3-3 Hz

Stimulus: pressure

Ruffini (SA II)



static and dynamic skin deformation

skin stretch

Shape: many-branched fibers inside a roughly cylindrical capsule

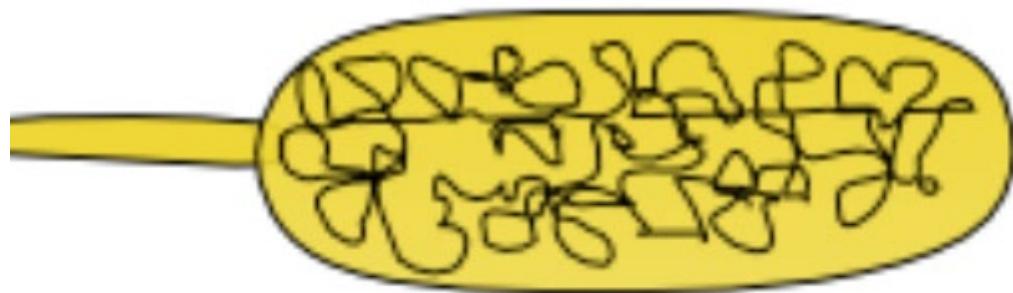
Location: dermis

Type: SA II

Best Frequencies: 15-400 Hz

Stimulus: stretching of skin or movement of joints

Meissner (RA I)



motion, slip/grip

dynamic skin deformation

Shape: stack of flattened cells, with a nerve fiber winding its way through

Location: in dermis just below epidermis

Type: RA I

Best Frequencies: 3-40 Hz

Stimulus: taps on skin

Pacinian Corpuscle (PC / RA II)



high frequency vibration

gross pressure changes

Shape: layered capsule surrounding nerve fiber

Location: deep in skin

Type: PC

Best Frequencies: 10 to >500 Hz

Stimulus: rapid vibration

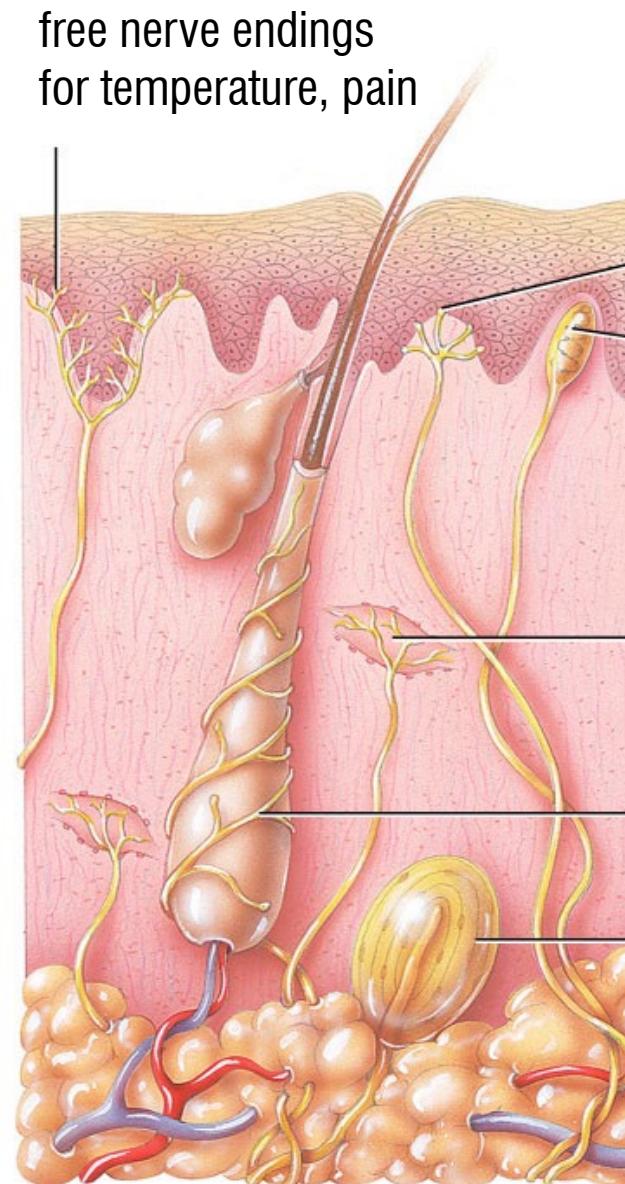
	Receptor	Diam.	Density (Fibers/cm ²)	Response	Percep. Function
SA I	Merkel	2mm	100	curvature	form & texture
	Meissner	5 mm	150	motion	motion & grip control
	Ruffini	8mm	20	stretch	hand shape, lateral force
	Pacinian	Hand	20	vibration	tools & probes

Thermal sensing

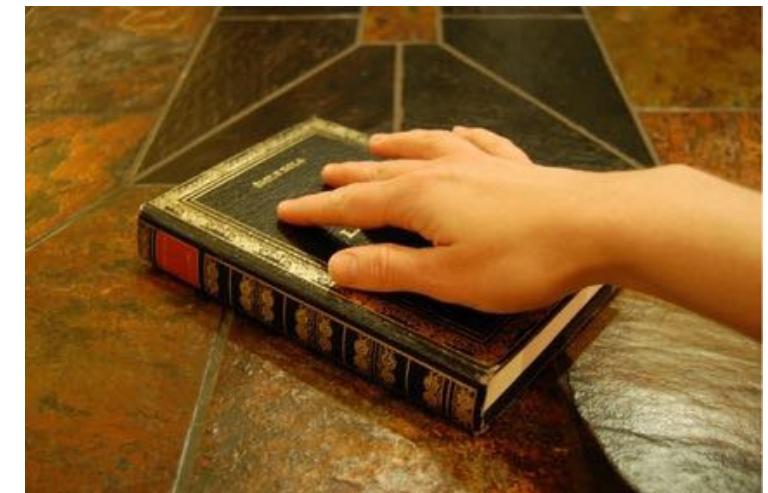
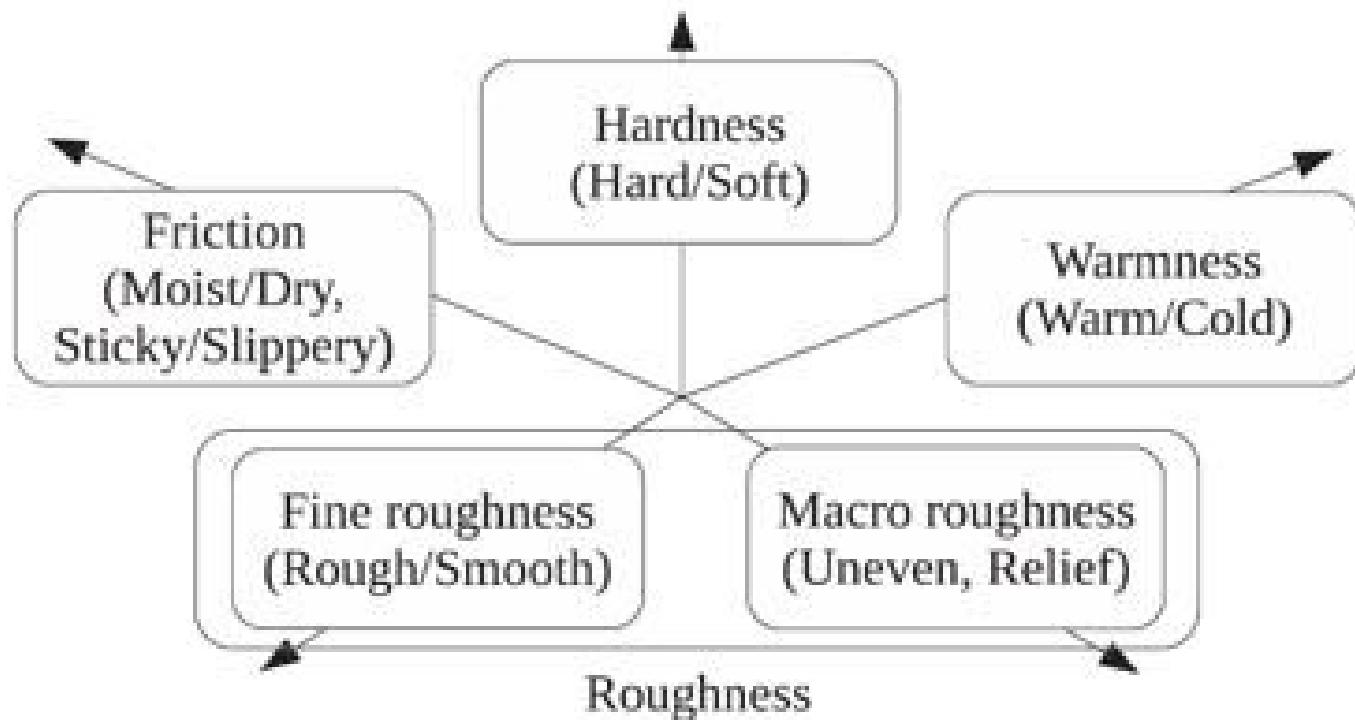
separate warm and cold receptors whose firing rate depends on magnitude of difference w.r.t body temperature

both slowly adapting (SA) and rapidly adapting (FA) characteristics, so depends on both T and dT/dt

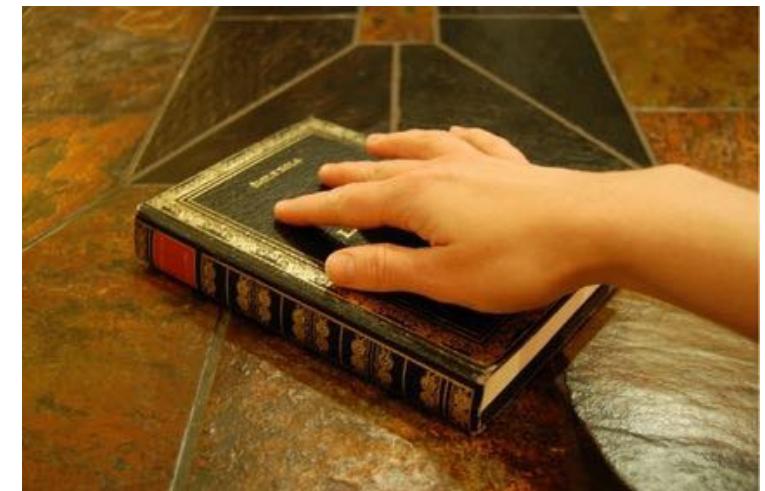
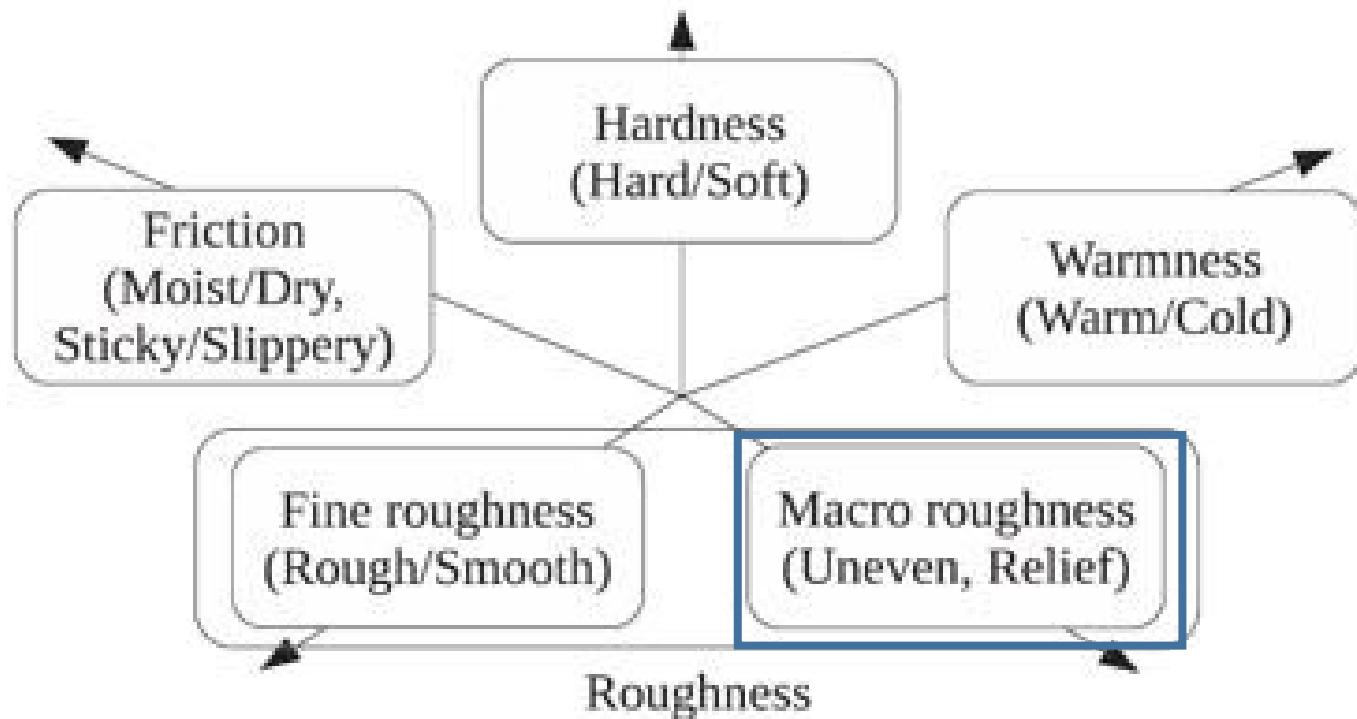
perception strongly affected by body temperature versus temperature at surface of skin (aluminum feels cooler at room temperature than wood) -- an important component of material identification



What does the human hand feel?

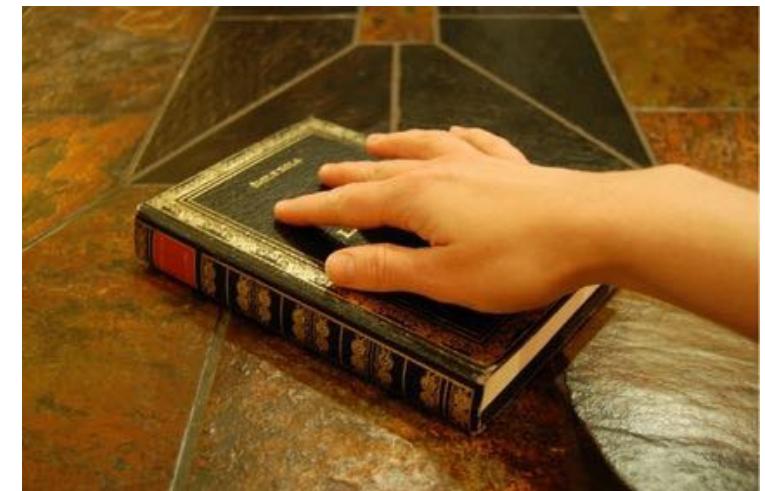
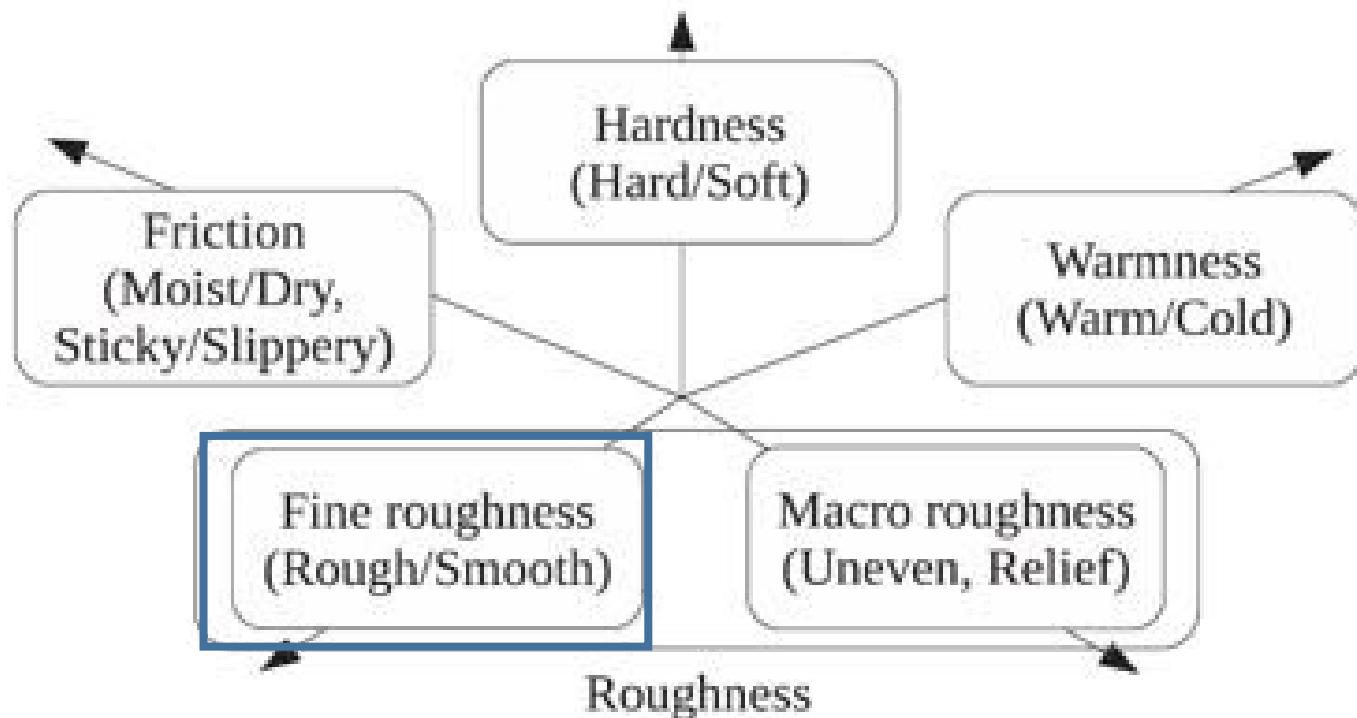


What does the human hand feel?



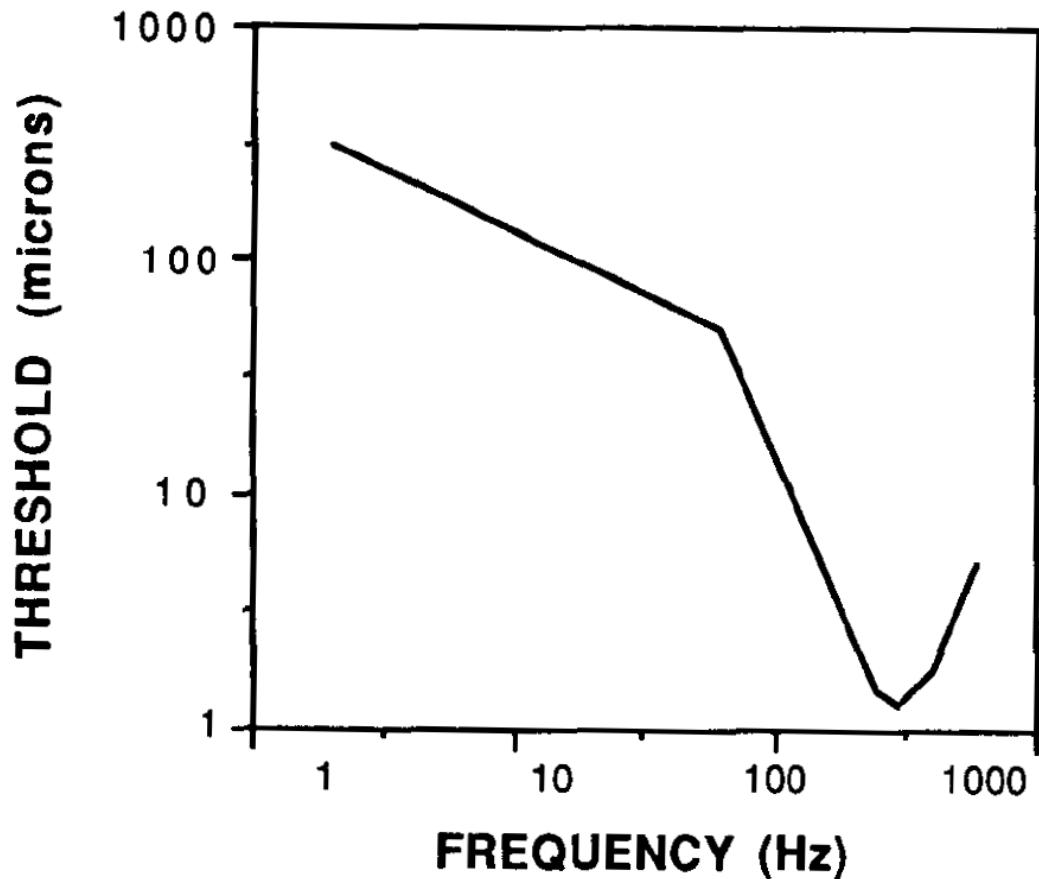
Spatial distribution of SA I
No temporal information

What does the human hand feel?



Vibratory information
RA I and RA II

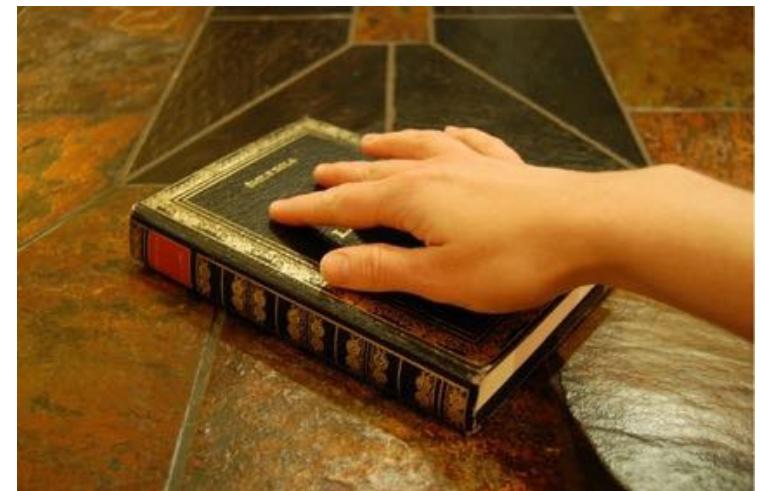
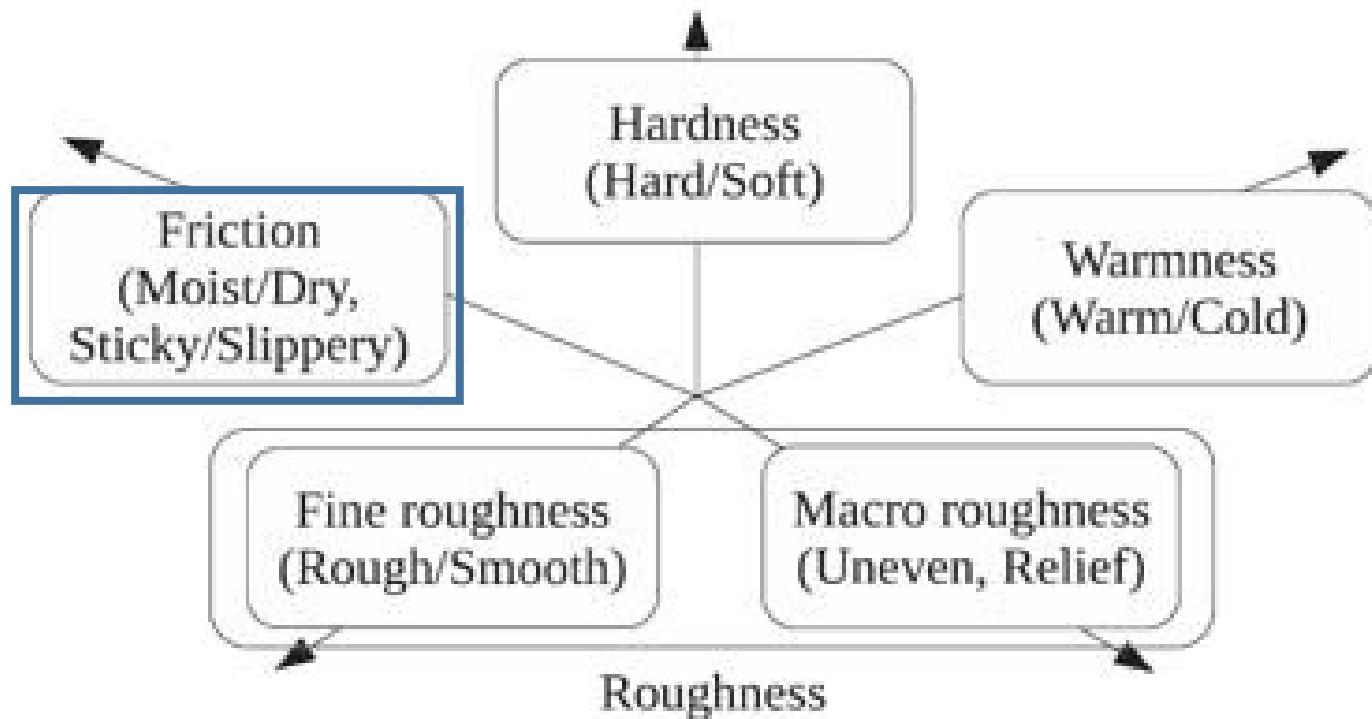
Pacinian corpuscle (FA-II) sensitivity to vibrations and Meissner (FA-I) sensitivity to small features



Peak sensitivity around 300 Hz.

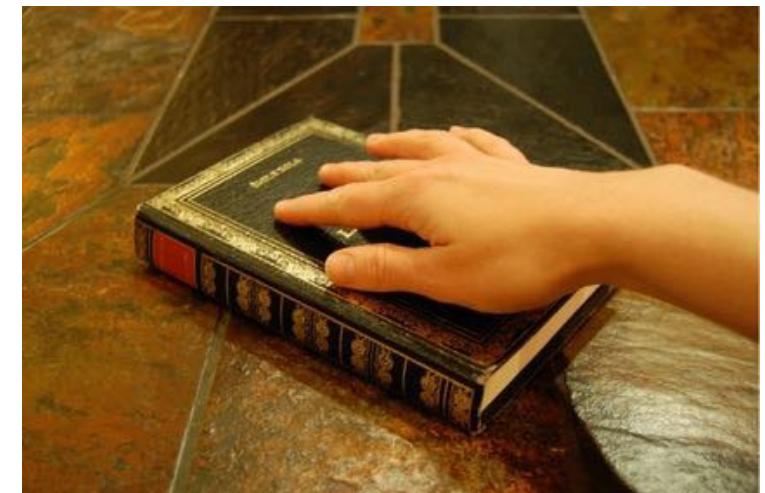
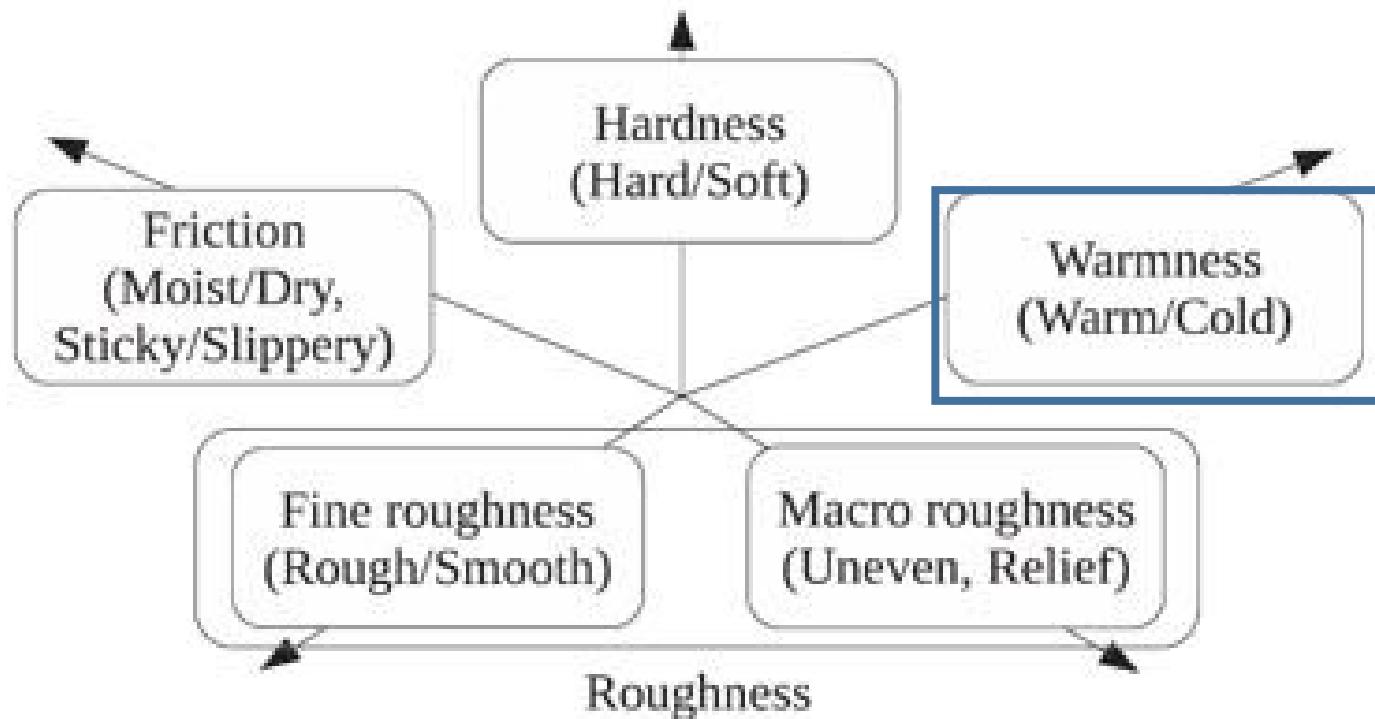
Able to detect bumps of a few microns under ideal conditions

What does the human hand feel?



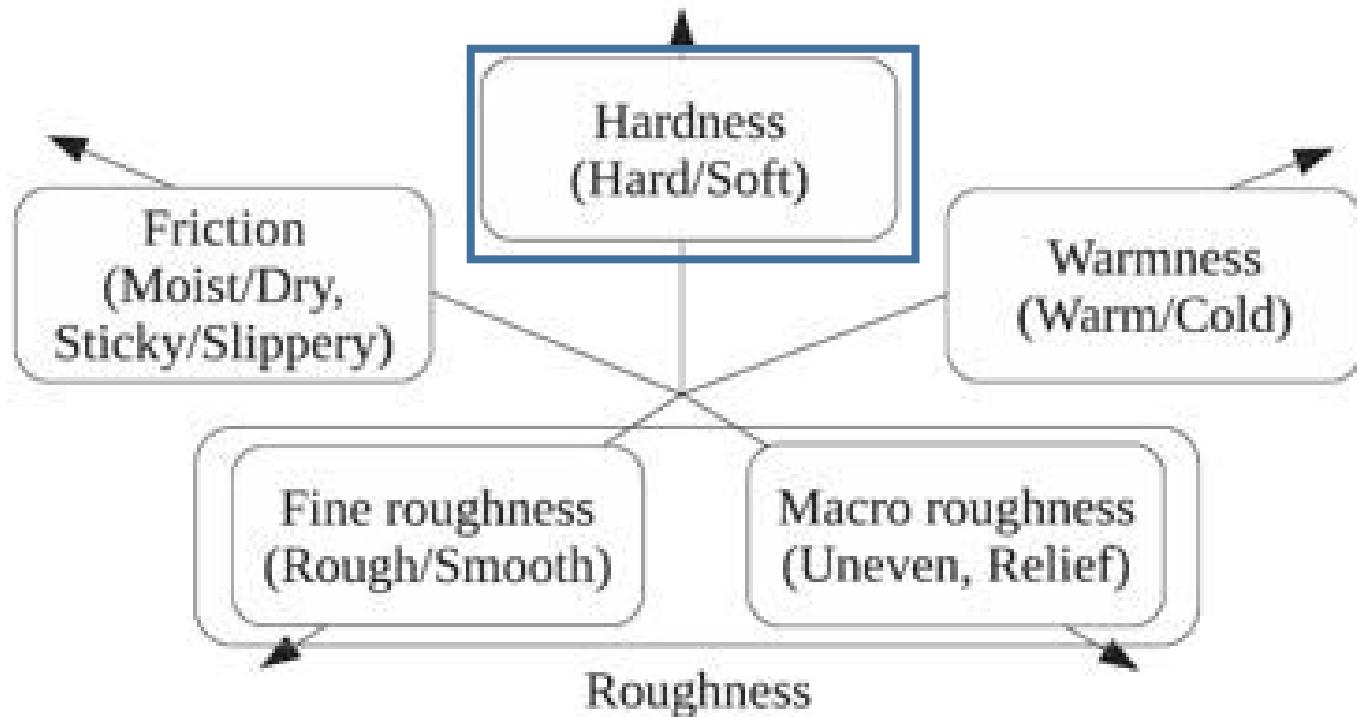
Mediated by skin of finger pad
Skin stretch or adhesion

What does the human hand feel?



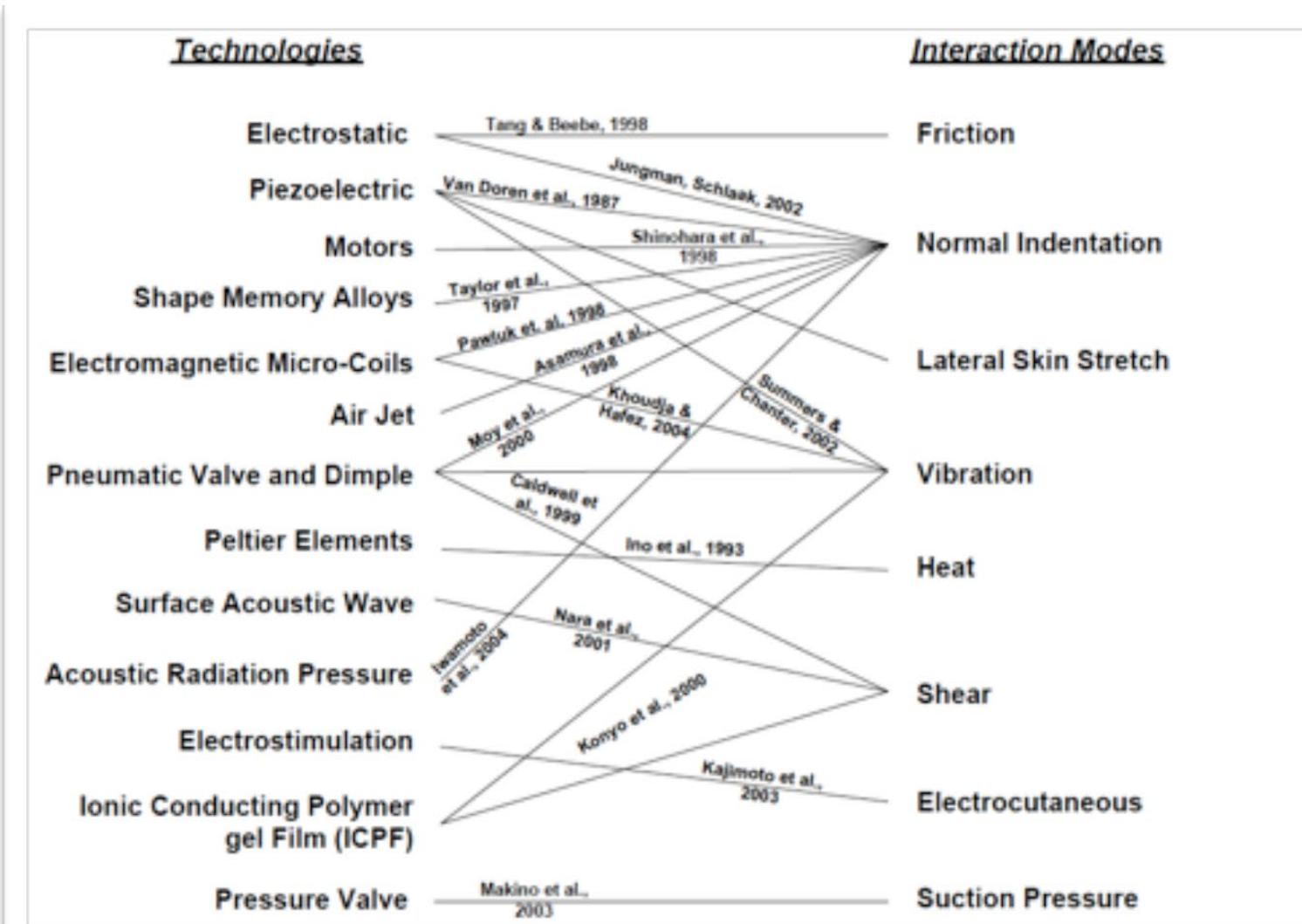
Heat transfer property between texture and finger
TRP ion-channels on free nerve endings

What does the human hand feel?

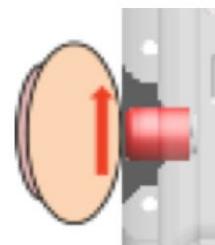
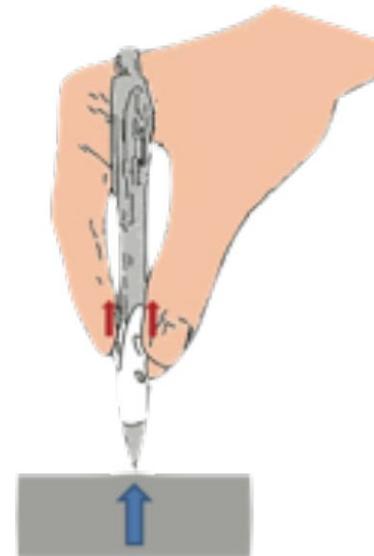


Tactile cues
Contact area between finger pad and object is important

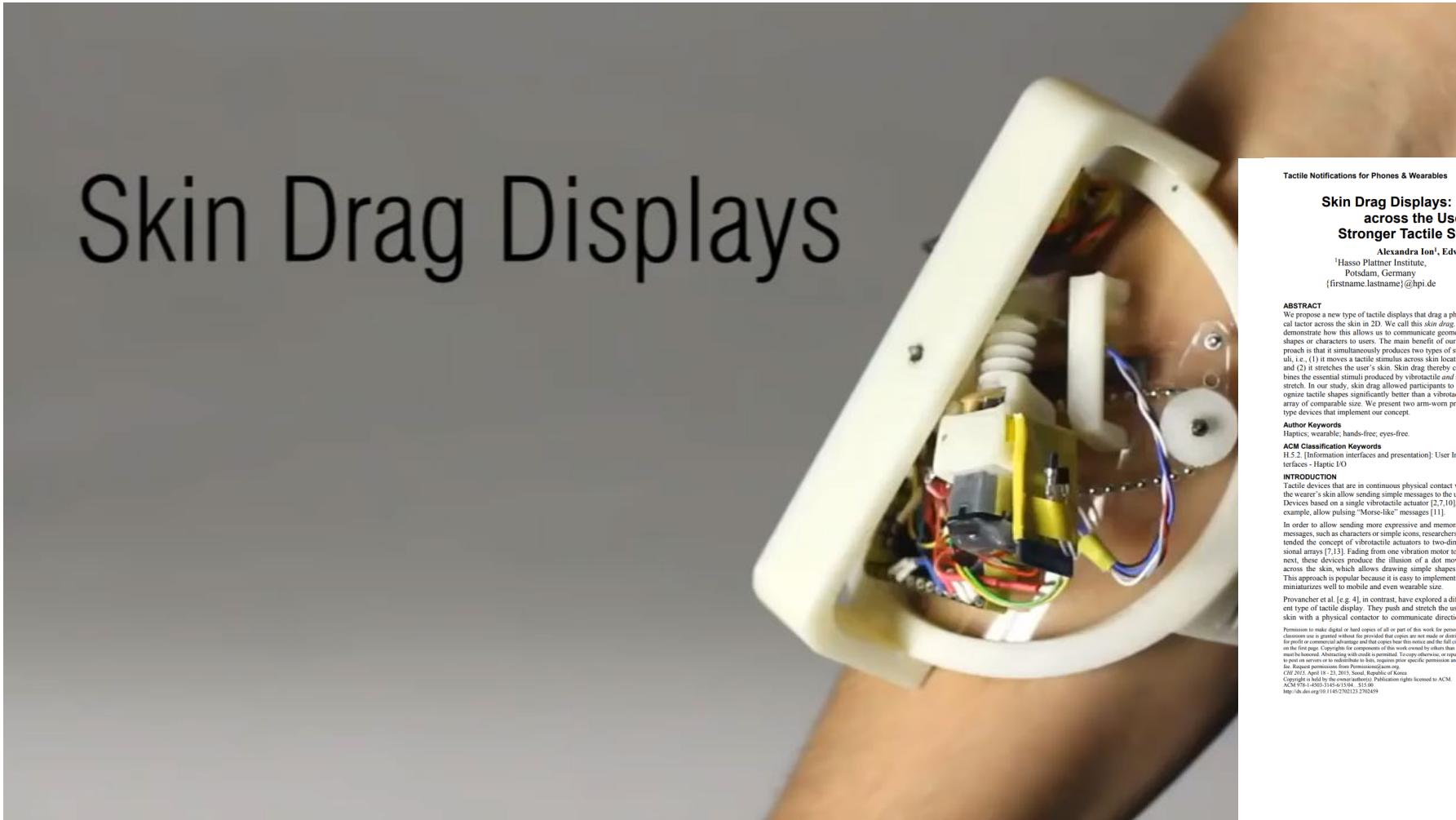
Different technologies and interaction modes mapping



Skin-Stretch/dragging Mechanism



Skin-Stretch/dragging Mechanism



Tactile Notifications for Phones & Wearables

CHI 2015, Crossings, Seoul, Korea

Skin Drag Displays: Dragging a Physical Tactor across the User's Skin Produces Stronger Tactile Stimulus than Vibrotactile

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cues, i.e., north, south, east, west. The resulting skin stretch triggers the skin's directional sensitivity [9].



Figure 1: Skin drag displays drag a tactor over the wearer's skin in order to communicate a spatial message. (a) e.g. write a 'C' on the user's arm. (b) Our self-contained prototype.

ABSTRACT
We propose a new type of tactile displays that drag a physical tactor across the skin in 2D. We call this *skin drag*. We demonstrate how this allows us to communicate geometric shapes or characters to users. The main benefit of our approach is that it simultaneously produces two types of stimuli, i.e., (1) it moves a tactor using a servomotor to indicate locations and (2) it stretches the user's skin. Skin drag thereby combines the essential stimuli produced by vibrotactile and skin stretch. In our study, skin drag allowed participants to recognize geometric shapes significantly better than a vibrotactile array of comparable size. We present two arm-worn prototype devices that implement our concept.

Author Keywords
Haptics; wearable; hands-free; eye-free.

ACM Classification Keywords
H.5.2 [Information interfaces and presentation]: User Interfaces based on a single vibrotactile actuator [2,7,10], for example, allow pulsing "Morse-like" messages [11].

INTRODUCTION
Tactile displays that are in continuous physical contact with the wearer's skin allow sending simple messages to the user. Devices based on a single vibrotactile actuator [2,7,10], for example, allow pulsing "Morse-like" messages [11].

In order to allow more complex and continuous communicable messages such as characters or simple icons, researchers extended the concept of vibrotactile actuators to two-dimensional arrays [7,13]. Fading from one vibration motor to the next, these devices produce the illusion of a dot moving across the skin, which allows drawing simple shapes [5]. This approach, however, is limited to the movement and miniaturizes well to mobile and even wearable size.

Provancher et al. [e.g. 4] in contrast, have explored a different type of tactile display. They push and stretch the user's skin with a physical contactor to communicate directional

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<http://doi.acm.org/10.1145/2702123.2702459>



Figure 2: (a) Skin drag combines the benefit of both, (b) vibrotactile arrays which excite a large number of receptors, and (c) skin stretch, which reaches two types of receptors.

Skin-Stretch/dragging Mechanism

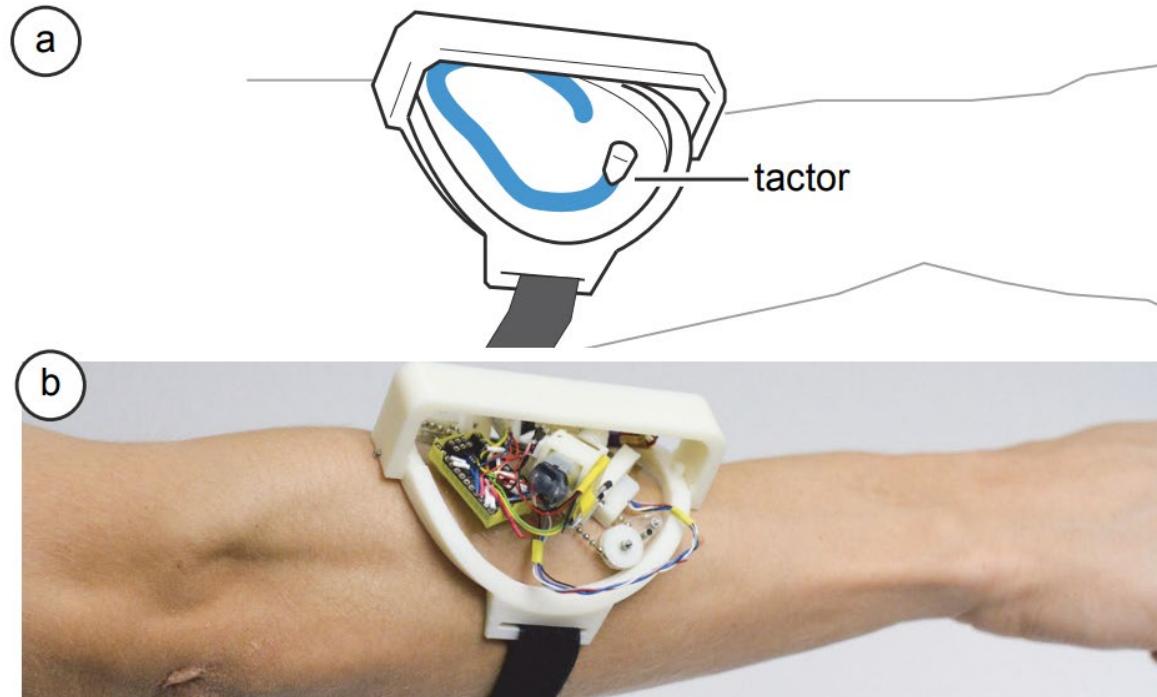


Figure 1: Skin drag displays drag a tacter over the wearer's skin in order to communicate a spatial message, (a) e.g. write a 'C' on the user's arm. (b) Our self-contained prototype.

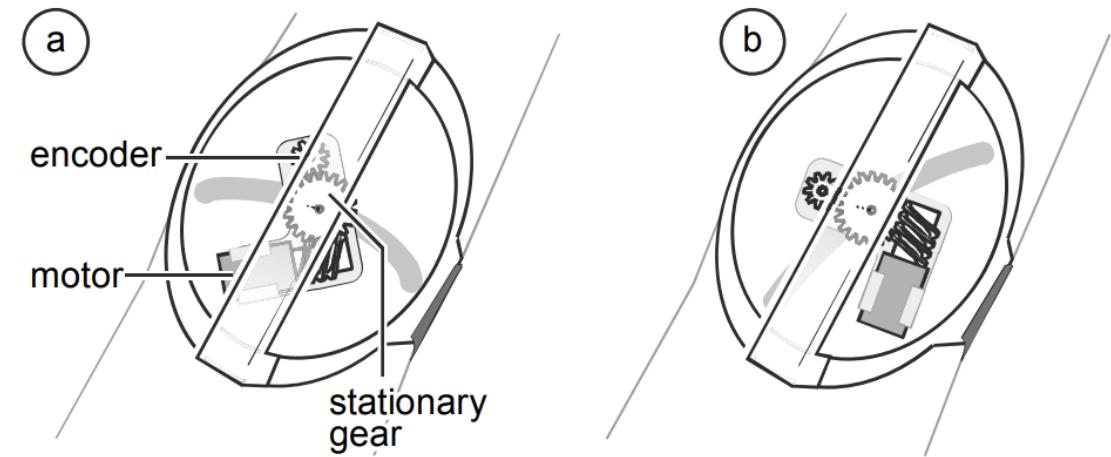


Figure 5: (a) A motor using a worm drive actuates the rotation of the diaphragm. (b) All components rotate with the diaphragm, e.g., 45° counterclockwise.

Skin-Stretch/dragging Mechanism



id KAI

tactoRing

A Skin-Drag Discrete

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² Mathematical S

³ Computer Science, National Chiao

Haptics on Skin

CHI 2017, May 6–11, 2017, Denver, CO, USA

tactoRing: A Skin-Drag Discrete Display

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ABSTRACT

Smart skins are an emerging wearable technology particularly suitable for discrete notifications based on haptic cues. Previous work mostly focused on tactile actuators that stimulate only specific skin receptors on the finger, resulting in limited expressiveness. In this paper we present *tactoRing*, a novel tactile display that, by dragging a small tacto ring across the skin around the finger, excites multiple skin areas resulting in more accurate recognition. In this paper we present the hardware and a user study to understand the ability of users to recognize eight distinct points around the finger. Moreover, we show how different techniques encode information through skin dragging motion with accuracy up to 94%. We finally showcase a set of applications that, by combining sequences of tactile stimuli, achieve higher expressiveness than prior methods.

AUTHOR KEYWORDS

Haptics; wearable ring; eye-free; skin-drug.

ACM Classification Keywords

H.5.2 [Information interfaces and presentation]: User Interfaces—Haptic I/O

INTRODUCTION

Smart skins, becoming more popular, receive both commercial endorsement and attention from researchers [29]. Like other wearable devices, they benefit from the social acceptability of traditional jewelry [22], but also from direct contact with the finger skin. These properties make them promising candidates for haptic displays for interactions [1, 5, 18, 24, 35], and rich but subtle notifications [21, 28]. It is therefore unsurprising that researchers have explored a variety of notification modalities for smart skins, including: vibration [3, 12, 21]; pressure [17]; temperature [20]; compression devices including light [16]; small displays [30]; sound [28]; and, in particular, tactile feedback. Several types of tactile feedback have been considered, including: vibration patterns [3, 12, 21] pressure shear [36]; force [18, 19, 26]; and, pulse and thermal [28].

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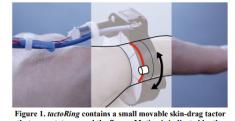


Figure 1. *tactoRing* contains a small movable skin-drug tacto ring that rotates around the finger. Motion is indicated by the blue arrow on the ring.

However, while tactile notifications have the benefit of not requiring constant attention from users, and support eye-free interactions, the expressiveness and the amount of information that can be displayed to users through the tacto ring is currently available for most of these wearable devices is quite limited. In fact, most of these devices operate by exciting only a small set of tactile skin receptors [17]. They fail to exploit the spatial resolution of the finger skin, which is capable of distinguishing points as close as 2.5mm [14, 33].

In this paper we present *tactoRing*, a novel haptic ring that excites the user's skin by dragging a small movable tacto ring (i.e., a small tactile actuator) such as a pinball across the skin. By simultaneously stimulating the Merkel cells on the epidermis (SA1) through pressure, and the Meissner corpuscles (RA1) and the Ruffini endings (SA2) in the dermis [17], we are able to achieve higher discrete spatial resolution on the finger and convey richer and more expressive messages to users than traditional tacto rings.

This paper describes the *tactoRing* prototype in detail, and demonstrates its accuracy with a series of user studies. Specifically, we investigated the capability of users to perceive the movable tacto ring to discern its dragging motion and direction. Then, we evaluated the effect of the low spatial resolution, we present two different interaction techniques based on skin dragging (*DoublePoint* and *VerticalLine*) and compare them with the tacto ring. They are reliable for accurate identification of eight unique points around the finger. Finally, we instantiate concrete examples of usage for the presented techniques in four applications, and indicate possible future research directions.

CHI 17
Je et.al.

Practical jamming

Haptic Jamming: A Deformable Geometry, Variable Stiffness Tactile Display using Pneumatics and Particle Jamming

Haptic Jamming: A Deformable Geometry, Variable Stiffness Tactile Display using Pneumatics and Particle Jamming

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² Department of Biomedical Engineering, Johns Hopkins University

ABSTRACT

Many conceivable tactile displays present the user with either variable mechanical properties or adjustable surface geometries, but controlling both simultaneously is challenging due to electromechanical complexity and the size/weight constraints of haptic applications. This paper discusses the design, manufacturing, control, and performance of a novel tactile display that achieves both variable stiffness and deformable geometry via air pressure and a technique called particle jamming. The surface of the device consists of a grid of small spherical cells, each containing coffee grounds and coffee grounds. It selectively softens in different regions when the air is varied. The entire layer is clamped over a chamber with regulated air pressure. Different sequences of air pressure and vacuum level adjustment allow regions of the surface to display a small rigid lump, a large soft plane, and various other combinations. As the air pressure is increased, the individual spherical cells show that surface stiffness increases with vacuum level and the elliptical shape of the cells becomes increasingly spherical with increasing air pressure.

Index Terms: H.5.2 [Information Interfaces and Presentation: User Interfaces—Haptic I/O]

1 INTRODUCTION

An ideal tactile display would be capable of controlling and transmitting multiple tactile quantities simultaneously, such as geometry, compliance, texture, and temperature. However, most tactile displays are limited in the scope of tactile sensations they can evoke. In haptic research, there are several approaches associated with developing devices that meet the physical constraints of many haptic applications. Researchers have developed displays optimized for one changing surface geometry at a time [e.g., [5], [9], [9], [11], [21]], although these displays do not allow for independent control of surface compliance. Others have developed displays that focus on controlling compliance and surface properties (e.g., [2], [10], [11], [12]), but do not allow for independent control of geometry. Recently, air-jet-based tactile devices have been used to create simple displays that can control geometry, compliance, and surface pressure simultaneously and independently [8], [10].

Distributed tactile displays that enable “enclosed-type” interactions are particularly attractive because they allow users to freely explore a surface or object. Several existing tactile displays are very heavy and do not require the user to wear or hold onto a device. The concept of “digital clay” [18] was proposed for 3D computer input/output interfaces; several potential methods have been conceived

*These authors contributed equally to this work.
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14–18 April, Daegu, Korea
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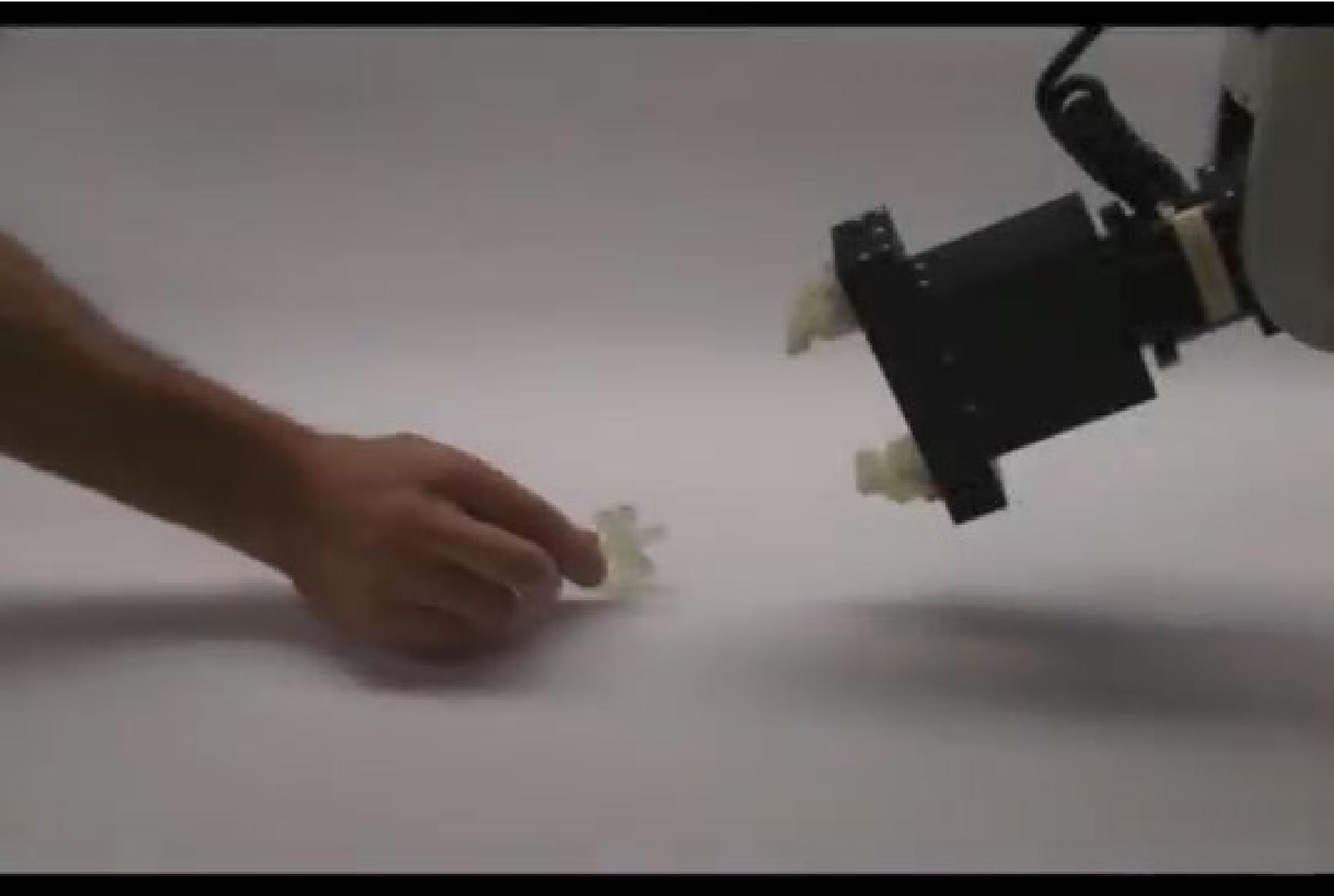


Figure 1: Haptic jamming array prototypes with four hexagonal cells. Many conceivable tactile displays present the user with either variable mechanical properties or adjustable surface geometries, but controlling both simultaneously is challenging due to electromechanical complexity and the size/weight constraints of haptic applications. This paper discusses the design, manufacturing, control, and performance of a novel tactile display that achieves both variable stiffness and deformable geometry via air pressure and a technique called particle jamming. The surface of the device consists of a grid of small spherical cells, each containing coffee grounds and coffee grounds. It selectively softens in different regions when the air is varied. The entire layer is clamped over a chamber with regulated air pressure. Different sequences of air pressure and vacuum level adjustment allow regions of the surface to display a small rigid lump, a large soft plane, and various other combinations. As the air pressure is increased, the individual spherical cells show that surface stiffness increases with vacuum level and the elliptical shape of the cells becomes increasingly spherical with increasing air pressure.

In this paper, we review prior work in particle jamming robotics and interfaces, explain our manufacturing approach, experimentally evaluate the device, and present its use as a haptic feedback display. The current design is appropriate as an output device only, although it can be integrated with other components to allow user input. We also discuss the potential of this technology for medical applications; it was originally designed to be a component of an encased-type combined cutaneous/kinesthetic display for medical training.

2 BACKGROUND
Particle jamming provides a method to quickly adjust the physical properties of an object. In most jamming designs, the object con-

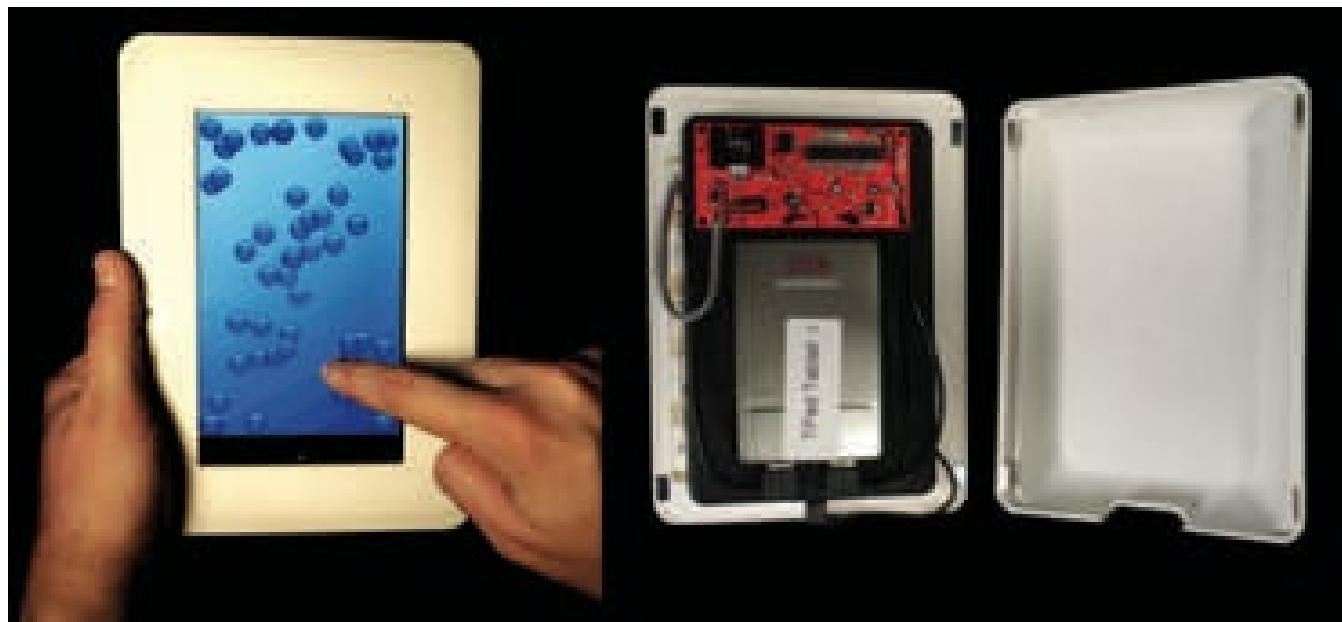
IEEE Haptics 13
Stanley et.al.



Brown, Eric, Nicholas Rodenberg, John Amend, Annan Mozeika, Erik Steltz, Mitchell R. Zakin, Hod Lipson, and Heinrich M. Jaeger. "Universal robotic gripper based on the jamming of granular material." *Proceedings of the National Academy of Sciences* 107, no. 44 (2010): 18809-18814.

Variable friction surfaces

Ultrasonic vibration could reduce the coefficient of friction of sandpaper; the same principle is here applied to glass.



Northwestern TPad



Variable friction surfaces

reported that dragging a dry finger over a conductive surface covered with a thin insulating layer and excited with a 110 V signal, created a characteristic “rubbery” feeling...called electrovibration.

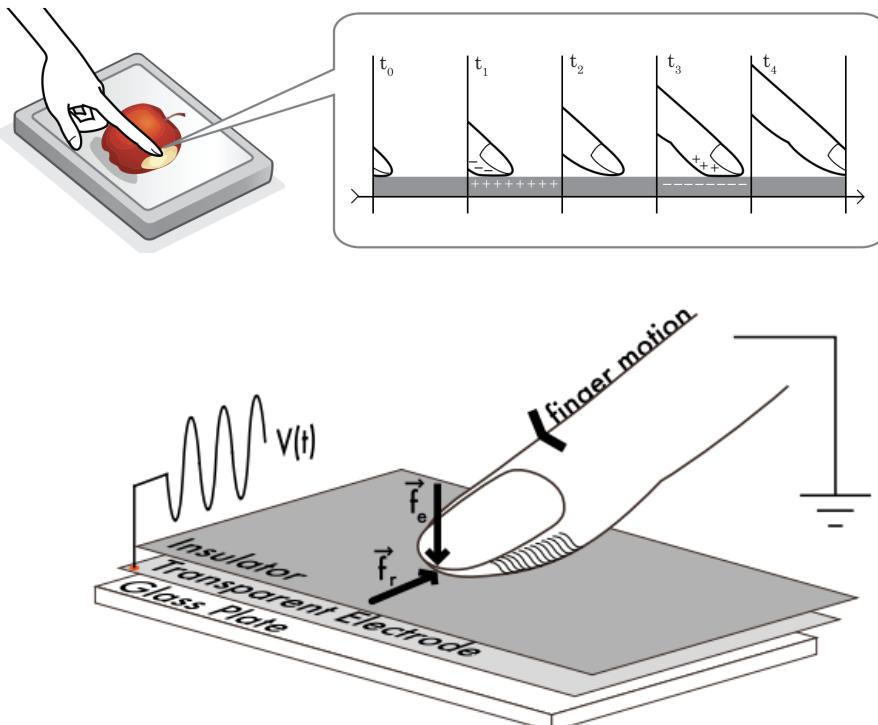
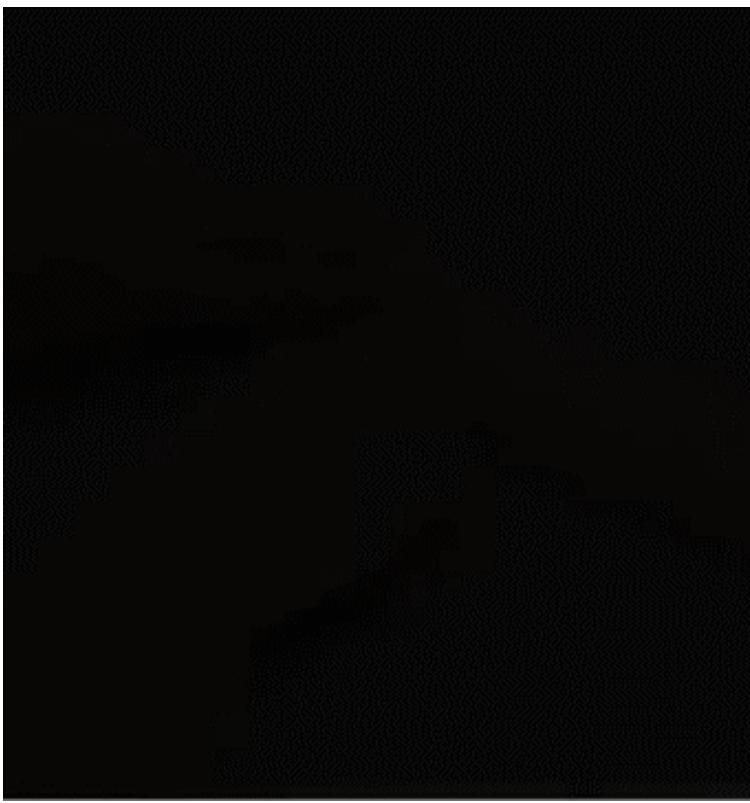


Figure 2: TeslaTouch operating principle.



TeslaTouch: Electrovibration for Touch Surfaces

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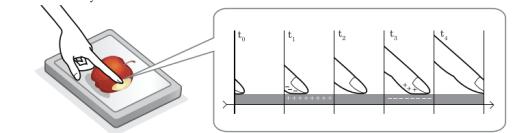


Figure 1: TeslaTouch uses electrovibration to control electrostatic friction between a touch surface and the user's finger.

ABSTRACT
We present a new technology for enhancing touch interfaces with tactile feedback. The proposed technology is based on the electrovibration principle: does not use any moving parts and provides a wide range of tactile feedback sensations to fingers moving across a touch surface. When combined with an interactive display and touch input, it enables the design of a wide variety of interfaces that allow the user to interact with elements through touch. We present the principles of operation and the main benefits of the technology. We also report the results of three controlled psychophysical experiments and a subjective user evaluation that describe and characterize users' perception of this technology. We conclude with an exploration of the design space of touch screens using two comparable setups, one based on electrovibration and another on mechanical vibrotactile actuators.

ACM Classification: H5.2 Information interfaces and presentation; H5.2.1 Haptic Interfaces; Graphical user interfaces, Input devices and strategies, Haptic I/O

General terms: Design, Measurement, Human Factors

Keywords: Tactile feedback, touch screens, multi-touch

Interest in designing and investigating haptic interfaces for touch-based interactive systems has been rapidly growing. This interest is partially fueled by the popularity of touch-based interfaces in research and user-centered applications. Despite their potential, a major problem with touch interfaces is the lack of dynamic tactile feedback. Indeed, as observed by Buxton as early as 1985 [6], a lack of haptic feedback: 1) obscures the location of visual elements, 2) breaks the metaphor of direct interaction, and 3) reduces interface efficiency, because the user can not rely on familiar haptic cues for accomplishing even the most basic interaction tasks.

Most previous work on designing tactile interfaces for interactive touch surfaces falls into two categories. First, the touch surface itself can be actuated with various electromechanical actuators such as piezoelectric bending motors, voice coils, and solenoids [10, 27]. The actuators can be designed to move the surface in one direction in the normal [27] or lateral directions [4]. Second, the tools used to interact with a surface, such as pens, can be enhanced with mechanical actuation [9, 19].

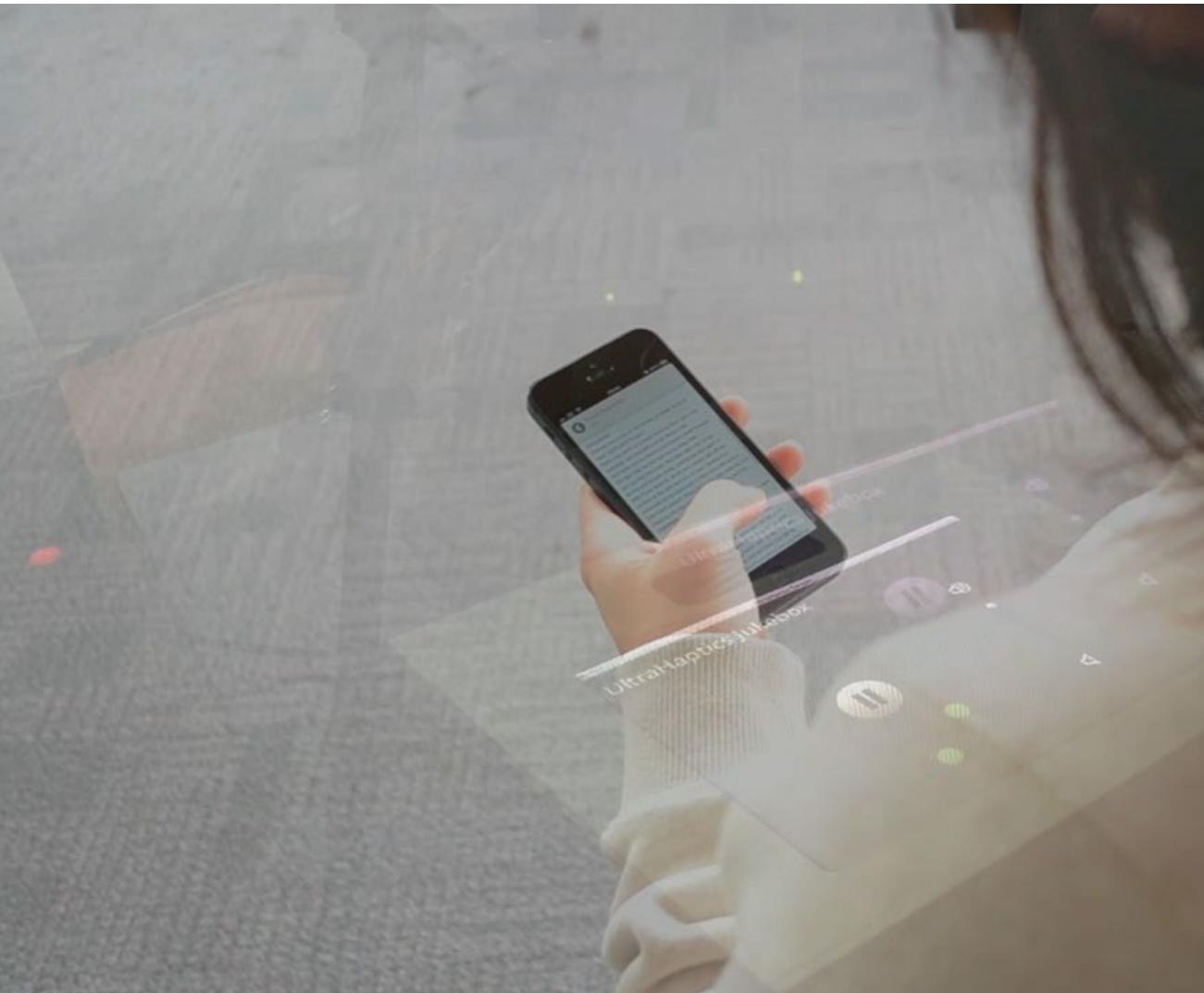
In this paper we propose an alternative approach for creating tactile interfaces for touch surfaces that does not rely on mechanical actuation. Instead, the proposed technique exploits the principle of *electrovibration*, which allows us to create a broad range of tactile sensations by controlling *electrostatic forces* between an instrumented touch surface and the user's finger. When combined with an input-capable interactive display, it enables a wide variety of interactions augmented with tactile feedback.

Tactile feedback based on electrovibration has several compelling properties. It is fast, low-powered, dynamic, and can

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Mid-air haptics

Ultrasonic haptics



Haptics

UIST'13, October 8–11, 2013, St Andrews, UK

UltraHaptics: Multi-Point Mid-Air Haptic Feedback for Touch Surfaces

Tom Carter¹, Sue Ann Seah¹, Benjamin Long¹, Bruce Drinkwater², Sriram Subramanian¹
Department of Computer Science¹ and Department of Mechanical Engineering²
(t.carter, s.a.seah, b.long, stram.subramanian, b.drinkwater)@bristol.ac.uk



Figure 1: The UltraHaptics system. Left: the hardware. Centre: a simulation of two focal points, with colour representing phase and brightness representing amplitude. Right: receiving two independent points of feedback while performing a pinch gesture.

ABSTRACT
We introduce *UltraHaptics*, a system designed to provide multi-point haptic feedback above an interactive surface. *UltraHaptics* generates feedback at multiple points simultaneously, allowing users to receive haptic feedback through the display and directly on to users' unadorned hands. We investigate the desirable properties of such a system and demonstrate its potential. We show that the system is capable of creating multiple localised points of feedback in mid-air. Through psychophysical experiments we show that users are able to distinguish between different vibration frequencies and amplitudes of points of feedback. Finally, we explore a number of exciting new interaction possibilities that *UltraHaptics* provides.

INTRODUCTION
Multi-touch surfaces have become common in public settings, with large displays appearing in hotel lobbies, shopping centres and restaurants. These surfaces are able to dynamically change their interface allowing multiple users to interact at the same time and with very little instruction. However, they do not provide any physical feedback, which can be useful for certain applications. This lack of physical interaction and encourages spontaneous use. However, in return for this flexibility we have sacrificed the tactile affordance offered by the screen.

Most previous research has focused on recreating this feedback on interactive surfaces. This can be achieved through vibration [2, 4] or by physically changing the shape of the surface [3, 5].

There are situations when receiving haptic feedback before touching the surface would be beneficial. These include when vision of the display is restricted, such as while driving, or when the user doesn't want to touch the device, such as when their hands are dirty. Receiving haptic feedback before the surface would also allow for an additional information channel alongside the visual. Previous methods capable of providing this feedback have involved a device worn upon the user's body [33, 30, 32].

Author Keywords
Haptic feedback; touch screens; interactive tabletops.
ACM Classification Keywords
H.5.2. Information Interfaces and Presentation: User Interfaces

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<http://doi.acm.org/10.1145/2490198.2512014>

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Cater et.al.

Mid-air haptics

Ultrasonic haptics

Student Innovation Contest

Submission deadline Friday July 29, 2022 11:59pm AoE (Anywhere on Earth)

Acceptance notification Wednesday August 3, 2022

Submission of Project Tuesday October 25, 2022 11:59pm AoE
Video

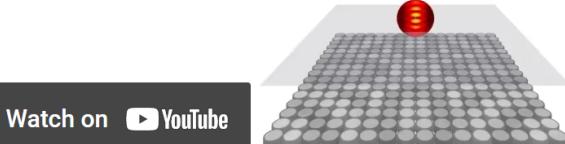
Presentation of final demo At the in-person UIST conference in Bend, Oct 29 - November 2, 2022

Apply here: [SIC registration page](#).

In the UIST Student Innovation Contest (aka the "SIC"), we explore how novel input, interaction, actuation, and output technologies can augment interactive experiences! This year, in partnership with UCL we are seeking students who will push the boundaries of input and output techniques with the **ultrasound haptics/levitation toolkit**. Join the UIST SIC team and turn your ideas into reality! Meet amazing people! Win fabulous prizes! You can apply here: <https://forms.gle/cSgRyiVLQ114Lnp3A>.



Watch on YouTube



Mid-air haptics

Vortex haptics

Session: Novel Interfaces UbiComp'13, September 8–12, 2013, Zurich, Switzerland

AirWave:
Non-Contact Haptic Feedback Using Air Vortex Rings

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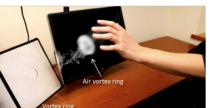
ABSTRACT
Input modalities such as speech and gesture allow users to interact with computers without holding or touching a physical device, thus enabling at-a-distance interaction. It remains challenging, however, to provide meaningful haptic feedback into such interaction. In this work, we explore the use of air vortex rings for this purpose. Unlike standard jets of air which are turbulent and dissipate quickly, vortex rings can be used to travel several meters and remain perceptible. In this paper, we review vortex formation theory and explore specific design parameters that allow us to precisely control the position and timing of haptic feedback. Applying this theory, we developed a prototype system called AirWave. We test through objective measures and subjective user studies whether users can resolve less than 10 cm at a distance of 2.5 meters. We further demonstrate through a user study that this can be used to direct tactile sensations to different regions of the human body.

Author Keywords:
Non-contact haptic feedback; air vortex rings

ACM Classification Keywords:
H.5.m Information interfaces and presentation: Miscellaneous

INTRODUCTION
Haptic feedback – more generally, the sense of touch – is a critical component of our interactions with the physical world. Numerous studies have demonstrated that haptic feedback can reduce error rates[9], increase efficiency [3], and improve user satisfaction [2] in a number of tasks. Vibrotactile feedback, one form of haptic feedback that has achieved widespread adoption in consumer devices, ranging from mobile phones to game controllers [1], mobile phones, and game controllers. All these systems assume the device is in physical contact with the user, an actuator can be embedded within the input de-

Figure 1: AirWave prototype filled with fog to visualize a vortex ring being used for providing precise non-contact haptic feedback to a user.



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<http://doi.acm.org/10.1145/2494312.2494361>

The specific contributions of this paper are:

UbiComp 13
Gupta et.al.

Mid-air haptics

Vortex haptics

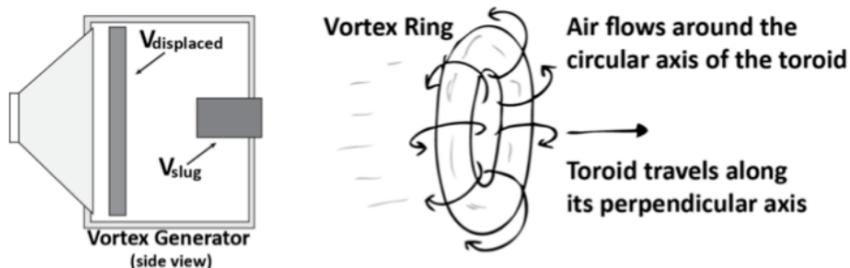


Figure 2: (left) Volume of air moved by speaker equals the volume of the slug used to model the vortex formation. (right) Vortex ring is a toroid where air flows around the circular axis as the entire toroid travels along its perpendicular axis.

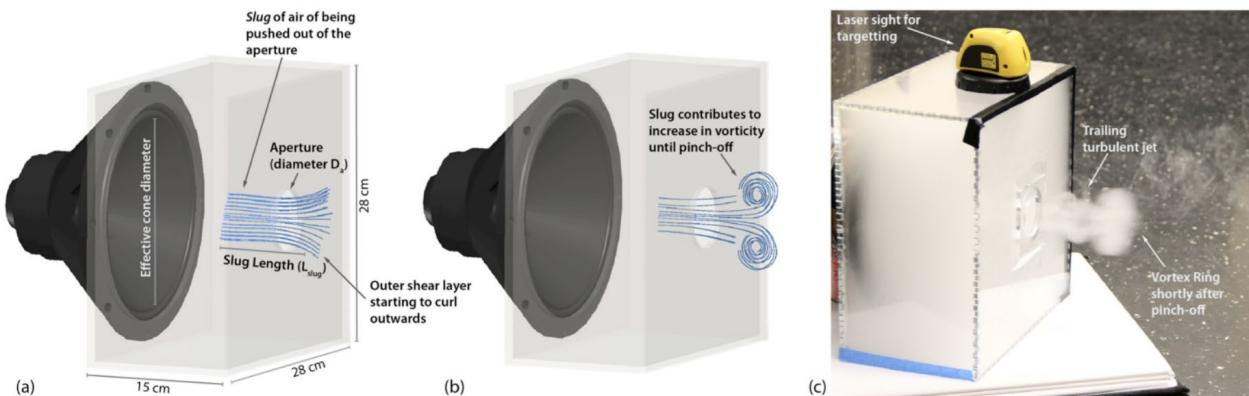
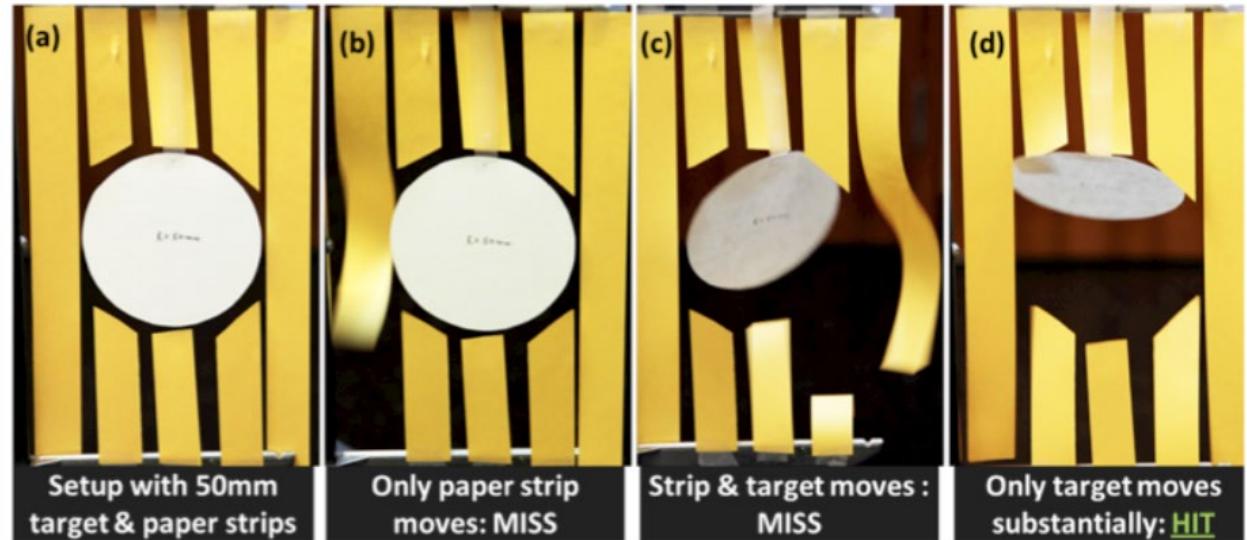
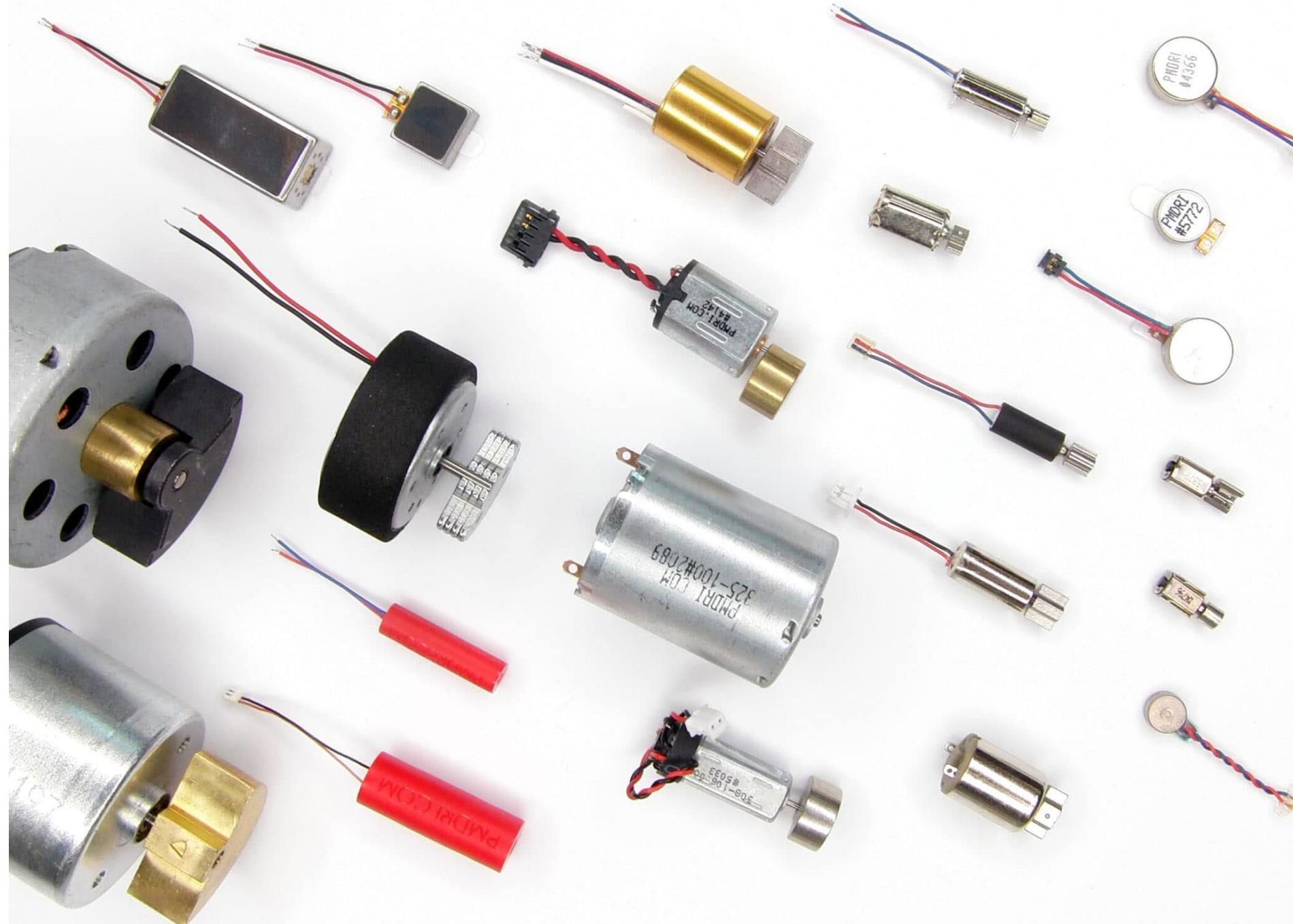


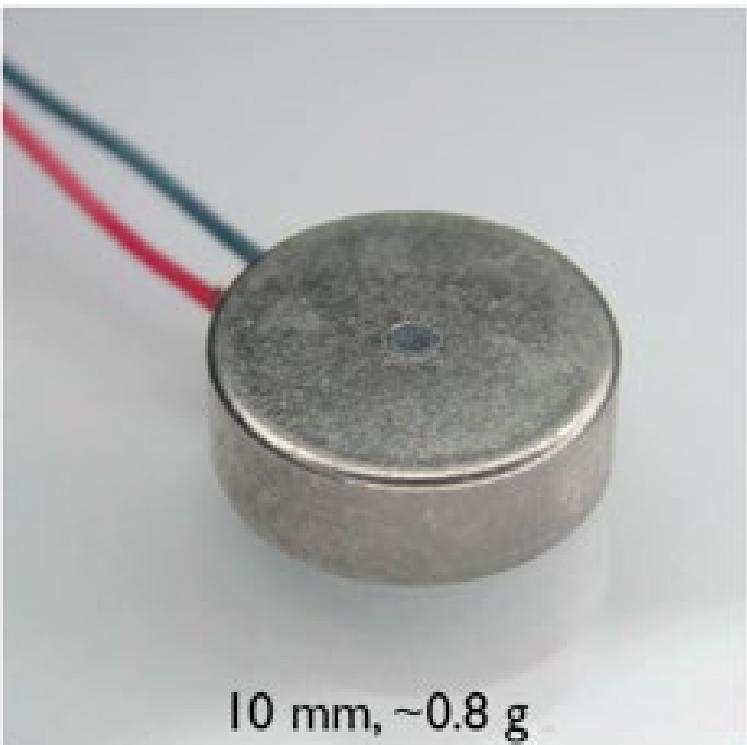
Figure 3: Vortex generator prototype and vortex ring formation process. (a) As the slug of air is pushed out of the aperture, the boundary layer starts to curl outwards as it exits, then (b) vorticity increases until pinch-off, causing the vortex to detach. (c) AirWave prototype filled with fog to visualize a vortex ring shortly after pinch-off.

Vibration feedback

eccentric rotating
mass motors
(ERM)



Shaftless vibration motors



10 mm, ~0.8 g

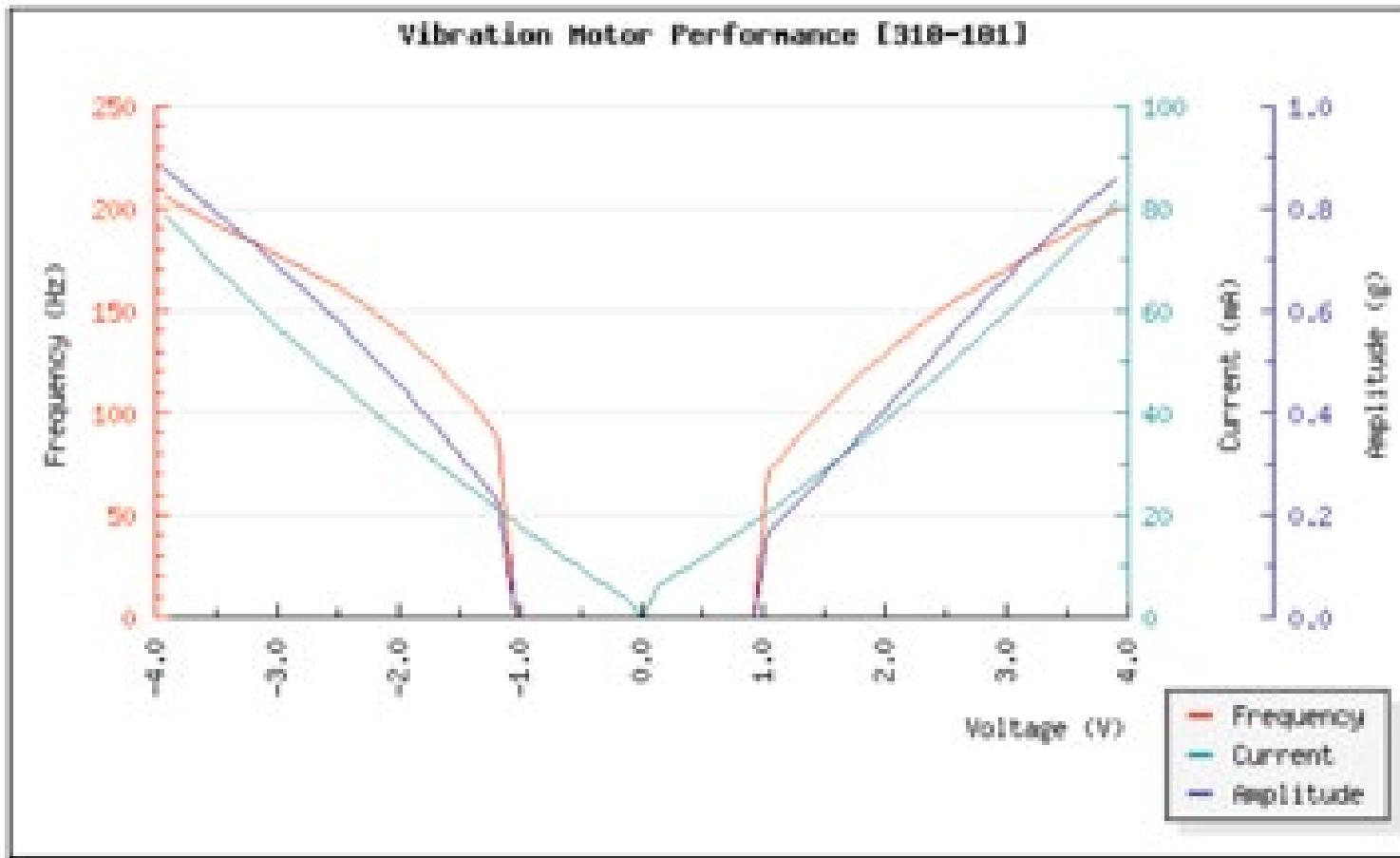
www.precisionmicrodrives.com

Three pole DC motor
with eccentric coil



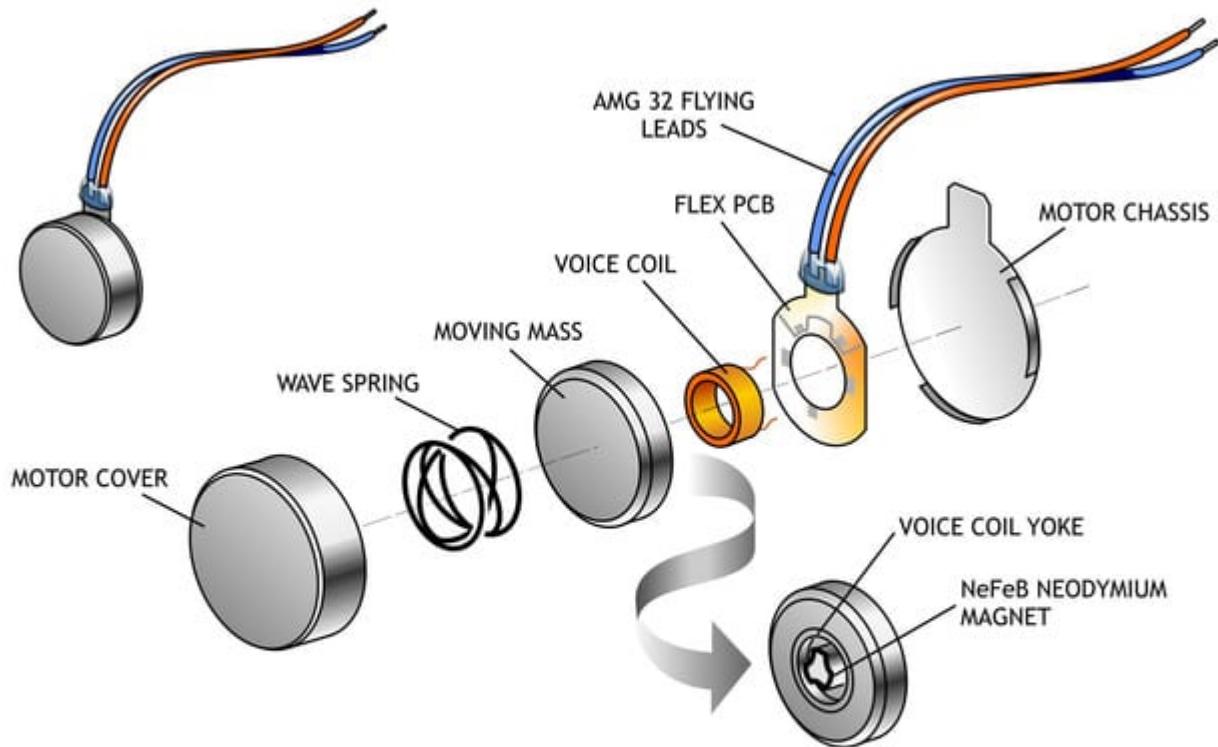
K. J. Kuchenbecker

Shaftless vibration motors



Frequency and magnitude are often coupled.

Linear resonant actuator (LRA)



PRECISION MICRODRIVES
PRECISION HAPTIC™
Y-AXIS LINEAR RESONANT ACTUATOR

Linear resonant actuator

MagnetIO: Passive yet Interactive Soft Haptic Patches Anywhere

Alex Mazursky, Shan-Yuan Teng,
Romain Nith, Pedro Lopes

Figure 1: (a) We propose a new type of haptic actuator, which we call MagnetIO, that is comprised of two parts: any number of soft interactive patches that can be applied anywhere and one battery-powered voice-coil worn on the user's fingertip. (b) When the finger-worn device contacts any of the interactive patches it detects its magnetic signature and (c) makes the patch vibrate via a voice-coil. (d) The device can be attached to any surface (e.g., wall, objects, body, etc.) and (e) can be used with neodymium powder, resulting in soft and stretchable magnets. (f) This novel decoupling of traditional vibration motors allows users to add interactive patches to their surroundings by attaching them to walls, objects or even other devices or appliances without instrumenting the object with electronics.



MagnetIO: Passive yet Interactive Soft Haptic Patches Anywhere

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Figure 1: (a) We propose a new type of haptic actuator, which we call MagnetIO, that is comprised of two parts: any number of soft interactive patches that can be applied anywhere and one battery-powered voice-coil worn on the user's fingertip. (b) When the finger-worn device contacts any of the interactive patches it detects its magnetic signature and (c) makes the patch vibrate via a voice-coil. (d) The device can be attached to any surface (e.g., wall, objects, body, etc.) and (e) can be used with neodymium powder, resulting in soft and stretchable magnets. (f) This novel decoupling of traditional vibration motors allows users to add interactive patches to their surroundings by attaching them to walls, objects or even other devices or appliances without instrumenting the object with electronics.

ABSTRACT
We propose a new type of haptic actuator, which we call MagnetIO, that is comprised of two parts: one battery-powered voice-coil worn on the user's fingertip and any number of interactive soft patches that can be attached onto any surface (everyday objects, user's body, appliances, etc.). When the user's finger wearing our voice-coil contacts any of the interactive patches, it detects the magnetic signature via magnetometer and vibrates the patch, adding haptic feedback to otherwise input-only interactions. To allow these passive patches to vibrate, we propose a new type of haptic actuator composed with polarized neodymium powder, resulting in soft and stretchable magnets. This stretchable form-factor allows them to be wrapped around any surface, such as a wall or a table, and even stretched. We demonstrate how these add haptic output to many situations, such as adding haptic buttons to the walls of one's home. In our live demonstration, we show how MagnetIO can be attached to a wall and can be excited across a wide range of frequencies (0–500 Hz) and be tuned to excite at specific frequencies based on the patch's geometry. Furthermore, we demonstrate that MagnetIO's vibration intensity is as powerful as a typical linear resonant actuator (LRA); yet, unlike these rigid actuators, our passive patches operate as stretchable and conformable actuators of vibration, which enables a wider band around its resonant frequency than an equivalent LRA.

CCS CONCEPTS
• Human computer interaction (HCI) • Interaction devices.
• Haptic devices.

KEYWORDS
soft magnets, ubiquitous haptics, fabrication

ACM Reference Format
Alex Mazursky, Shan-Yuan Teng, Romain Nith, and Pedro Lopes. 2021. MagnetIO: Passive yet Interactive Soft Haptic Patches Anywhere. In *CHI Conference on Human Factors in Computing Systems (CHI '21)*, May 8–13, 2021, Yokohama, Japan. ACM, New York, NY, USA, 15 pages. <https://doi.org/10.1145/3411768.3445545>

1 INTRODUCTION
Today's interactive devices increasingly instrument every kind of surface, effectively adding haptic functionality even to non-sensory surfaces. However, this instrumentation is often rigid and inflexible, leading to a lack of naturalness, durability, and scalability of these devices. To enable sensing these interactions, researchers engineered conformable/stretchable sensing devices so that these can comfortably

CHI 21

Mazursky et.al.

Recap

Haptic concept
Types of haptic
Tactile feedback and Mechanoreception
Examples of tactile devices



Optional readings

Session: Novel Interfaces

UbiComp'13, September 8–12, 2013, Zurich, Switzerland

AirWave: Non-Contact Haptic Feedback Using Air Vortex Rings

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ABSTRACT

Input modalities such as speech and gesture allow users to interact with computers without holding or touching a physical device, thus enabling at-a-distance interaction. It remains an open problem, however, to incorporate haptic feedback into such interaction. In this work, we explore the use of air vortex rings for this purpose. Unlike standard jets of air, which are turbulent and dissipate quickly, vortex rings can be focused to travel several meters and impart perceptible feedback. In this paper, we review vortex formation theory and explore specific design parameters that allow us to generate vortices capable of imparting haptic feedback. Applying this theory, we developed a prototype system called AirWave. We show through objective measurements that AirWave can achieve spatial resolution of less than 10 cm at a distance of 2.5 meters. We further demonstrate through a user study that this can be used to deliver tactile stimuli to different regions of the human body.

Author Keywords

Non-contact haptic feedback; air vortex rings

ACM Classification Keywords

H.5.m Information interfaces and presentation: Miscellaneous

INTRODUCTION

Haptic feedback – more generally, the sense of touch – is a critical component of our interactions with the physical world. Numerous studies have demonstrated that haptic feedback can reduce error rates [9], increase efficiency [5], and increase user satisfaction [2] in sensorimotor tasks. Vibrotactile feedback, the use of vibrating motors to create tactile sensations, is one form of haptic feedback that has achieved widespread adoption in consumer devices, having been used to augment the mouse [13], touch screen [11], mobile phones, and game controllers. All these systems assume that because the device is in physical contact with the user, an actuator can be embedded within the input de-

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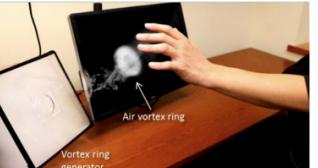


Figure 1: AirWave prototype filled with fog to visualize a vortex ring being used for providing precise non-contact haptic feedback to a user.

vice and provide direct mechanical stimulation. However, this assumption is no longer universal, as non-contact and at-a-distance sensing (e.g., computer vision and speech recognition) is becoming more prevalent in our computing environments. The Microsoft Xbox Kinect, for example, allows immersive gaming and media control through computer vision and speech recognition, which require no physical contact between the user and the computer. This presents a new challenge to haptic feedback systems, and our core research question:

How do we restore haptic realism to virtual environments when the user is meters away from the computer, and is neither carrying nor wearing an interface device?

In order to restore haptic realism to at-a-distance, non-contact interfaces, we investigate the use of *air vortex rings* as a technique for delivering haptic feedback. We describe vortex formation theory and parameterize the design of new vortex generators capable of haptic feedback so that subsequent work can build upon our formulation. We then describe a prototype called AirWave (Figure 1), which provides at-a-distance haptic feedback that requires no physical contact or instrumentation of the human body. We provide an analysis of the spatial resolution of this prototype, and we assess how well vortices are perceived by users when targeted at 8 different locations on the body. In a study with 10 users, we found that the mean error between the intended target point and where users sensed the vortex was less than 10 cm, at a distance of 2.5 m.

The specific contributions of this paper are:

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Gupta et.al.

TeslaTouch: Electrovibration for Touch Surfaces

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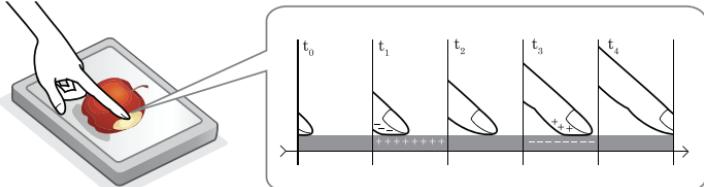


Figure 1: TeslaTouch uses electrovibration to control electrostatic friction between a touch surface and the user's finger.

ABSTRACT

We present a new technology for enhancing touch interfaces with tactile feedback. The proposed technology is based on the electrovibration principle, does not use any moving parts and provides a wide range of tactile feedback sensations to fingers moving across a touch surface. When combined with an interactive display and touch input, it enables the design of a wide variety of interfaces that allow the user to feel virtual elements through touch. We present the principles of operation and an implementation of the technology. We also report the results of three controlled psychophysical experiments and a subjective user evaluation that describe and characterize users' perception of this technology. We conclude with an exploration of the design space of tactile touch screens using two comparable setups, one based on electrovibration and another on mechanical vibrotactile actuation.

ACM Classification: H.5.2 [Information interfaces and presentation]: User Interfaces - Graphical user interfaces, Input devices and strategies, Haptic I/O.

General terms: Design, Measurement, Human Factors.

Keywords: Tactile feedback, touch screens, multitouch.

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INTRODUCTION

Interest in designing and investigating haptic interfaces for touch-based interactive systems has been rapidly growing. This interest is partially fueled by the popularity of touch-based interfaces, both in research and end-user communities. Despite their popularity, a major problem with touch interfaces is the lack of dynamic tactile feedback. Indeed, as observed by Buxton as early as 1985 [6], a lack of haptic feedback: 1) decreases the realism of visual environments, 2) breaks the metaphor of direct interaction, and 3) reduces interface efficiency, because the user can not rely on familiar haptic cues for accomplishing even the most basic interaction tasks.

Most previous work on designing tactile interfaces for interactive touch surfaces falls into two categories. First, the touch surface itself can be actuated with various electromechanical actuators such as piezoelectric bending motors, voice coils, and solenoids [10, 27]. The actuation can be designed to create surface motion either in the normal [27] or lateral directions [4]. Second, the tools used to interact with a surface, such as pens, can be enhanced with mechanical actuation [9, 19].

In this paper, we present an alternative approach for creating tactile interfaces for touch surfaces that does not use any form of mechanical actuation. Instead, the proposed technique exploits the principle of *electrovibration*, which allows us to create a broad range of tactile sensations by controlling *electrostatic friction* between an instrumented touch surface and the user's fingers. When combined with an input-capable interactive display, it enables a wide variety of interactions augmented with tactile feedback.

Tactile feedback based on electrovibration has several compelling properties. It is fast, low-powered, dynamic, and can

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Bau et.al.