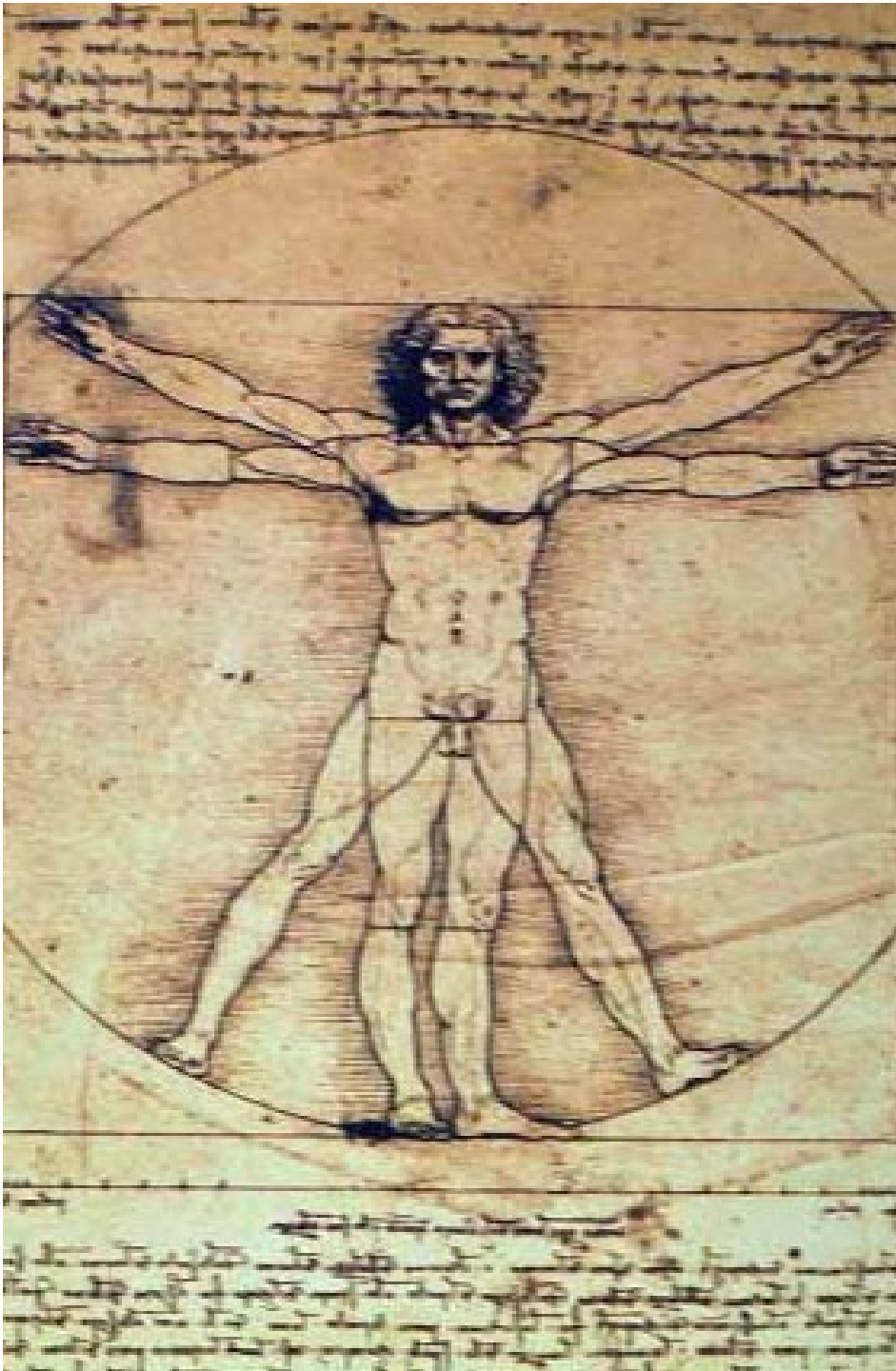




Interactive System インタラクティブ システム特論 (6)

Hiroyuki Kajimoto
kajimoto@uec.ac.jp
Twitter kajimoto



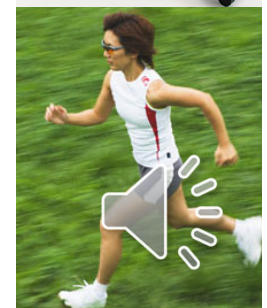
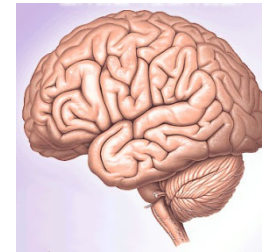
Schedule

講義番号/No.	講義日/Date	内容/Contents	pdf	video	レポート締切日/Report Deadline
1	4/05	人間計測手法/Measuring Human	[ pdf] 2023年版	video 	4/12
-	4/12	出張のため休講/Class cancelled			
2	4/19	視覚/Human Vision System	[ pdf] 2023年版	video 	4/26
3	4/26	視覚センシング/Visual Sensing	[ pdf] 2023年版	video 	5/3
4	5/10	視覚ディスプレイ/Visual Display	[ pdf] 2023年版	video 	5/17
-	5/17	出張のため休講/Class cancelled			
5	5/24	聴覚、聴覚インタフェース/Auditory Interface	[ pdf] 2023年版	video 	5/31
-	5/31	出張のため休講/Class cancelled			
6	6/7	触覚、触覚インタフェース/Tactile Interface	[ pdf] 2023年版	video 	6/14
7	6/14	触覚、触覚インタフェース2/Tactile Interface2	[ pdf] 2023年版	video 	6/21
8	6/21	力覚、力覚インタフェース/Haptic Interface	[ pdf] 2023年版	video 	6/28
9	6/28	移動感覚インタフェース/Locomotion Interface	[ pdf] 2023年版	video 	7/5
-	-	プレゼンビデオ提出締切/Presentation video upload	[ pdf]	-	7/12
-	-	プレゼンビデオ評価(1)/Watch group 1 video	-	-	7/19
-	-	プレゼンビデオ評価(2)/Watch group 2 video	-	-	7/26
-	-	プレゼンビデオ評価(3)/Watch group 3 video	-	-	8/2



Outline of the lecture

1. 人間計測手法／Measuring Human
2. 視覚／Human Vision System
3. 視覚センシング／Visual Sensing
4. 視覚ディスプレイ／Visual Display
5. 聴覚、聴覚インタフェース／Auditory Interface
6. 触覚、触覚インタフェース／Tactile Interface
7. 触覚、触覚インタフェース応用／Tactile Interface2
8. 力覚、力覚インタフェース／Haptic Interface
9. 移動感覚インタフェース／Locomotion Interface



触覚＝体性感覚＋皮膚感覚

Haptic Sense = Proprioception + Cutaneous Sense



触覚＝接**触**によって生じる感**覚**

(Haptic＝「接触(Contact)」(ギリシャ語／in Greece))

- 皮膚表面の変形(皮膚感覚／Cutaneous Sense, Skin Sense)
- 筋肉の伸縮, 関節角(深部感覚・力覚／Proprioception, Force Sense)

今日の話: 狭義の皮膚感覚／Today's Talk focuses on skin

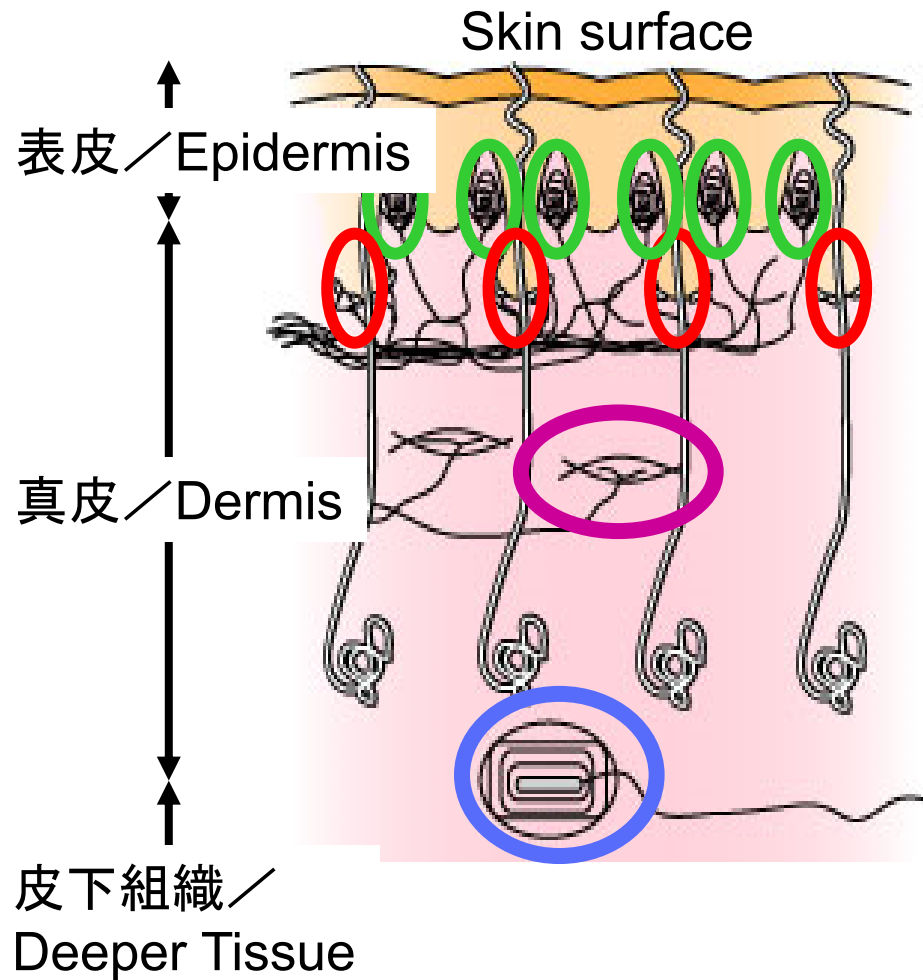


TODAY's TOPIC

1. Skin Sensation Mechanism
2. Tactile Illusion
3. Tactile Display



皮膚構造(無毛部)Skin Structure (Hairless Parts)



機械受容器: 機械的変形に応答
Mechanoreceptor: Sense Mechanical Deformation

浅部 / Shallow part

● マイスナー小体 / Meissner Corpuscle

● メルケル細胞 / Merkel Cell

深部 / Deep part

● ルフィニ終末 / Ruffini Ending

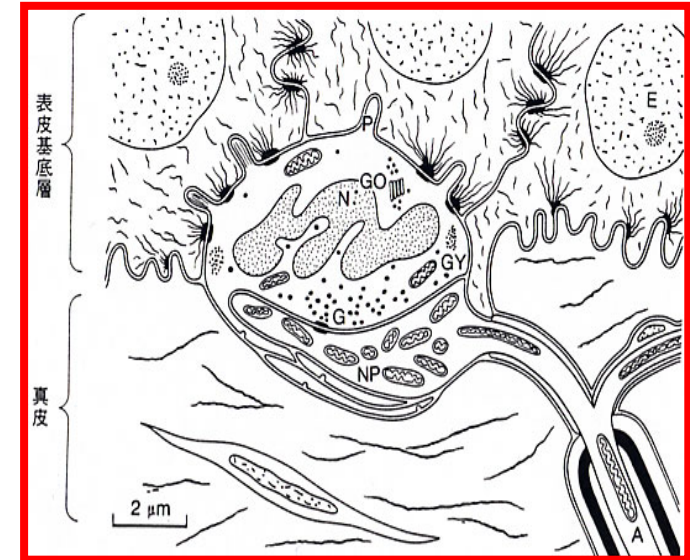
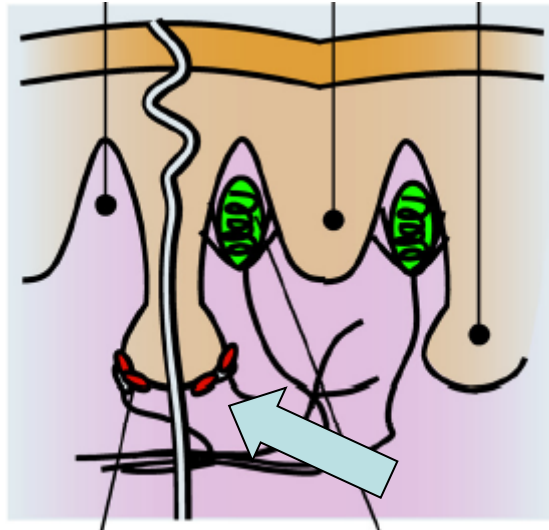
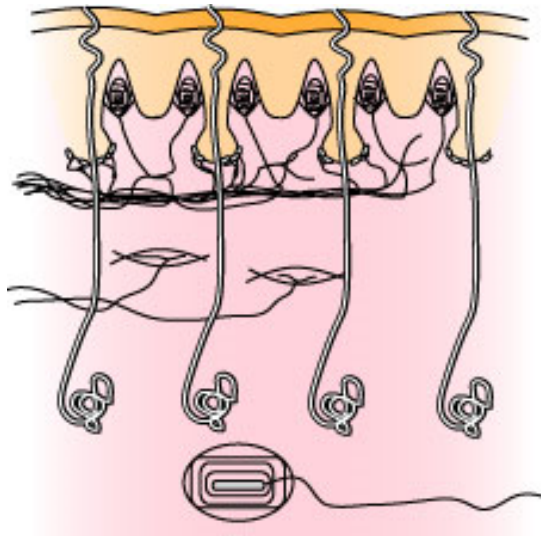
● パチニ小体 / Pacinian Corpuscle

その他 / Misc

自由神経終末 (痛覚、温度感覚)
Free Ending (Pain, Temperature)



メルケル細胞／Merkel Cell



新編 感覚・知覚心理学ハンドブック

<http://www.seishinshobo.co.jp/book/b88071.html>



- 表皮と真皮の境界に密に存在.
- 唯一の細胞性受容器. 神経とシナプス接合
- 静的な歪に応答
- 発火頻度は歪の大きさに比例
- 単独の活動では純粋な圧覚を生成
- Densely Populated at the bottom of epidermis.
- Sense Static Deformation.
- Pulse Frequency is Proportional to Deformation.
- When activated, Pure Pressure Sensation is generated.

カandel神経科学(Principles of Neural Science)

<https://www.medsai.co.jp/kandel/syousai/index.html>

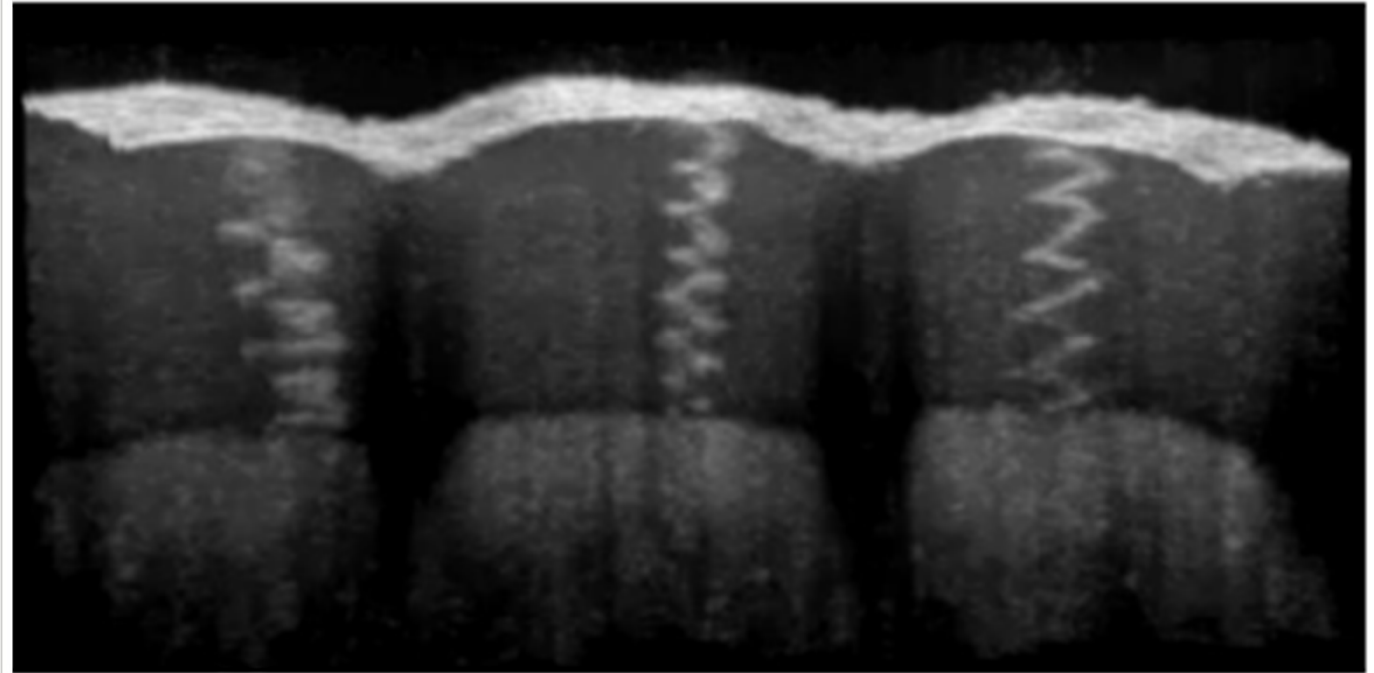
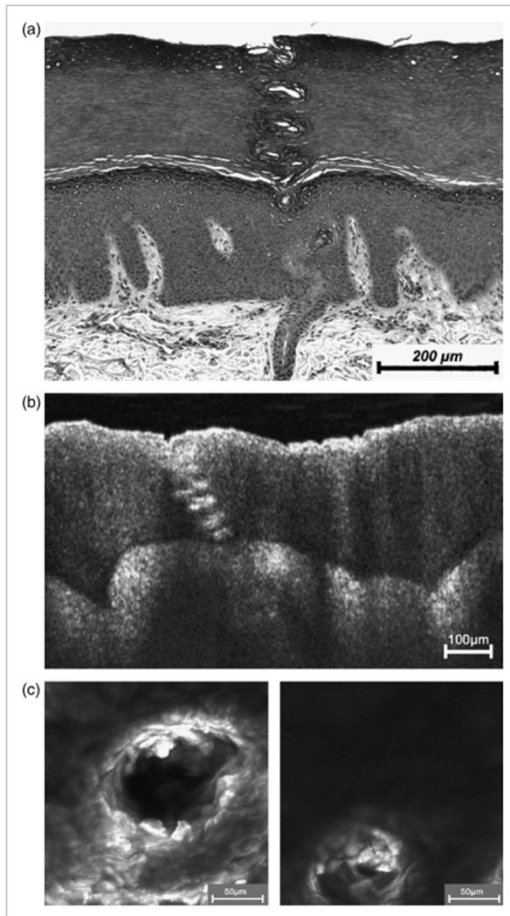
(参考) 蒸気圧覚 Pressure sensation by hot steam



[T. Kai, Y. Kojima, Y. Hashimoto, H. Kajimoto, "Mechanism of Pressure Sensation Generated by Hot Steam", ISVRI2011.](#)



(参考) 汗腺の構造 Structure of sweat ducts



- 従来の図に書かれているような「直線的な穴＋塊」ではなく、らせん構造をもつ？
- Not a "linear hole" as described in the conventional diagram, but a helical structure?

Juergen Lademann, Nina Otberg, Heike Richter, Lars Meyer, Heike Audring, Alexa Teichmann, Steven Thomas, Alexander Knüttel, Wolfram Sterry: Application of optical non-invasive methods in skin physiology: a comparison of laser scanning microscopy and optical coherent tomography with histological analysis

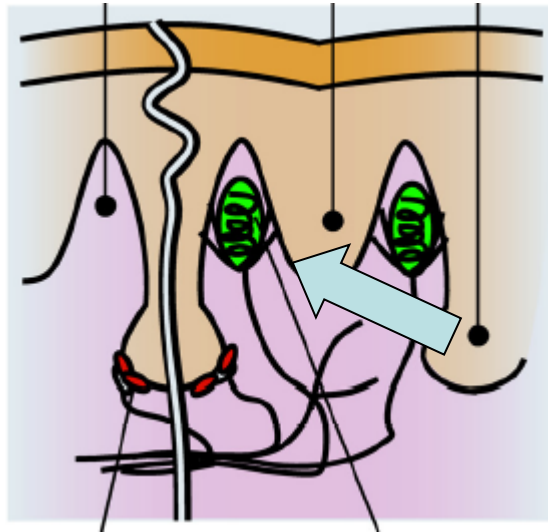
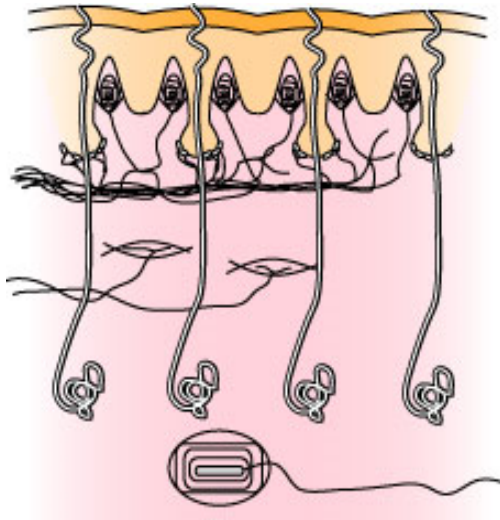
<https://onlinelibrary.wiley.com/doi/full/10.1111/j.1600-0846.2007.00208.x>

A Kochnev, Betzael, N. , Ben Ishai, P. , and Feldman, Yu.. 6/10/2018. "Human Sweat Ducts As Helical Antennas In The Sub-Thz Frequency Range-An Overview". Terahertz Science And Technology, 11, 3, Pp. 43-56.

<https://yurifeldman.huji.ac.il/publications/human-sweat-ducts-helical-antennas-sub-thz-frequency-range-overview>



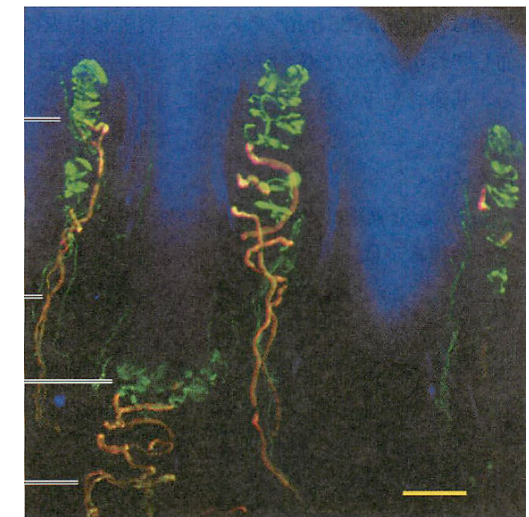
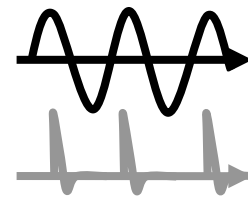
マイスナー小体／Meissner Corpuscle



新編 感覚・知覚心理学ハンドブック

<http://www.seishinshobo.co.jp/book/b88071.html>

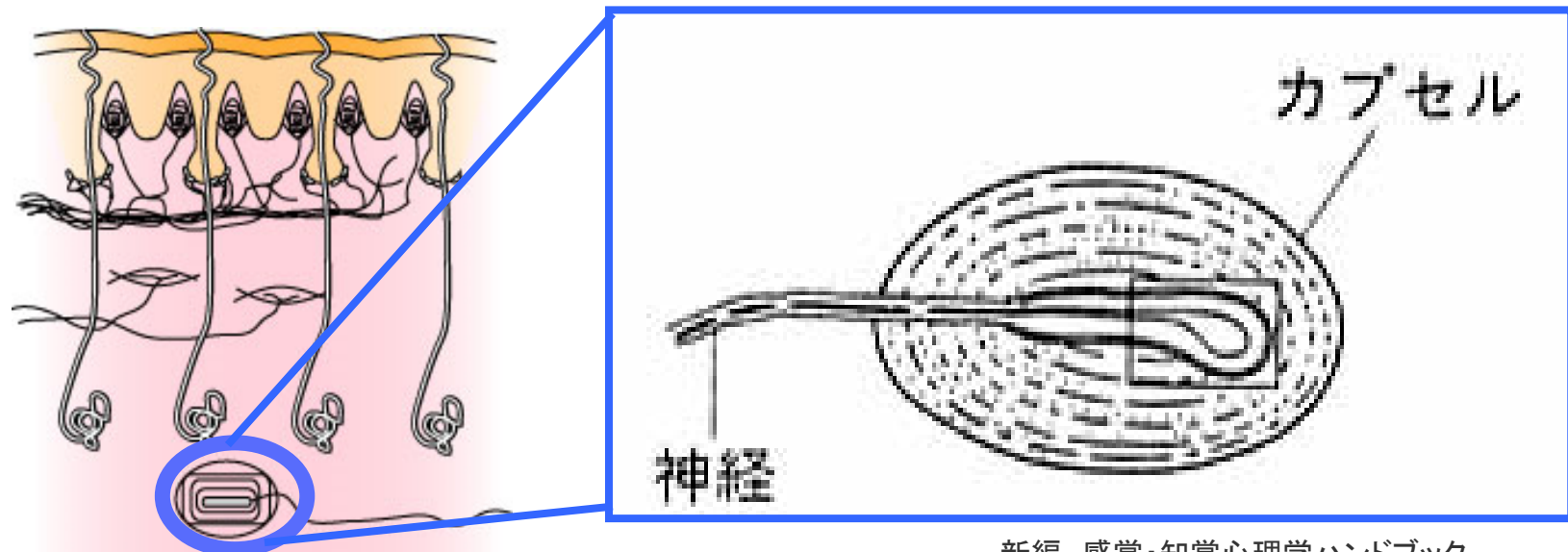
- 真皮乳頭部に密に存在.
- 低周波振動(15-100Hz)に応答(共振30Hz)
- 発火周波数～振動周波数
- 単独の活動では振動感覚, パタパタ感を生じる
- Densely populated at 0.5 – 0.7mm depth.
- Sense Low Frequency Vibration (15-100Hz)
- Has Resonant Frequency (30Hz)
- Pulse Frequency ~ Vibration Frequency
- Single Activity Generates “Flutter” Vibratory Sensation



カandel神経科学(Principles of Neural Science)

<https://www.medsai.co.jp/kandel/syousai/index.html>

パチニ小体／Pacinian Corpuscle



新編 感覚・知覚心理学ハンドブック

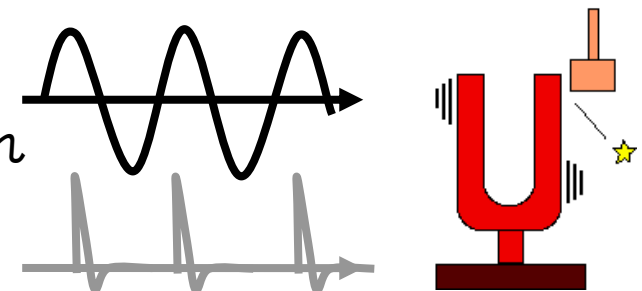
<http://www.seishinshobo.co.jp/book/b88071.html>

- 皮下組織にまばらに存在.
- 高周波振動に応答(60-800Hz)(共振250Hz)
- 発火周波数～振動周波数
- 単独の活動では音叉に触れたような振動感覚, 指全体の痺れ

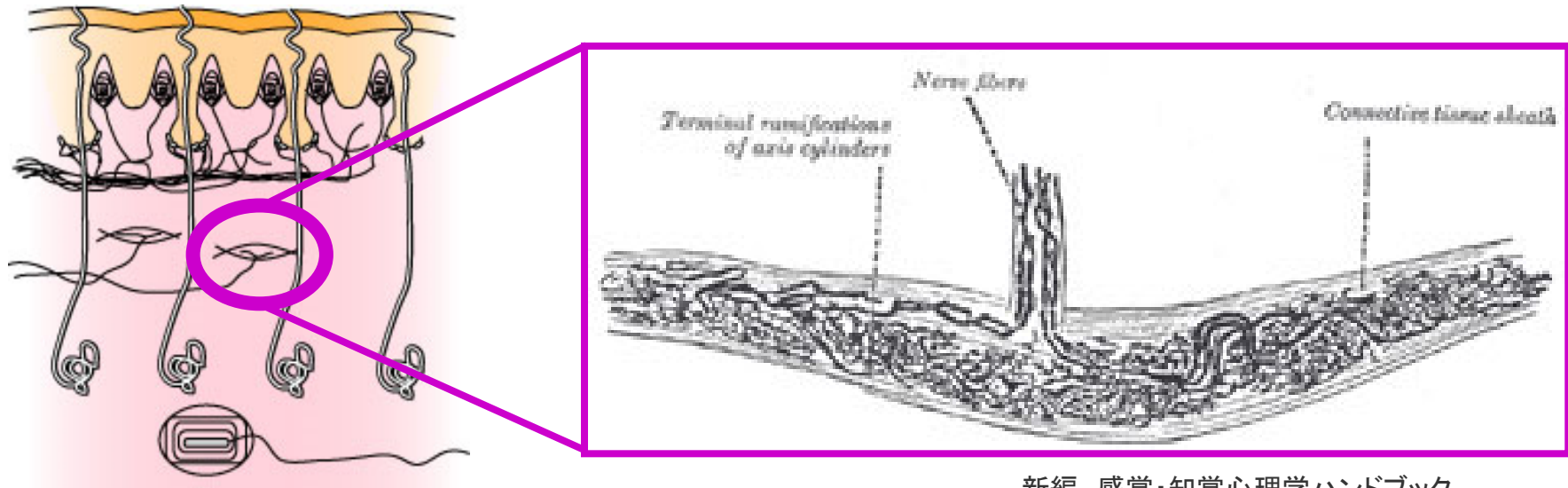
- Sparsely populated at deep region
- Sense High Frequency Vibration (60-800Hz)
- Has Resonant Frequency (250Hz)

- Pulse Frequency～Vibration Frequency

- Single Activity Generates “numb” sensation, just like touching a tuning fork or speaker



ルフィニ終末／Ruffini Ending



新編 感覚・知覚心理学ハンドブック

<http://www.seishinshobo.co.jp/book/b88071.html>

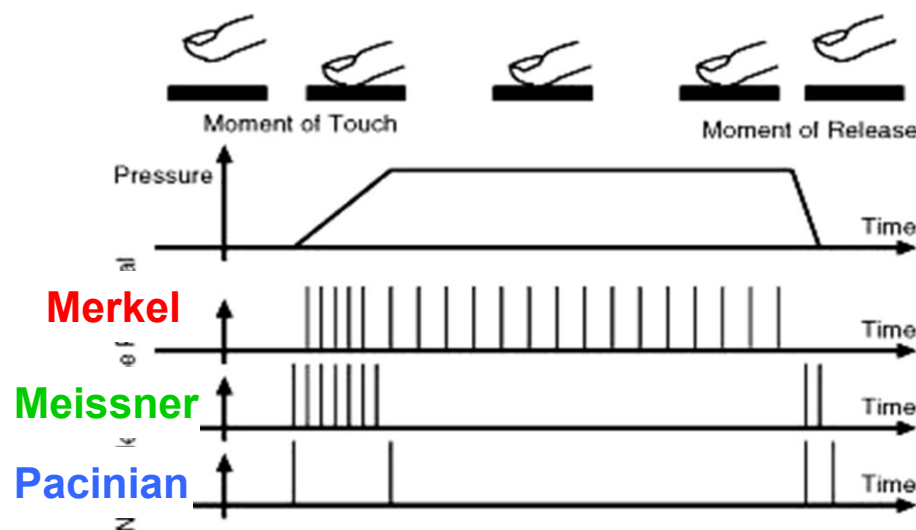
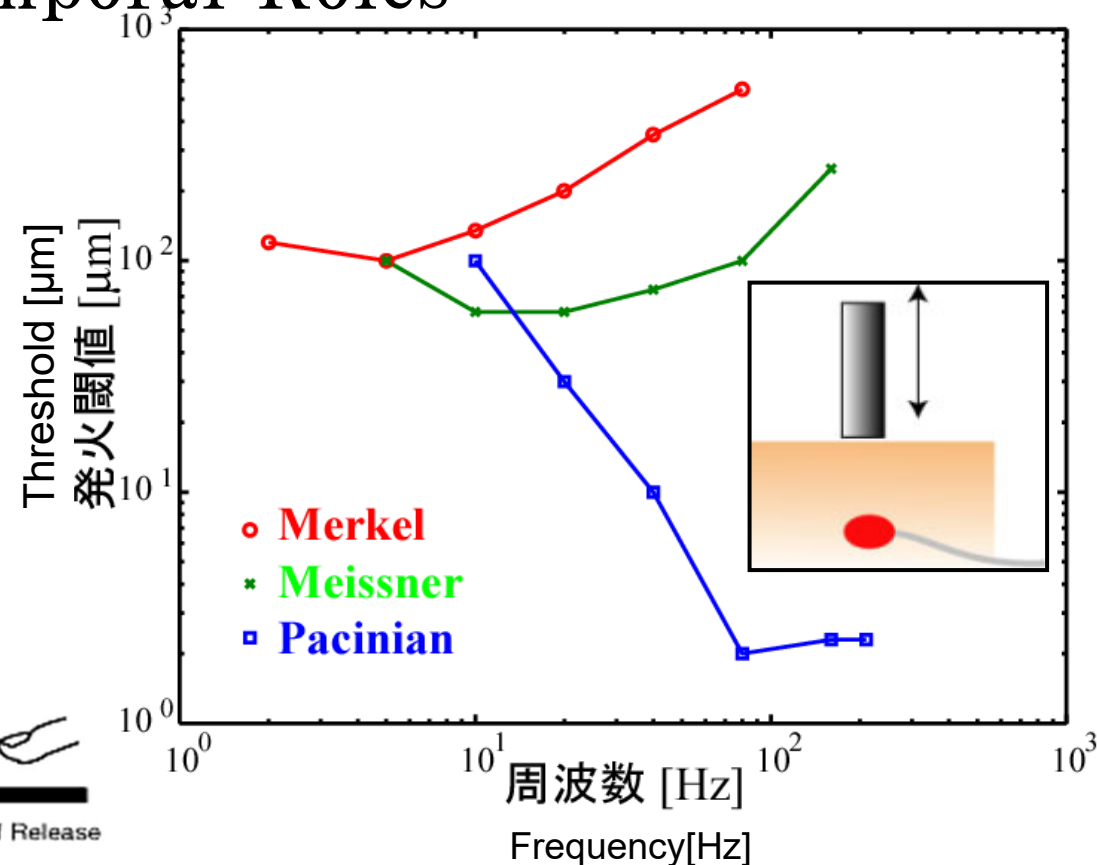
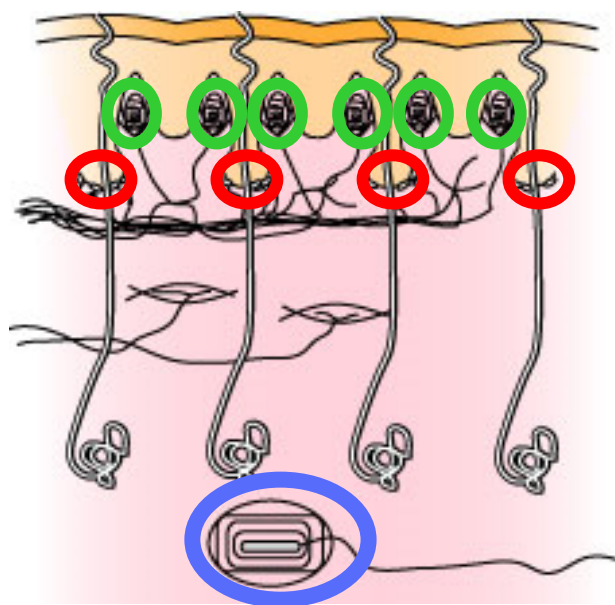
- 皮下組織に疎らに存在.
- 静的な横ずれに応答
- 発火頻度は横ずれの大きさに比例
- 単独の活動では感覚を生じない(?)→最近は感覚を生じるが「広い圧覚」との報告
- Sparsely Populated in a deep region (2mm ~ depth)
- Senses Static **Horizontal** Deformation
- Pulse Frequency is Proportional to Horizontal Deformation.
- Single activation does not generate sensation(?)→it does but broad pressure**



受容器と役割の対応について／

- SA-I、SA-II、RA(FA-I)、PC(FA-II)という4種類の活動の種類がある。
 - 様々な傍証から、SA-IはMerkel、SA-IIはRuffini、RAはMeissner、PCはPaciniだろうと推測される。
 - ただし、SA-IIIについては不思議なことも。
-
- 指先の受容器：爪周辺にMerkelがたくさんある。これがSA-IIの役割を果たしているのでは？
 - 最近の研究で、SA-IIを電気刺激すると広い圧迫感が生じるが横ずれ感は(あまり)生じない。<https://physoc.onlinelibrary.wiley.com/doi/10.1113/JP282873>
-
- SA-IIIについて話をするときは注意

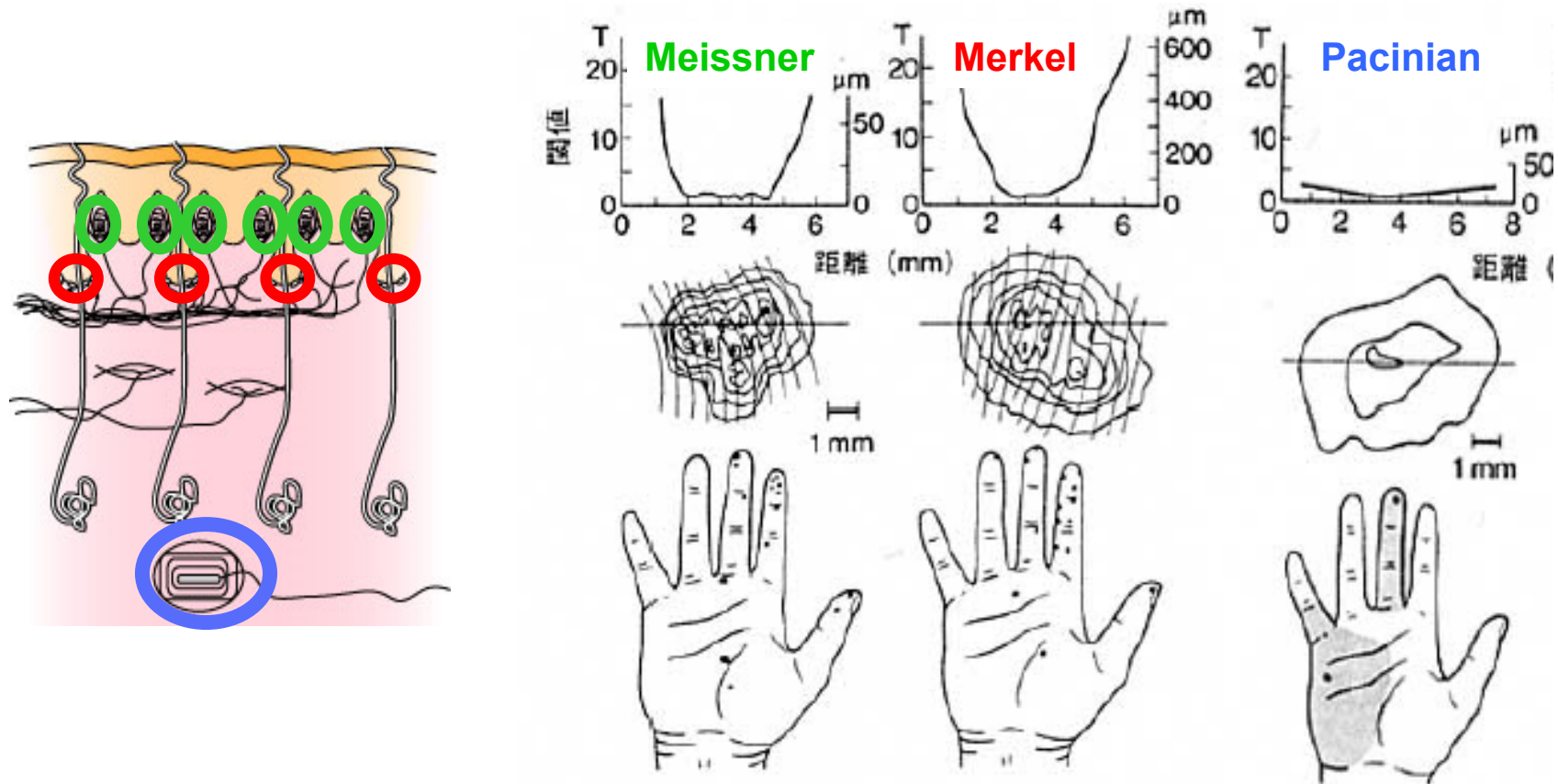
時間的役割分担／Temporal Roles



- **Merkel**: 直流成分／圧力
- **Meissner**: 低周波成分／速度
- **Pacinian**: 高周波成分／加速度

- **Merkel**: DC / Displacement & Pressure
- **Meissner**: Low Freq. Vibration / Velocity
- **Pacinian**: High Freq. Vibration / Acceleration

空間的役割分担／Spatial Roles



新編 感覚・知覚心理学ハンドブック

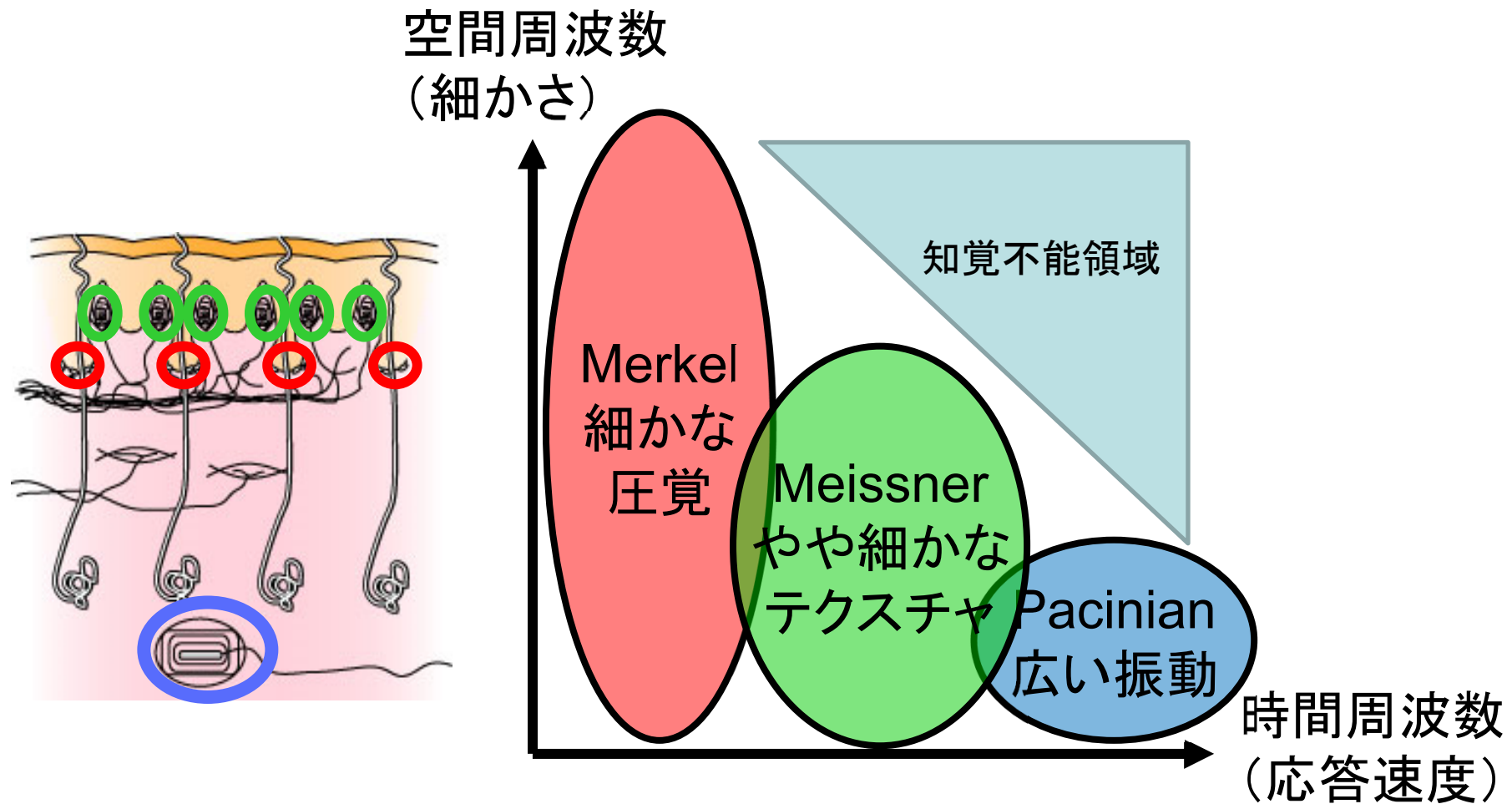
<http://www.seishinshobo.co.jp/book/b88071.html>

- Merkel: 細かいパターン／Small Pattern
- Meissner: 皮膚上の細かい動き／Small Area Movement
- Pacini: 広い面積の動き／Large Area Movement



各機械受容器の役割分担

Spatial temporal roles

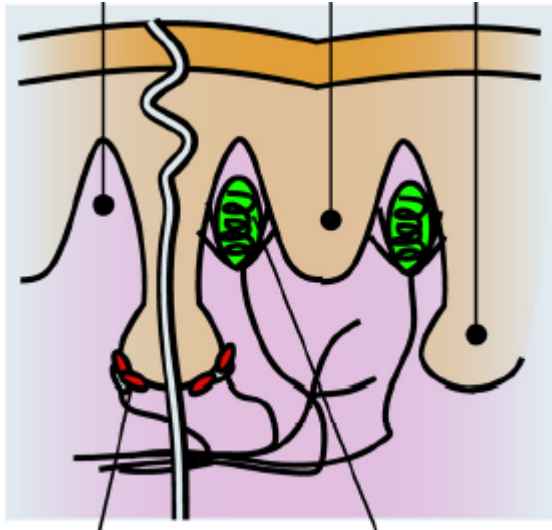


ポイント: 時間的, 空間的な相補性



皮膚構造と受容器

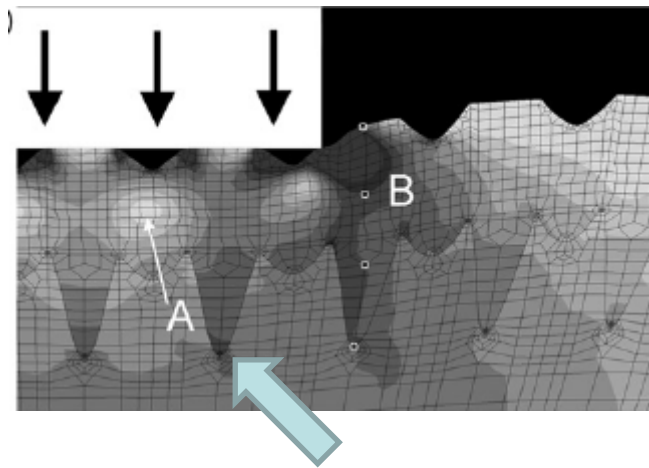
Skin Structure and Mechanoreceptors



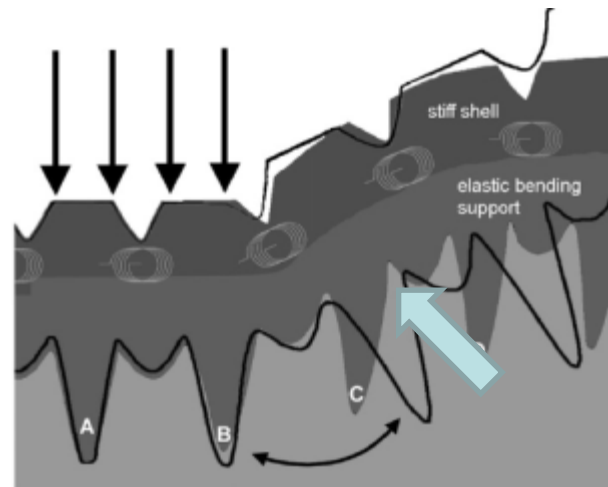
- ・表皮：硬い
- ・真皮：柔らかい
- ・MerkelとMeissnerは境界に存在

- ・Epidermis: Hard
- ・Dermis: Soft

Merkel and Meissner are at the interface of the two layers.



Stress is Concentrated at Merkel

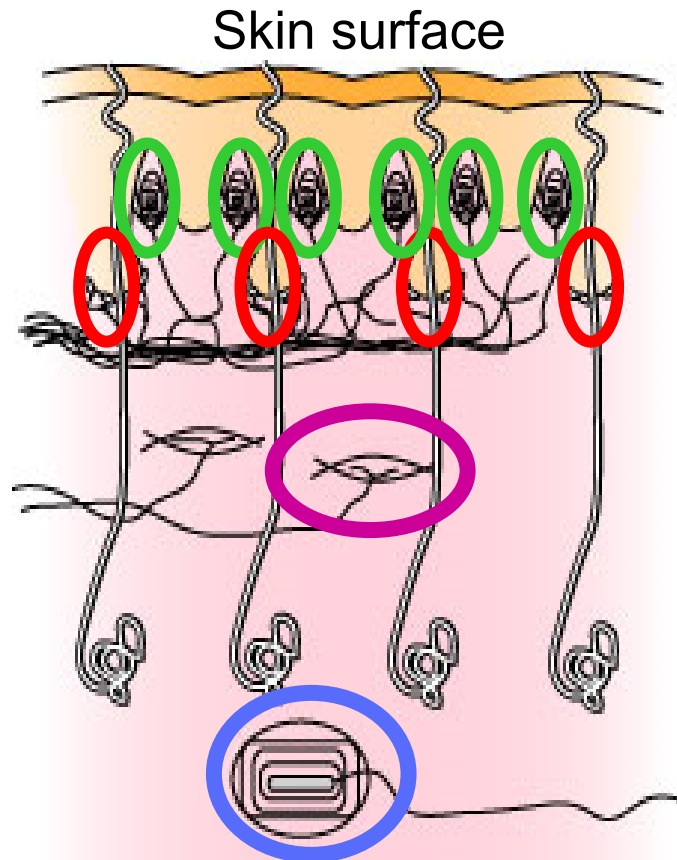


Strain is Largest at Meissner



形状は主にMerkelによってコーディングされる

Shape is mainly coded by Merkel Cells



浅部/Shallow part

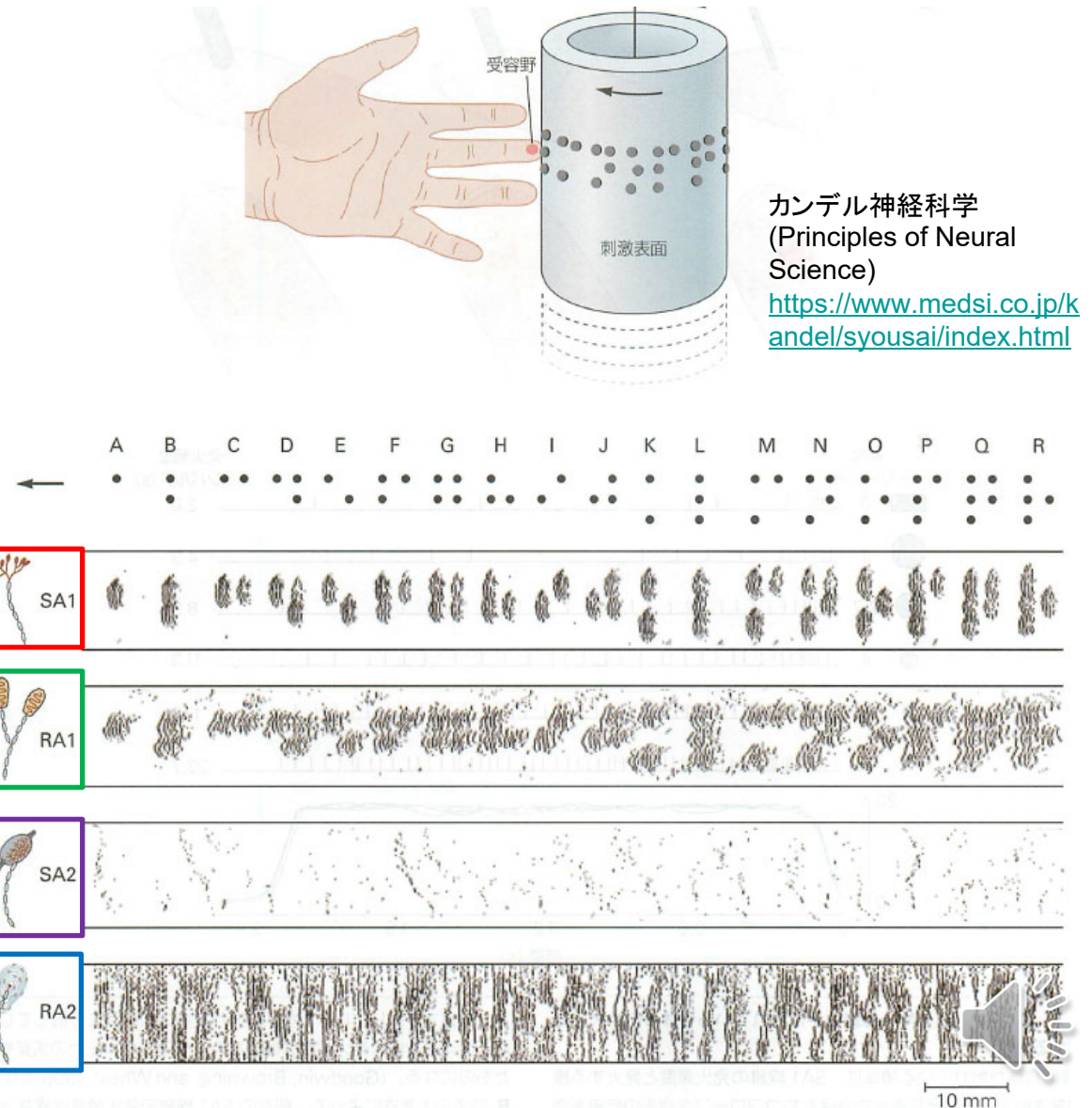
●マイスナー小体/Meissner Corpuscle

●メルケル細胞/Merkel Cell

深部/Deep part

●ルフィニ終末/Ruffini Ending

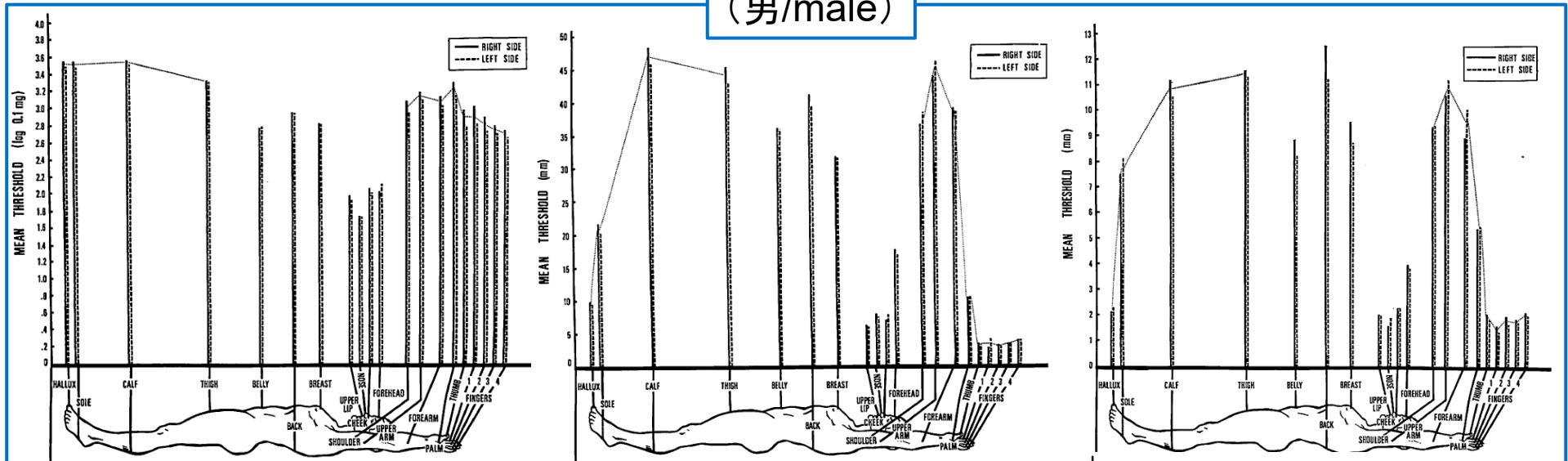
●パチニ小体/Pacinian Corpuscle



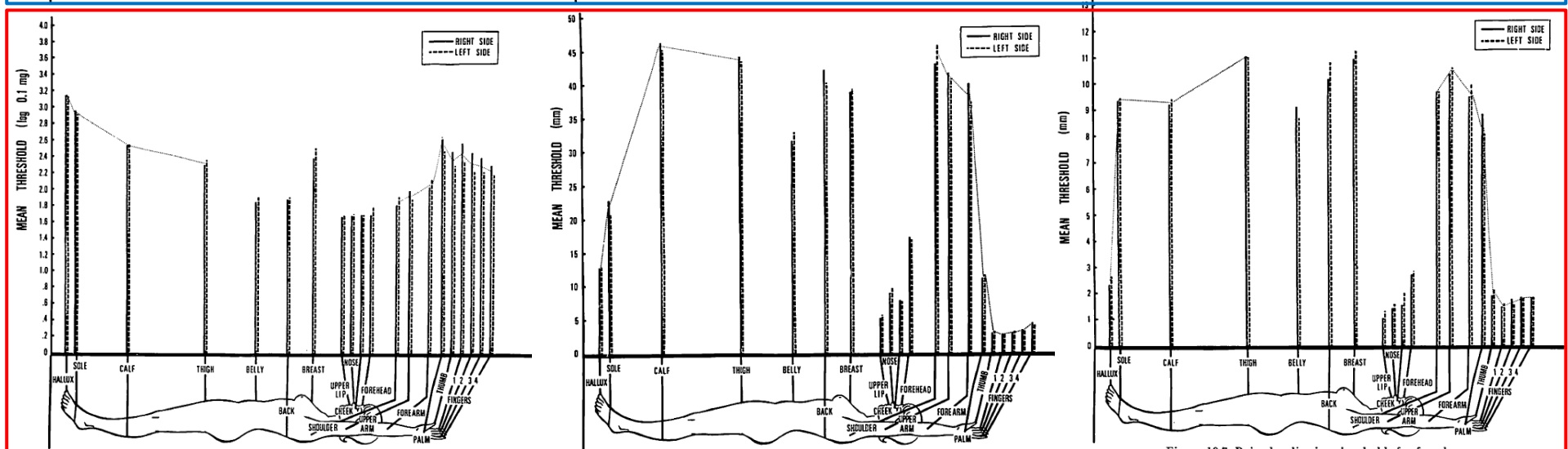
身体部位依存性

S. Weinstein, Intensive and Extensive Aspects of Tactile Sensitivity as a Function of Body Parts, Sex, and Laterality. In D. R. Kenshalo (Ed.), The skin senses, 1968.

(男/male)



(女/female)



圧力知覚閾
Pressure threshold

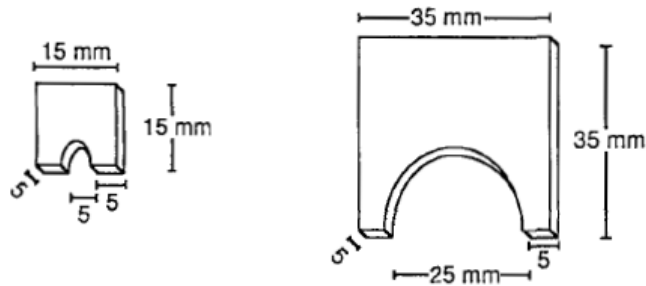
同時的な二点弁別閾
Two point discrimination

経時的な定位閾
Point localization

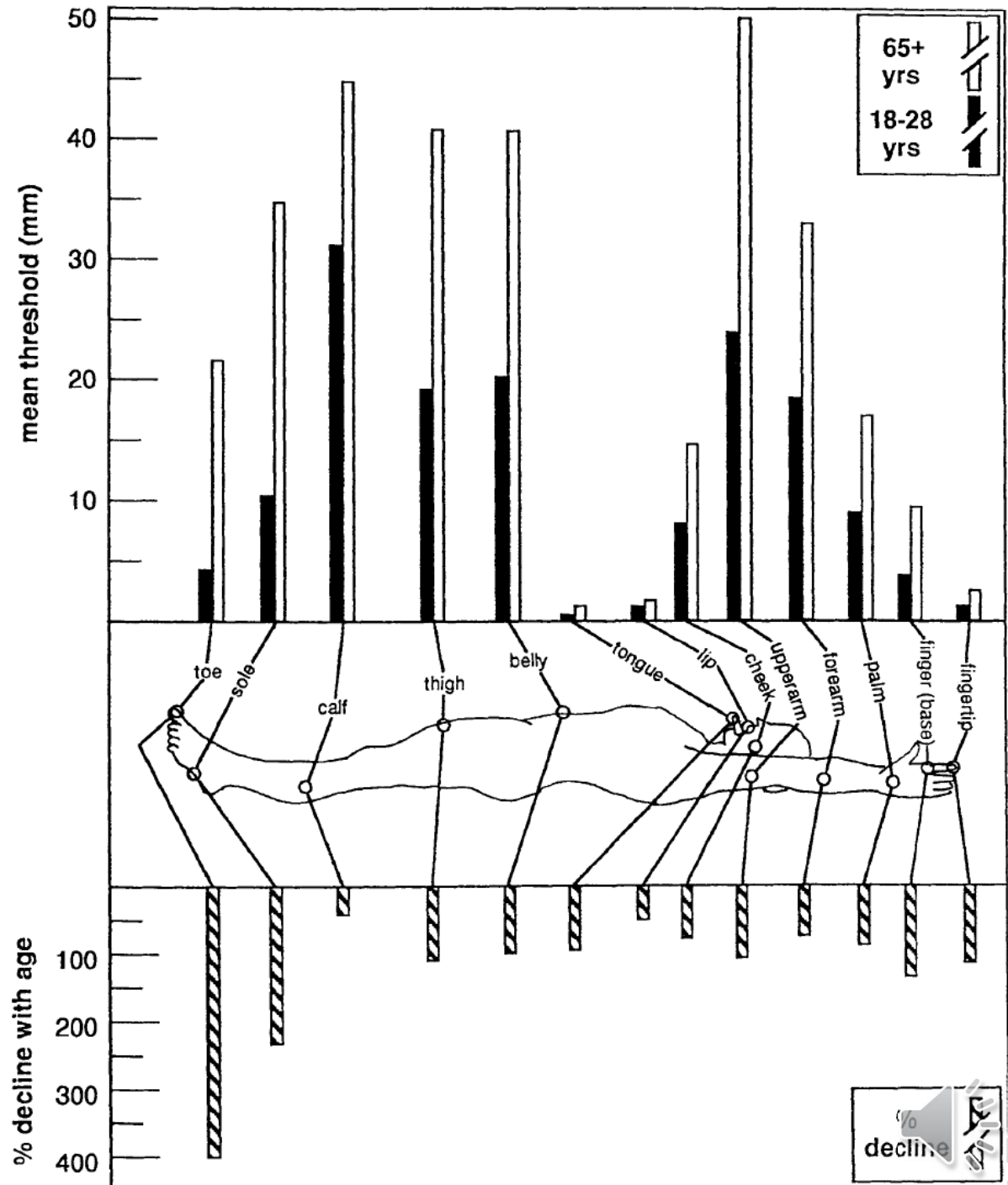


二点弁別閾と加齢

Joseph C. Stevens & Kenneth K. Choo (1996) Spatial Acuity of the Body Surface over the Life Span, Somatosensory & Motor Research, 13:2, 153-166

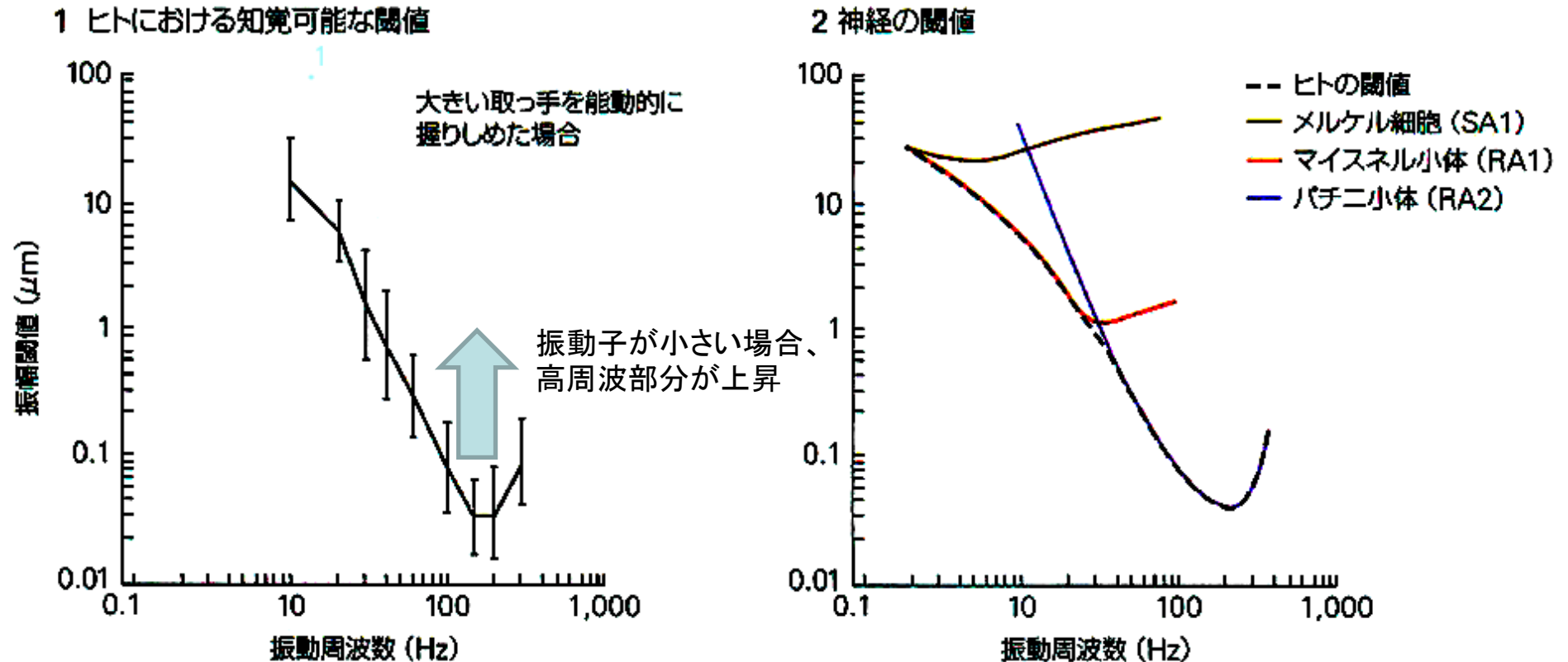


- 足裏の触覚の減退は著しい。
- 唇、ふくらはぎの減退は少ない(ただしふくらはぎは元々かなり悪い)
- 前腕、頬も減退がやや少ない。



周波数は受容器の活動比率でコーディングされる

Frequency is mainly coded by combination of receptor activities.



カンデル神経科学(Principles of Neural Science) <https://www.medsai.co.jp/kandel/syousai/index.html>

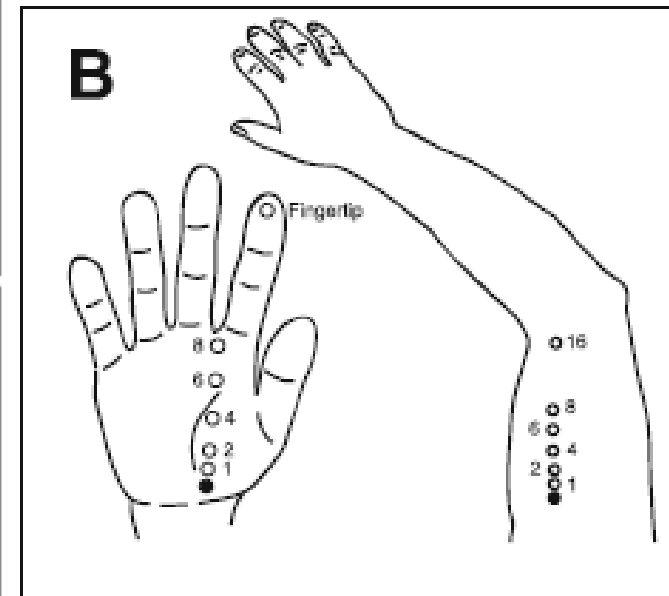
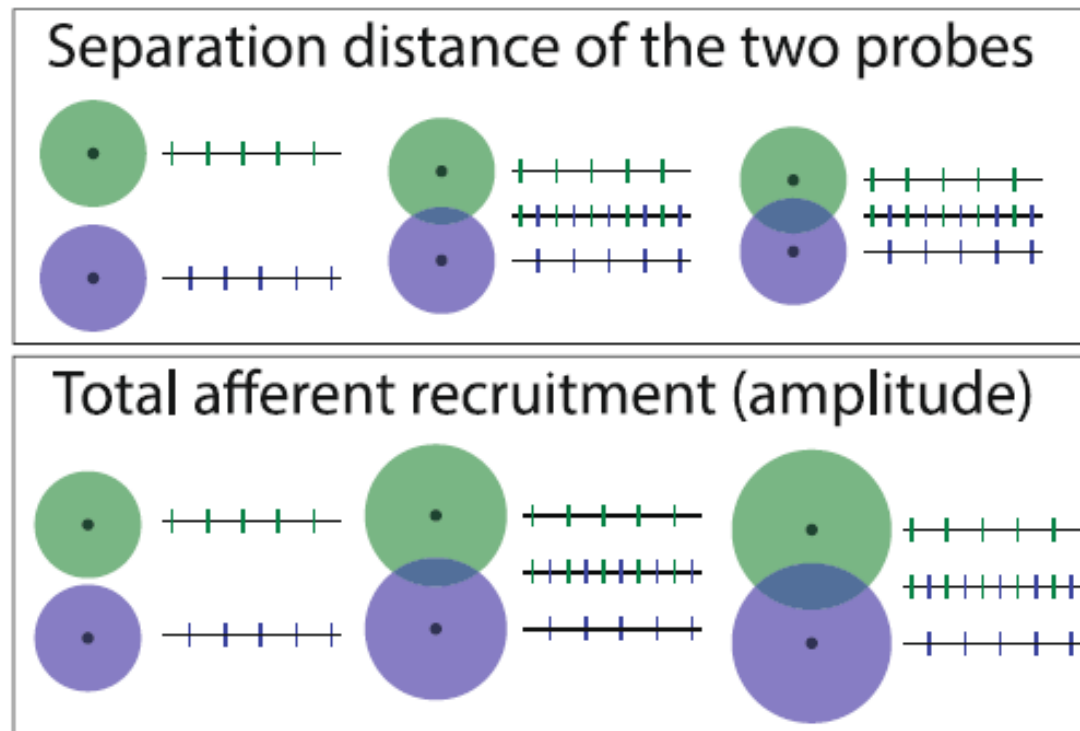
主にMeissnerとPacinianが関与。

ただし振動子が小さいとPaciniの「空間加算」効果が無くなり、高周波を感じなくなる

Vibration is coded by Meissner + Pacinian. If the vibrator size is small, high freq. threshold rises, (“spatial summation effect” of Pacinian corpuscle)

(EuroHaptics2016) Temporal integration of tactile inputs from multiple sites

Sarah McIntyre, Ingvars Birznieks, Robin Andersson, Gabriel Dicander, Paul Breen, Richard Vickery

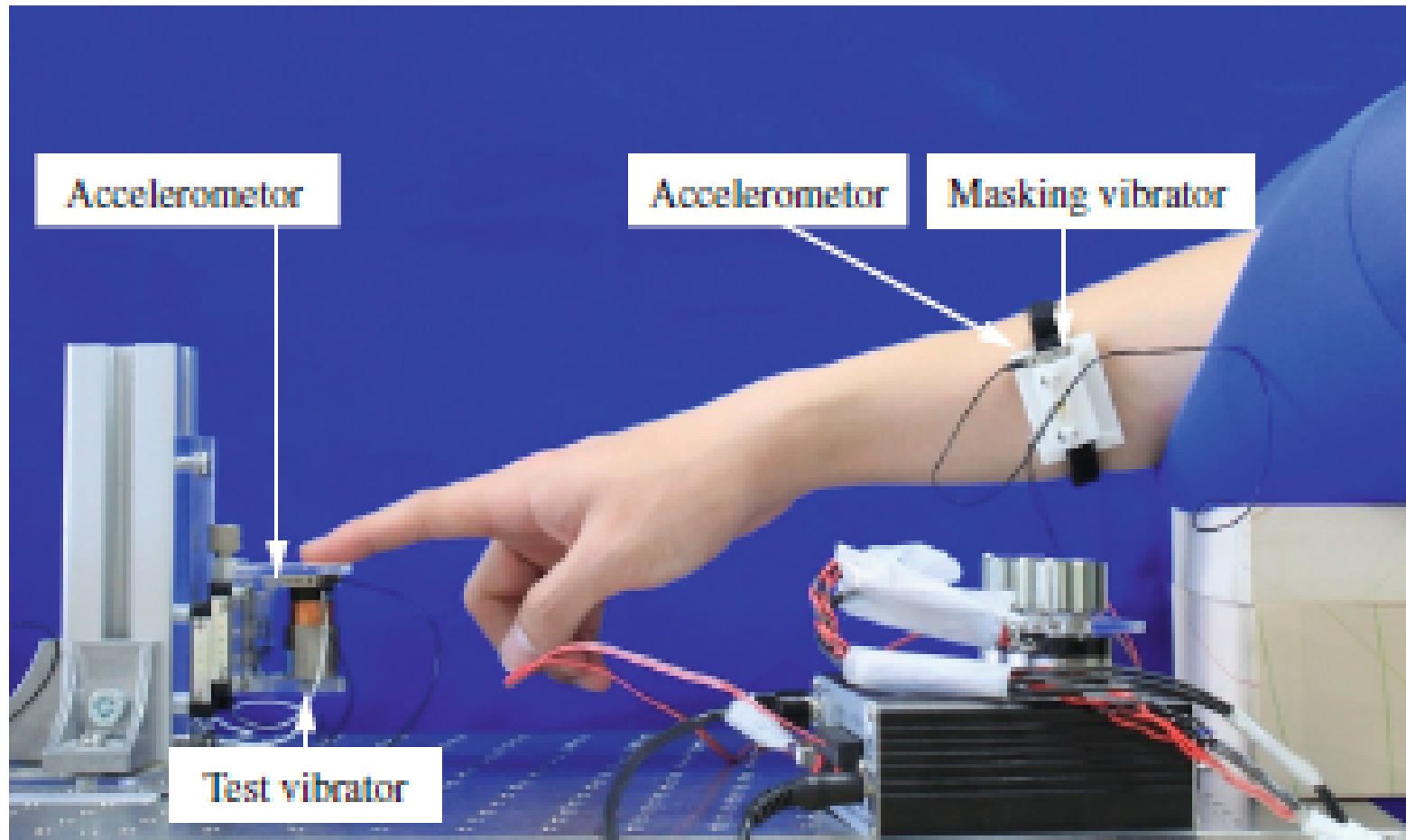


異なる二箇所に振動を与える。振動の周波数は同じで位相をずらす。これは脳にとっては例えば2倍の周波数に感じられないかという研究→非常に近い時は当然2倍近くに感じる。しかし腕の場合16cmくらい離れていても結構高い周波数に感じる。これは振幅を小さくしても同じなので、機械的に伝わったためとは考えにくい。

Simultaneously presenting vibration to two sites elicit “doubled” frequency feeling, although the positions are quite separated.



(EuroHaptics2016) Frequency-Specific Masking Effect by Vibrotactile Stimulation to the Forearm, Yoshihiro Tanaka, Shota Matsuoka, Wouter Bergmann Tiest, Astrid Kappers, Kouta Minamizawa, Akihito Sano



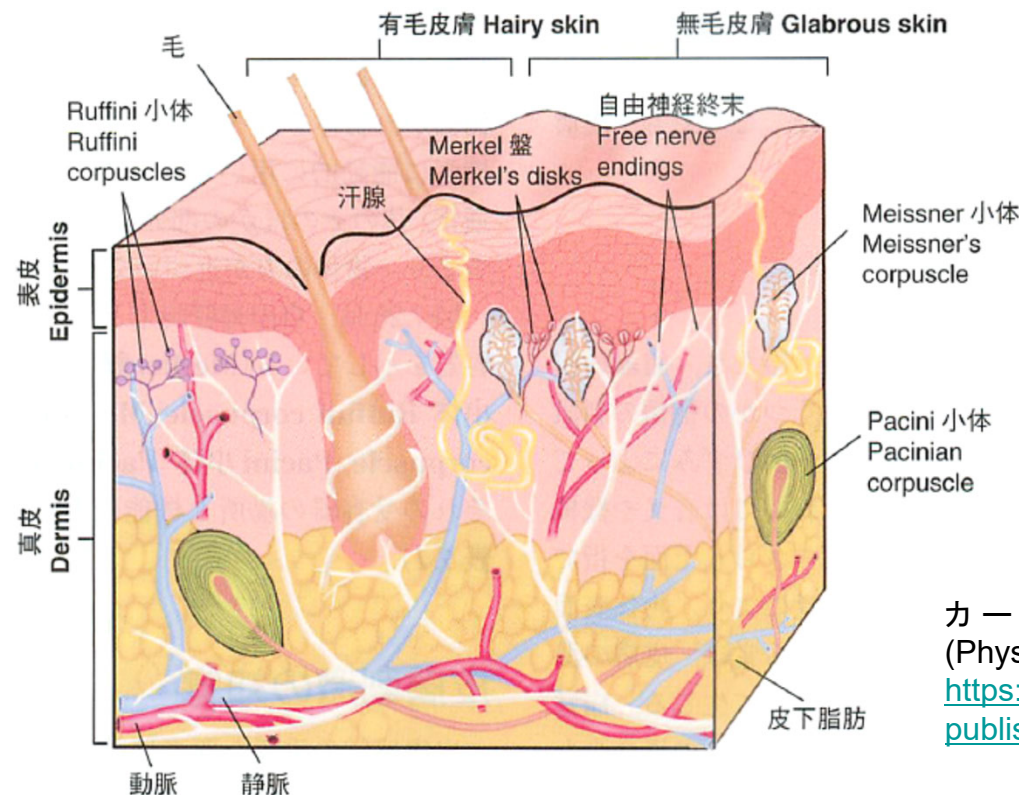
指先に閾値より少し上の振動を与えておき、腕にやや強い振動を与えると指先の感覚が完全に消えてしまう。異なる周波数ではこれは生じない。劇的に消えるので面白い。

Presentation of vibration to forearm dramatically “mask” vibration feeling at fingertip.



その他の触覚／Other cutaneous sensations

有毛部
Hairy part



無毛部
Glabrous part

カールソン神経科学テキスト
(Physiology of Behavior)
<https://www.maruzen-publishing.co.jp/item/b294439.html>

皮膚表面付近の自由神経終末 Free nerve ending

- 温度感覚：冷繊維と温繊維／Temperature sensation by two fibers.
- 痛覚：鋭痛と鈍痛はA γ 繊維とC繊維が担当／Pain sensation by two fibers

有毛部／Hairy skin

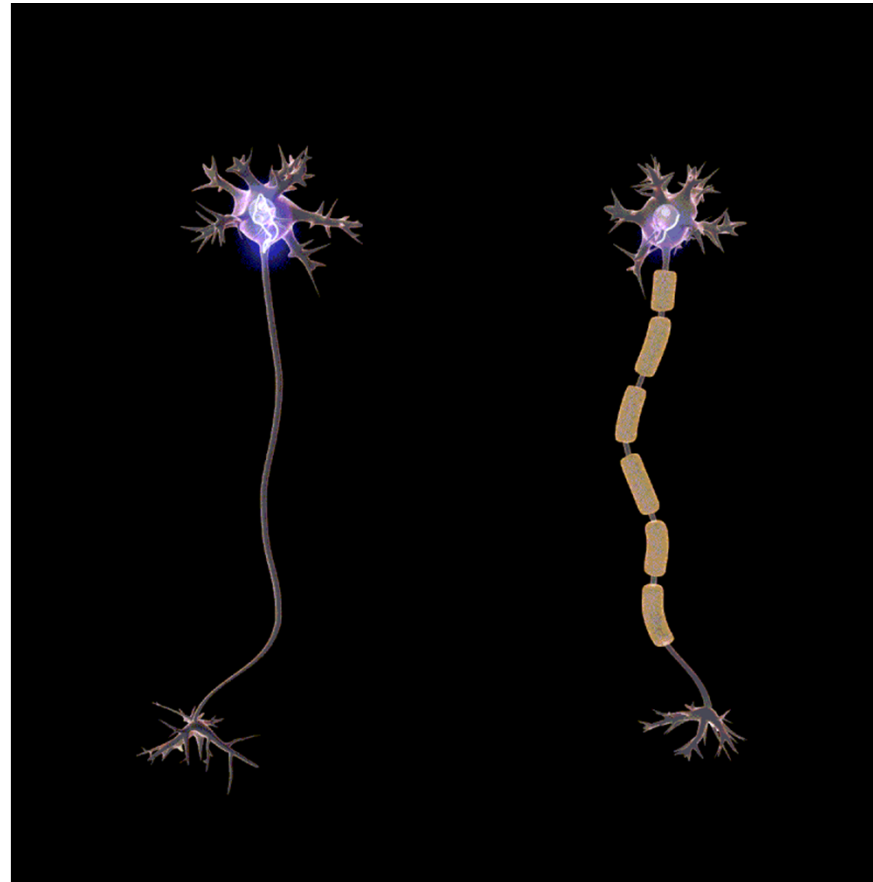
- 毛包受容器／Follicle Receptor

毛が曲がる時のみ活動(速度検出)。これに代わり, Meissner小体は無い。

Activated by low frequency vibration, substituting Meissner corpuscle



C繊維？



Myelin (Wikipedia)

<https://en.wikipedia.org/wiki/Myelin>

機械受容器につながる多くの神経：A β 繊維、一部A γ 繊維

- 高速に情報を伝えるMyelinatedな神経

C繊維：Unmyelinatedな神経。伝達速度が遅い。

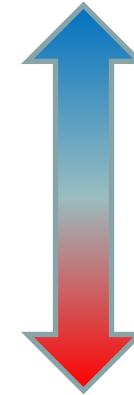
- 温度感覚：A γ 繊維とC繊維
- 痛覚：A γ 繊維とC繊維（緊急の痛みと鈍痛）
- 無毛部のMeissner小体に入り込む繊維：数本C繊維が存在。
- 有毛部にも機械的変形に応答するC繊維が存在。情動に関与？



温度感覚と神経の種類/Temperature & nerve

Table 7-2 Sets of Afferents Sensitive to Temperature

	Group	Axon	Threshold (°C)	Range (°C)
侵害性冷覚	Noxious cold	<u>C-fibers</u> , 0.5–2.0 m/sec, rare	26–27	Down to tissue destruction
冷覚	Cooling	<u>A-delta</u> , 13–15 m/sec, density 50–70 fibers/cm ²	34	34–26
温覚	Warming	<u>C-fibers</u> , 0.5–2.0 m/sec, density 50–70 fibers/cm ²	36	36–42
侵害性温覚	Noxious heat	(1) <u>C-fibers</u> , 0.2–2.0 m/sec	42	42–52
		(2) <u>A-delta-I</u>	42	42–52
	Extreme heat	<u>A-delta-II</u> , rare	52	Up to tissue destruction



神経の種類と伝導速度: Aδ神経は13-15m/s, C繊維0.5-2m/s.

C繊維は圧倒的に遅い

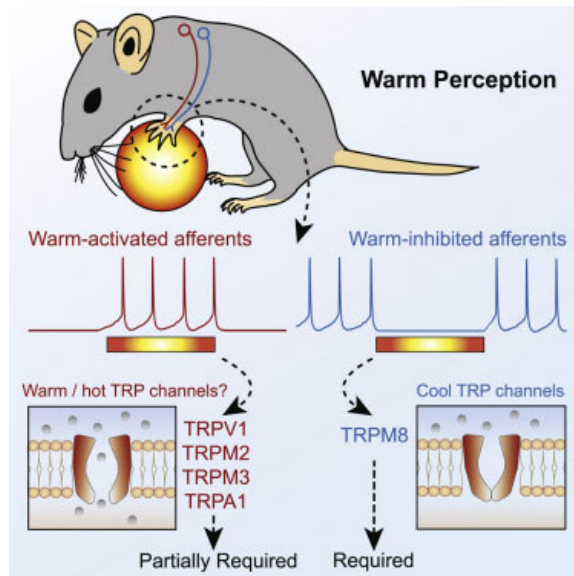
温度感覚神経の伝達速度はなぜそれぞれ異なるのか？

おそらく可能な説明:

- 冷覚:「触った瞬間の温度変化」から, 材質感を判定⇒素早いAδが必要
- 侵害性冷覚・温覚:「環境の温度」から, その場を離れるかどうかを判断⇒遅いC
- 侵害性温覚:熱い火, 直射日光等を避ける⇒素早いAδ
- Moderate cool sensation is used for material identification, which requires fast response (Aδ). Noxious cold is environmental, and does not need to be quick. Noxious heat might be used to avoid sun?



温度感覚：最近の話題 / Recent Topics on Thermal Sense



Ricardo Paricio-Montesinos et al. (2020) The Sensory Coding of Warm Perception

[https://www.cell.com/neuron/fulltext/S0896-6273\(20\)30186-0](https://www.cell.com/neuron/fulltext/S0896-6273(20)30186-0)

- マウスに暖かさ、冷たさを判断させるタスク。
- 暖かさを伝えるTRPM2またはTRPV1イオンチャネルを欠損させても、暖かさの認識は鈍化するが、消失はしない。
- **冷たさを伝えるTRPM8チャネルを欠損させたりすると、温熱を感知する能力が失われる。**
- 従来の「暖かさ、冷たさは別々のチャネルで」というモデルとは異なり、冷たさ側のチャネルの活動の「減衰」自体を暖かさの情報として使っていることを示している。

Mice were asked to judge warmth and coldness. Deletion of TRPM2 or TRPV1 ion channels, which convey warmth, blunted but did not eliminate the perception of warmth. On the contrary, losing the cold-transmitting TRPM8 channel, resulted in a loss of the ability to perceive warmth. This supports a model in which the "attenuation" of activity in the cold-side channel itself is used as warmth information, rather than the conventional "warmth and cold are in separate channels" model.

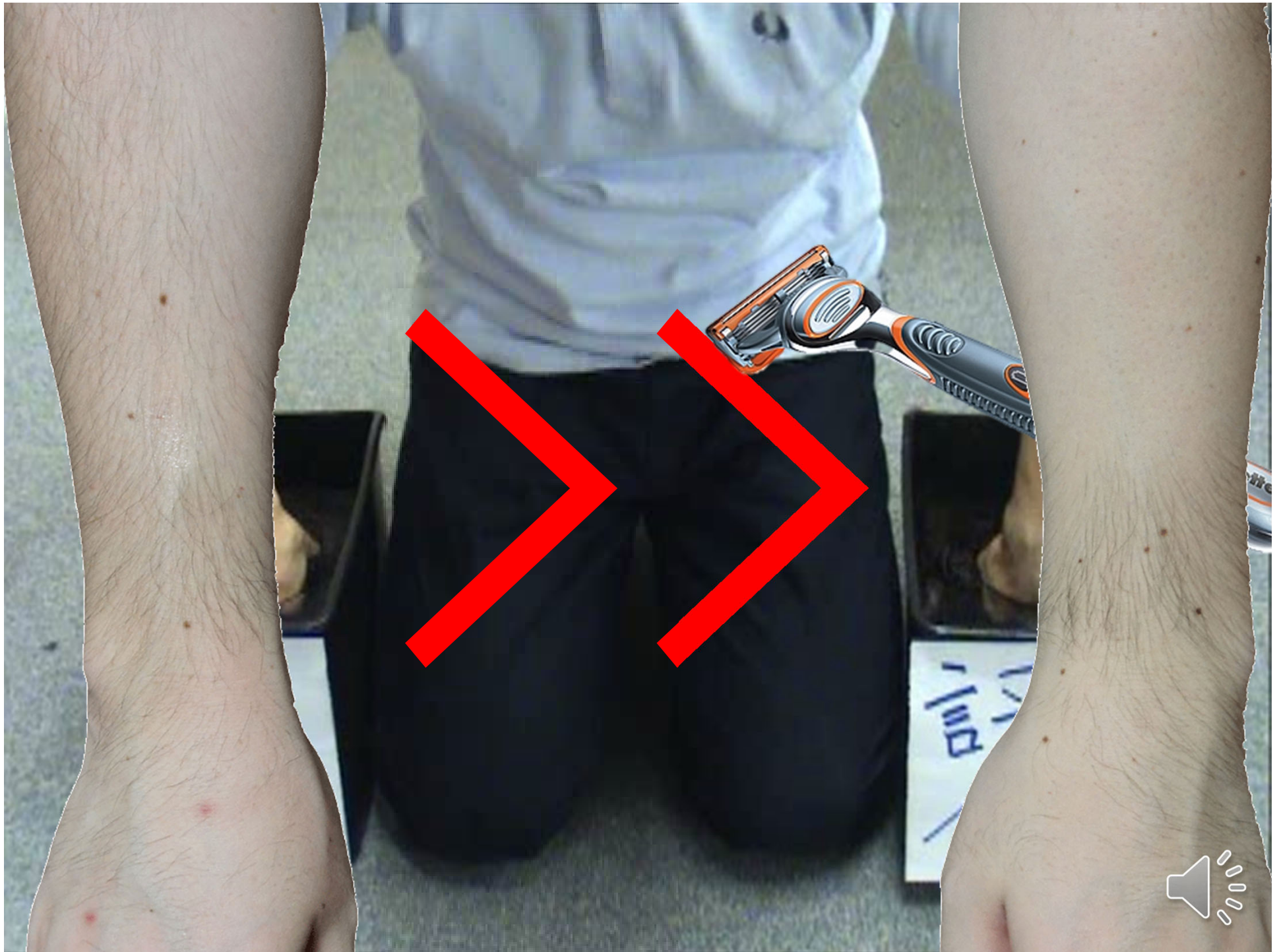
(参考)水面知覚

水銀に指を入れると
線を感じる(1859)



Meissner





どうやって調べる：神経活動

How we know?: nerve activity



By using needle, we can directly measure nerve activities. Vallbo, "Sensations evoked from the glabrous skin of the human hand by electrical stimulation of unitary mechanosensitive afferents," Brain Res., 1981.



Procedure

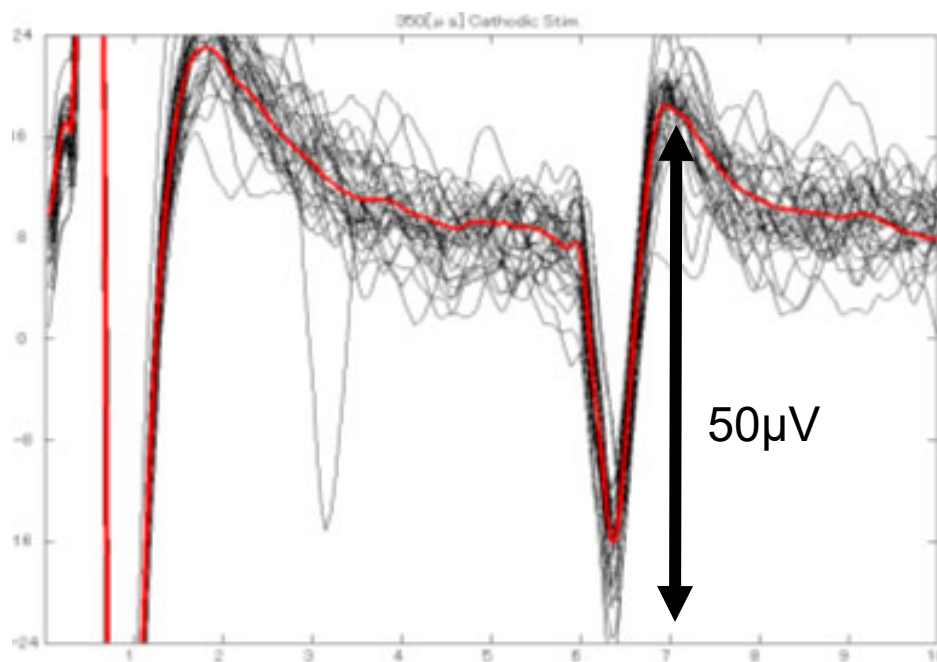
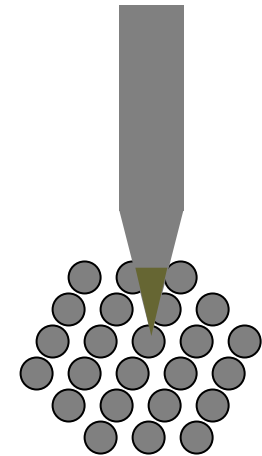
(Medical Doctor's License Required)

(0) See where the nerve bundle is. (by ultrasonography)

(1) Insert a needle ($\phi 0.1\text{mm}$), which is connected to Amp&Speaker

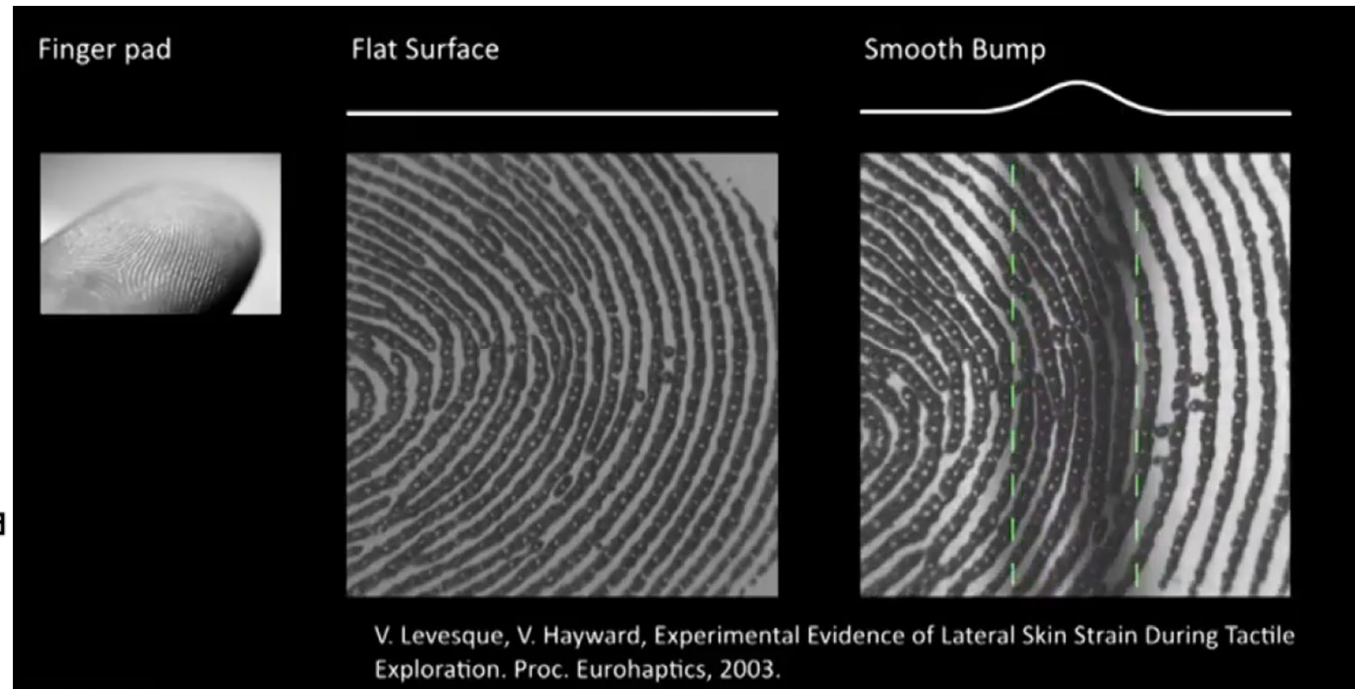
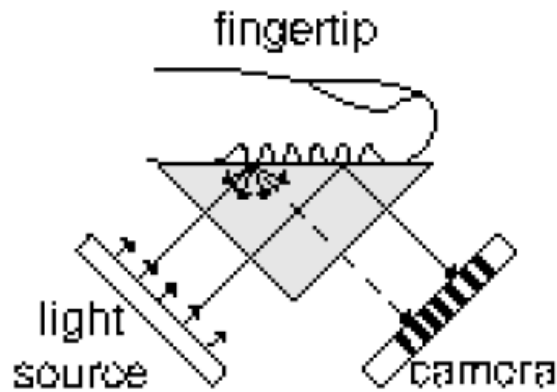
(2) Identify Location and Type of Receptor by the Sound.

(3) Do Experiment on that Location.



どうやって調べる?: 皮膚変形

How we know?: Skin recording



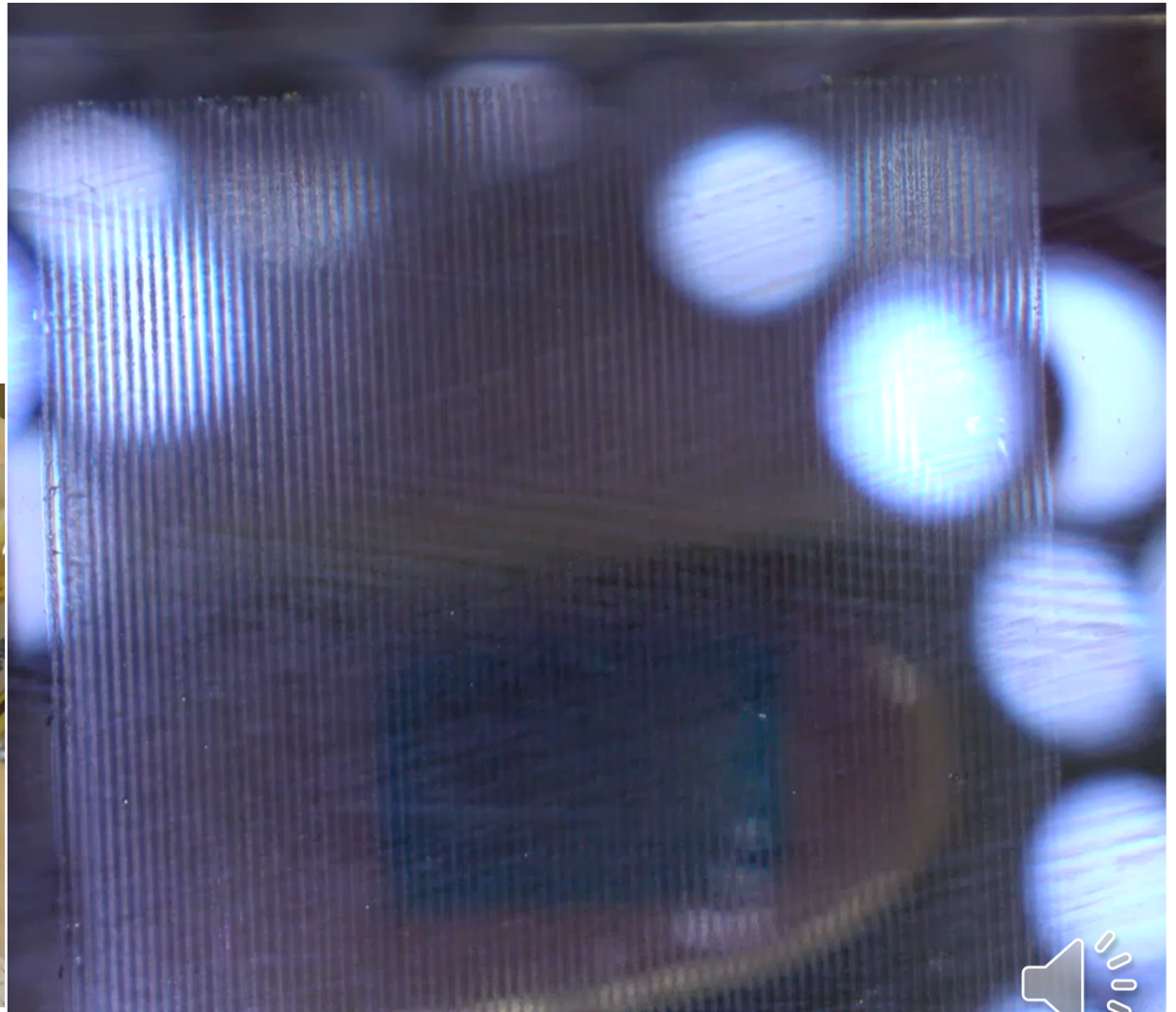
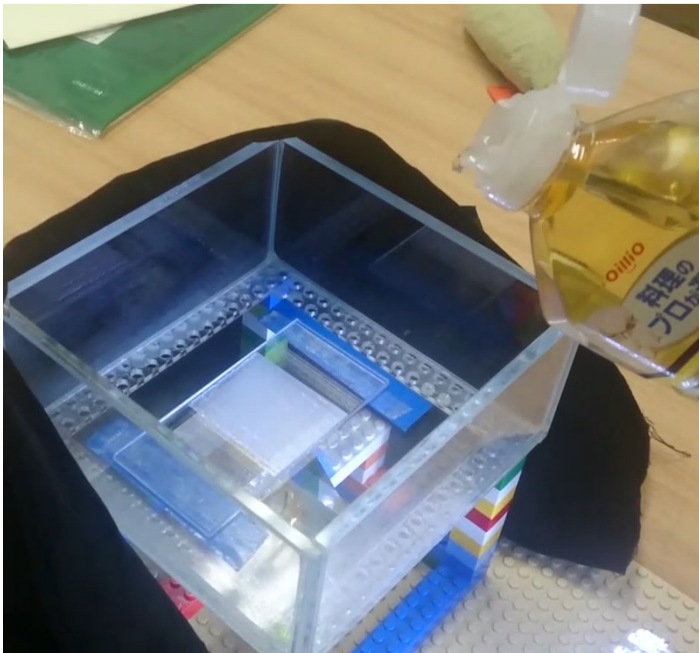
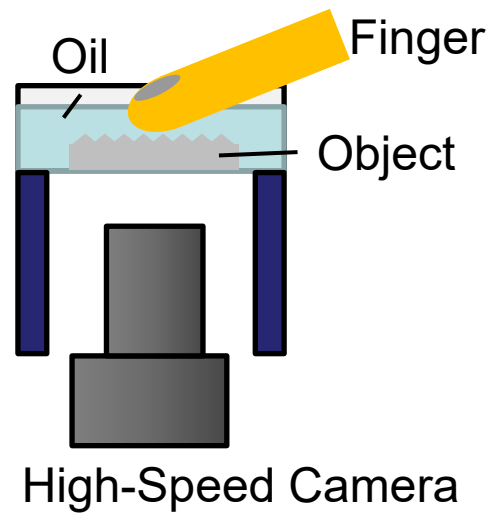
<https://youtu.be/bdgmGrESe14?t=681>

Levesque (2003) Experimental evidence of lateral skin strain during tactile exploration

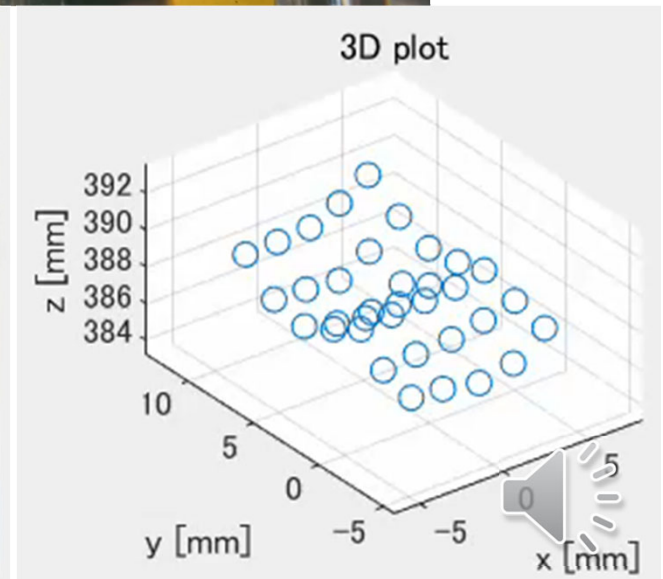
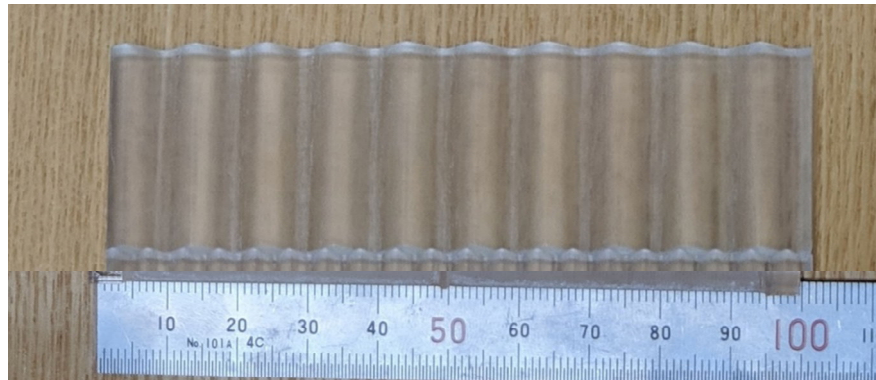
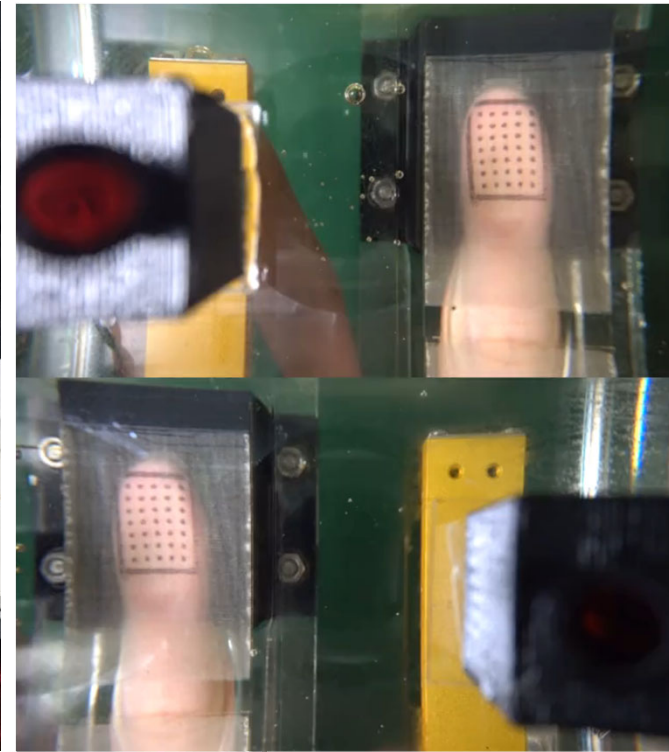
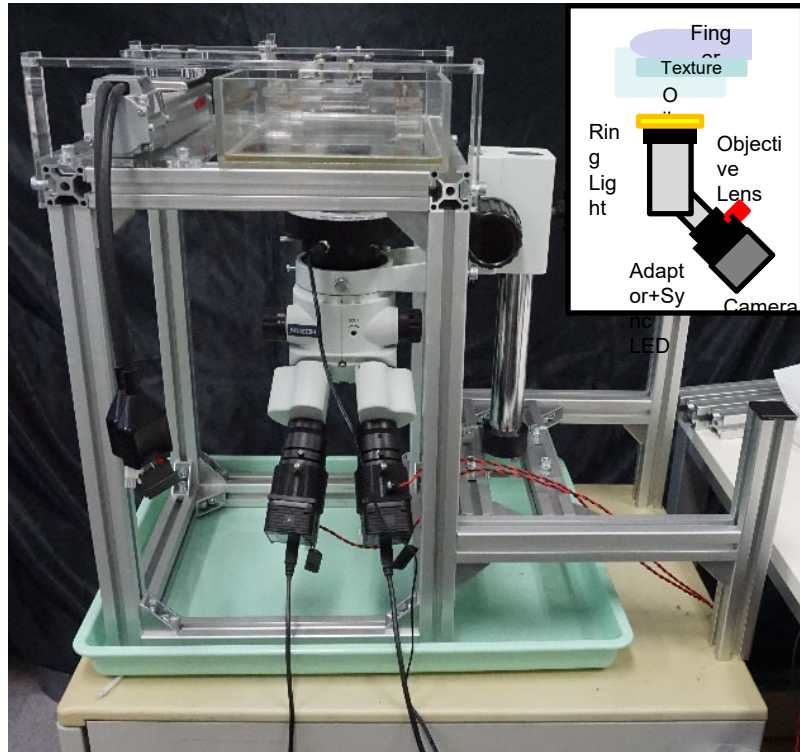
Optical observation only for flat or smooth surface.



Make It Optically Transparent



Skin Deformation on Textured Surface



S.Tanaka, S. Kaneko, H. Kajimoto: Three-dimensional Measurement of Skin Displacement, Haptics Symposium 2020.

Measurement using telecentric lens

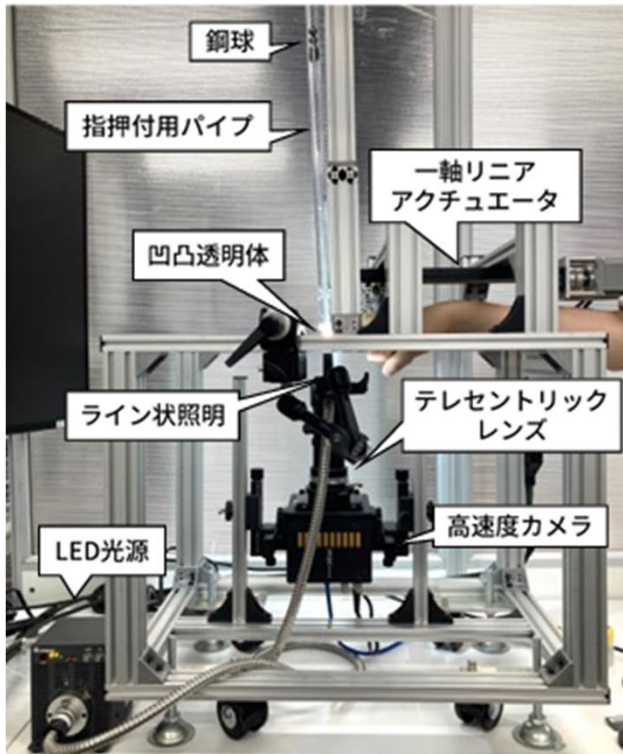


図 3: 計測システムの構成 (全体)

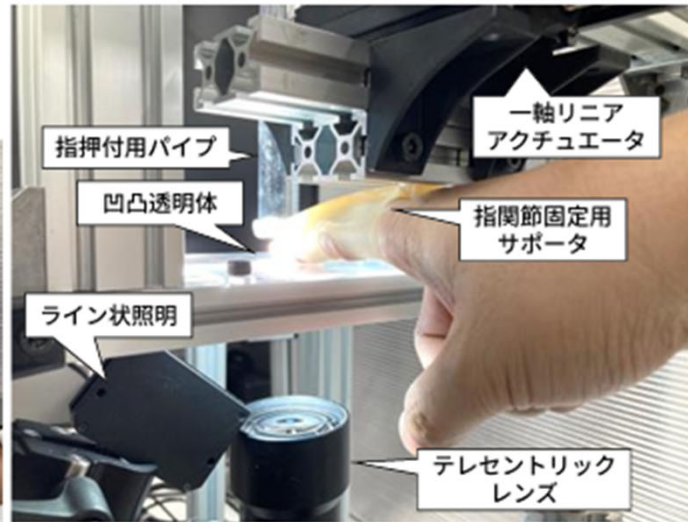


図 4: 計測システムの構成 (指先周辺)

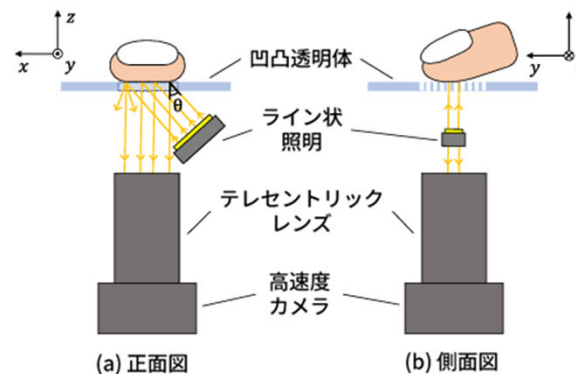


図 2: 計測システムの光学設計

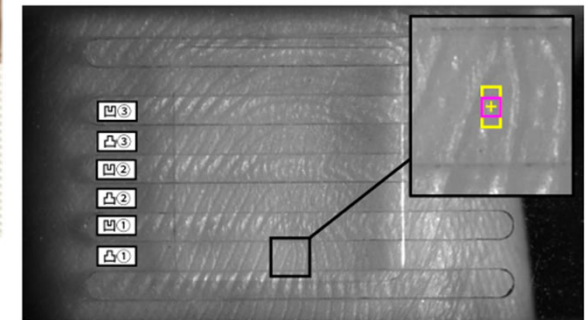


図 6: 初期位置における画像例
(黄色十字部分: 汗腺孔, 紫色枠内: テンプレート画像, 黄色枠内: テンプレートマッチングの探索範囲)

テレセントリックレンズを使い、光軸と平行な光のみを通過させることによって余計な反射光等を除去。
スリットをなぞる際の皮膚変形を計測

○境、田川、広田、井上、唐山、日本バーチャルリアリティ学会大会2023 3D2-06

凹凸面なぞり時における指腹部表面の変位分布のマーカレス計測システム

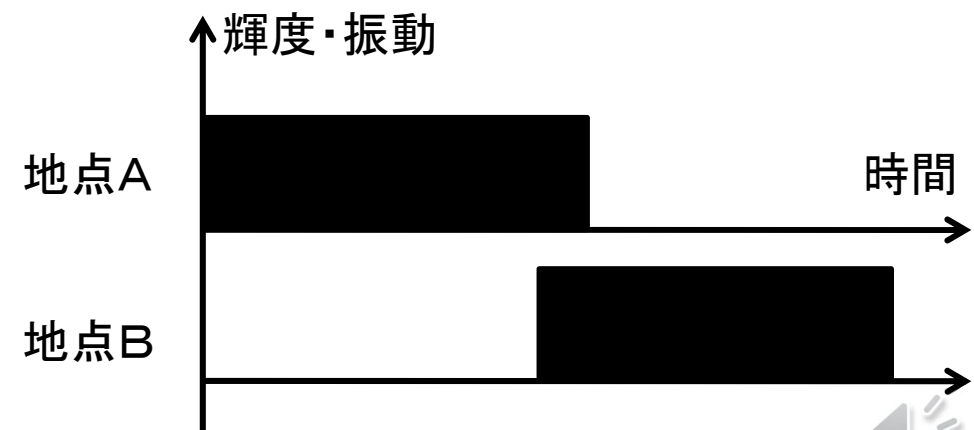
TODAY's TOPIC

1. Skin Sensation Mechanism
2. Tactile Illusion
3. Tactile Display



時空間能力の不完全さから生じる錯触(1): 仮現運動

Illusion related to spatio-temporal interaction: Apparent motion

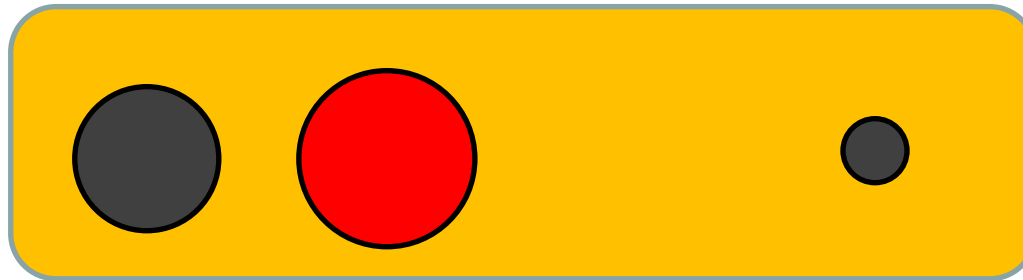
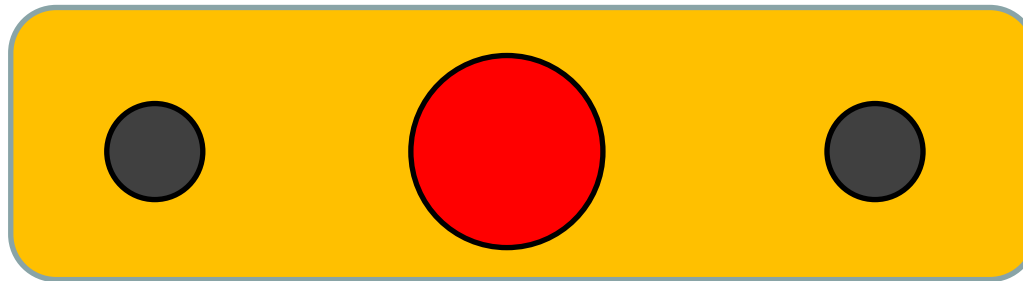


触覚の仮現運動では、時間的なオーバーラップが有る方が明瞭

時空間能力の不完全さから生じる錯触(2):ファントムセンセーション

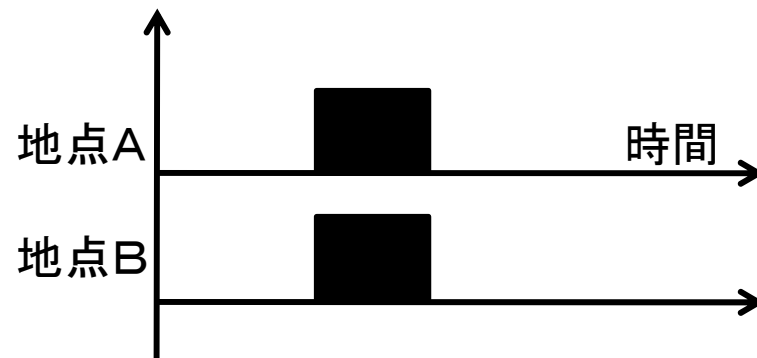
Illusion related to spatio-temporal interaction: Phantom Sensation (Funneling)

地点A 知覚位置 地点B

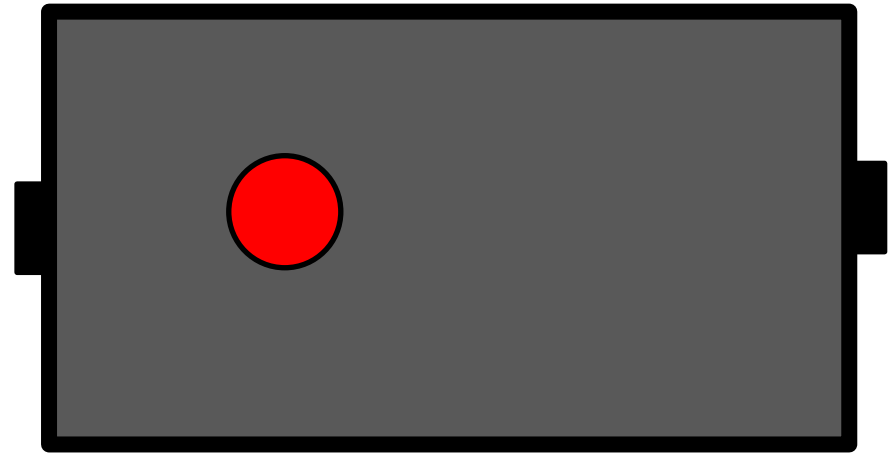
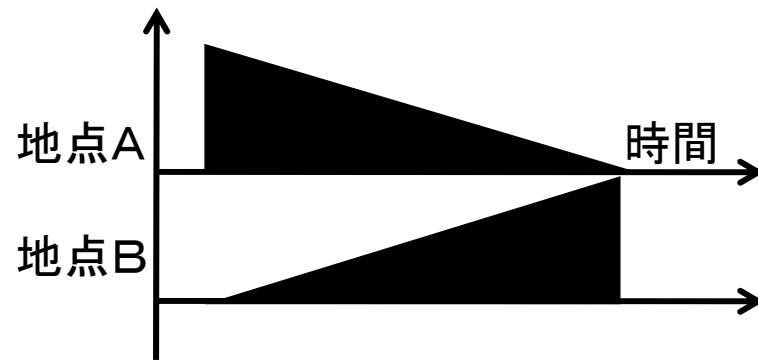


- 特に短パルス刺激で強く発生
- 複数刺激子の間に知覚
- 位置は移動できる

- Generated by short pulses
- Image generated between stimulators
- Position can be controlled



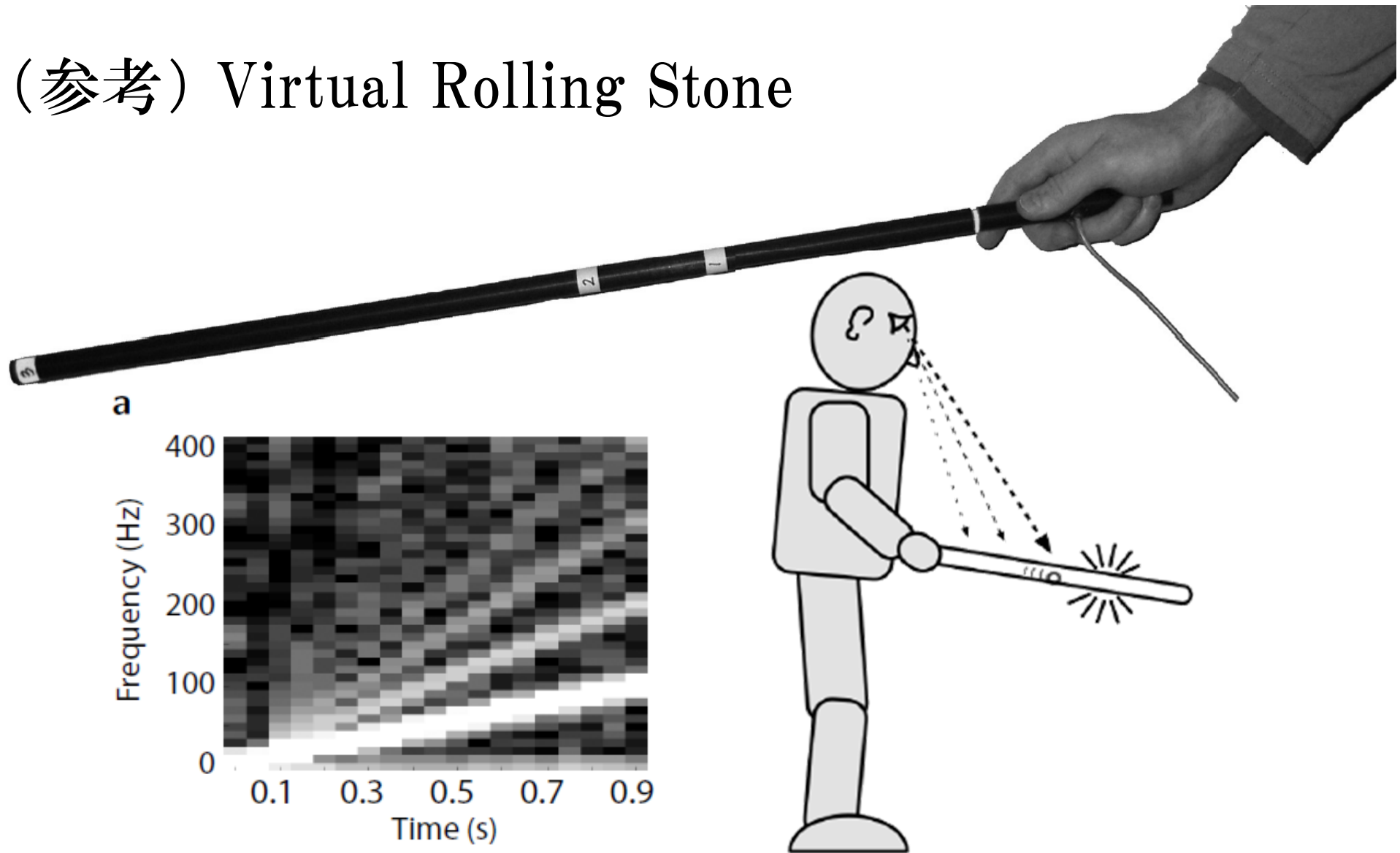
把持物体中のファントムセンセーション



- 持っている物体上に振動位置が定位する。
- 重心位置の移動によって滑らかに移動
- 仮現運動では不可能な連続的な動きを表現可能



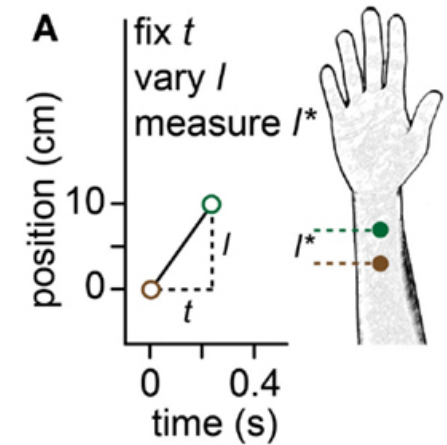
(参考) Virtual Rolling Stone



筒の中を転がっていく金属球をモデル化。転がる振動と衝突振動を振動子によって再生。ボールの衝突位置を把握でき、かつ非常にリアル。

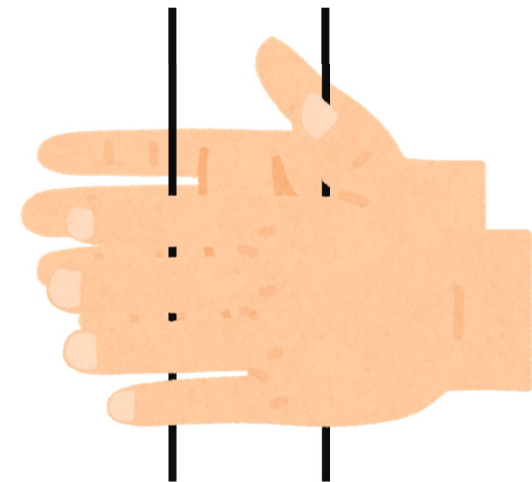
Yao, Hsin-Yun & Hayward, Vincent. (2006). An experiment on length perception with a virtual rolling stone. Proceedings of Eurohaptics.

A diagram of a human arm, colored orange, with three colored dots (red, green, and blue) placed along its length. A black arrow points from the red dot towards the right, passing through the green and blue dots.



触感に関する錯触(1):ベルベットイリュージョン

Illusion related to tactile feeling: Velvet Illusion

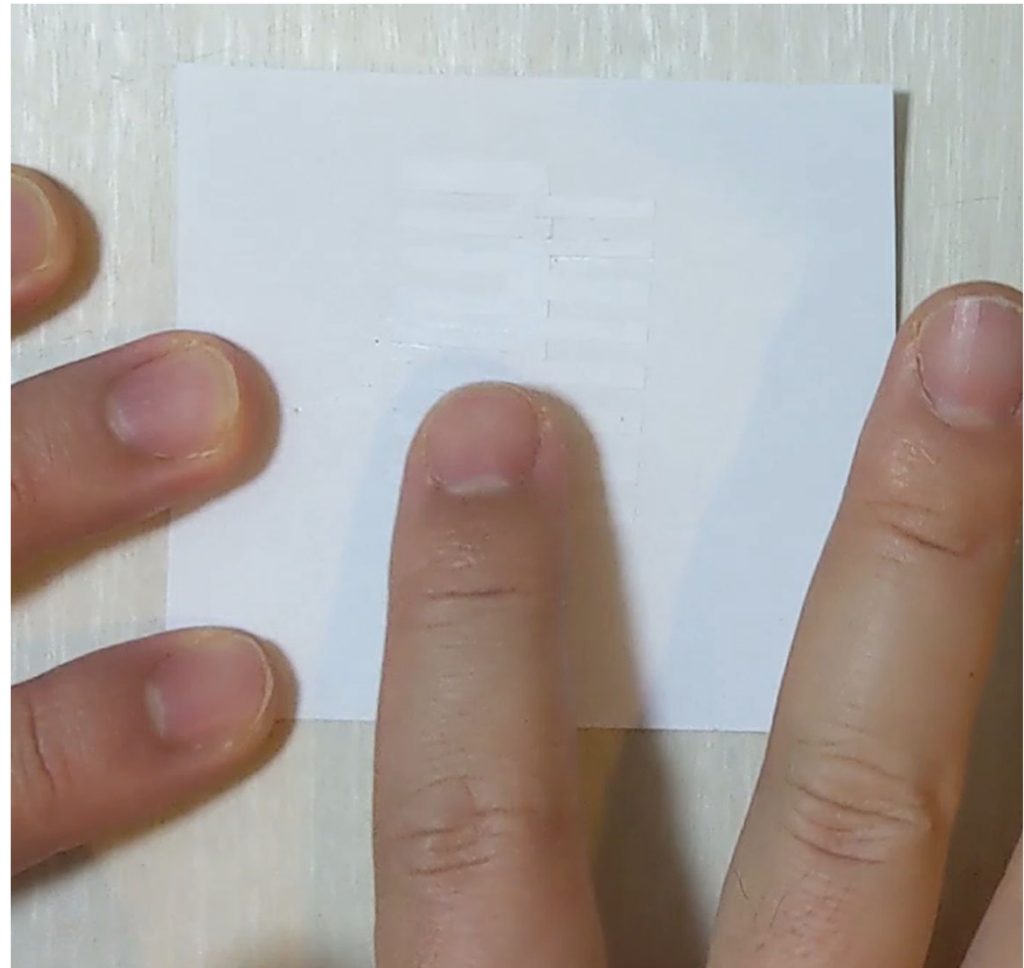
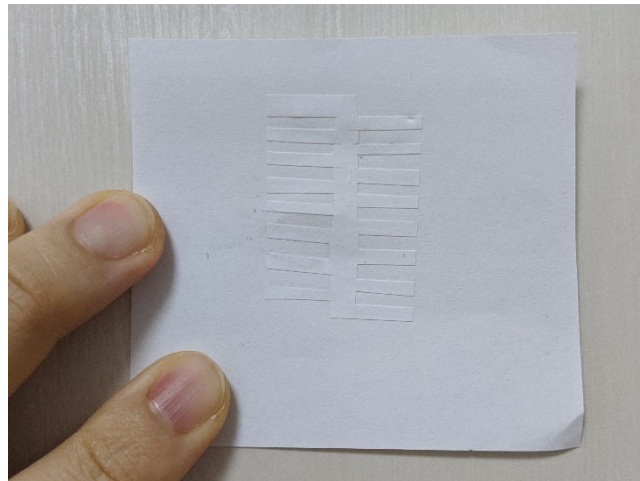
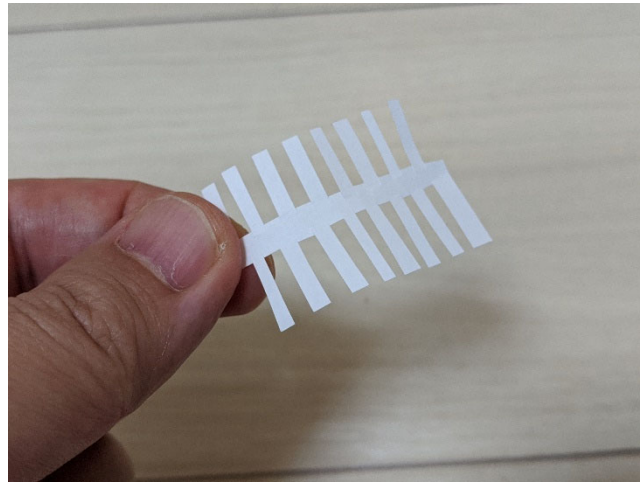


荒い網の目(テニスラケットなど)を両手で挟み、
前後に動かすと、**モワツとしたベルベット感**を生じる。(家で試しましょう)
細いワイヤ2本でも生じる。(2人で試しましょう)

Sandwiching coarse mesh of a net, such as tennis racket by two hands, and moves. Then, smooth surface like velvet is felt.



触感に関する錯触 Illusion related to tactile feeling (2): Fishbone錯覚



Nakatani, M., Howe, RD., and Tachi, S. Surface texture can bias tactile form perception. Exp Brain Res., Springer, 208(1), pp. 151-6, 2011. PMID: 20981539.

背骨状に切った紙を台紙に貼布。背骨中央部をなぞると、物理的には高いはずの中央部が周辺より凹んで感じる。(家で試しましょう)

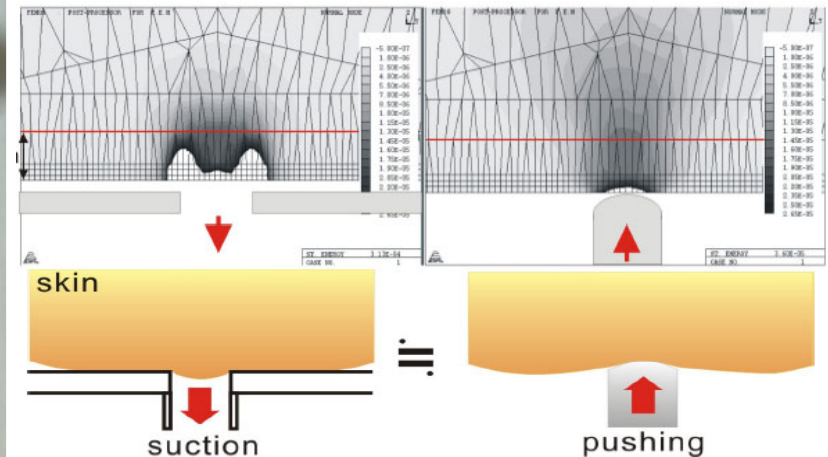
物理的な凹凸ではなく受容器活動から凹凸を判断している。



触感に関する錯触(3): 吸引を圧迫と錯覚

Illusion related to tactile feeling: Air suction perceived as pressed.

Y. Makino, N. Asamura, H. Shinoda: A cutaneous feeling display using suction pressure. SICE Annu. Conf., 2003.



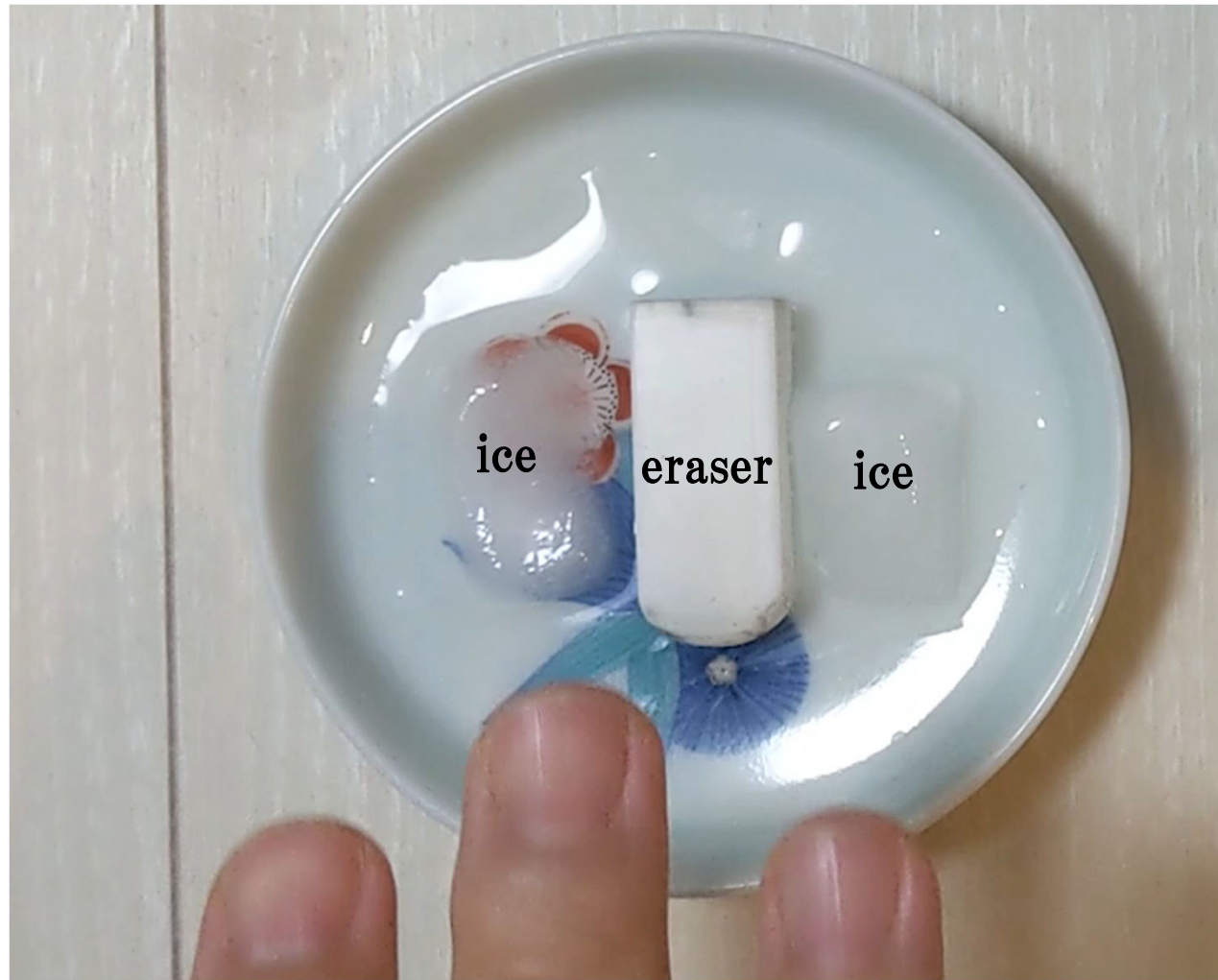
空気吸引による圧覚生成／Using air suction (家で試しましょう)

吸引と押下で、受容器位置に生じる歪エネルギーが同じ→人は区別できない。
実際の物理ではなく受容器活動で知覚することによって生じる齟齬現象。

Suction and push produces the same strain energy, so human cannot distinguish.



温度関連錯覚 Temperature related illusion (1): Thermal Referral

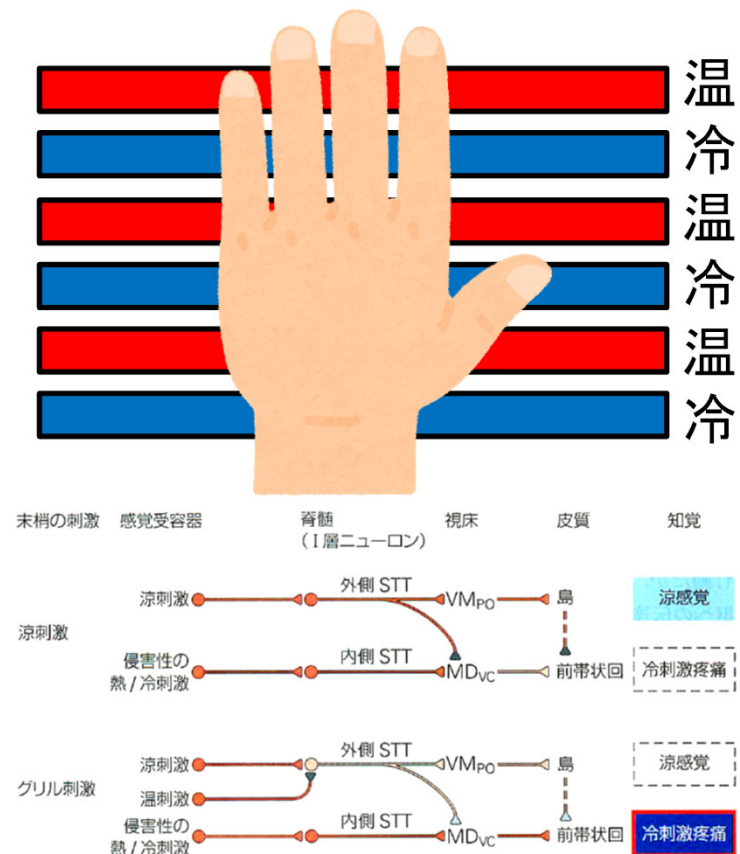


人差し指と薬指を冷やしながら中指でものを触ると、中指で触れているものが冷たく感じる。温かい側でも生じる。**(家で試しましょう)**

Two cold stimuli generate illusory cold sensation at the middle.



温度関連錯覚 Temperature related illusion(2): Thermal Grill Illusion



- 近距離の温 + 冷同時提示で痛覚生起。(家で試しましょう)
- 通常、冷刺激は侵害性受容器も刺激するが、冷刺激によって痛みが抑制されて知覚しない。温刺激を加えるとこの抑制が外れ、痛みが知覚される、と説明される。
- Simultaneous presentation of warm + cold at close range to generate pain.
- Normally, cold stimulation simultaneously excites nociceptors, but it also suppresses pain pathway. The application of warm stimulus removes this suppression.

温度の交互提示による痒み抑制 / Itch relief by hot/cold stimuli

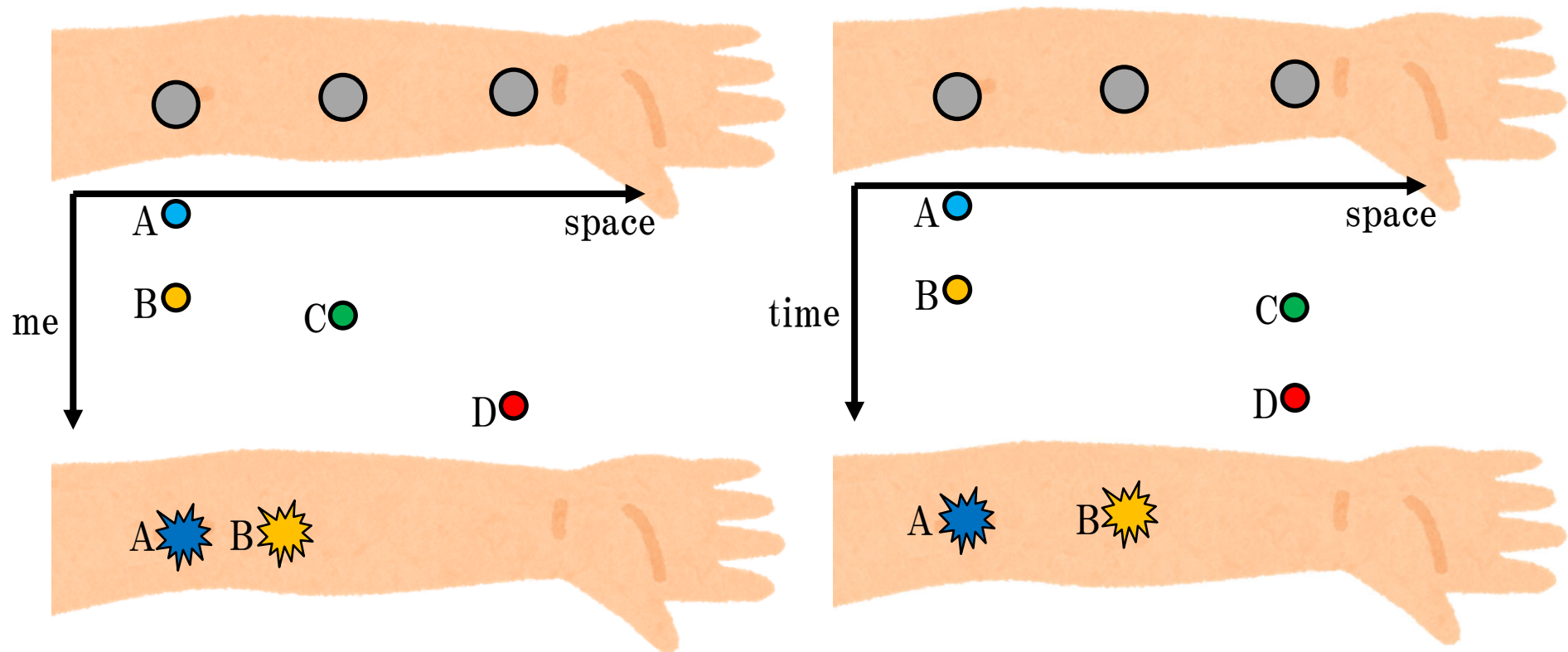


R. Watanabe, N. Saito, Y. Mori, T. Hachisu, M. Sato, S. Fukushima, H. Kajimoto: Development of Roller-Type Itch-Relief Device Employing Alternating Hot and Cold Stimuli, CHI 2013 (Ex-tended Abstracts), April27-May2, 2013, Paris, France.



温度の跳躍運動 / Thermal cutaneous rabbit

[HapticsSymposium2016] Space-Time Interactions and the Perceived Location of Cold Stimuli. Anshul Singhal, Lynette Jones



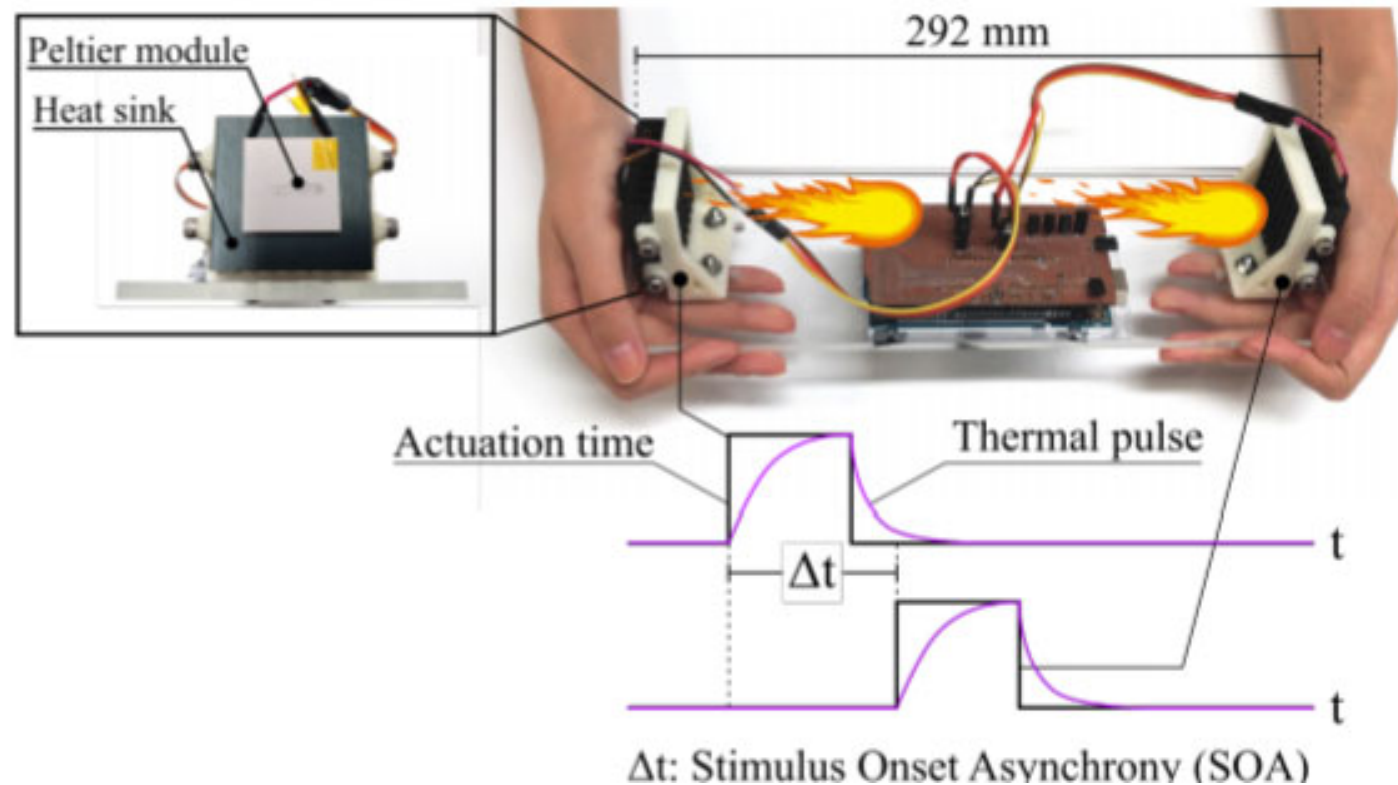
断続的に複数の冷覚を異なる場所に提示した時、途中の冷覚の知覚位置が提示タイミングに応じて変化。温度感覚においても時空間相互作用が有ることを示した。

Several cold sensations are presented intermittently at different locations. The perceived position of the cold sensation during the presentation is dependent on the timing of the presentation.



両手間の温度仮現運動感覚 Apparent motion of thermal sensation between two hands

(Towards Intermanual Apparent Motion of Thermal Pulses, Daniel Gongora et al., UIST2017)

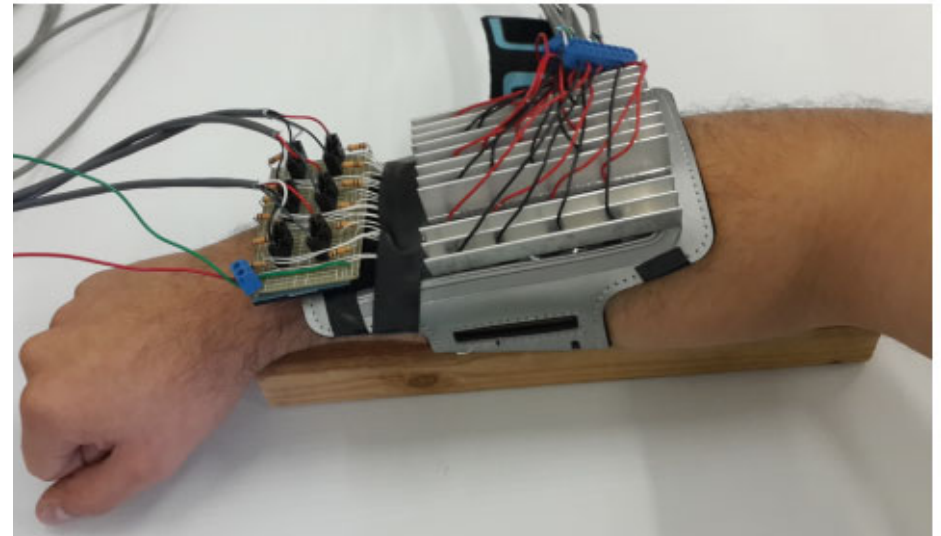
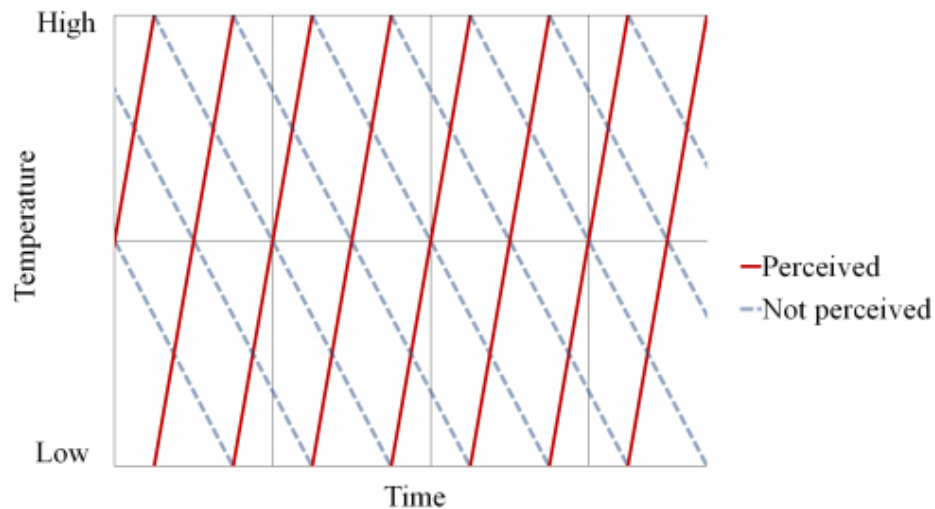


両手の掌に1秒程度の時間差を設けて温度提示すると、
両手間に仮現運動を生じる。



温度感覚の無限音階 Continuous heating

(WorldHaptics2017) Asymmetrically-Applied Hot and Cold Stimuli Gives Perception of Constant Heat. Ahmad Manasrah, Nathan Crane, Rasim Guldiken, Kyle B. Reed



複数のペルチェ素子を、「温度急上昇となだらかな低下」で駆動すると、上昇側だけを知覚し、ある種の無限に上昇する温度感覚を知覚できる。

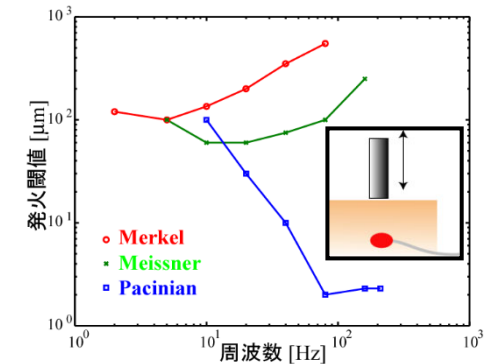
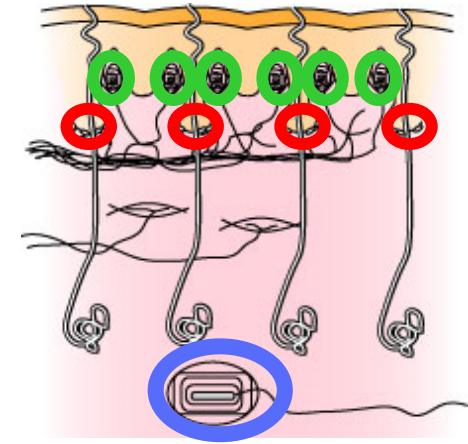
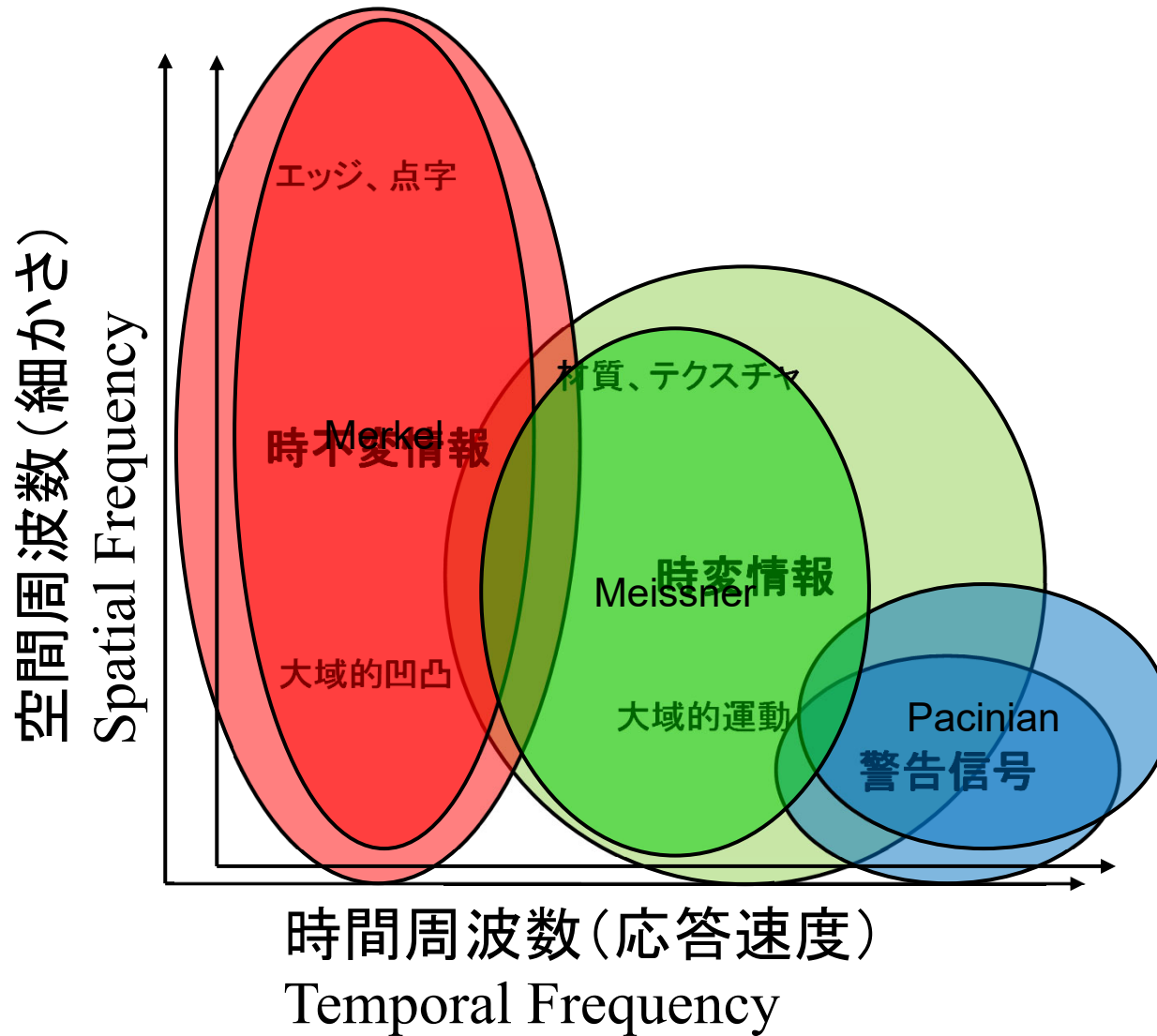


TODAY's TOPIC

1. Skin Sensation Mechanism
2. Tactile Illusion
3. Tactile Display

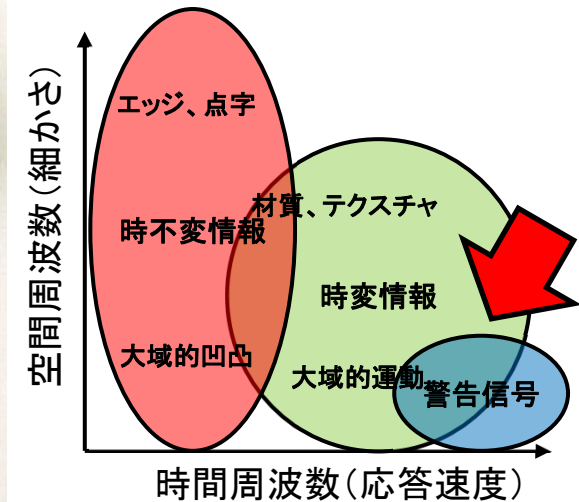
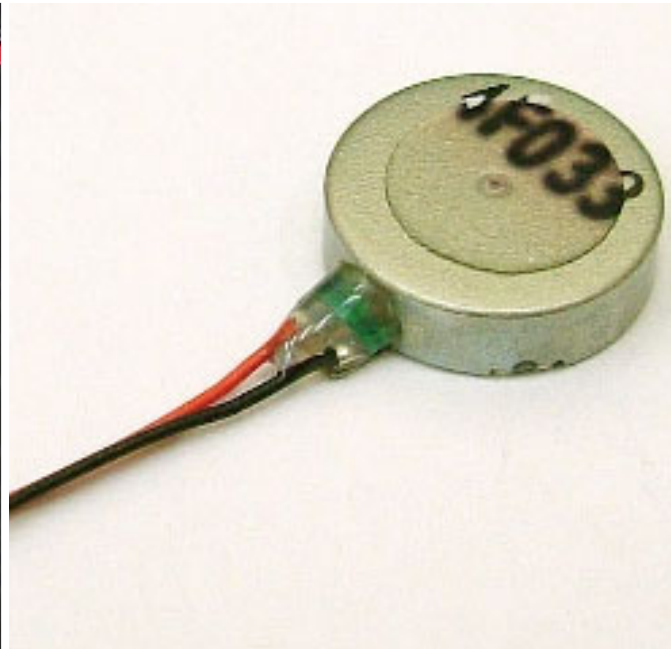
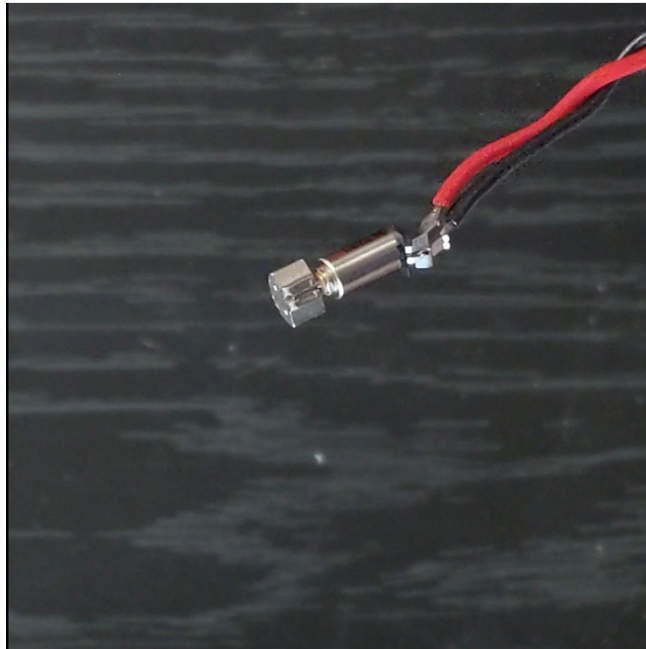


提示したい情報 / Information to present



提示したい情報⇒必要なスペック
ハードウェアと密接な関係(すべての領域を提示できる手法は無い)

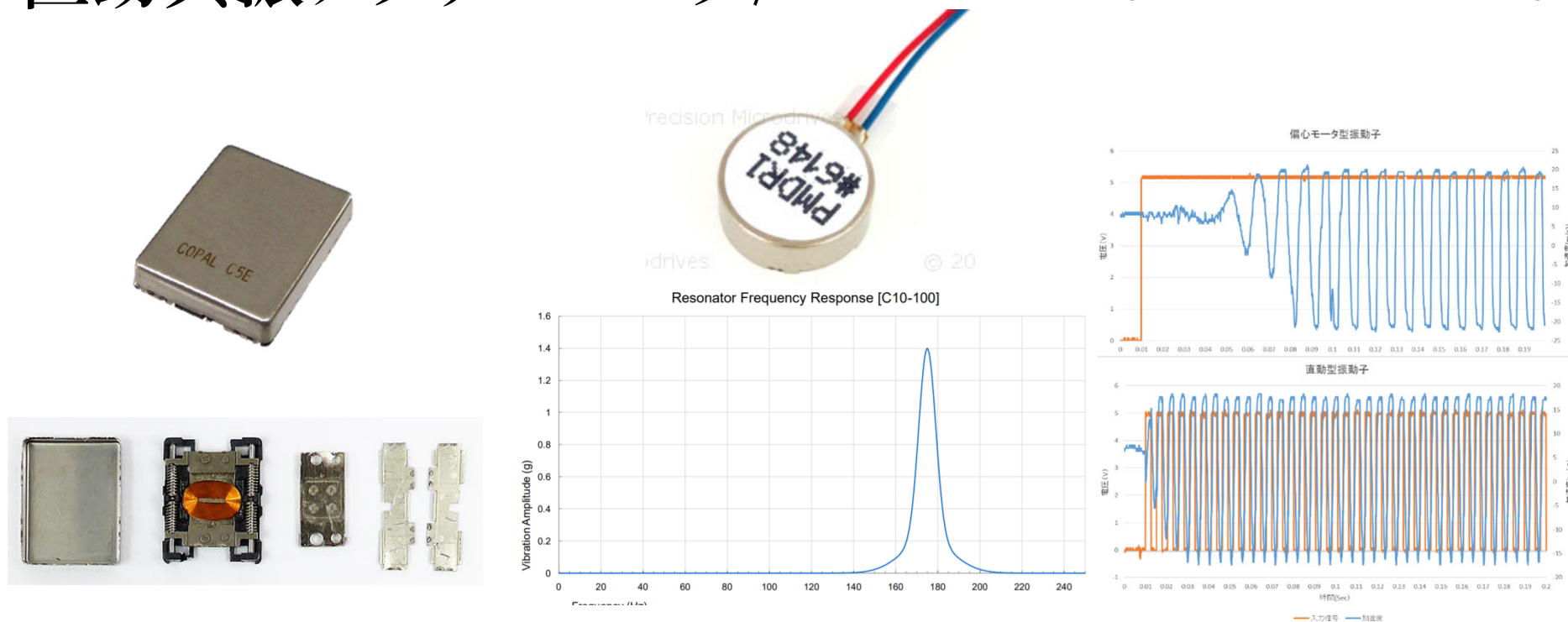
振動モータによる警告/Vibration Motor



- ・ モータ＋偏心おもり motor + eccentric mass
 - 電圧を変えると振動の周波数と振幅が同時に変更。Frequency & amplitude change according to applied voltage.
 - 材質、テクスチャの呈示には不向き。Not suitable for hi-fi tactile feeling.
 - 定格電圧でPacini小体の周波数領域で振動するように設計。Frequency at rated voltage is at the range of Pacinian corpuscles.
 - 警告信号、大域的運動に好適。Good for notification.



直動共振アクチュエータ/Linear Resonant Actuator



<http://akizukidenshi.com/catalog/g/gP-06838/>

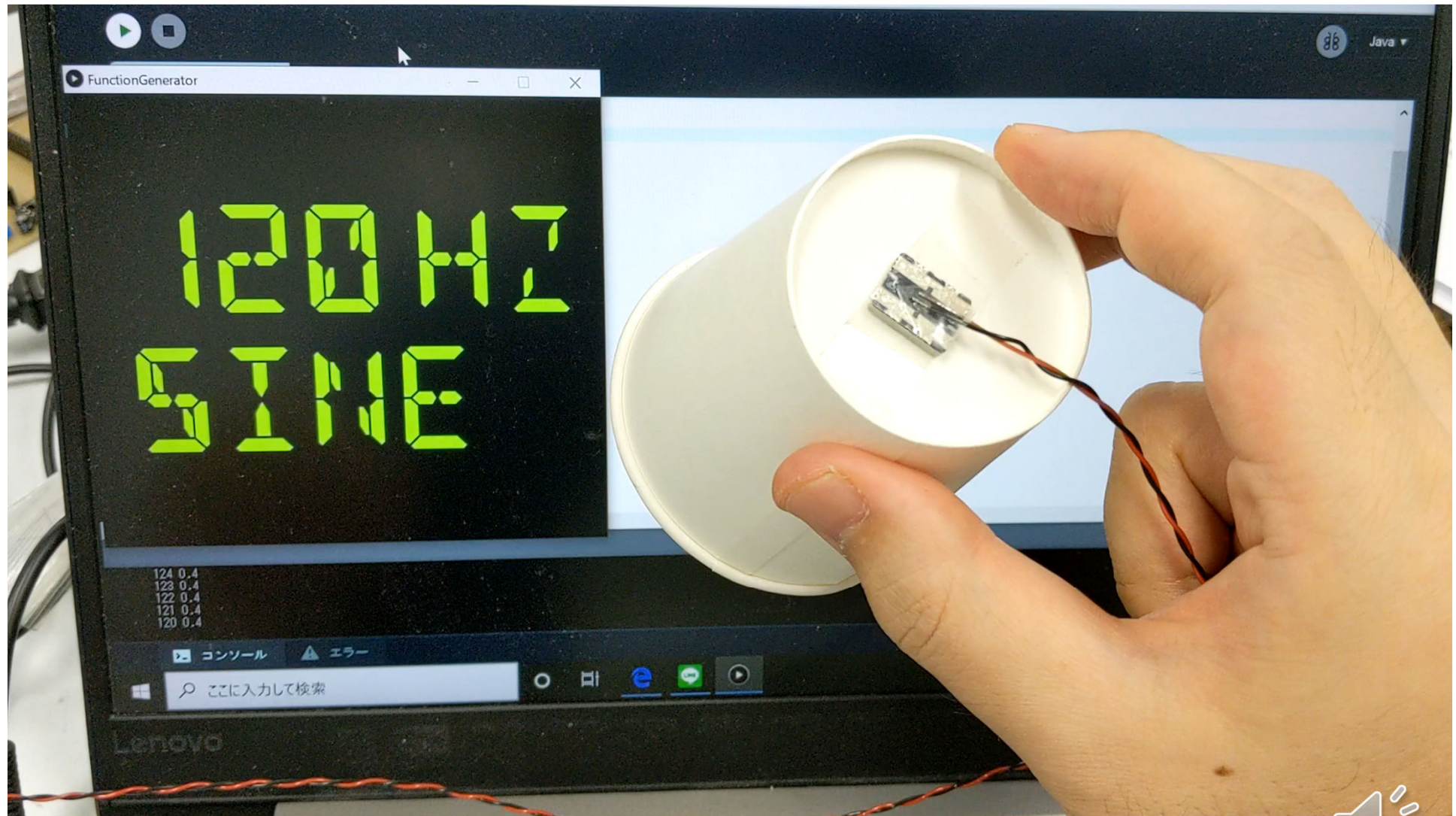
<https://www.precisionmicrodrives.com/product/c10-100-10mm-linear-resonant-actuator-4mm-type>

田辺他: 多数の直動型振動子を用いた手全体への触覚提示が可能なグローブの開発, SICE-SI2014

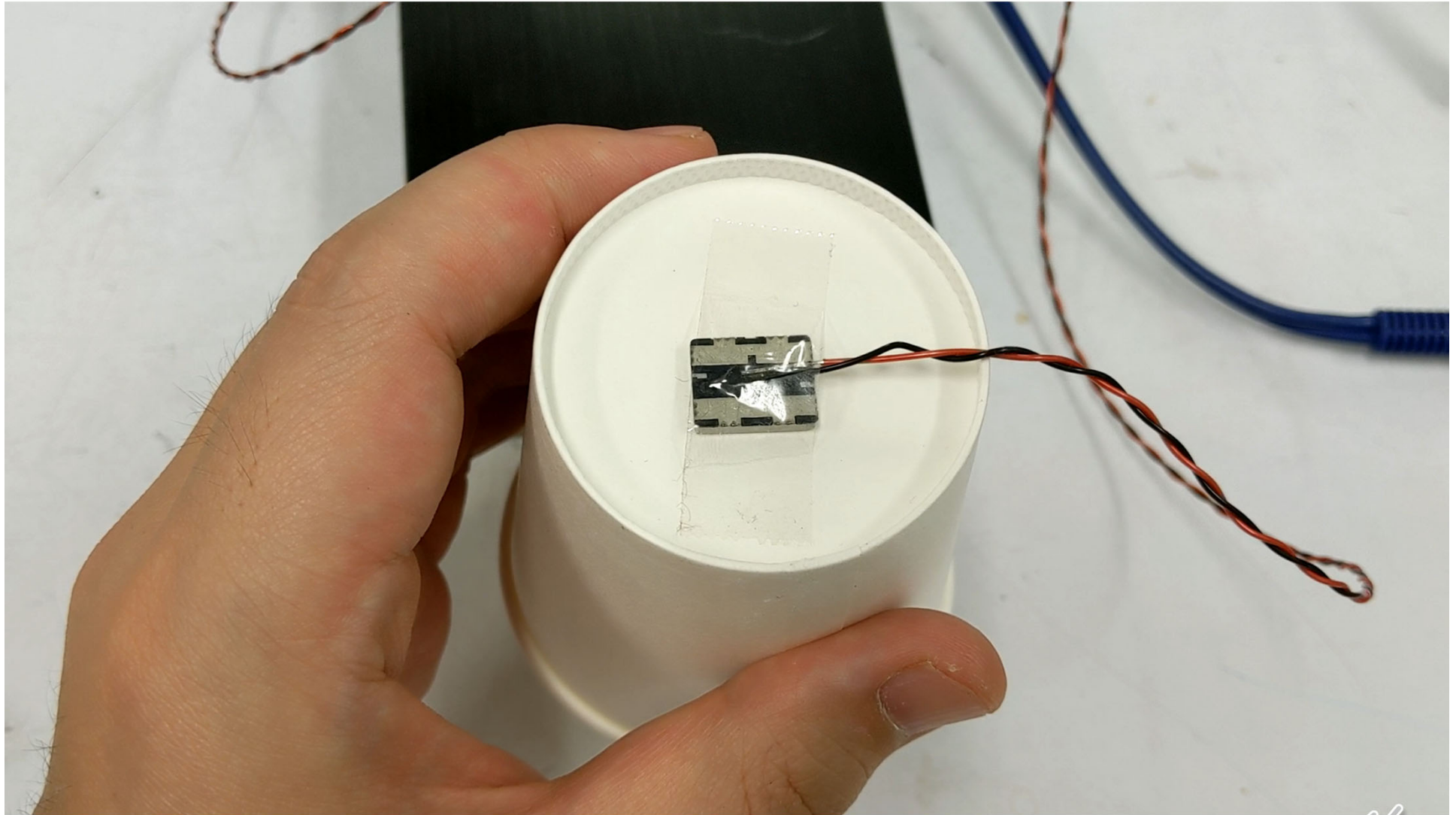
- ・ 偏心おもり: 一定回転速度に達するまでの時間遅れ: 80ms程度
- ・ ボイスコイル振動子に共振特性をもたせたLinear Resonant Actuator: 遅延10ms以下.
- ・ 共振周波数150Hz~200Hz. Pacini領域を狙う
- ・ 現在スマートフォン、スマートウォッチに内蔵



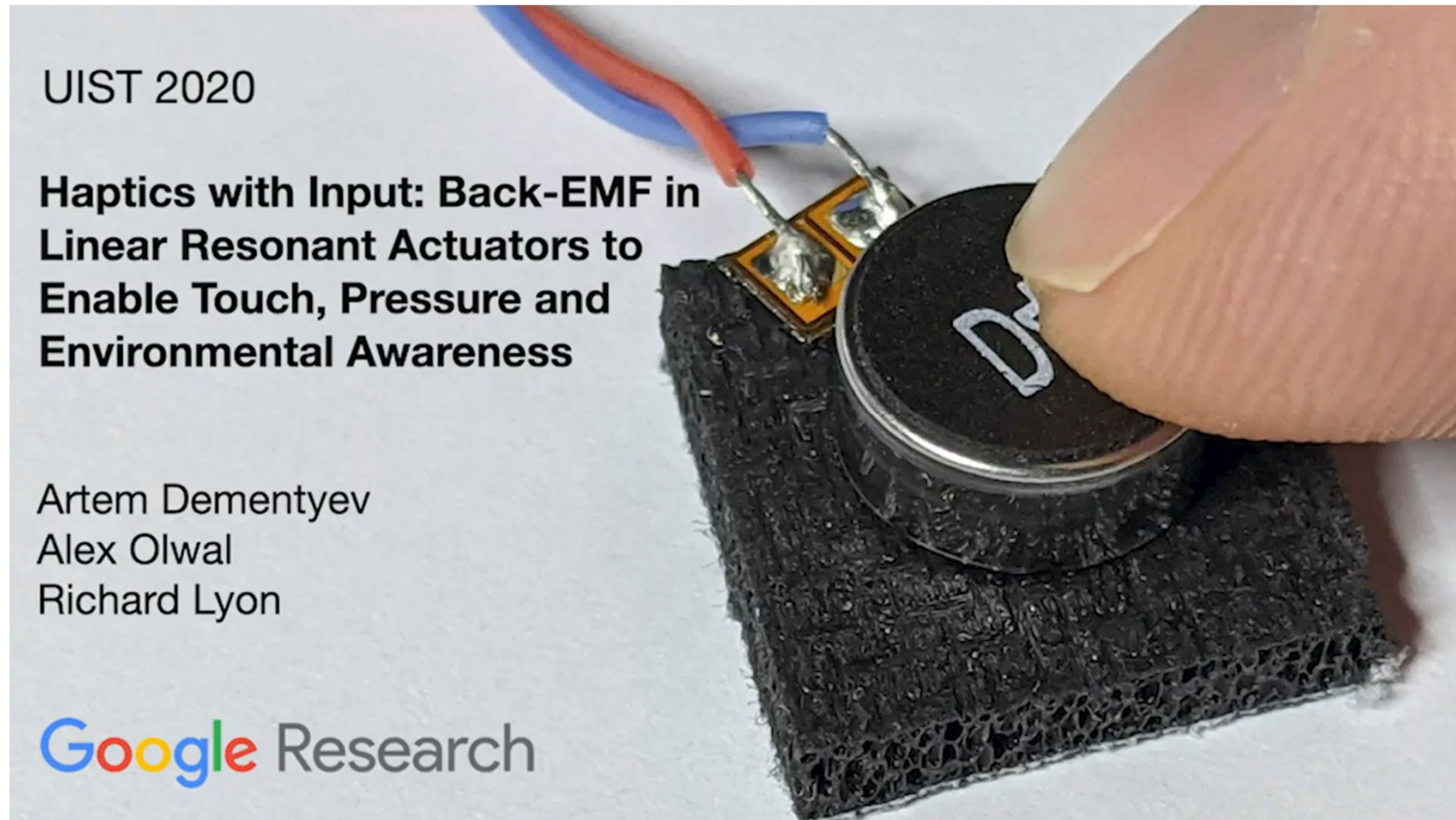
直動共振アクチュエータ/Linear Resonant Actuator



直動共振アクチュエータ/Linear Resonant Actuator



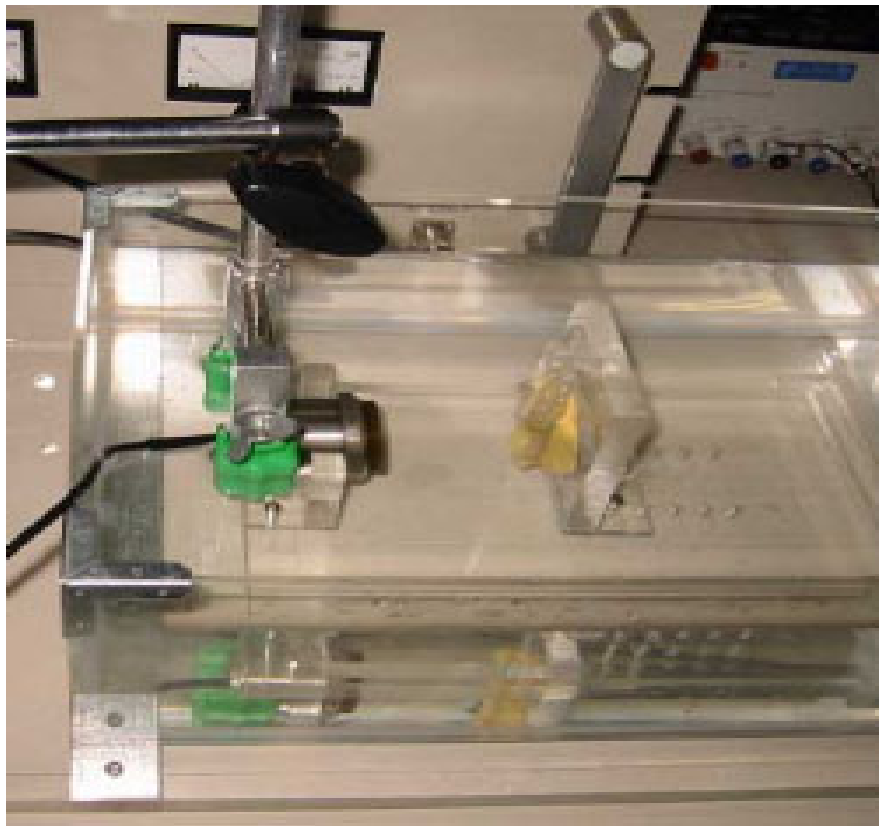
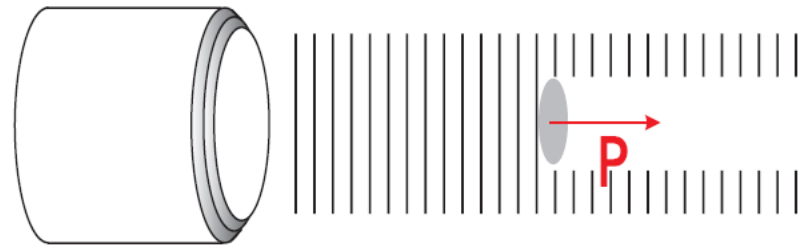
(UIST2020) Haptics with Input: Back-EMF in Linear Resonant Actuators to Enable Touch, Pressure and Environmental Awareness
Artem Dementyev, Alex Olwal, Richard F Lyon



<https://www.youtube.com/watch?v=f4mckHLWBd4>

- ・ LRAの逆起電力を測定することで、LRAが触られているか、どのくらいの力で押されているかを計測する。LRAの逆起電力測定はすでに多くのドライバに内蔵されている。

Actuator should disappear?

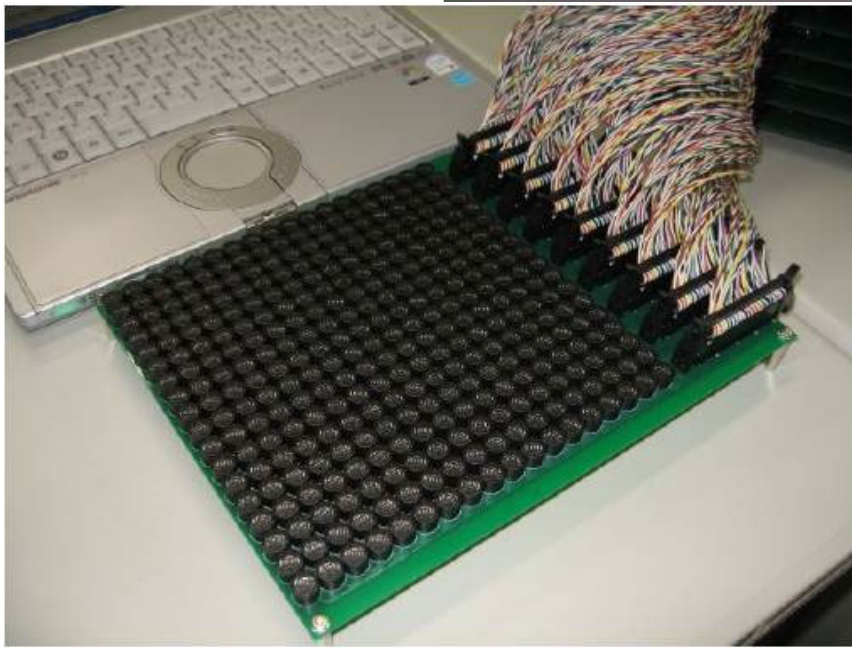


Ultrasound generates Static Pressure

[Iwamoto, Maeda and Shinoda "Focused ultrasound for tactile feeling display," In Proc. of ICAT2001.](#)



空中超音波の収束による触覚提示 Airborne Ultrasound Tactile Display



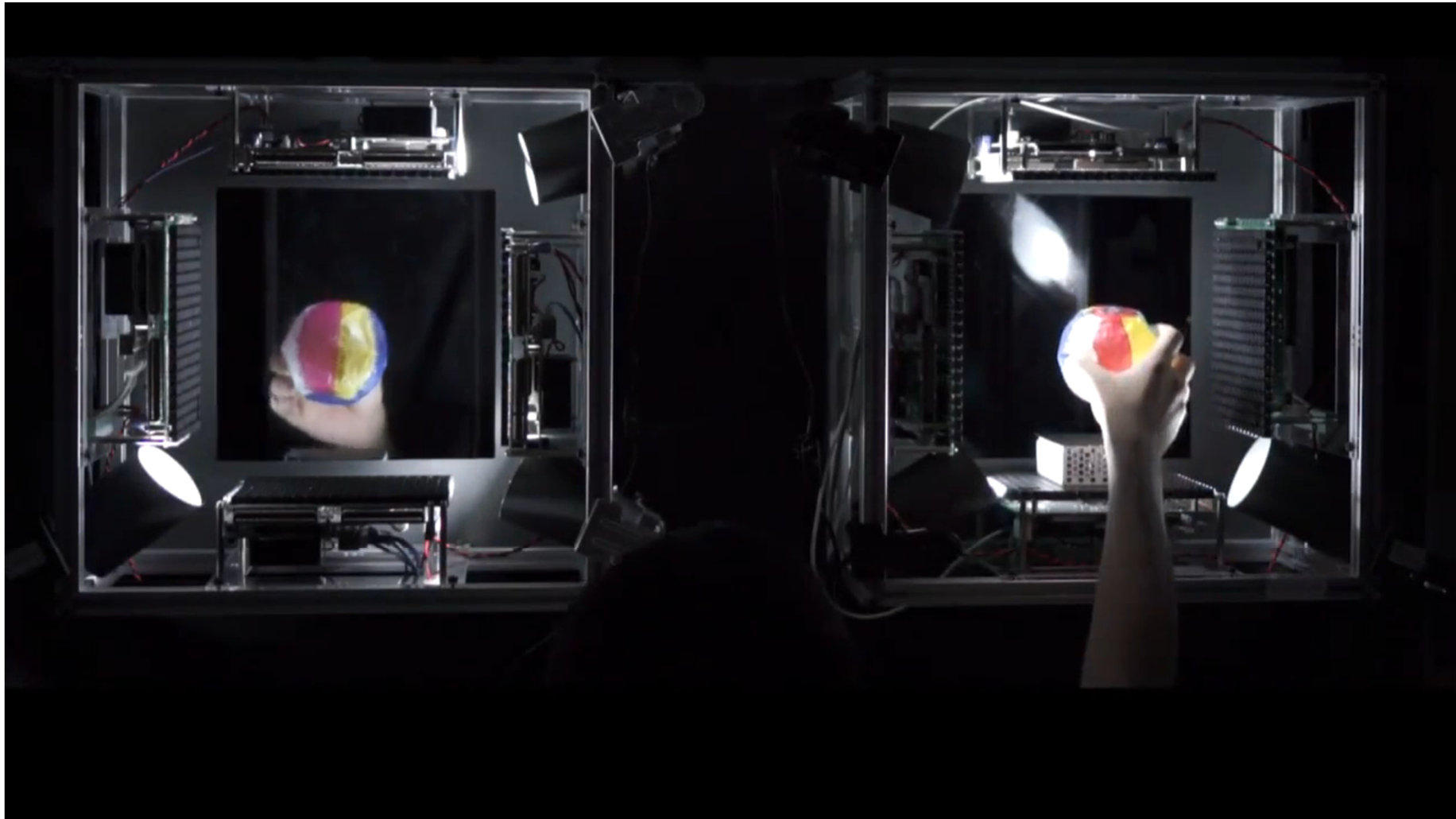
<https://www.youtube.com/watch?v=hSf2-jm0SsQ>

Hiroyuki Shinoda, Airborne Ultrasound Tactile Display. Journal of the Robotics Society of Japan, 2018



(CHI2016) HaptoClone (Haptic-Optical Clone) for Mutual Tele-Environment by Real-time 3D Image Transfer with Midair Force Feedback

Yasutoshi Makino, Yoshikazu Furuyama, Seki Inoue, Hiroyuki Shinoda



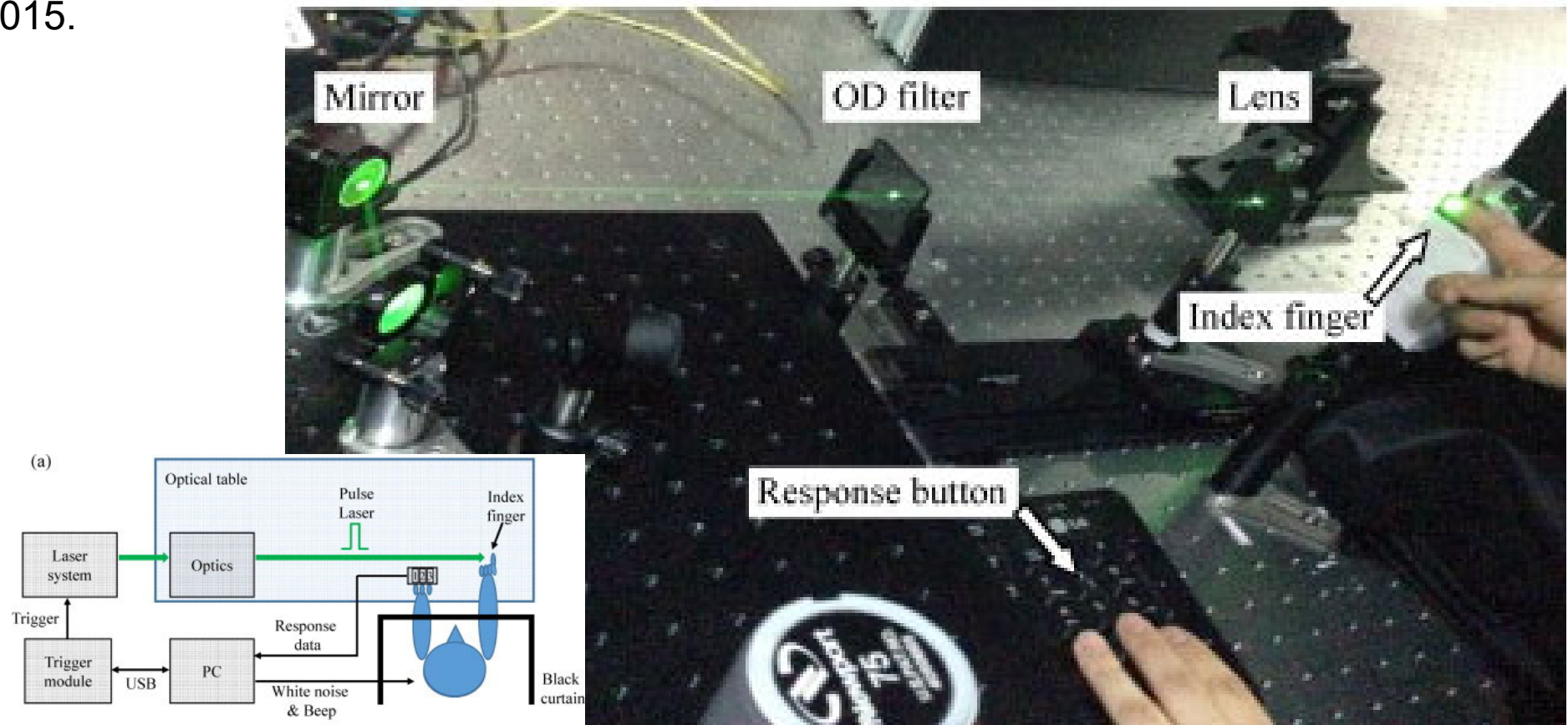
<https://www.youtube.com/watch?v=yxsgjqvSjQY>

超音波触覚を用いた遠隔触覚.



Mid-Air Tactile Stimulation Using Laser-Induced Thermoelastic Effects: The First Study for Indirect Radiation, WHC2015

Hyung-Sik Kim et al., "[Evaluation of the Possibility and Response Characteristics of Laser-induced Tactile Sensation](#)," *Neuroscience Letters*, Vol. 602, pp. 68-72, 2015.



超短時間の高エネルギーレーザー光を皮膚表面またはその上の弾性体に当てることでパルス状の衝撃波を生じ、触覚を提示できる。

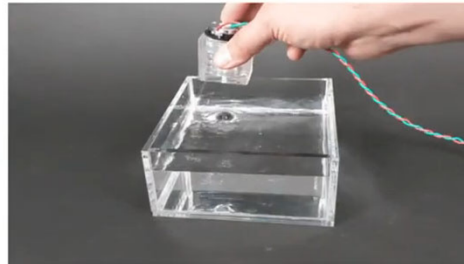
エアジェットで触覚提示 / Using airjet

LRAir: High Energy Synthetic Jets

We developed a prototype actuator in order to showcase the capabilities of this class of device.

Our contributions include:

- A design and model optimizing the acoustic resonances in the system
- Small signal validation of this model
- Large signal measurements quantifying thrust and flow velocity
- Psychophysical measurements showing the low power capabilities of these jets.



<https://www.youtube.com/watch?v=ecQ1dIAIT-k>

(HS2022) C. Shultz, C. Harrison, LRAir: Non-contact Haptics Using Synthetic Jets
振動子+エア開口により空気噴流を実現。

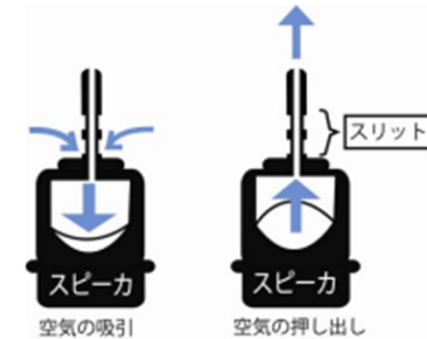
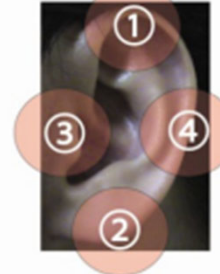


図 7 スピーカを利用した風提示の原理



皮膚を局所的に刺激するウェアラブル風覚提示
デバイスの基礎的検討

Basic Study on Wearable Wind Display for Local Skin Stimulation

[https://kaji-](https://kaji-lab.jp/ja/index.php?plugin=attach&pcmd=open&file=wind_VR2008.pdf&refer=publications)

[lab.jp/ja/index.php?plugin=attach&pcmd=open&file=wind_VR2008.pdf&](https://kaji-lab.jp/ja/index.php?plugin=attach&pcmd=open&file=wind_VR2008.pdf&refer=publications)

[refer=publications](https://kaji-lab.jp/ja/index.php?plugin=attach&pcmd=open&file=wind_VR2008.pdf&refer=publications)

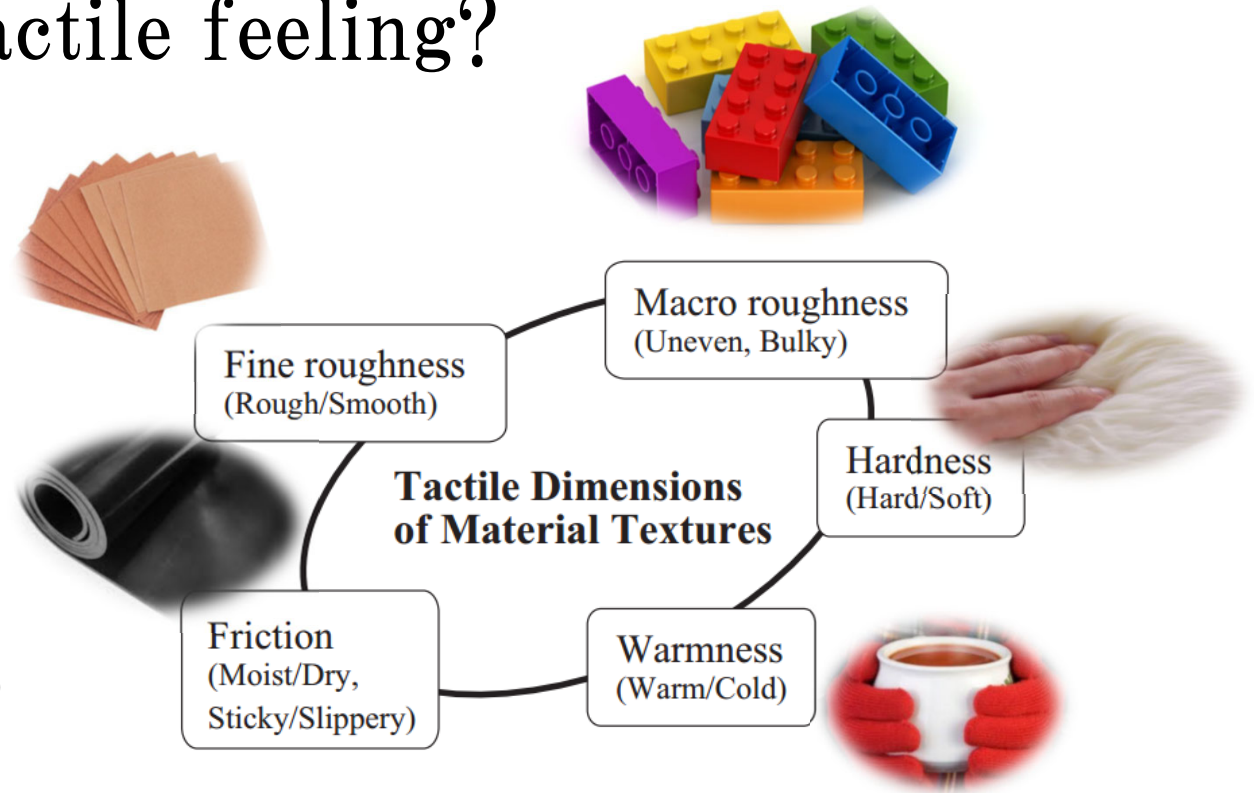
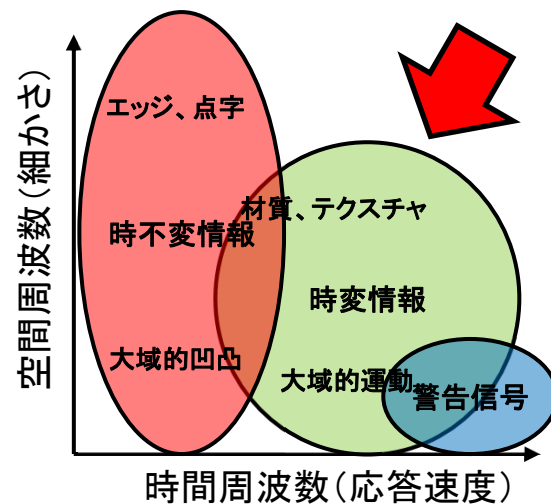
<https://dl.acm.org/doi/pdf/10.1145/1690388.1690399>

(CHI2024) Expressive, Scalable, Mid-Air Haptics with
Synthetic Jets, Vivian Shen, Chris Harrison, Craig Shultz

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

「触感」を提示する

How to present tactile feeling?

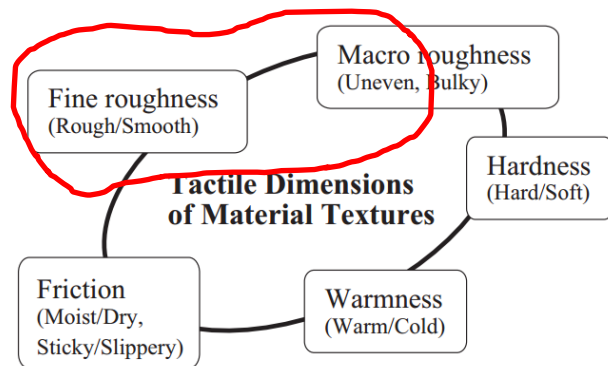
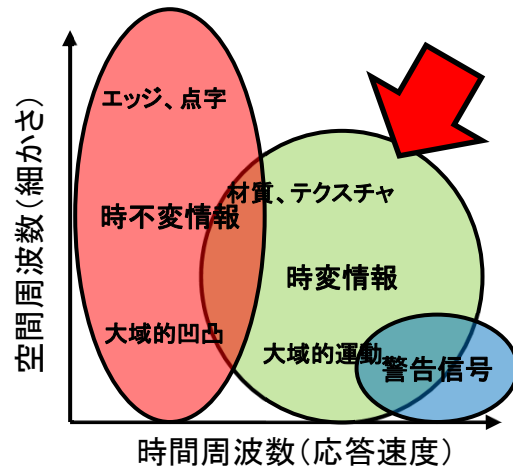


永野, 岡本, 山田: 触覚的テクスチャの材質感次元構成に関する研究動向, TVRSJ2011

- 触感は大域的粗さ、細かな粗さ、硬柔、摩擦、温度、で構成される。
- 触感の記録・再現は遠隔触覚を実用レベルに上げる。
- Tactile feeling is composed of macro/fine roughness, hardness, friction, and warmness.
- Record & replay of tactile feeling has big potential.



理想の振動子：スピーカ/ Audio speaker is ideal

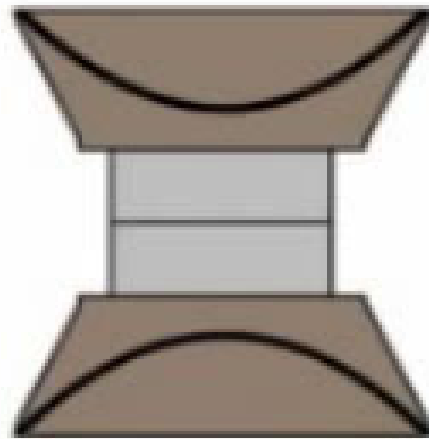


永野, 岡本, 山田: 触覚的テクスチャの材質感次元構成に関する研究動向, TVRSJ2011



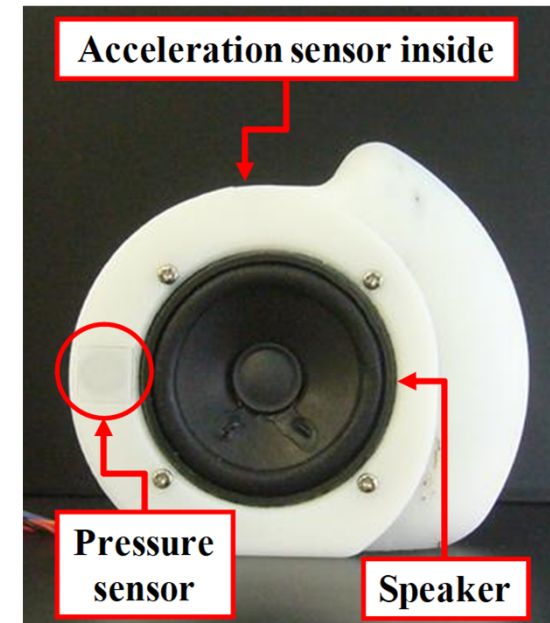
- ・ 偏心モータ、LRAに対してエネルギー効率は落ちるものの、任意の周波数／振幅を実現。Arbitrary frequency / amplitude can be replayed.
- ・ 駆動系はほぼオーディオアンプ。Audio system can be utilized.
- ・ 比較的細かな粗さ感、主にPacini小体が捉える(が故に空間的な特徴のない)触感成分か、把持物体を介する(が故に空間的な特徴のない)触感成分が得意。

スピーカ⇒材質感の実現：生物感



Users hold speakers with their hands and an elastic band around the speaker cone seals the air between the palm and the cone.

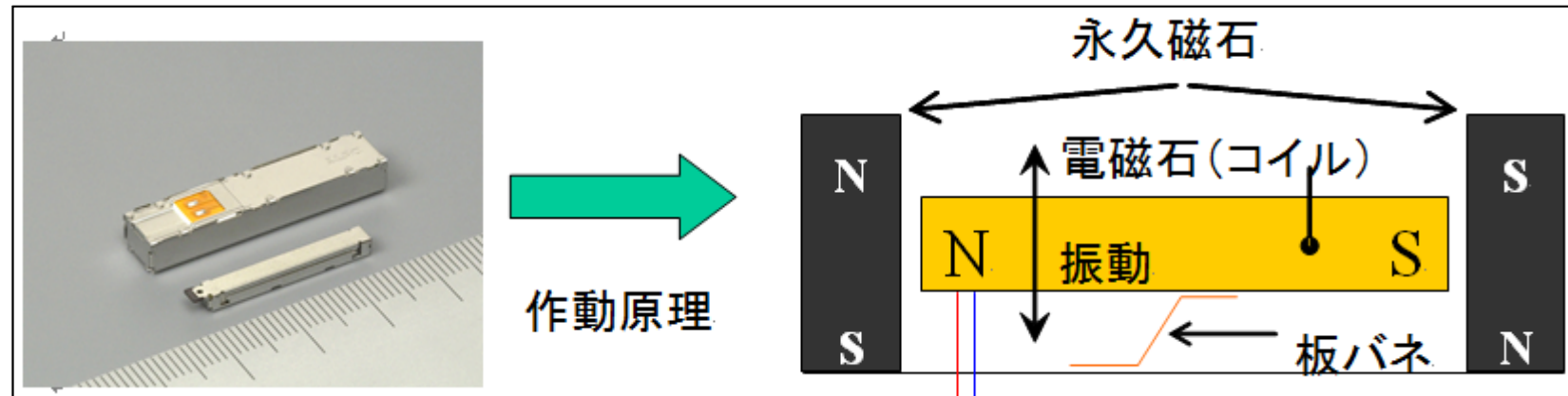
Y. Hashimoto A Novel Interface to Present Emotional Tactile Sensation to a Palm using Air Pressure, CHI2008



1Hz～2Hz程度の振動も提示できるため、例えば心拍も再現できる。スピーカを手で抑えると一種の空気圧駆動となり、本来的に「柔らかい」

スピーカ型アクチュエータの小型化

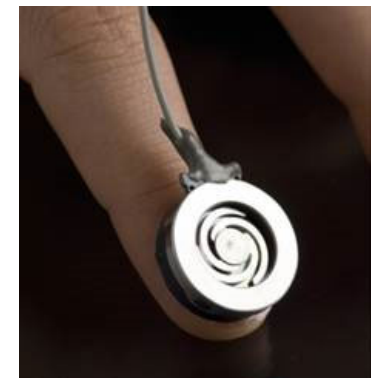
Miniaturalization of the speaker



ForceReactor構造

特に携帯電話用の振動子としていくつか開発された

- ・ 音声スピーカとの兼用を念頭においたもの
 - NECTーキン、マルチアクター(製造終了)
 - 並木精密宝石、振動スピーカ
- ・ アクチュエータの形状を工夫したもの
 - AlpsAlpine: ForceReactor⇒Haptic Reactor
- ・ 触覚提示研究用として販売されているもの
 - Haptuator (Tactile Labs)



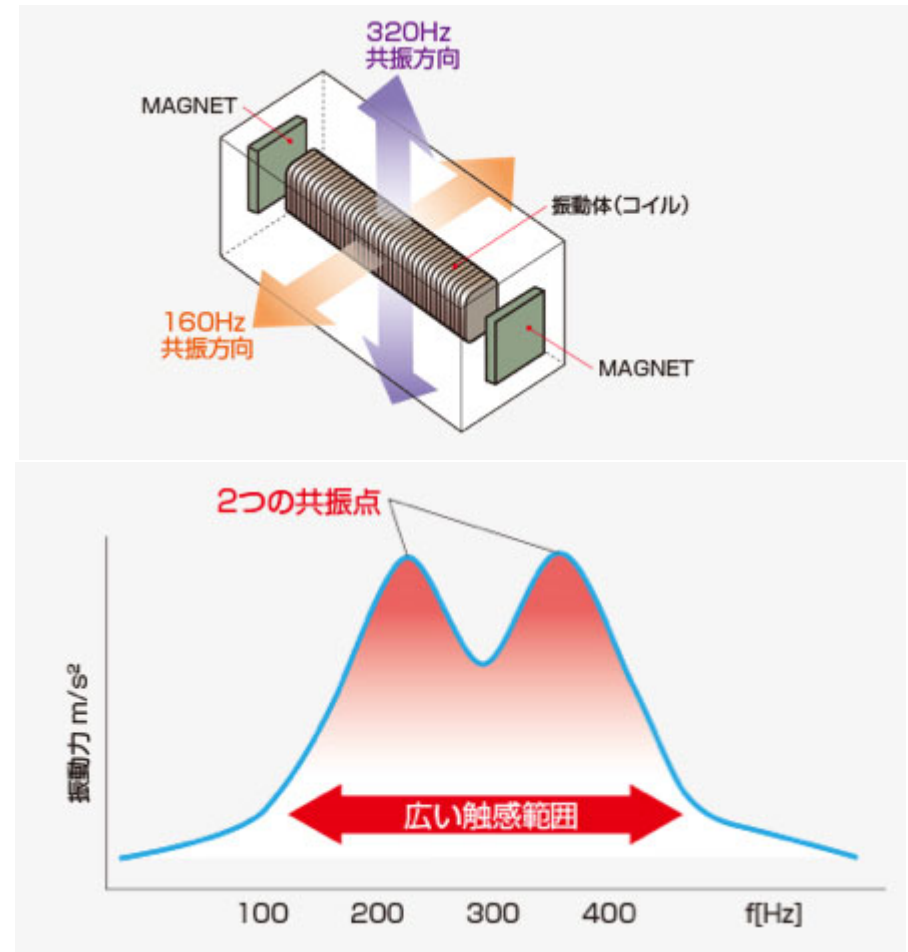
マルチアクター



Structure of HAPTIC Reactor (Alps Alpine)



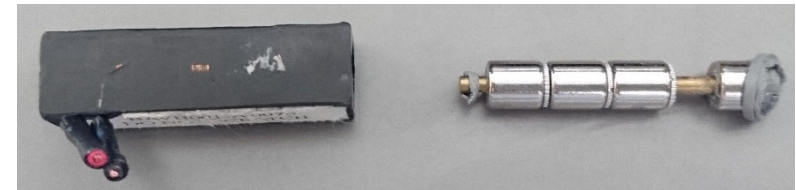
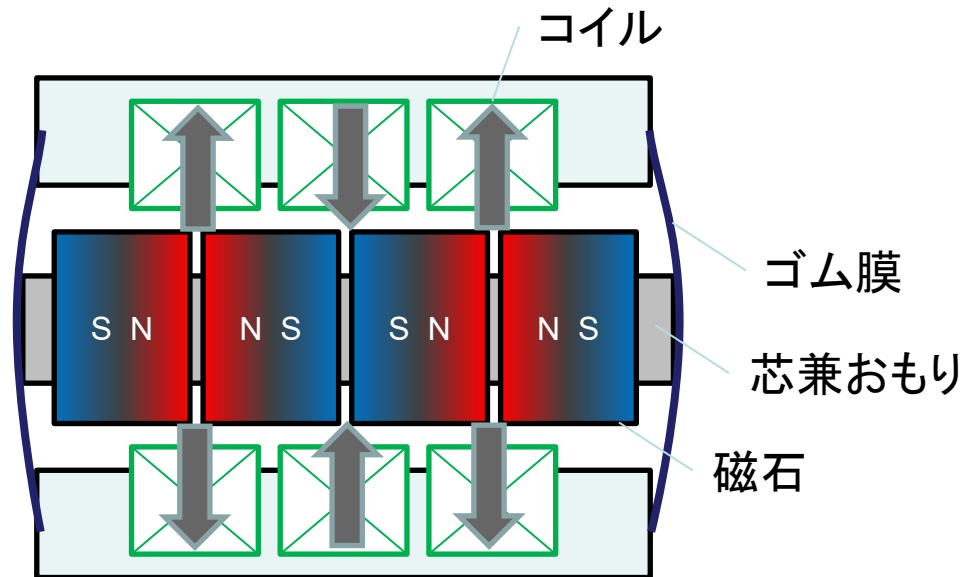
<https://tech.alpsalpine.com/prod/e/html/haptic/>



- 異なる軸に2つの共振点をもたせることで幅広い知覚が可能。
- Two resonant frequencies at different axes.
- LRAとスピーカ形アクチュエータの中間的位置。LRAと分類されることも。
- In between LRA and high-fi.



Structure of Haptuator mk2

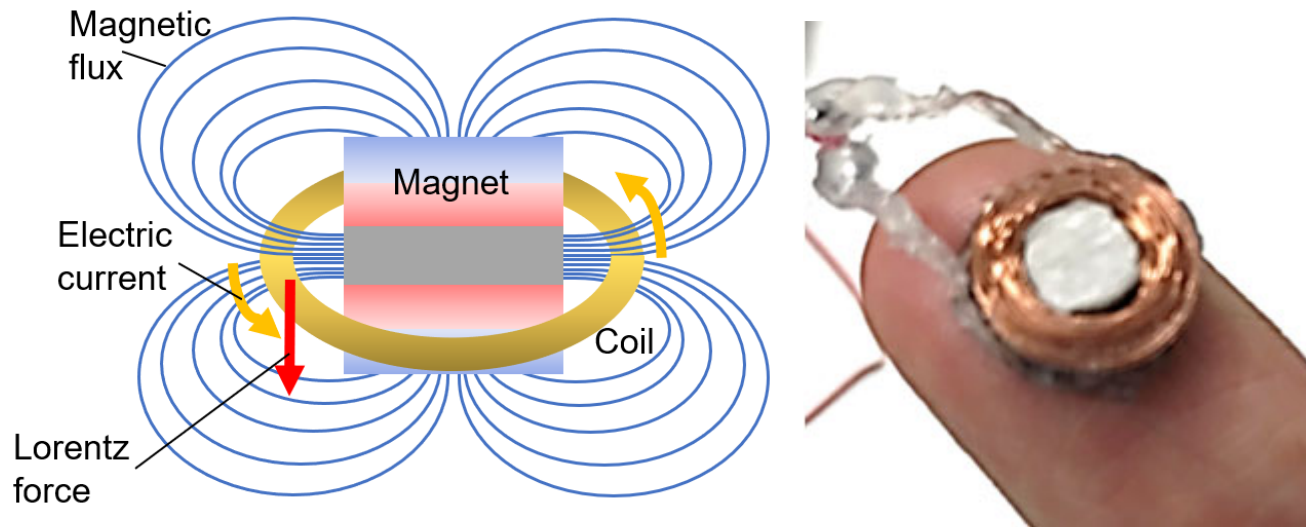


- 磁束がコイルを貫通するために、磁石同士を逆極性で接続
- コイルの広い面積に効率よく磁束が貫通。
- 振動体として磁石＋芯を用い、コイルが筐体側にくるため、振動体の重量比が大きい。これは筐体に触れる触覚提示では重要。



反発する磁石による漏れ磁束を用いたデバイス

Devices using leakage flux from repelling magnets

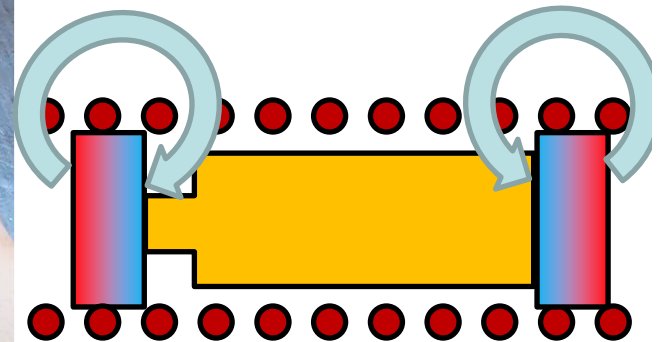
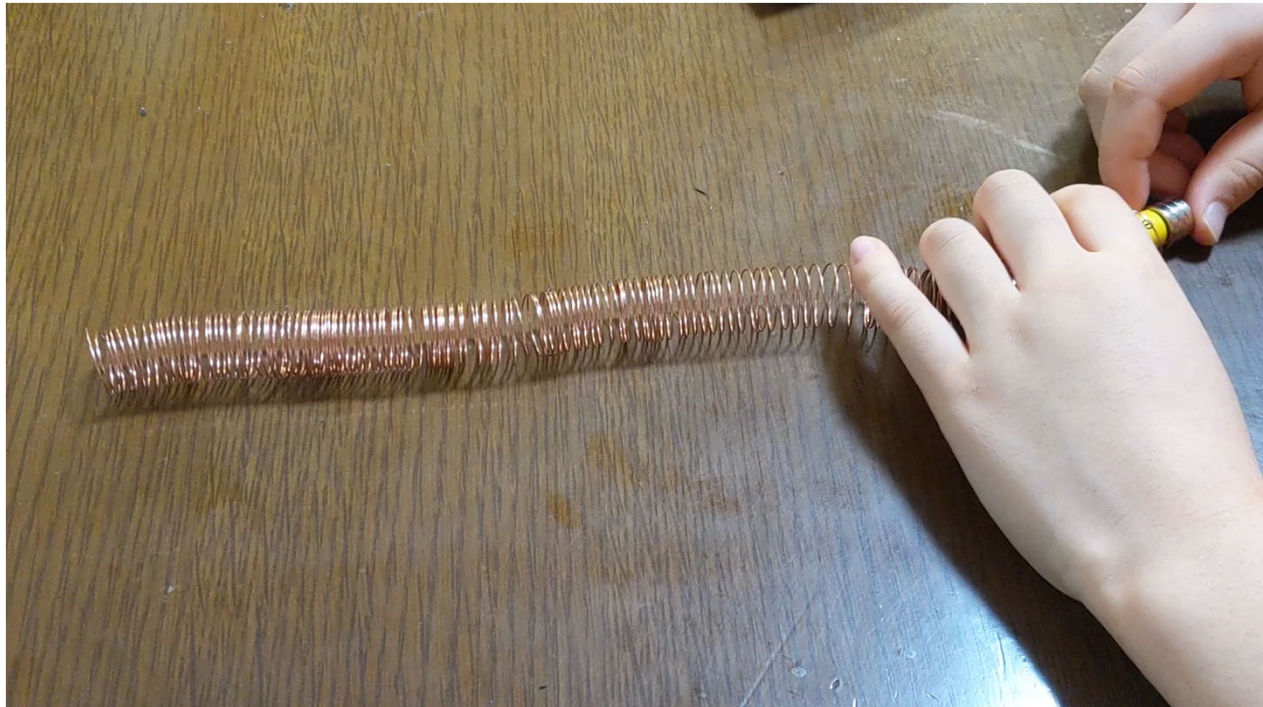


Mistuki Manabe, Keigo Ushiyama, Akifumi Takahashi, Hiroyuki Kajimoto, "Energy Efficient Wearable Vibrotactile Transducer Utilizing the Leakage Magnetic Flux of Repelling Magnets," in IEEE VR 2023

- 磁束がコイルを貫通するために、磁石同士を逆極性で接続
- コイルの広い面積に効率よく磁束が貫通.
- Magnets are connected with opposite polarity to allow the magnetic flux to penetrate the coil.
- The magnetic flux efficiently penetrates a large area of the coil.

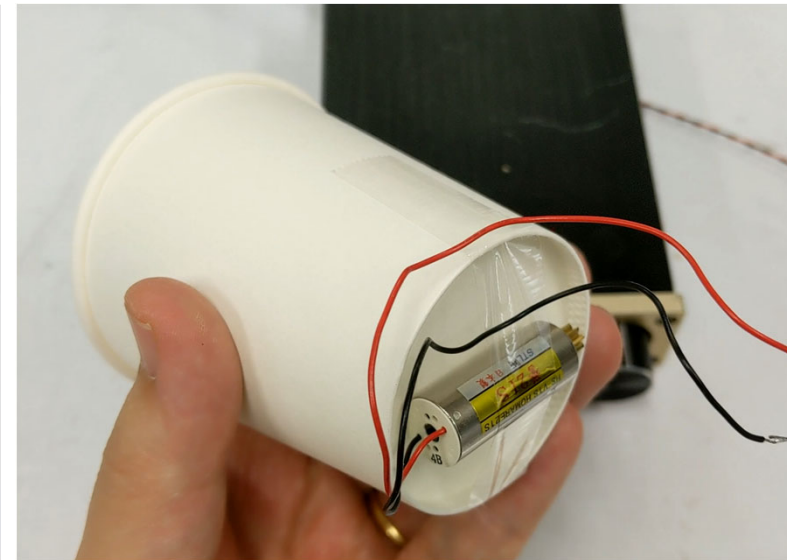
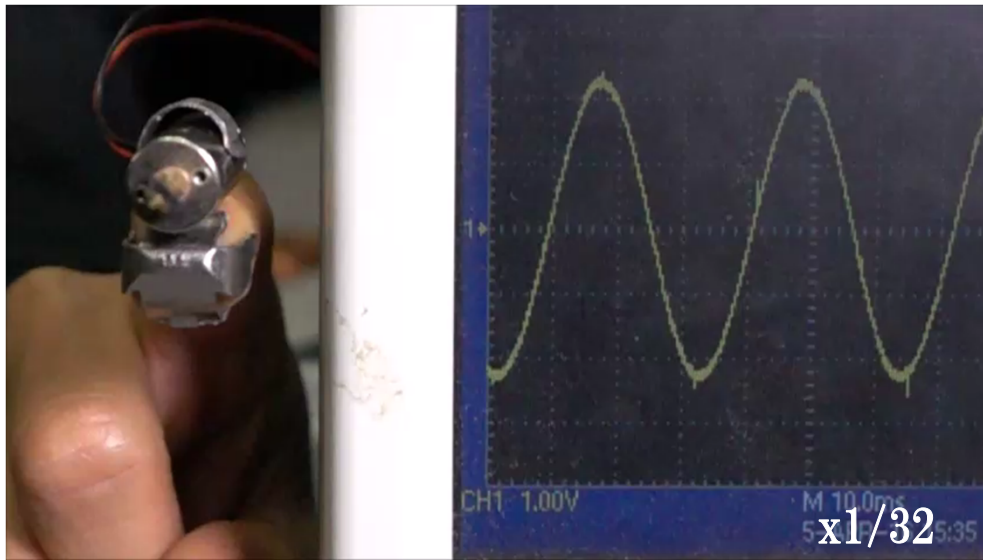


余談: Similar Structure: “Simplest Motor”

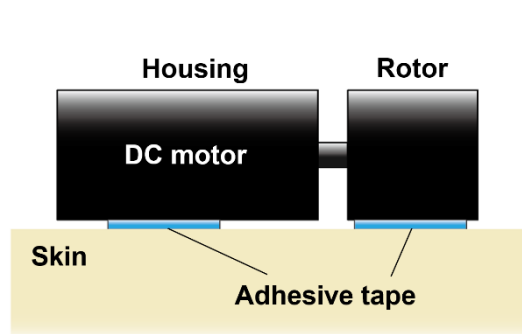


- 世界一簡単な(リニア)モータとして有名なおもちゃ。
- 単4電池＋ネオジウム磁石＋銅線で作れます。磁石は逆向き。
- よくある誤解: 銅線に電流が流れてできる磁場で、磁石と「反発」する。
- 実際はれっきとした電磁誘導現象。Haptuator Mk2と同じ構造。磁束がコイルを貫通する。

DCモータによる振動提示/Vibration by off-the-shelf DC motor

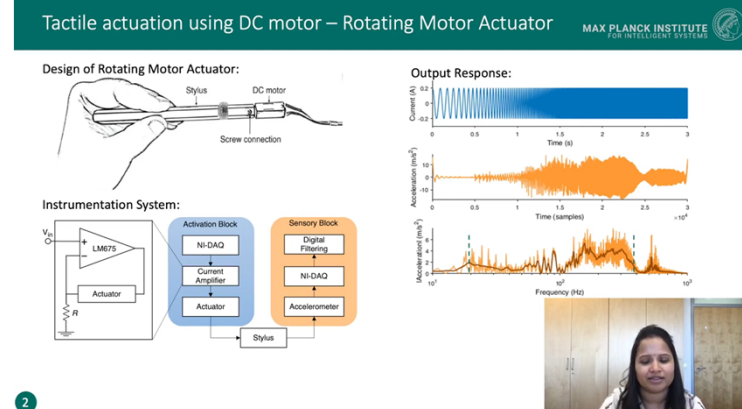


V. Yem, R. Okazaki and H. Kajimoto, "Vibrotactile and Pseudo Force Presentation using Motor Rotational Acceleration." Proc of IEEE HapticsSymposium, Philadelphia April 8-11th, pp. 47-51, 2016.



M. Manabe, K. Ushiyama, A. Takahashi, H. Kajimoto, "Vibrotactile Presentation using a Motor within a Housing and Rotor Fixed to the Skin," Proc. IEEE World Haptics Conference, 2021.

- 回転モータは偏心おもりがなくとも高品位な触覚提示に利用できる。出力軸も皮膚に固定すれば直流成分も提示できる。
- Rotating motors can be used for high-quality tactile presentation without eccentric weights. If the output shaft is also fixed to the skin, a direct current component can also be presented.



R. Gourishetti, K. J. Kuchenbecker, Evaluation of Vibrotactile Output from a Rotating Motor Actuator, HS2022
スタイラス+DCモータ

磁石だけで／磁石とコイルを分離して提示する



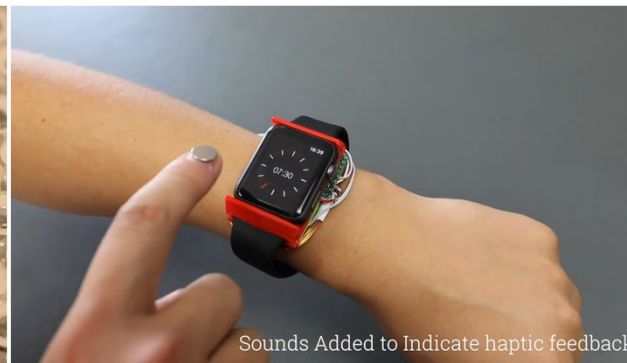
(CHI2019) Magnetact: Magnetic-sheet-based Haptic Interface for Touch Devices, Kentaro Yasu. <https://www.youtube.com/watch?v=v5s1byAfoc>
シート状磁石によるタブレット上の触感提示。カチカチ感など。



(CHI2021) A Computational Approach to Magnetic Force Feedback Design
Masa Ogata, Yuki Koyama <https://www.youtube.com/watch?v=RovY0aoNBj8>
磁石による触感設計の最適化。



タブレットの下に電磁石、指に磁石を取り付ける



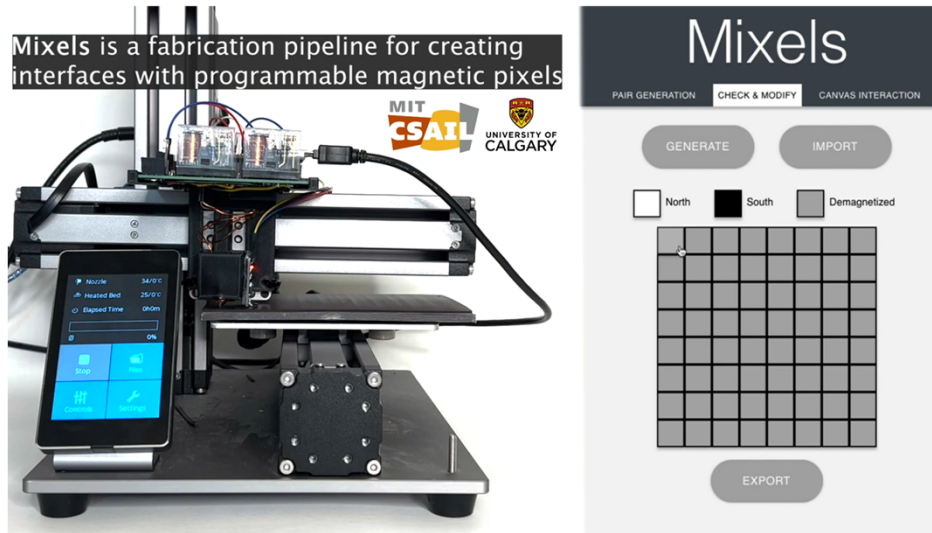
スマートウオッチの下に電磁石、指に磁石。磁石は位置検出にも用いる



(CHI2021) MagnetIO: Passive yet Interactive Soft Haptic Patches Anywhere
Alex Mazursky, Shan-Yuan Teng, Romain Nith, Pedro Lopes
<https://www.youtube.com/watch?v=hsCo3g?IKy0>
環境側に磁石埋め込み、指にコイル



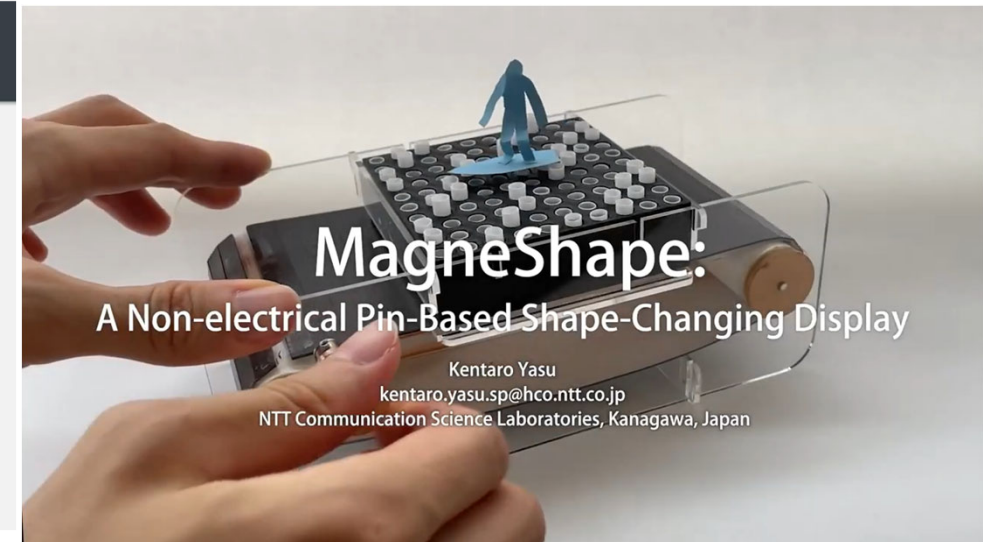
磁場のプログラム



<https://www.youtube.com/watch?v=JKuCthryzhA&list=PLqhXYFYmZ-VdaPIMTFVH5K5brMDJClfAn&index=66>

(UIST2022) Mixels: Fabricating Interfaces using Programmable Magnetic Pixels
Martin Nisser, Yashaswini Makaram, Lucian Covarrubias, Amadou Yaye Bah, Faraz Faruqi, Ryo Suzuki, Stefanie Mueller

プログラム可能な磁気ピクセルを、市販の3軸CNCマシンに取り付けられた電磁プリントヘッドで迅速に製作する。
Programmable magnetic pixels are quickly produced with an electromagnetic print head mounted on a commercial 3-axis CNC machine.



<https://www.youtube.com/watch?v=c4ewnWFIQAU&list=PLqhXYFYmZ-VdaPIMTFVH5K5brMDJClfAn&index=93>

MagneShape: A Non-electrical Pin-Based Shape-Changing Display
Kentarō Yasu

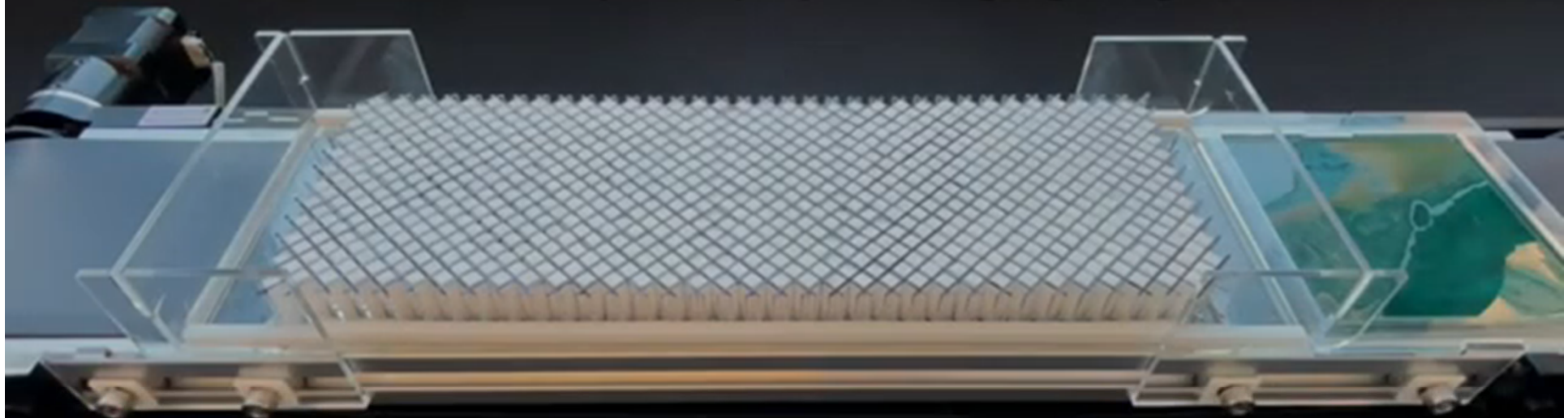
磁気シートと磁石ピンを使用したシンプルなピンベースの形状変化ディスプレイを提案

Proposal for a simple pin-based shape-changing display using magnetic pins and magnetic sheet

(CHI2024) MagneSwift: Low-Cost, Interactive Shape Display Leveraging Magnetic Materials, Kentaro Yasu <https://www.youtube.com/watch?v=YedLBJIPsGc>

MagneSwift:

Low-Cost, Interactive Shape Display Leveraging Magnetic Materials

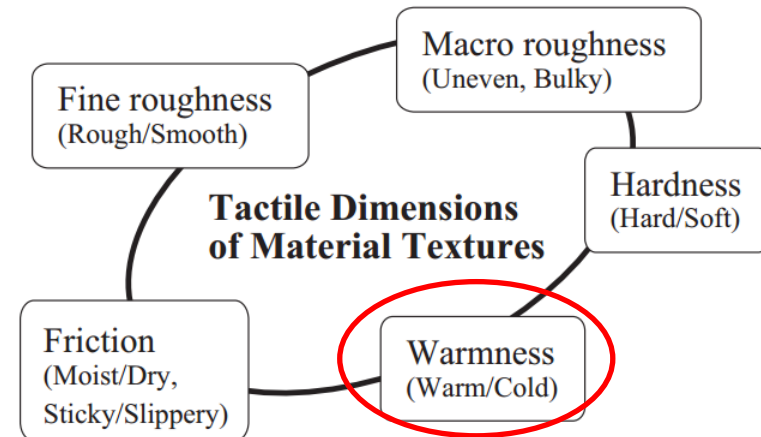
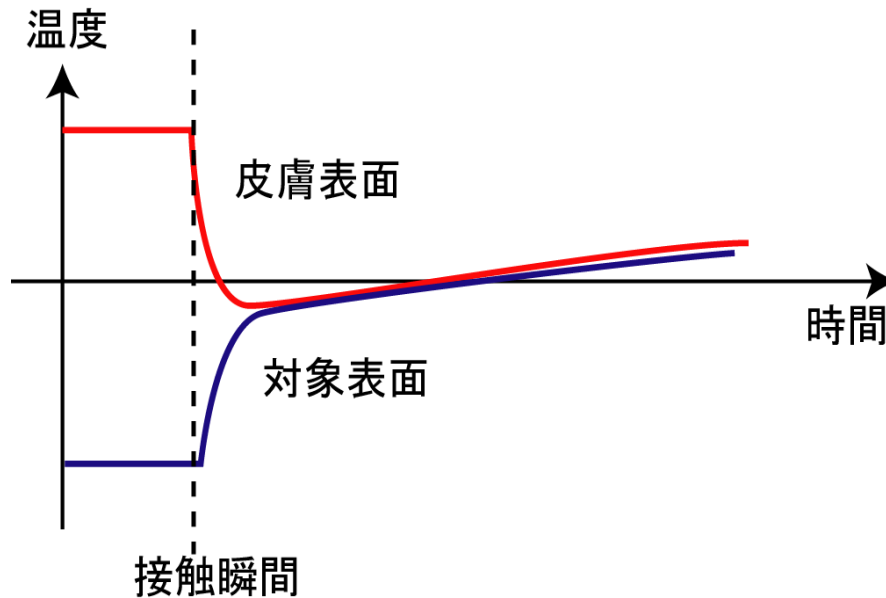
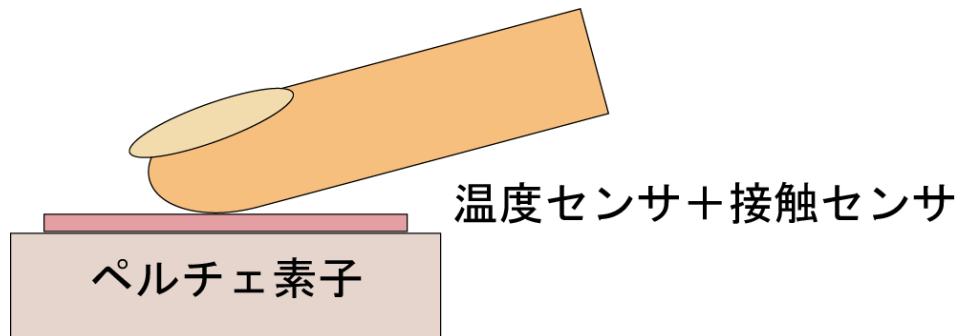


Kentaro Yasu

kentaro.yasu@ntt.com

NTT Communication Science Laboratories, Kanagawa, Japan

温度感覚ディスプレイ／Thermal Display



永野, 岡本, 山田: 触覚的テクスチャの材質感次元構成に関する研究動向, TVRSJ2011

接触瞬間から2～3秒間の温度変化が
材質感推定の強力な手がかり

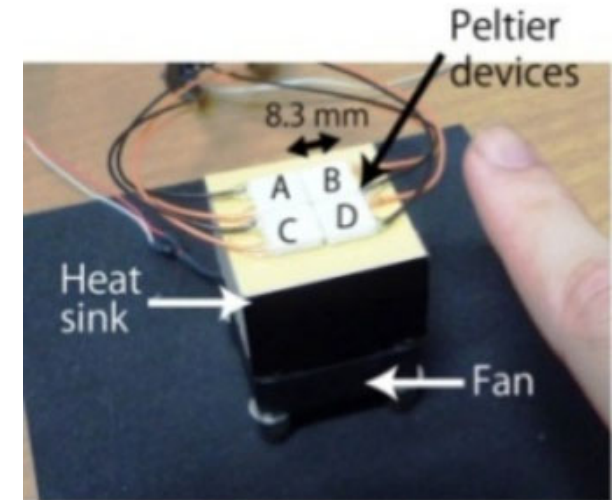
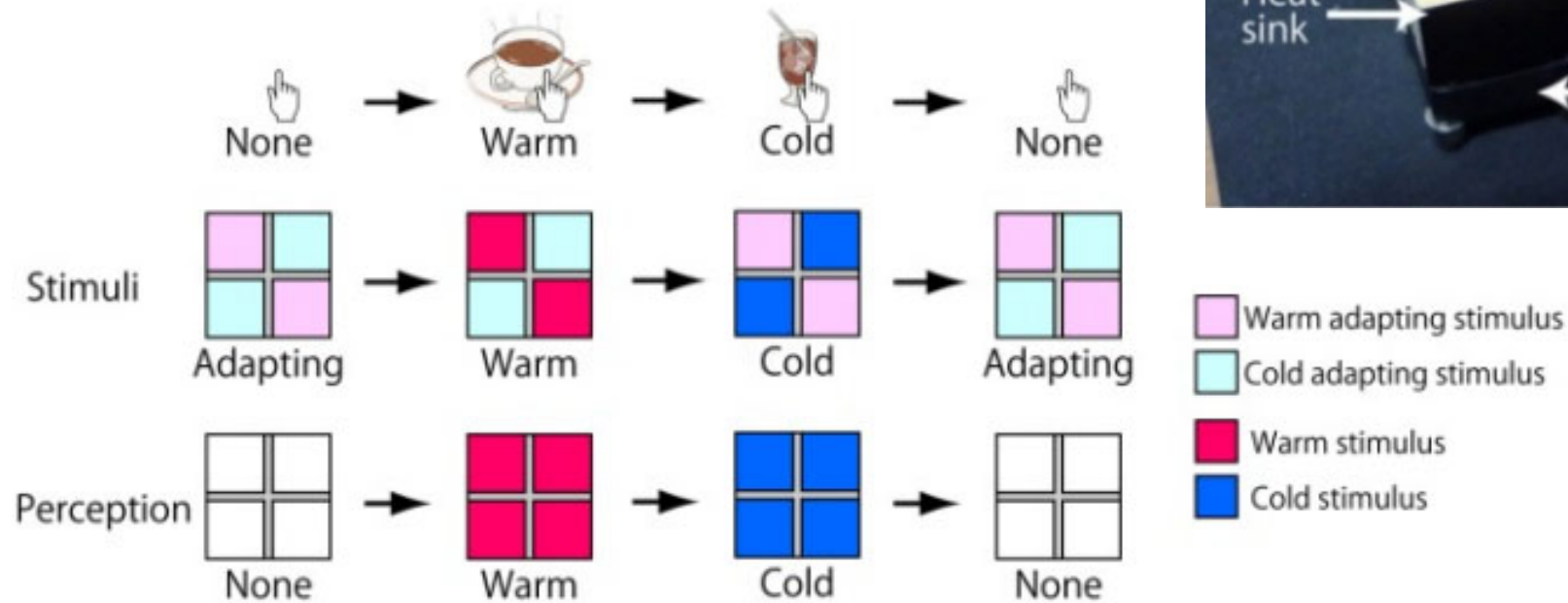
2 to 3s temperature change is the key
to detect object property.
Peltier device with temperature sensor
is used to reproduce the time course.

井野: 物体接触時の皮膚温度変化に着目した材質感触覚ディスプレイ方式の提案、計測自動制御学会論文集(1994)
Yamamoto, "Control of Thermal Tactile Display Based on Prediction of Contact Temperature," ICRA2004
Hsin-Ni Ho, Modeling the thermal responses of the skin surface during hand-object interactions , 2008



温度の高速・効率的な提示

Quick & efficient temperature presentation

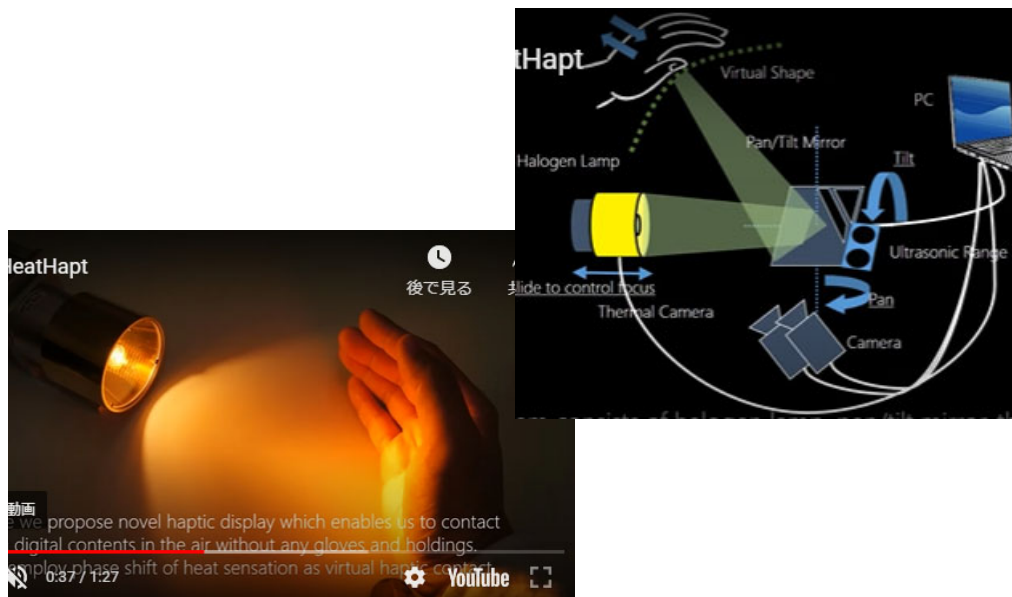


Katsunari Sato and Takashi Maeno: Presentation of Rapid Temperature Change using Spatially Divided Hot and Cold Stimuli, *Journal of Robotics and Mechatronics*, Vol.25, No.3, pp.497-505 (2013.6)

通常ペルチェ素子を用いて温／冷を提示。温冷提示を繰り返すと熱が溜まる悪循環。温める素子と冷やす素子を分けることで効率化、かつ温度の高速な提示が可能。温度そのものではなく変化成分のみを提示することでも効率化、高速化。

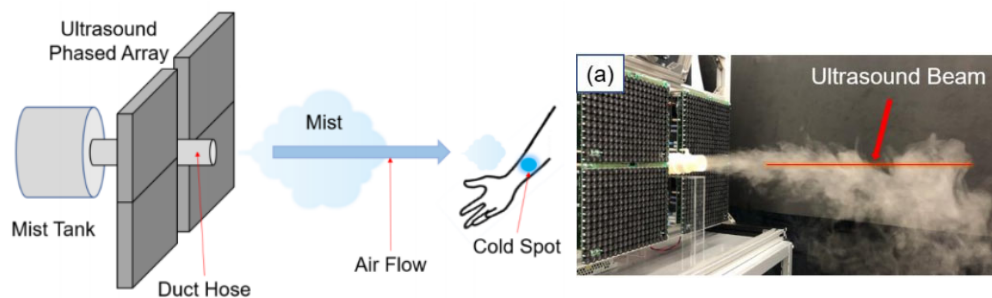
Peltier devices are often used to present hot and cold. If hot and cold presentation is repeated, heat accumulation occurs. This problem is solved by (1) separating the heating and cooling elements, and (2) presenting not the temperature itself, but only the components that change.

温度の非接触提示／Thermal Projection



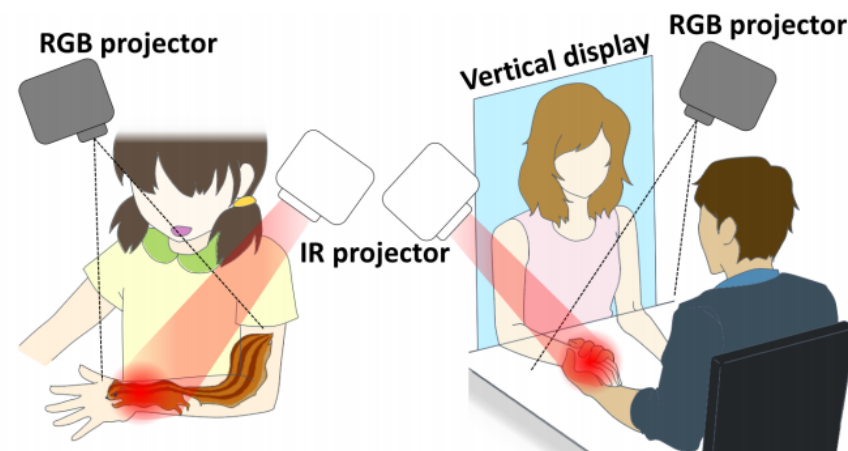
Satoshi Saga. HeatHapt:Thermal-Radiation-Based Haptic Display. In Proceedings of AsiaHaptics 2014, 2014.

<https://www.youtube.com/watch?v=EoWfFpsEpgs&t=41s>



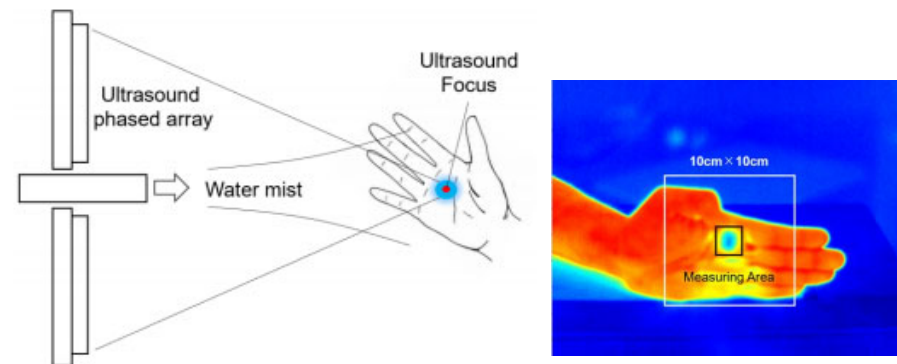
Nakajima et al., Remote Cooling Sensation Presentation Controlling Mist in Midair," in Proc. 2020 IEEE/SICE International Symposium on System Integration, 2020.

空中超音波によるミストの搬送を用いて温度(冷覚)を提示。
Presenting cool sensation by mist conveyed by ultrasound.



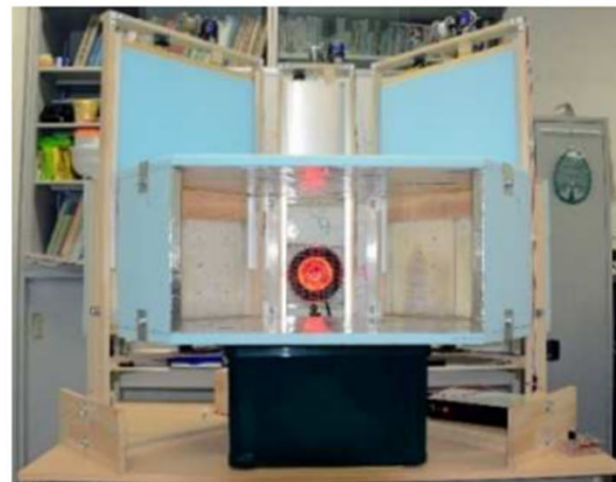
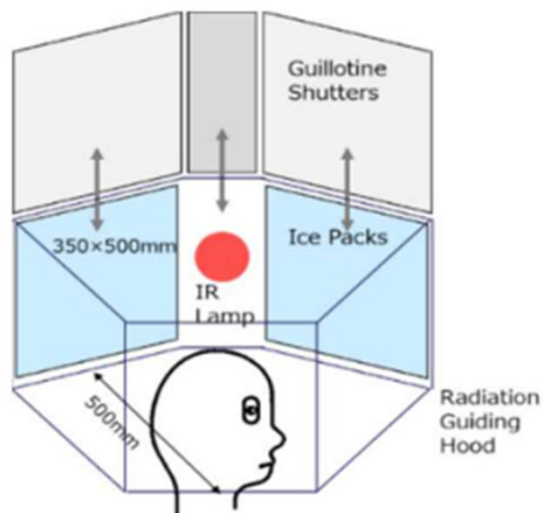
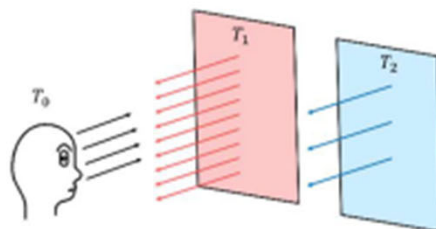
Daisuke Iwai et al., Non-Contact Thermo-Visual Augmentation by IR-RGB Projection, 2019 IEEE TVCG

赤外プロジェクタで温度を投影. Project thermal sensation by IR projector



Nakajima et al., Spatiotemporal Pinpoint Cooling Sensation Produced by Ultrasound-Driven Mist Vaporization on Skin, IEEE Trans. on Haptics 2021
ミストを空間に散布し、超音波のフォーカスによる気化熱で冷却

温度の非接触提示／Thermal Projection



<http://asiahaptics2022.com/upload/202212/12/2022121719307788.pdf>

(AsiaHaptics2022) A Non-Contact Thermal Display by High and Low Temperature Radiation Sources

Yuichiro KUME, Tota MIZUNO and Rio YONEZAWA

熱源からの放射熱によって提示。シンプルだがリアル。冷覚も提示できる。

Presented by radiant heat from a heat source. Simple but realistic. Can also present cold sensation.

温度の化学的提示(CHI2020) Trigeminal-based Temperature Illusions

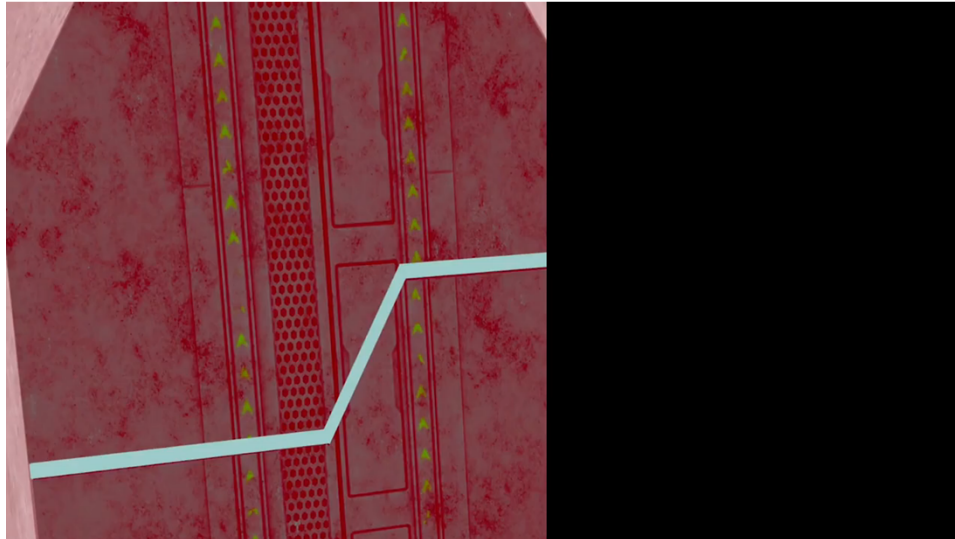
Jas Brooks;Steven Nagels;Pedro Lopes



- <https://www.youtube.com/watch?v=rEYslUk7bqk>
- 温度提示にカプサイシンとオイカリプトールを使う。鼻に噴霧

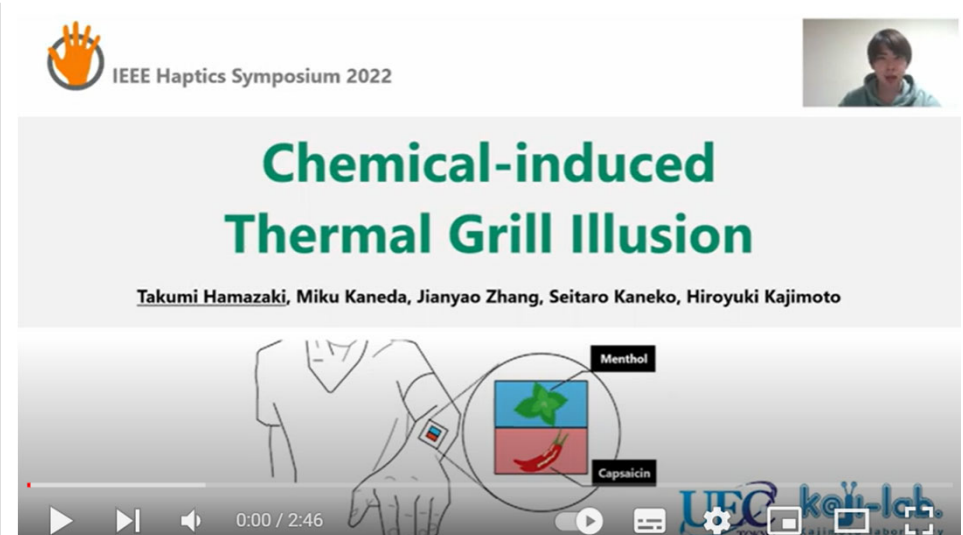


Chemical Haptics



Jasmine Lu, Ziwei Liu, Jas Brooks, Pedro Lopes,
Chemical Haptics: Rendering Haptic Sensations via
Topical Stimulants, UIST2021

https://www.youtube.com/watch?v=2nppa8iAMzg&list=P_LqhXYFYmZ-VeKUIuttbQWomTQ-oXF6PLf&index=43

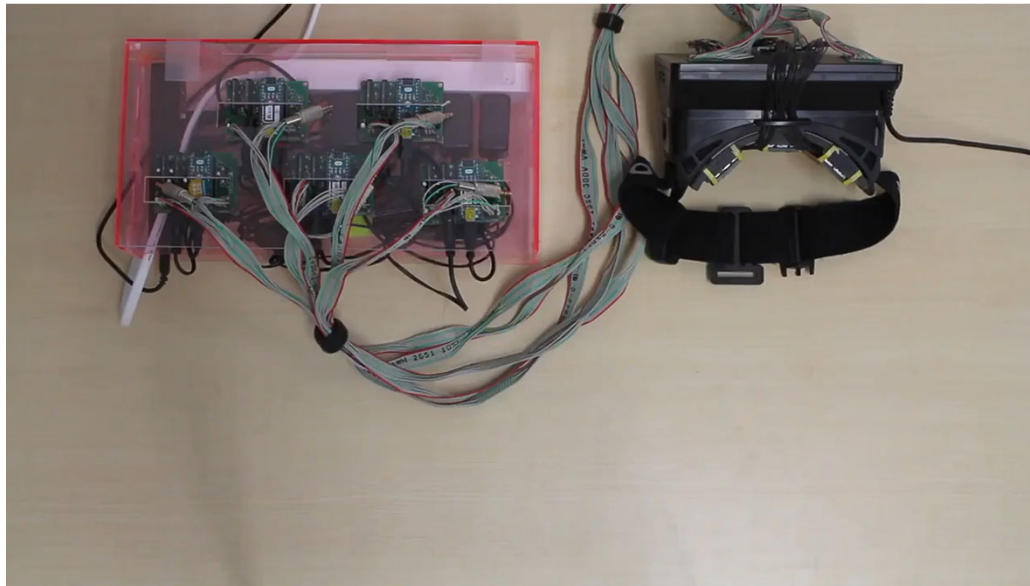


Takumi Hamazaki, Miku Kaneda, Zhang Jianyao,
Seitaro Kaneko, Hiroyuki Kajimoto : "Chemical induced
Thermal Grill Illusion", IEEE Haptics Symposium2022
Technical Paper, March 21-24, 2022
<https://www.youtube.com/watch?v=1yRpwHUPeKw>

化学薬品を使って温覚、冷覚、痛覚、麻痺感覚等を提示する。新しいタイプの触覚提示手法。
提示時間はかかるが定常的な感覚が得られる。

Using chemicals to present sensations of warmth, cold, pain, numbness, etc. This is a
new type of tactile sensation presentation method. It takes a long time to present, but
steady sensation can be obtained.

HMDと温度提示/ HMD and temperature presentation

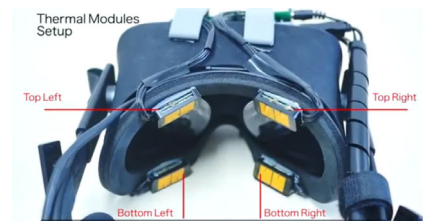
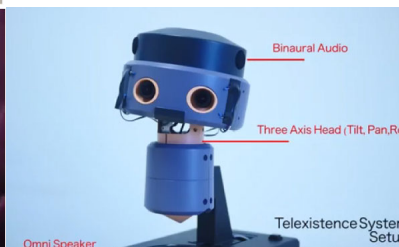


(CHI2017) ThermoVR: Exploring Integrated Thermal Haptic Feedback with Head Mounted Displays

Roshan L Peiris, Wei Peng, Zikun Chen, Liwei Chan, Kouta Minamizawa

<https://www.youtube.com/watch?v=kNXgA9xDwCo>

HMDに温度感覚(と振動感覚)を付与。臨場感を増強



(CHI2018) Ambient: Facial Thermal Feedback in Remotely Operated Applications

MHD Yamen Saraiji, Roshan Lalintha Peiris, Lichao Shen, Kouta Minamizawa, Susumu Tachi

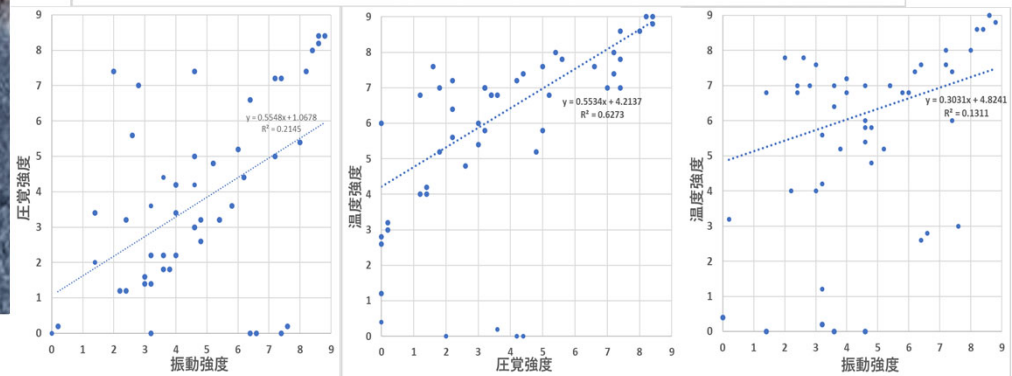
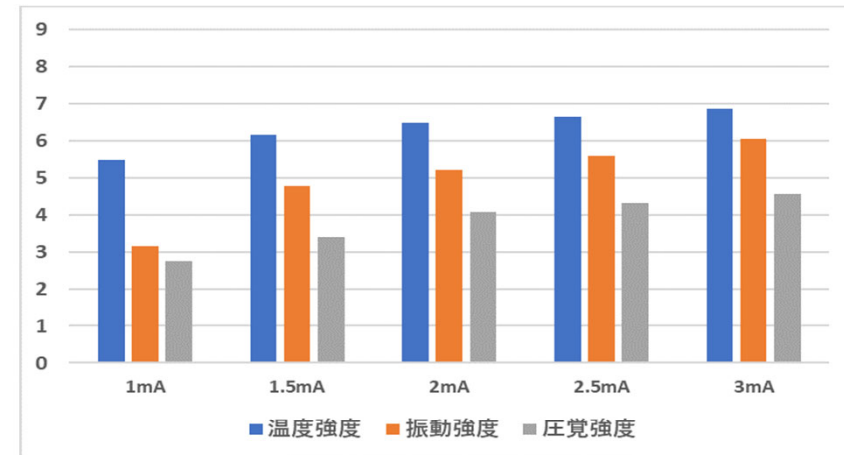
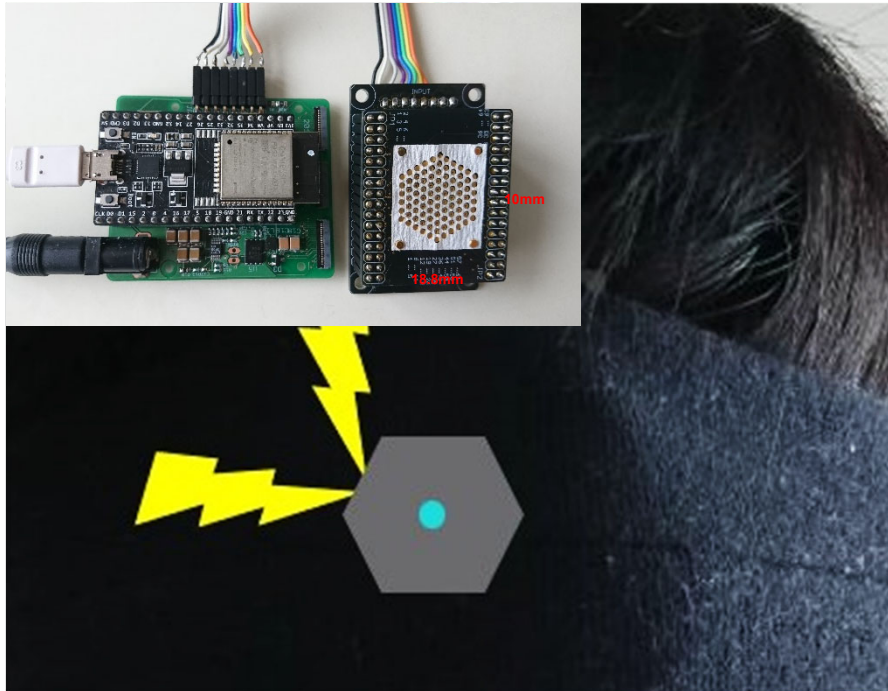
<https://www.youtube.com/watch?v=Ewe2X663NNE>

レイグジスタンス環境での温度感覚伝達を実現



額への電気刺激による温冷覚

Saito et al. Thermal sensation presentation to the forehead using electrical stimulation: comparison with other tactile modalities and polarity effect (WHC2021)

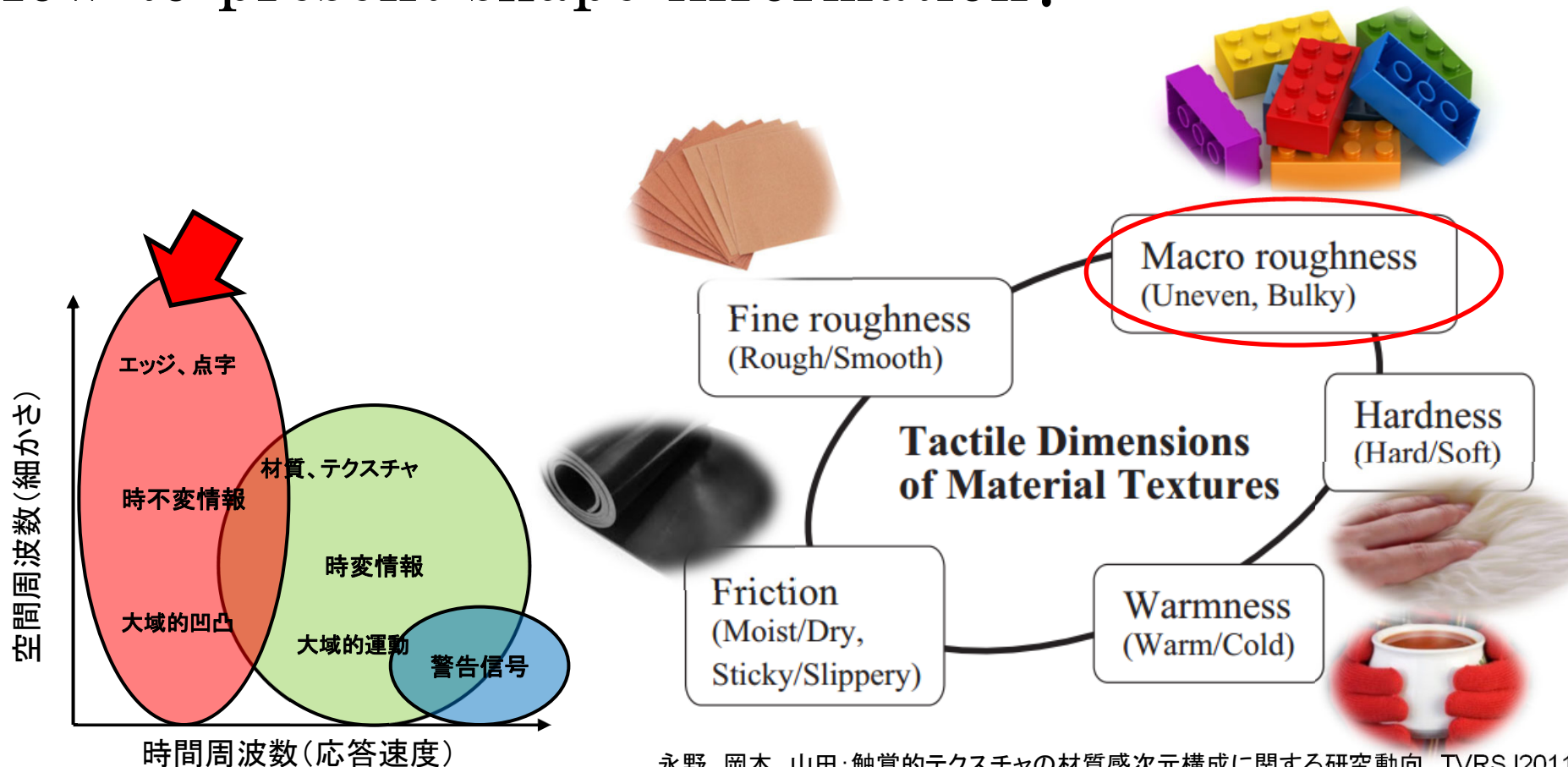


- 電気刺激で冷覚を生じる「ことがある」。生じる場所ではしっかり(氷のように)生じる。
- 以前から腕などでは観察されていた。今回は額での現象を詳細に検討。
- 圧覚との相関が高く、振動感覚との相関は低い。刺激の機序に近い？
- Electrical stimulation occasionally produce a cold sensation. High correlation with pressure sensation, low correlation with vibration sensation.



「形」を提示する

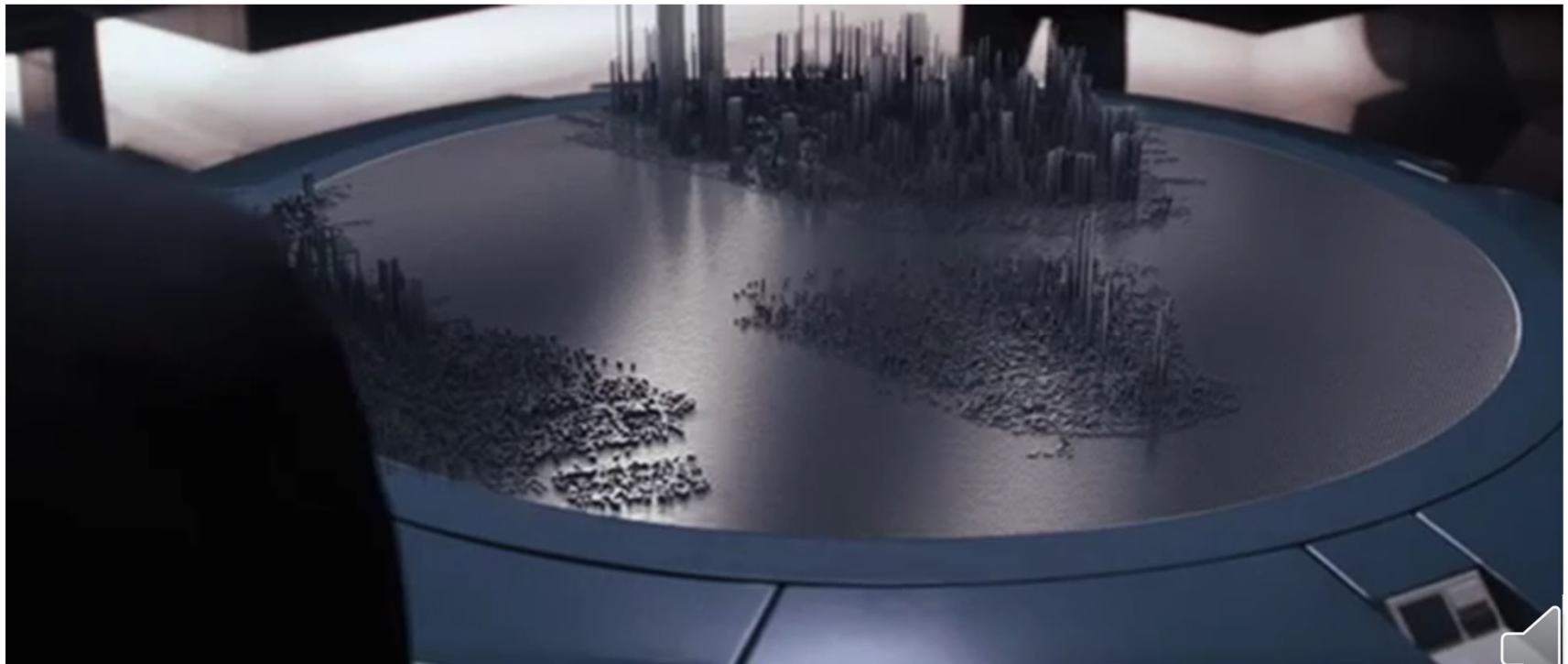
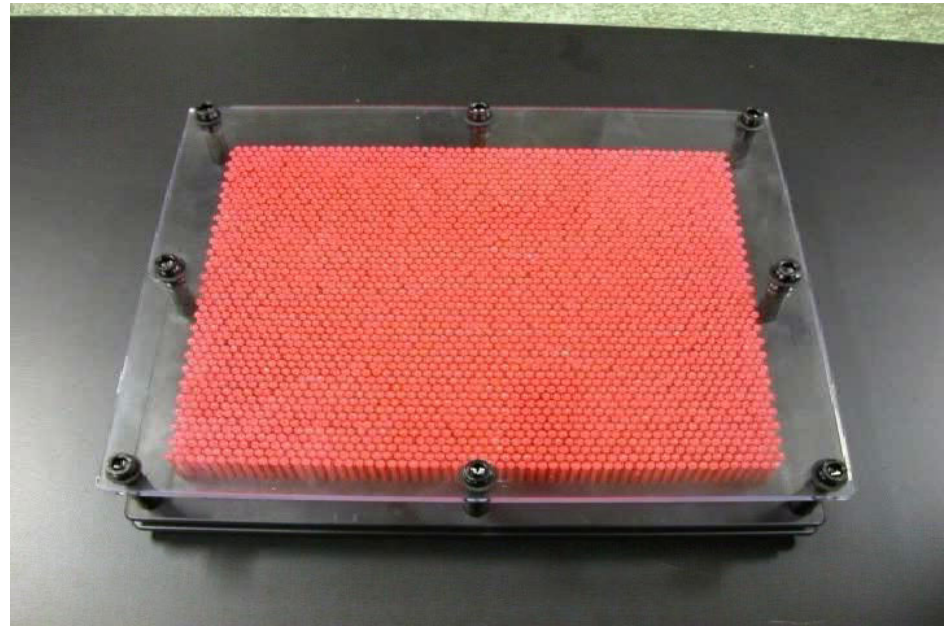
How to present shape information?



永野, 岡本, 山田: 触覚的テクスチャの材質感次元構成に関する研究動向, TVRSJ2011



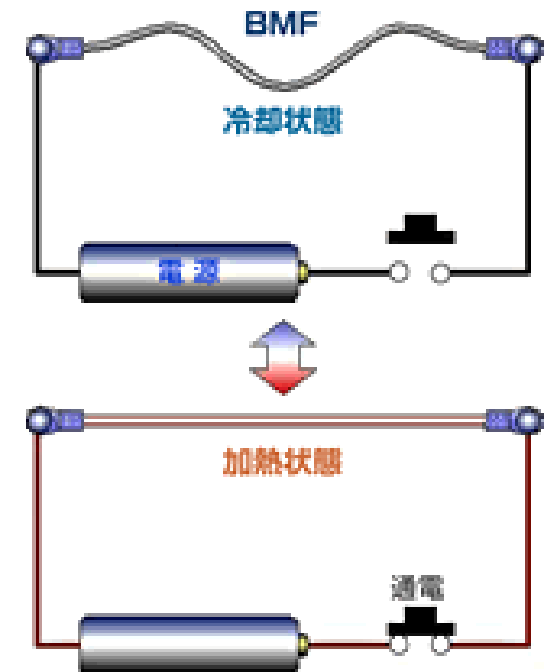
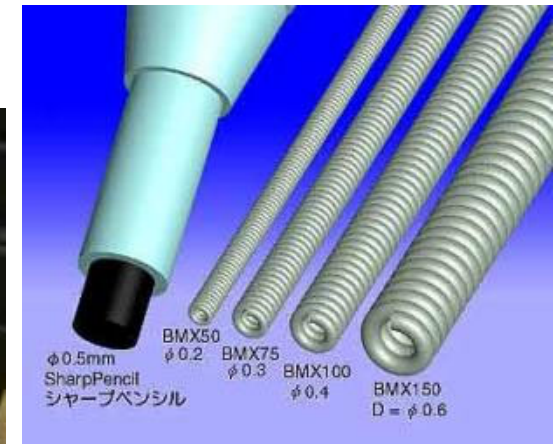
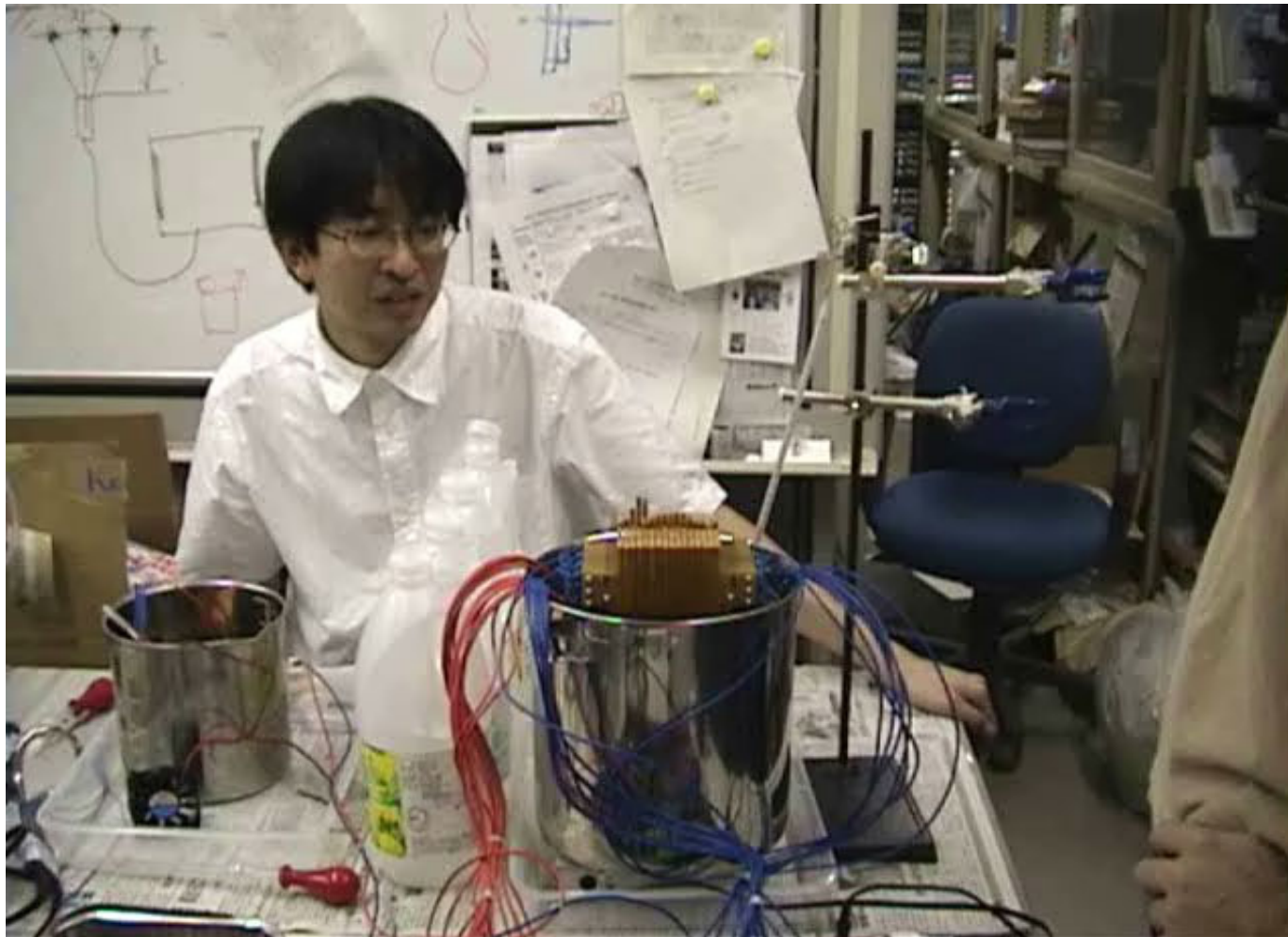
3D shape reconstruction



Xmen, 2000 <https://www.youtube.com/watch?v=55voa5Pee2M>



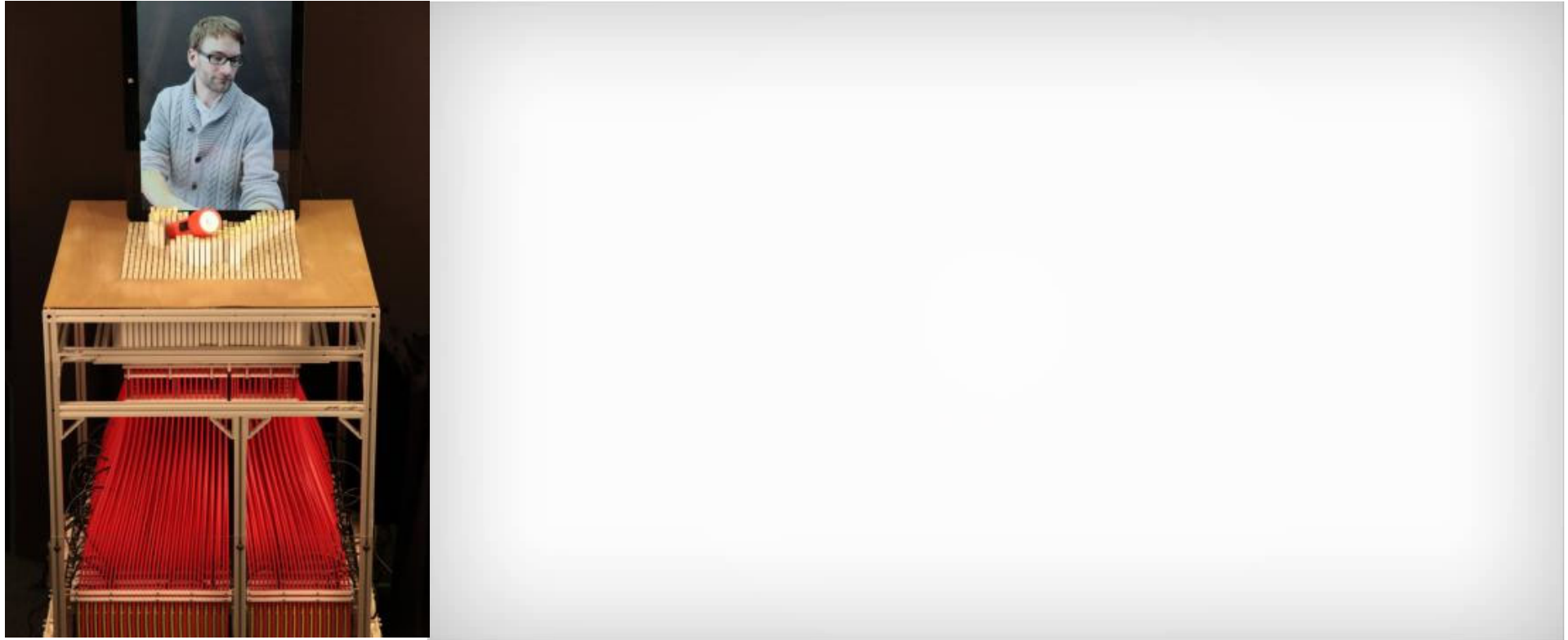
PopUp(Nakatani et al, 2005)



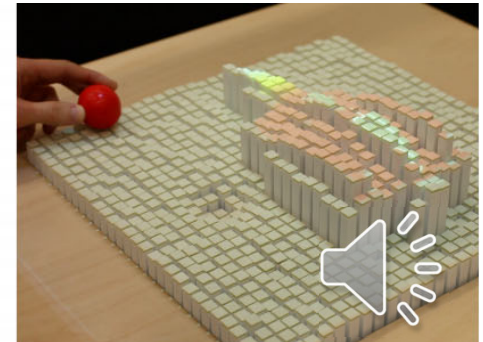
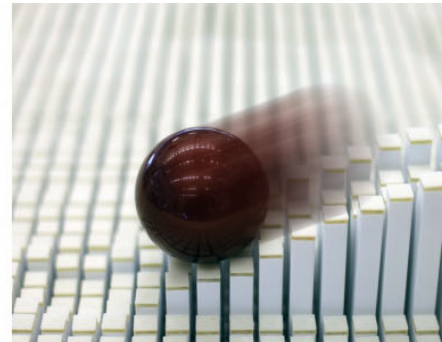
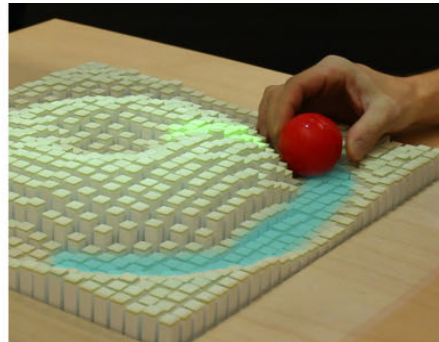
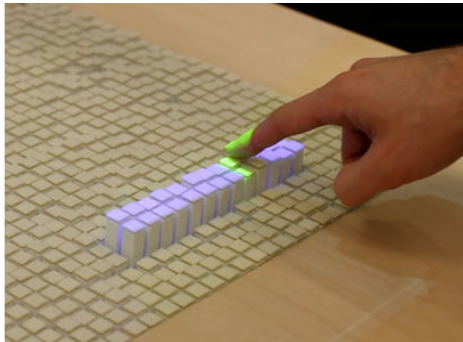
Coil-Type SMA (Shape Memory Alloy)
Extremely thin and large stroke



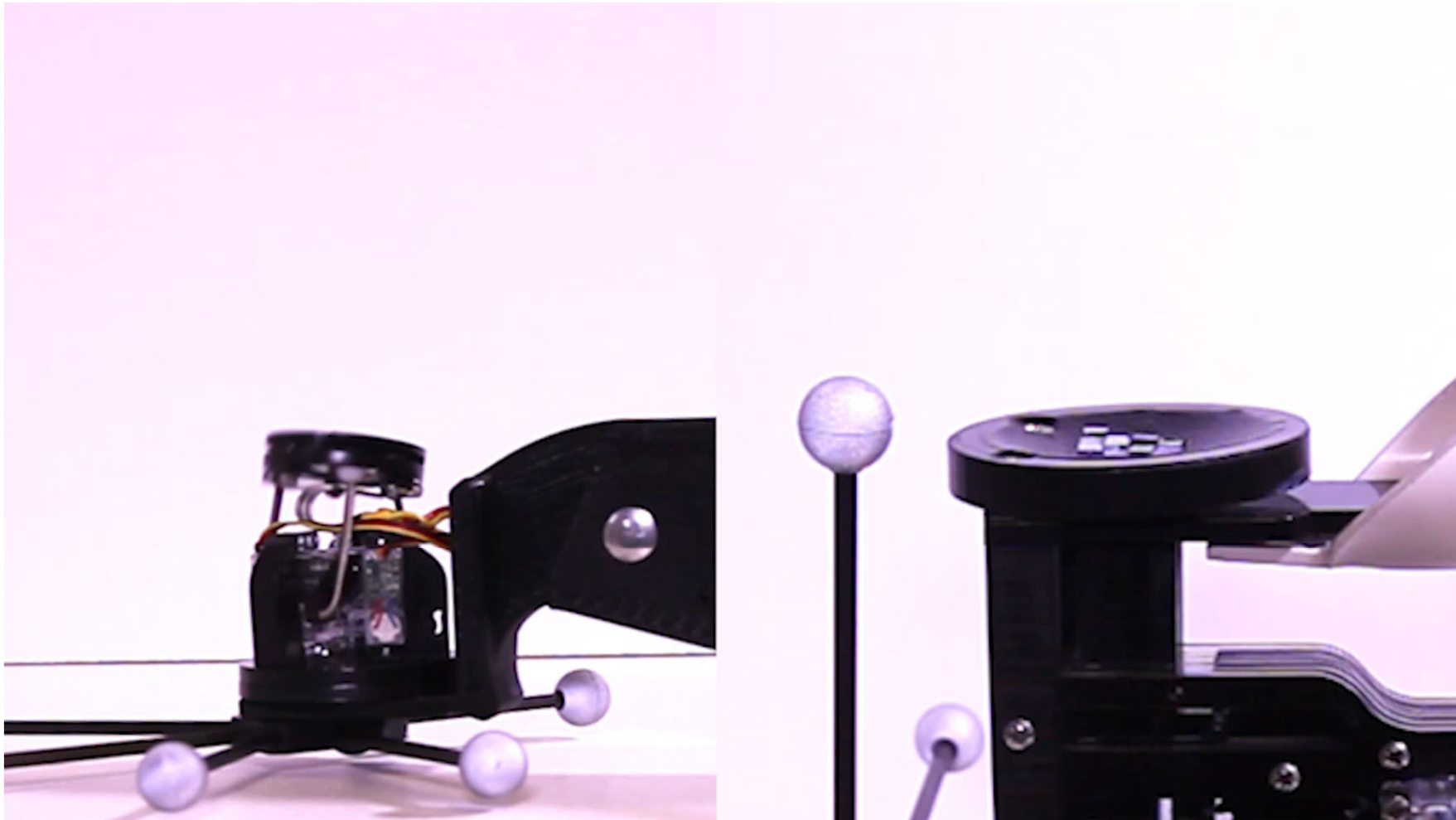
inFORM (Sean Follmer, 2013)



<https://www.youtube.com/watch?v=5EkkTV51Pg0>



(UIST2017) NormalTouch and TextureTouch: High-fidelity 3D Haptic Shape Rendering on Handheld Virtual Reality Controllers, Hrvoje Benko, Christian Holz, Mike Sinclair, Eyal Ofek



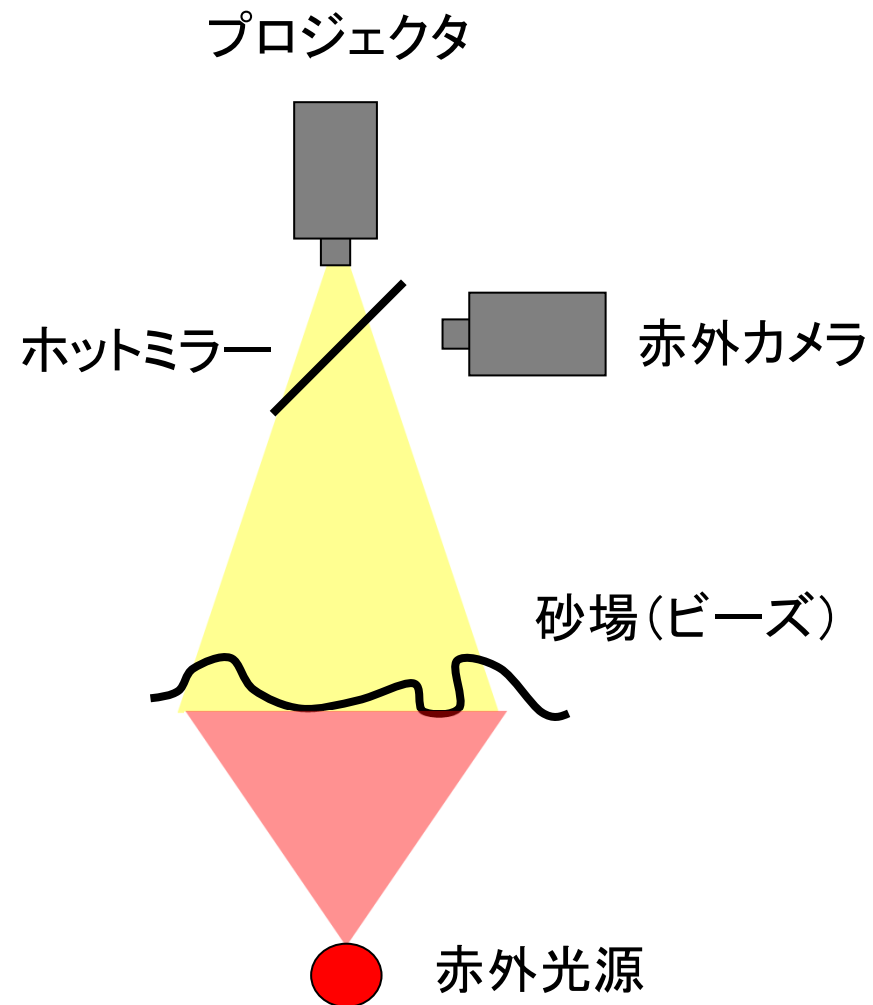
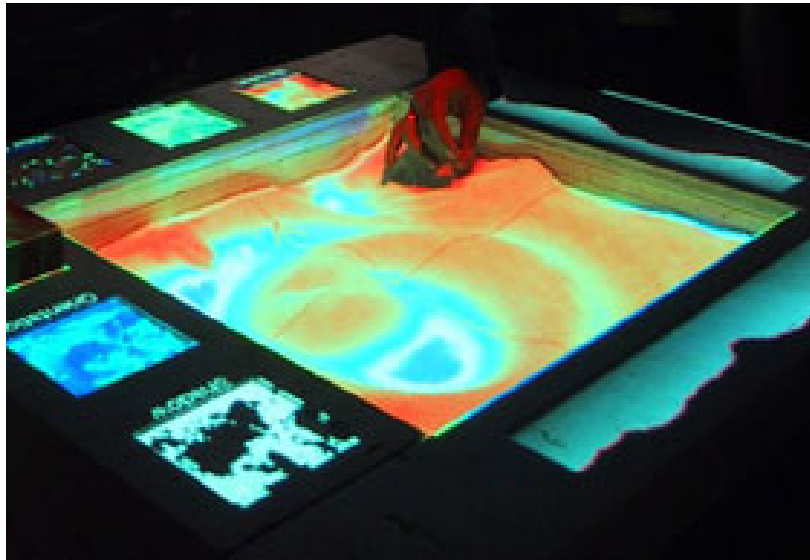
https://www.youtube.com/watch?v=KhbUg3_3T0I

- ・ ハンドヘルド型の2種類の触覚ディスプレイを提案。一つは傾きを提示し、もう一つはより細かく形状まで提示。共に従来の振動提示よりよく形状等提示できた。



Is Actuator really necessary?: SandScape

(Yao Wang et al., 2002)



<http://tangible.media.mit.edu/projects/sandscape/>



SEGA えーでるすなば(2015)

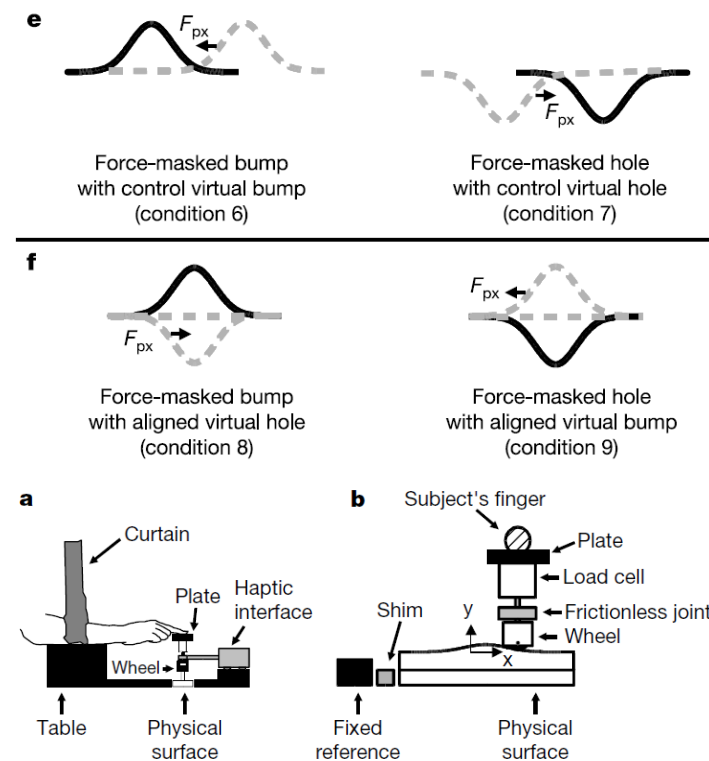
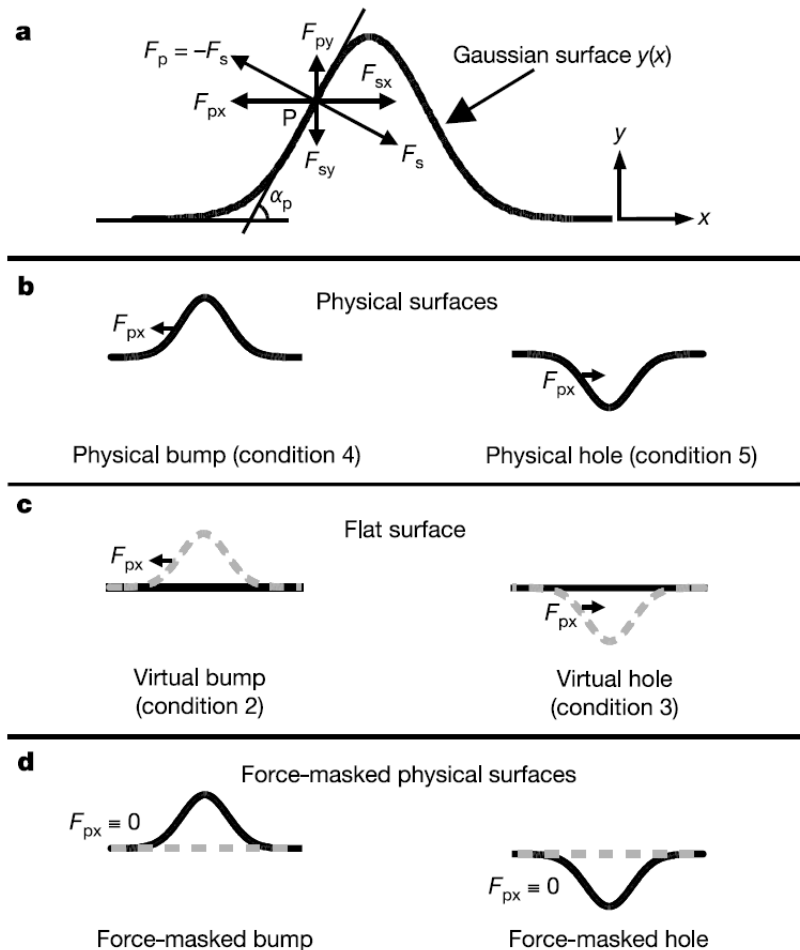


<https://www.youtube.com/watch?v=IKR4BDuwZIU>



凹凸感にとって重要なものは何か(1/3)

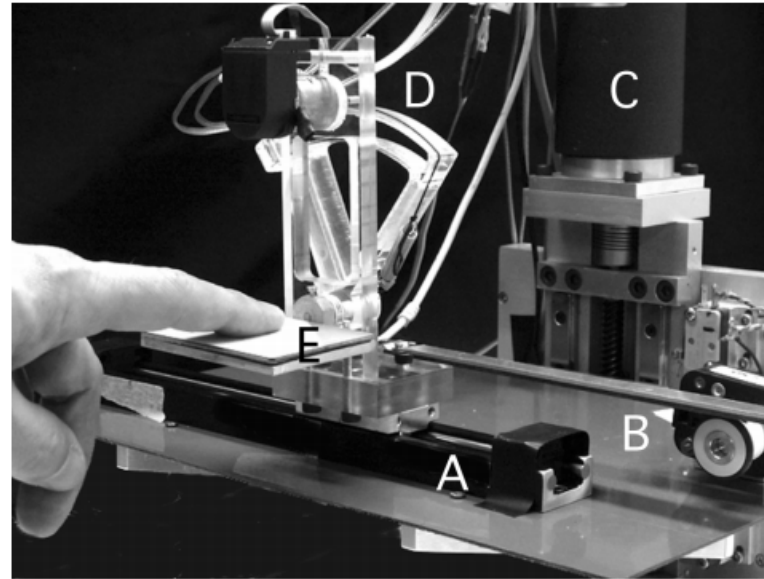
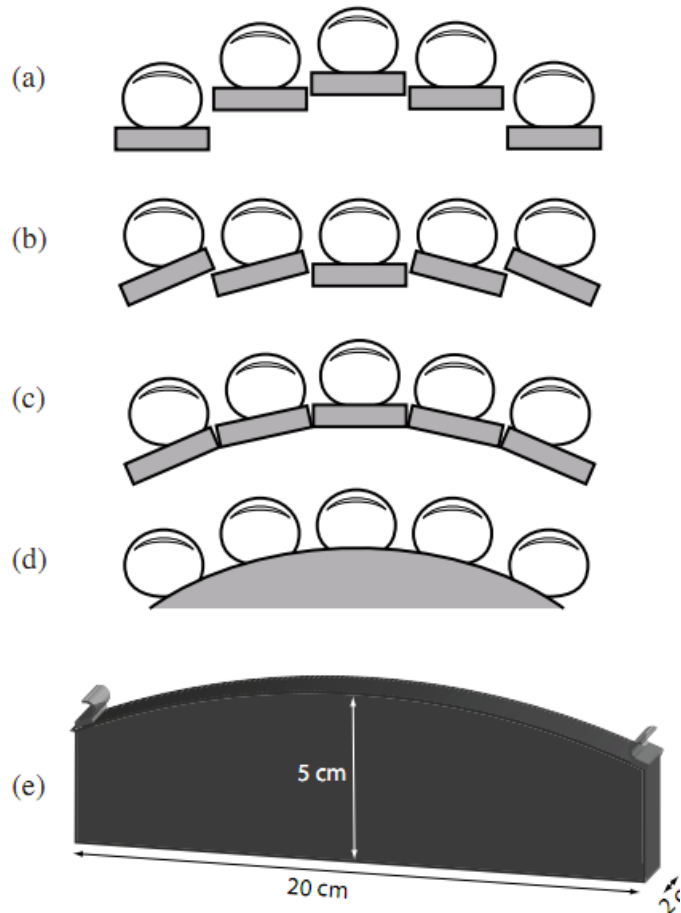
What is essential for bump sensation?



指なぞり時の凹凸⇒横方向の「力(ブレーキ)」と縦方向の「形状」という手がかり。
「形状」よりも「力」を優先して形状知覚をしている。

凹凸感にとって重要なものは何か(2/3)

What is essential for bump sensation?



大域的な凹凸感の手がかり:
板の「傾き」 $\gg$ 板の高さ



凹凸感にとって重要なものは何か(3/3)

What is essential for bump sensation?

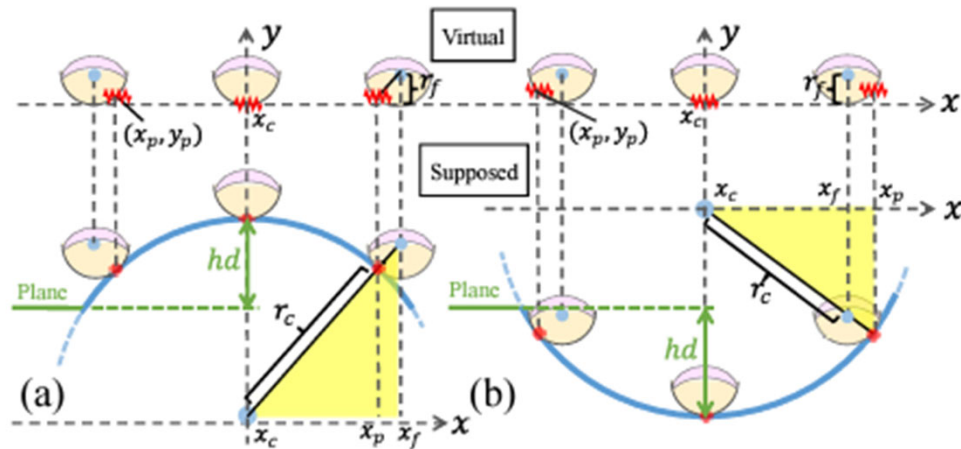


図 1: 位置法による (a): 1 凸面・(b): 1 凹面提示法.

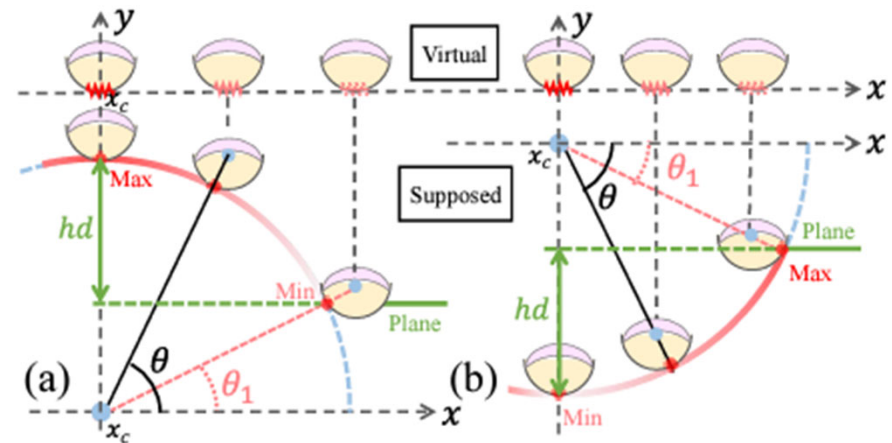


図 2: 強度法による (a): 1 凸面・(b): 1 凹面提示法.

空中超音波による大域的な曲面知覚の提示。指への提示「位置」を変える方が曲面感が強く出る。

モータによる水平力提示



<http://www.youtube.com/watch?v=Prq9-uJSqSE>



嵯峨他、剪断力を用いた2.5次元触覚ディスプレイにおける定量的凹凸感提示手法、VR学会大会2011

Passive type Horizontal Display

超音波振動による摩擦係数変化の利用

Controlling friction coefficient by ultrasonic vibration



- ・ スクイーズ効果: 高周波振動で摩擦係数が減少する
Squeeze effect: friction is reduced by high freq. vibration
- ・ 指位置計測と組み合わせ、摩擦係数の提示が可能
Combined with pos. sensing, friction distribution is displayed.

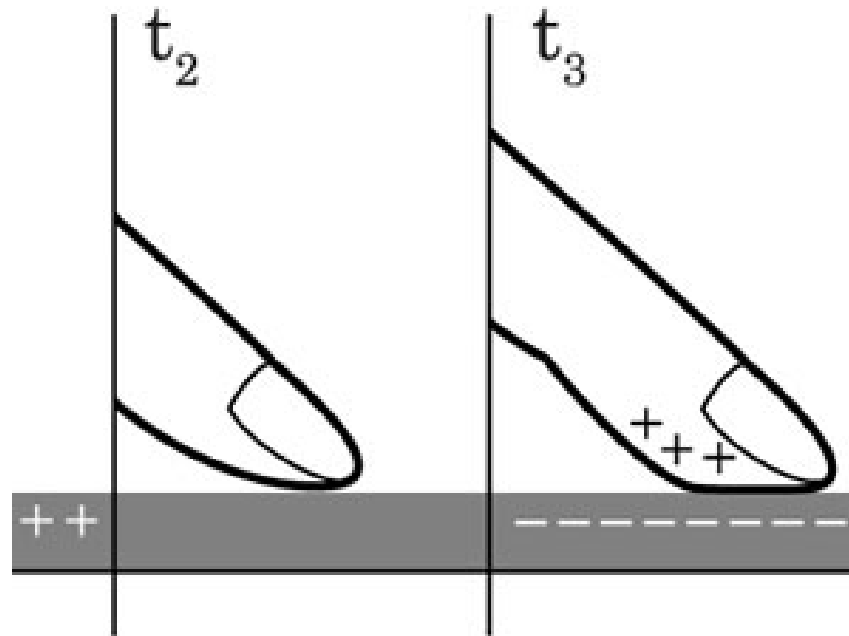
- ・ Nara et al., "Surface Acoustic Wave Tactile Display", IEEE CG&A, 2001.
- ・ Winfield et al., "*TPaD: Tactile Pattern Display Through Variable Friction Reduction*", World Haptics Conf. 2007



Passive type Horizontal Display

高压電極と皮膚の電氣的吸引利用

Using adhesion between skin and electrode by high voltage



Kaczmarek et al., "Polarity Effect in Electro vibration for Tactile Display," IEEE Trans. Biomedical Engineering,, 2006.

Olivier Bau et al., "TeslaTouch: Electro vibration for Touch Surfaces," UIST2010



TeslaTouch (2010)



<https://www.youtube.com/watch?v=3l3MDNZk-3l>



[Haptics Symposium 2016] eShiver: Force Feedback on Fingertips through Oscillatory Motion of an Electroadhesive Surface
Joe Mullenbach, Michael Peshkin, Ed Colgate

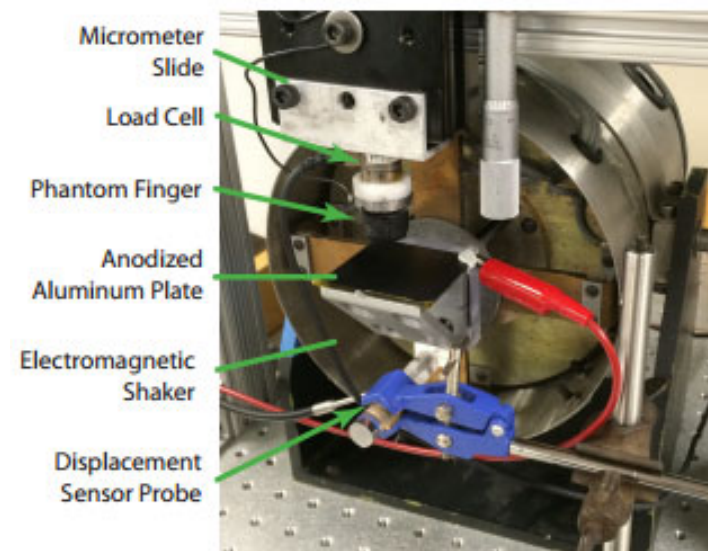
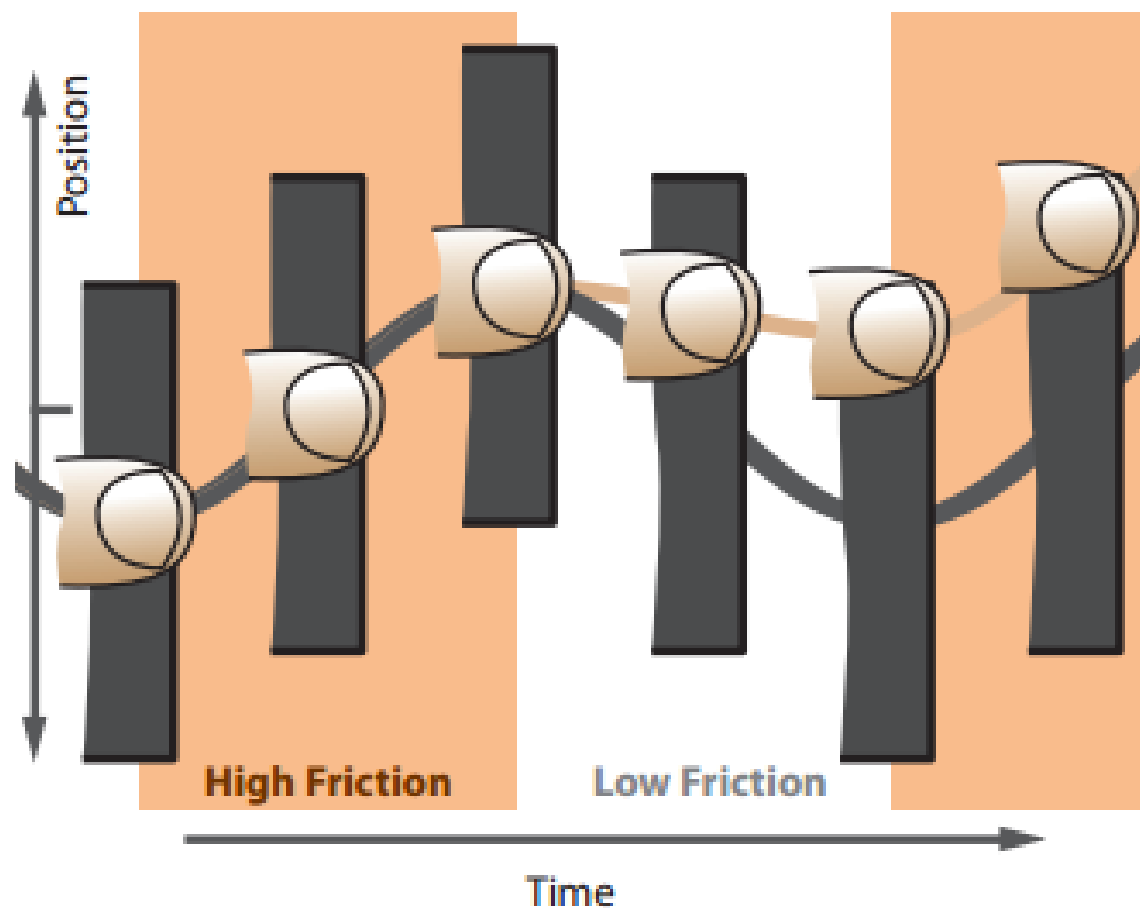
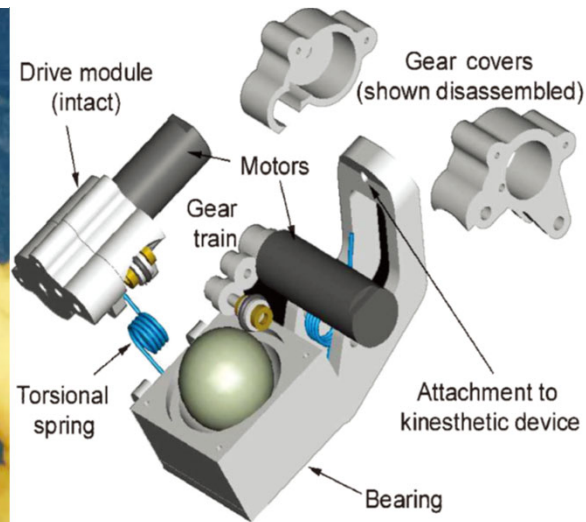
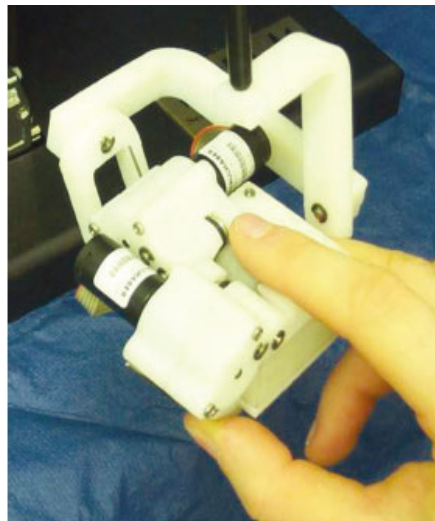


Fig. 4. eShiver Experimental Apparatus.

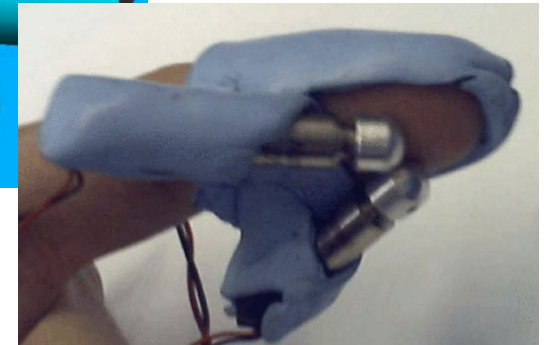
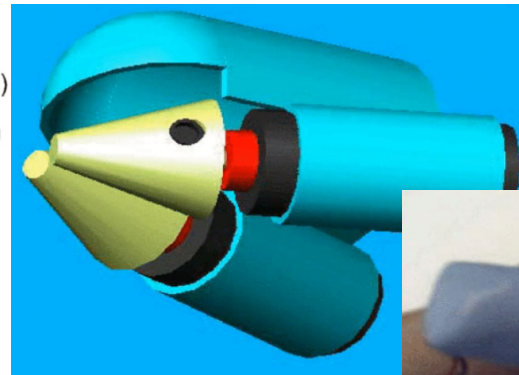
静電型の触覚ディスプレイを水平振動させ、振動と同期して摩擦係数を変化させることで方向に力を生じさせる。つまりタッチパネルでの力覚提示。



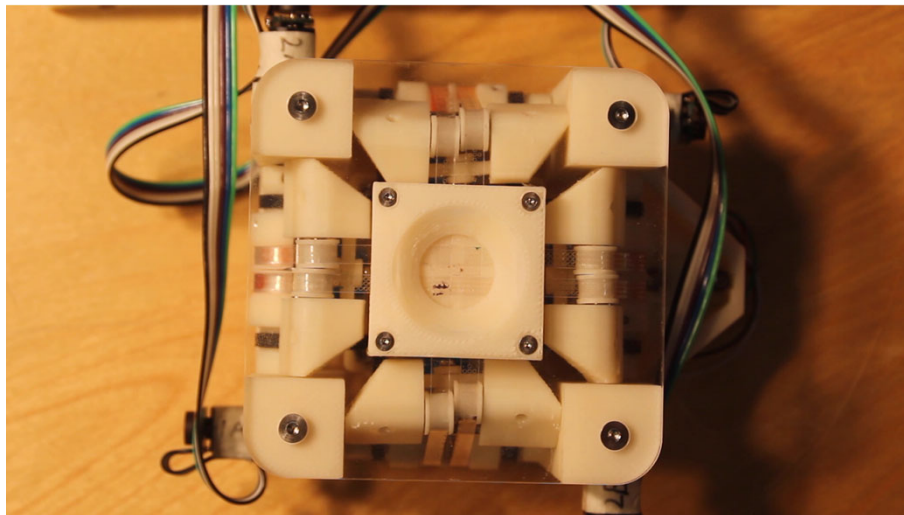
2D水平力提示



R. J. Webster III, T. E. Murphy, L. N. Verner, and A. M. Okamura, "A novel two-dimensional tactile slip display: design, kinematics and perceptual experiments," ACM Transactions on Applied Perception, 2005.
ボールを2自由度回転。昔のマウスのような



N. G. Tsagarakis, T. Horne, and D. G. Caldwell, "Slip aestheasis: a portable 2d slip/skin stretch display for the fingertip," WHC2005
ウェアラブルタイプでスリップ感

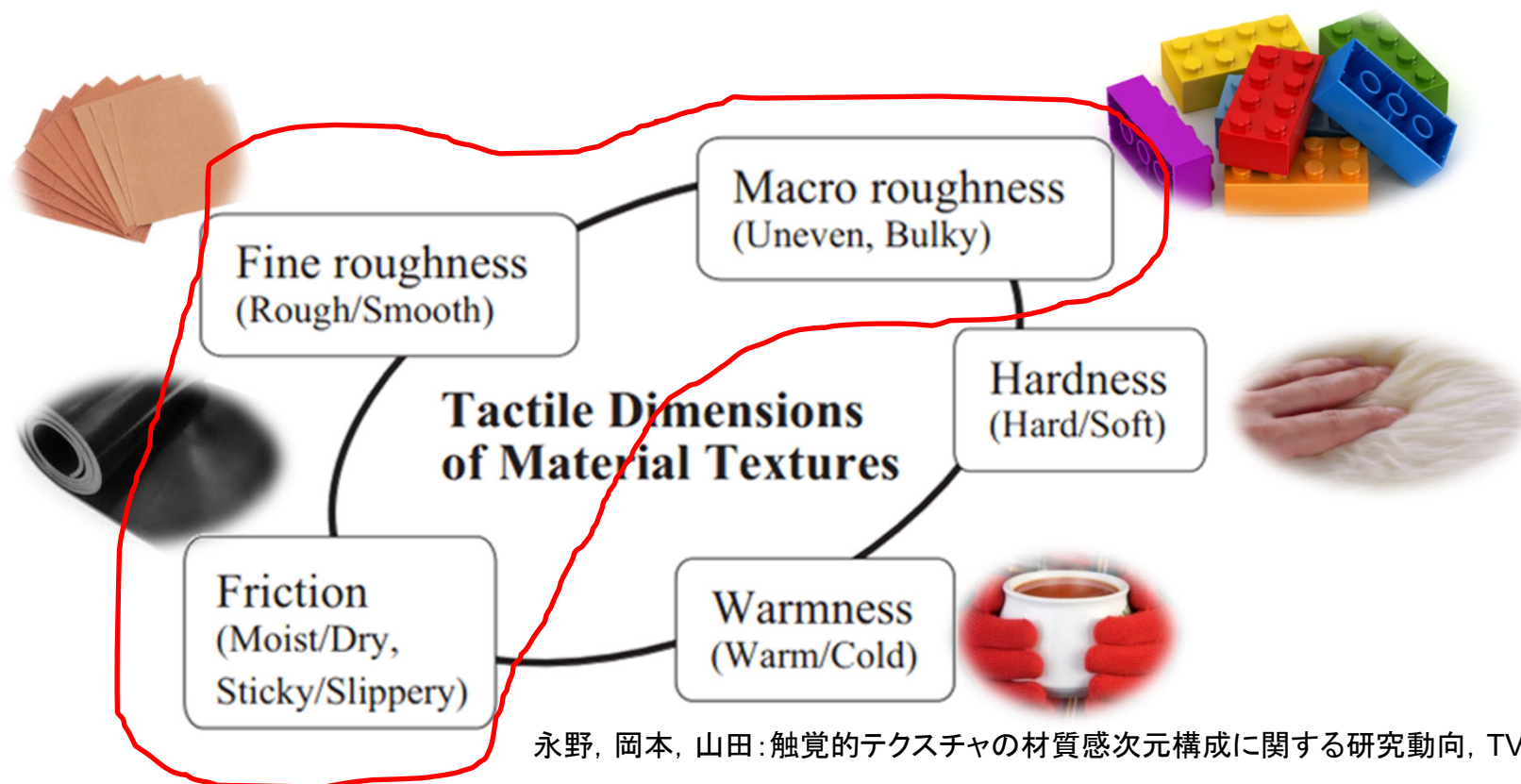


The Slip-Pad: A Haptic Display Using Interleaved Belts to Simulate Lateral and Rotational Slip, WHC2015

ベルトでスリップ感を提示する装置をXY2自由度で作成した。さらに工夫としてベルトに多数の穴を開けて触覚を感じやすくしている。



水平摩擦力提示によって得られた触感領域

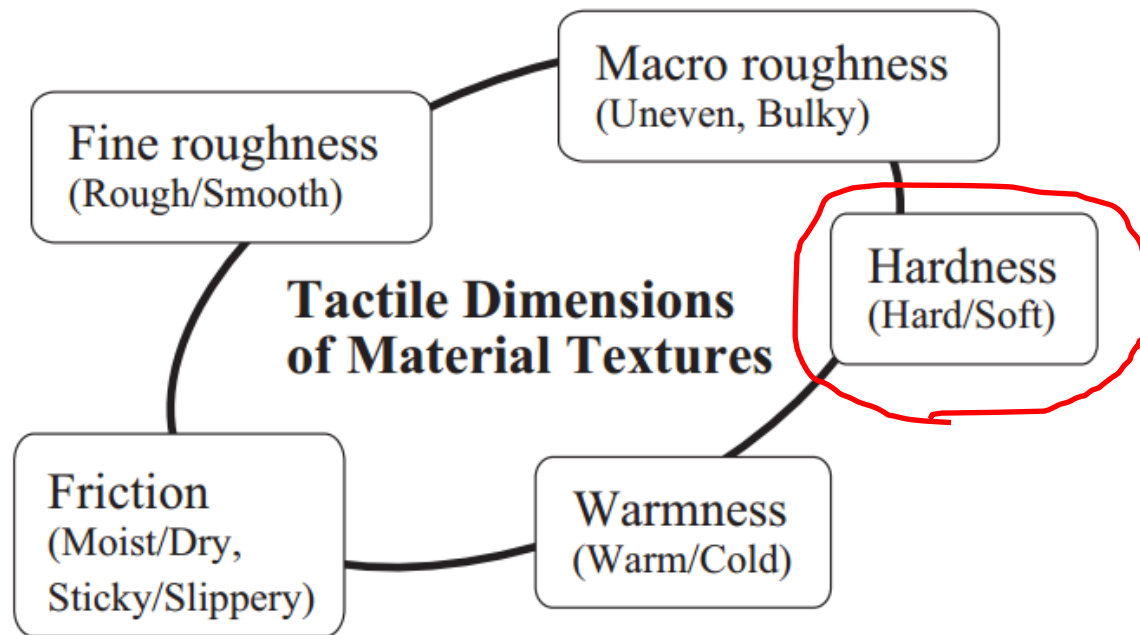


永野, 岡本, 山田: 触覚的テクスチャの材質感次元構成に関する研究動向, TVRSJ2011

形状情報のみならず, 高速応答性をもたせることでStick-Slip感等の表面状態まで提示可能に



硬さ／柔らかさは皮膚感覚で表現できるか？



永野, 岡本, 山田: 触覚的テクスチャの材質感次元構成に関する研究動向, TVRSJ2011



古典的には力覚提示装置でバネ／ダンパの挙動を模擬して表現



柔らかさの提示

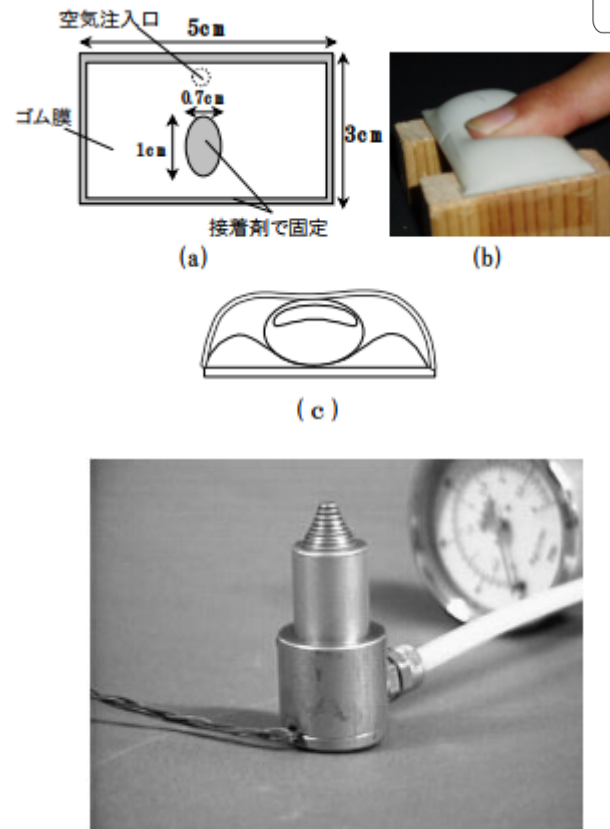
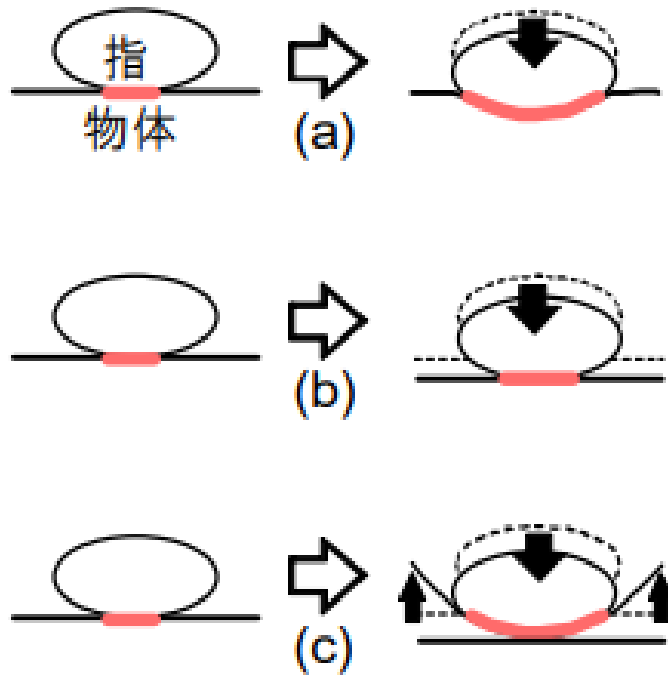
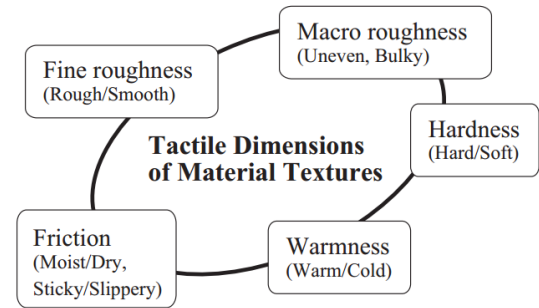
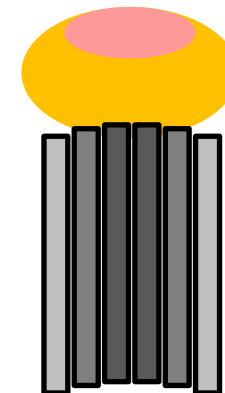


Figure 8: The prototype CASR display.



永野, 岡本, 山田: 触覚的テクスチャの材質感次元構成に関する研究動向, TVRSJ2011

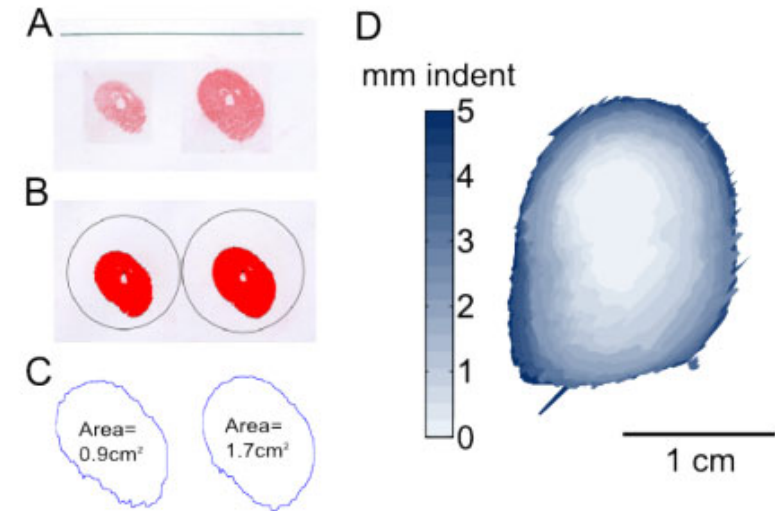
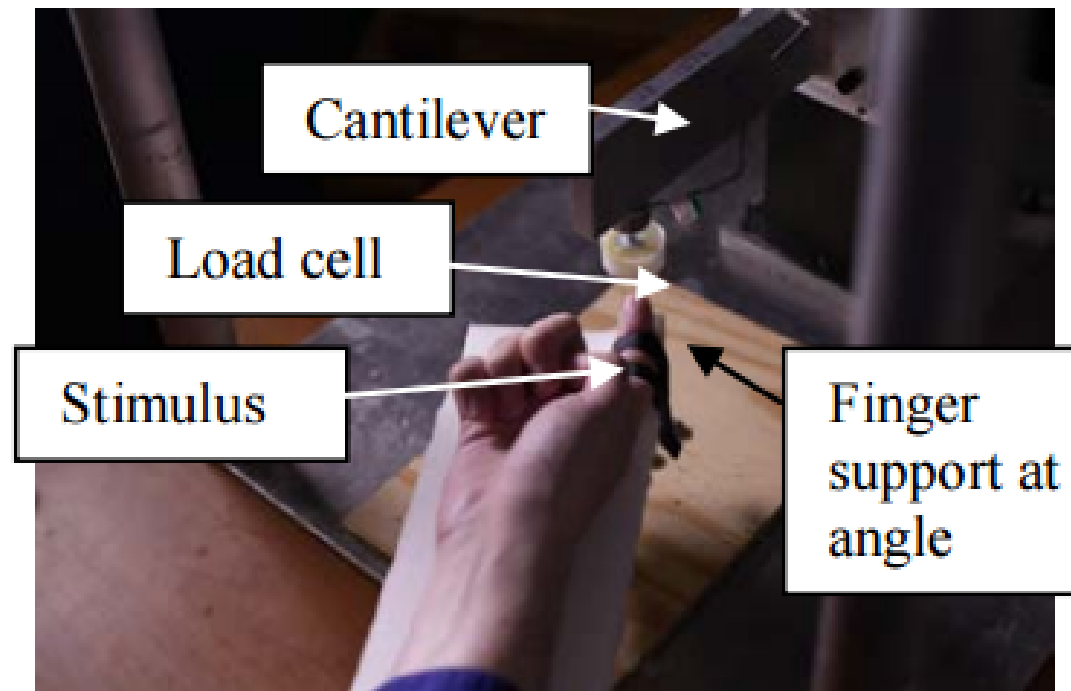


接触面積の変化を再現することで柔らかさを提示できる

- G. Ambrosi et al.: The role of contact area spread rate in haptic discrimination of softness, ICRA1999
- K. Fujita et al.: A new softness display interface by dynamic fingertip contact area control. SCI2001.
- M. Bianchi et al.: A new fabric-based softness display, Haptics Symposium2010



[HapticsSymposium2016] Measuring Tactile Cues at the Fingertpad for Object Compliances Harder and Softer than the Skin, Steven C. Hauser, Gregory J. Gerling

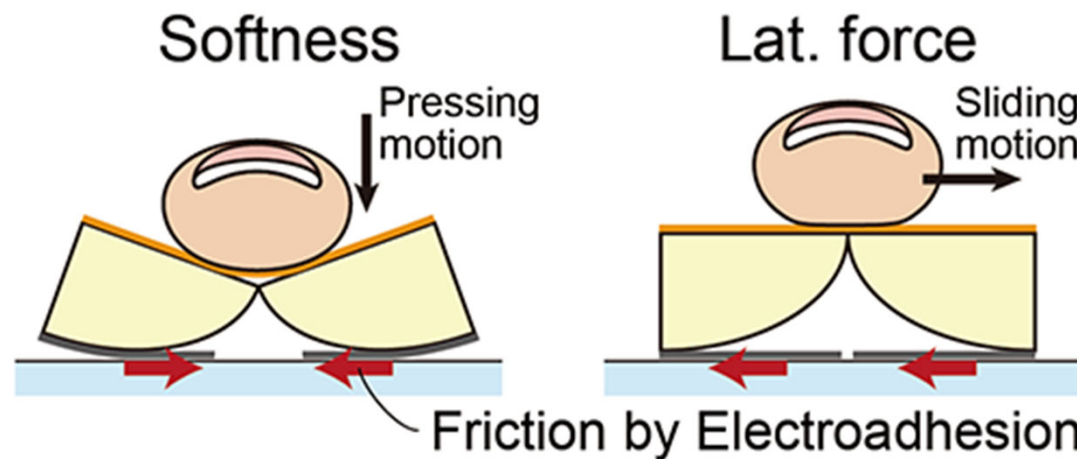


指を柔軟物体に押し当てた時に柔らかさを感じる鍵が何であることを確認. 実験は指についてのインクを紙に転写. 3Nの力を加えた時の接触面積の大きさと, 力と変位の関係が重要であることがわかった



[HapticsSympo2016] Extension of an Electrostatic Visuo-Haptic Display to Provide Softness Sensation

Taku Nakamura, Akio Yamamoto

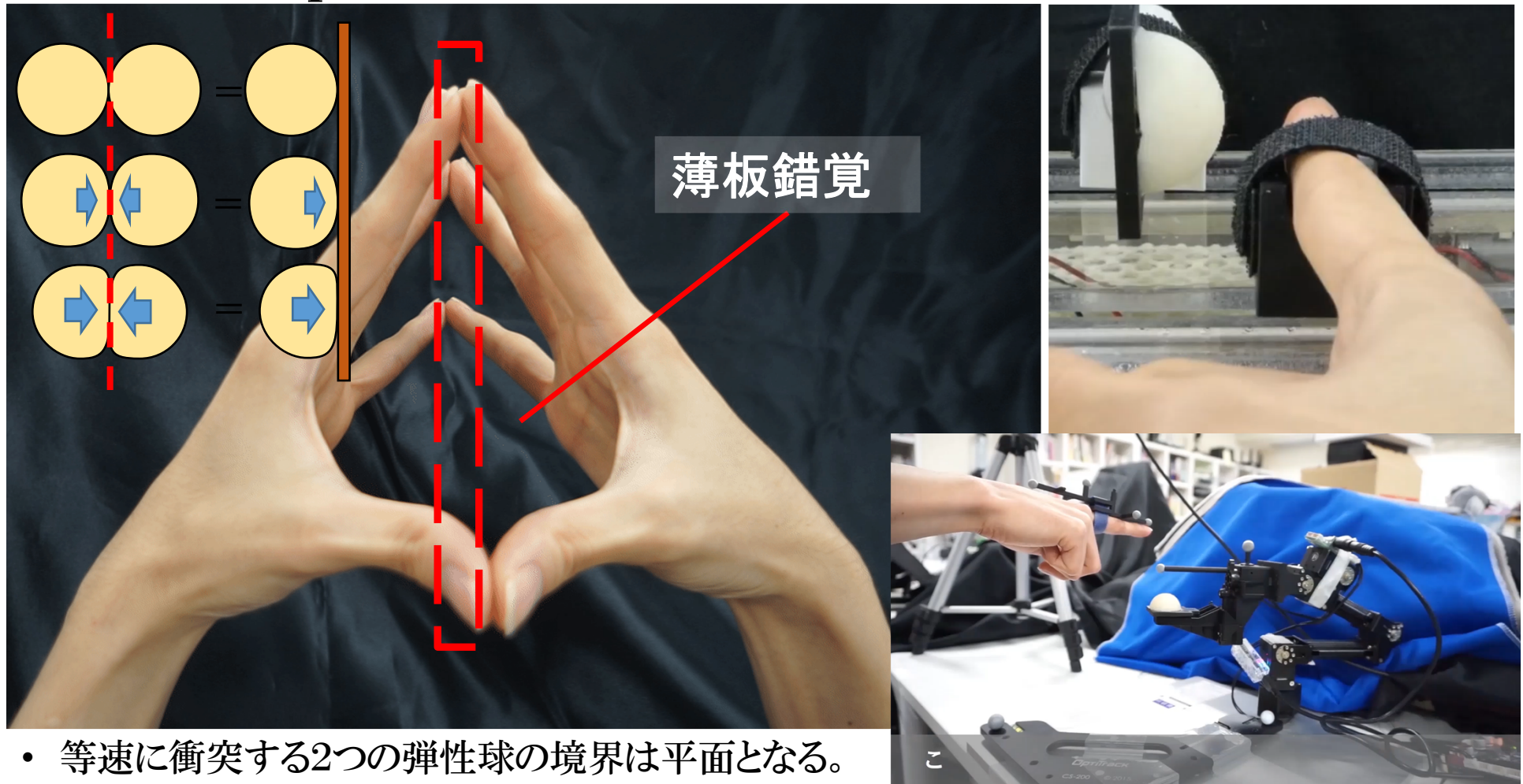


静電気型触力覚提示装置で柔らかさ感になるべく簡単な機構で出す手法を考案



硬さと曲率の相互作用

Relationship between Hardness and curvature



- 等速に衝突する2つの弾性球の境界は平面となる。
- よって、指と同じ速度で弾性球を対向動作させれば「硬い平面」を表現できる可能性。
- The boundary between two elastic spheres colliding at constant velocity is a plane. If we make the elastic spheres move in opposite directions at the same speed, it may be felt as a plane.
- M. Takeuchi: Presentation of a hard surface via a soft moving ball, Work-in Progress, Haptics Symposium 2020
- M. Takeuchi : Modulation of Curvature of Soft Ball by Facing Motion (WHC2021)

硬さと曲率の相互作用

Relationship between Hardness and curvature

Surfaces with
finger-sized concave
feel softer

Koki Inoue*, Shogo Okamoto†,
Yasuhiro Akiyama*, and Yoji Yamada*

* Nagoya University

† Tokyo Metropolitan University

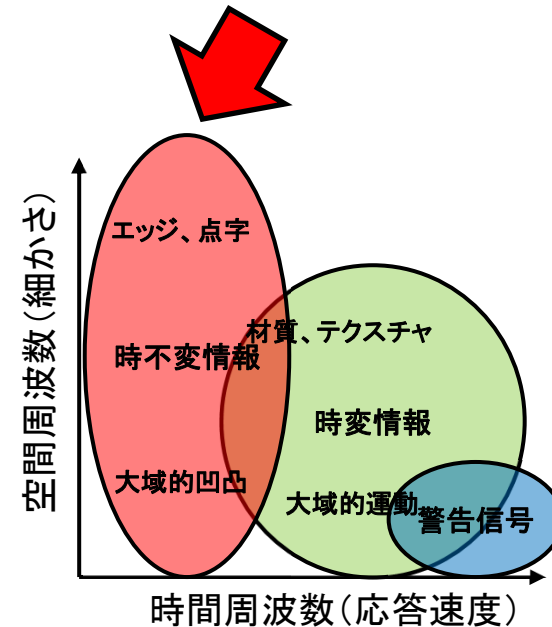


<https://www.youtube.com/watch?v=XGFXBV1LByo&list=PLXRBbyxY9IBXRWf-cfDqVvFqNDCxZ7CMq&index=4>

- (HS2022) K. Inoue, S. Okamoto, Y. Akiyama, Y. Yamada, Surfaces with finger-sized concave feel softer
- 凹面に触ると柔らかく感じる

「形」をより細かく提示する

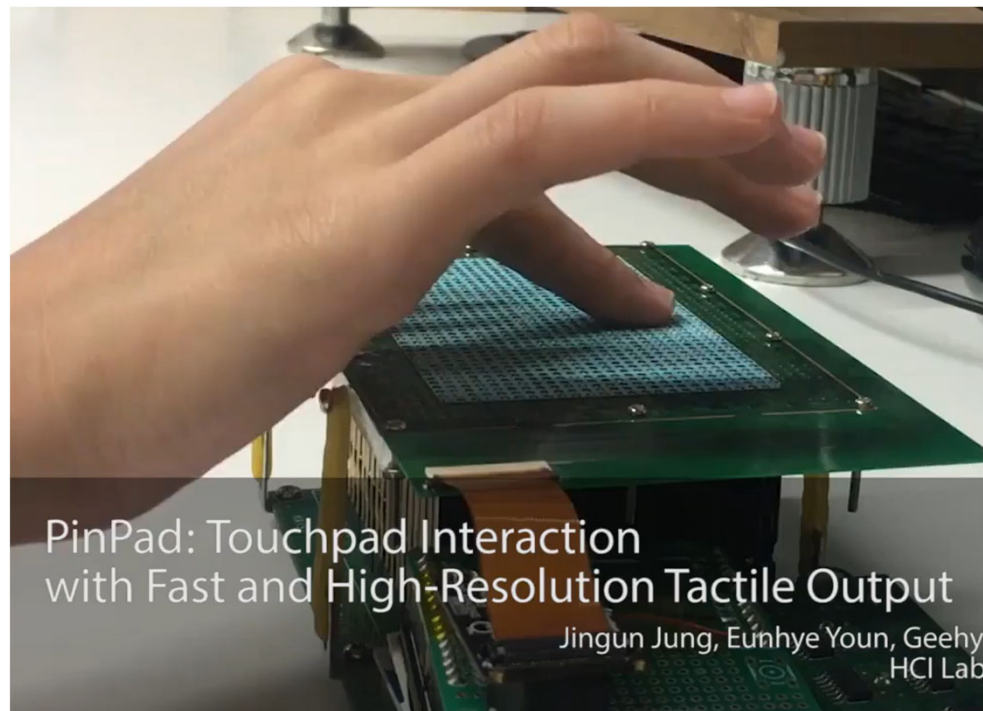
How to produce High-resolution Tactile display?



- これまで実はことごとく、「指一本全体」に対して触感を提示するもの。
- (意地悪に言うなら)高性能な力覚提示装置(PHANToM)で出せる感覚を, wearable化, portable化した, と見ることもできる。
- もし遠隔操縦を人が操るレベルで行うなら、指先皮膚の中の空間的な分布が提示できないといけない。
- Until here, most tactile displays are for “the whole finger”, but higher-resolution tactile information is required for precision tasks.

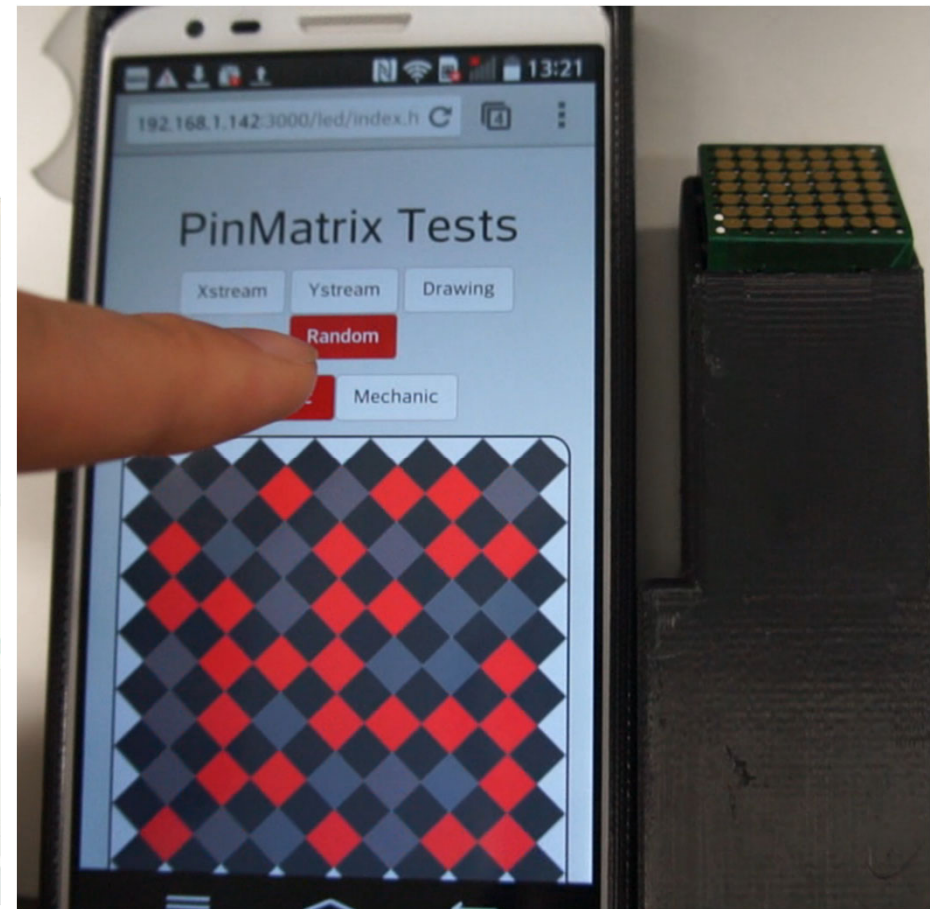


Pin matrix drive



<https://www.youtube.com/watch?v=B8UshkVpuAE>

CHI2017 PinPad: Touchpad Interaction with Fast and High-Resolution Tactile Output, Jingun Jung, Eunhye Youn, Geehyuk Lee



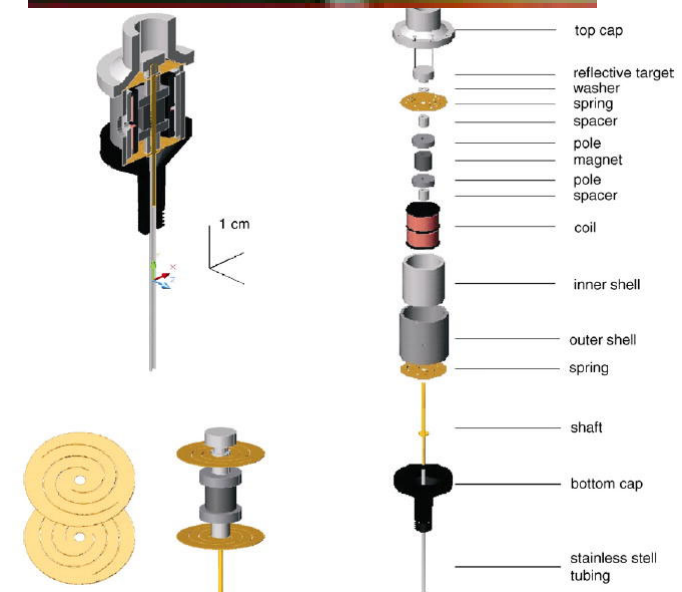
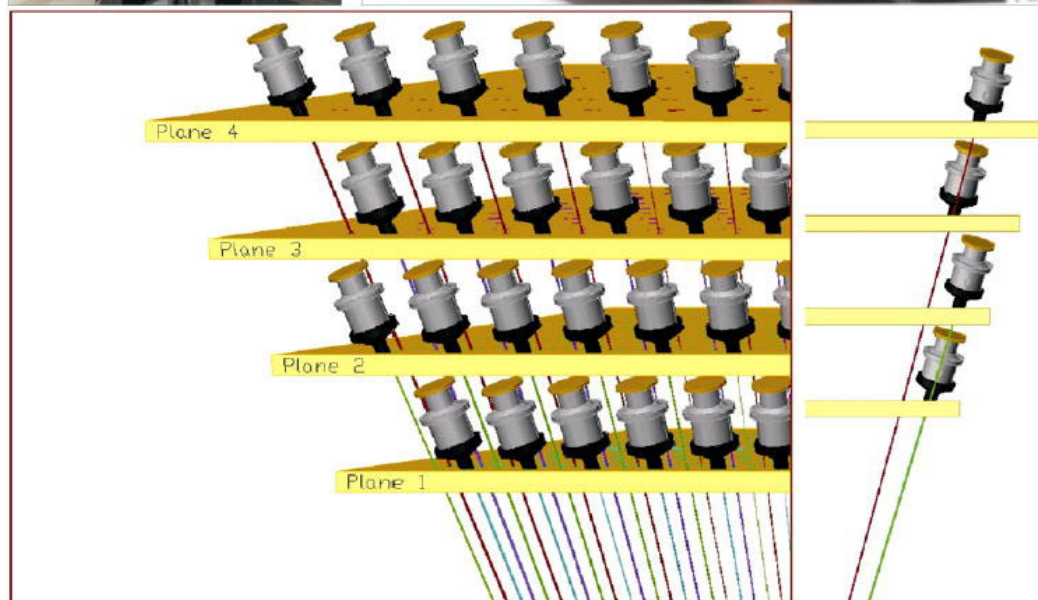
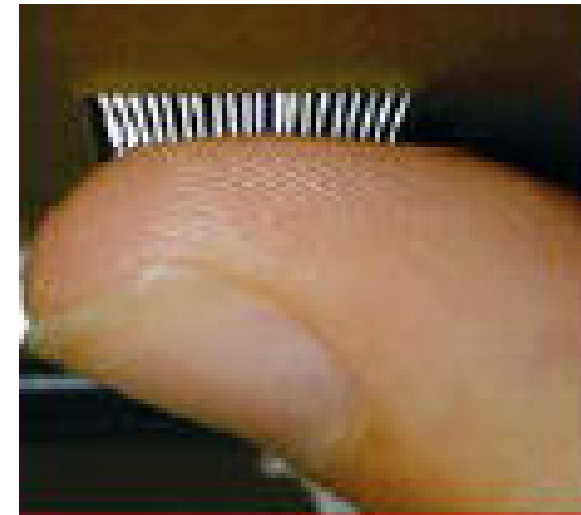
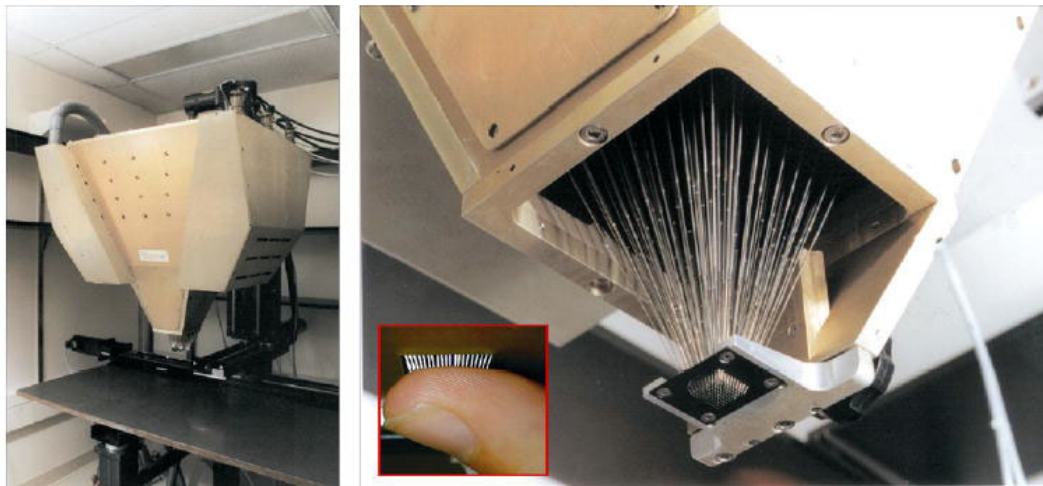
8x8ユニットの駆動（電気刺激との併用）

[Sugarragchaa Khurelbaatar, Hiroyuki Kajimoto. Tactile display combining electrical and mechanical stimulation. EuroHaptics'16 WIP](#)

- 大量の高密度実装→アクチュエータの小ささ、安さが鍵
- Numerous, dense arrays→Actuator needs to be small and cheap



高解像度触覚ディスプレイ/High resolution tactile display

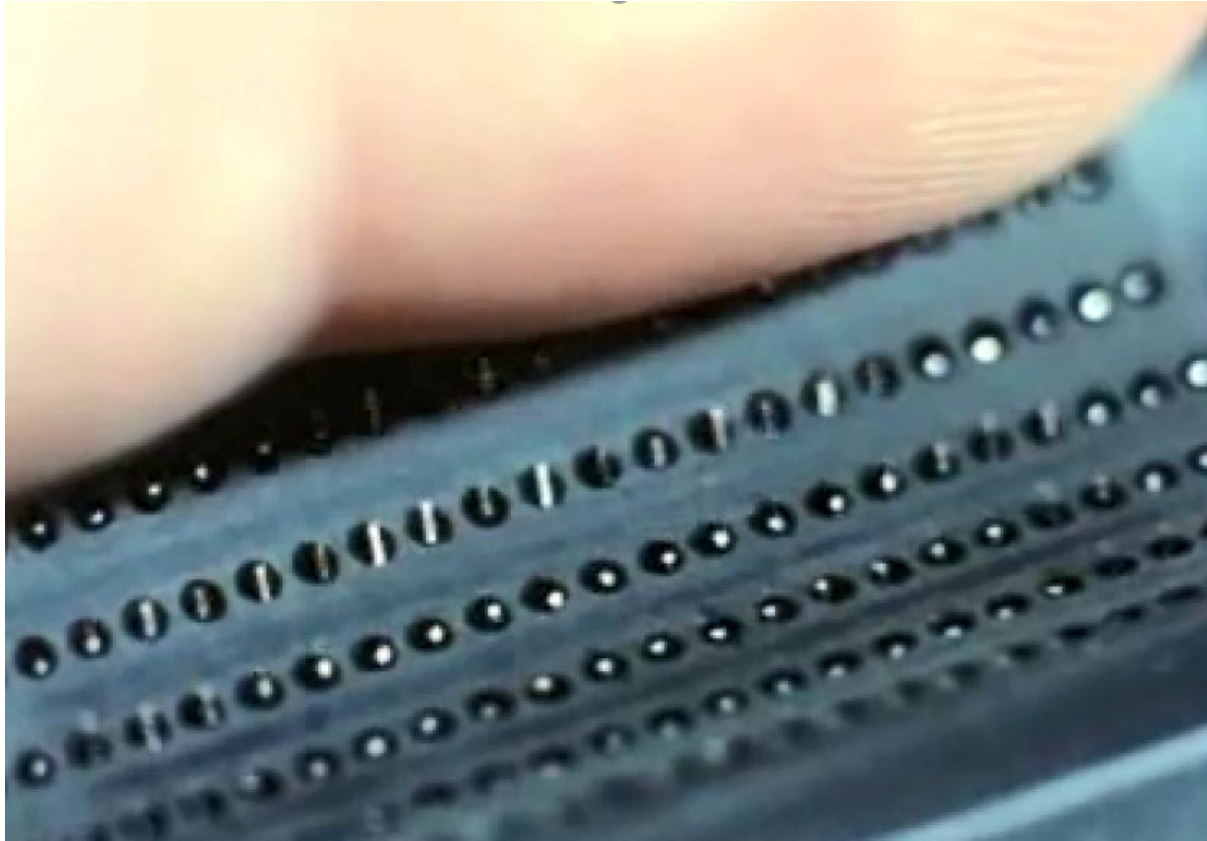


[J.H. Killebrew et al., "A Dense Array Stimulator to Generate Arbitrary Spatio-Temporal Tactile Stimuli," *J. Neuroscience Methods*, vol. 161, pp. 62-74, 2007.](#)

400ピン、特製のリニアアクチュエータ、DC～300Hz、0.5mm 間隔

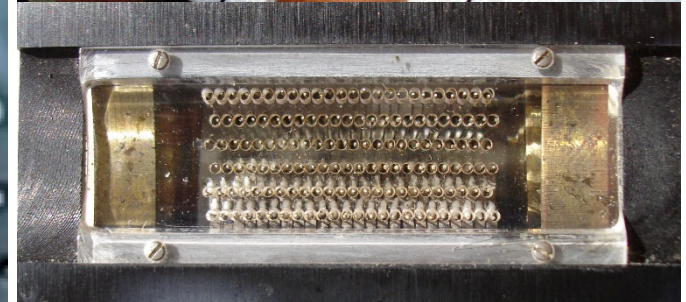


オプタコン: 視触覚変換装置／ Optacon: Vision-Tactile Converter (1976)



Braille Display (Optacon), Linville 1976

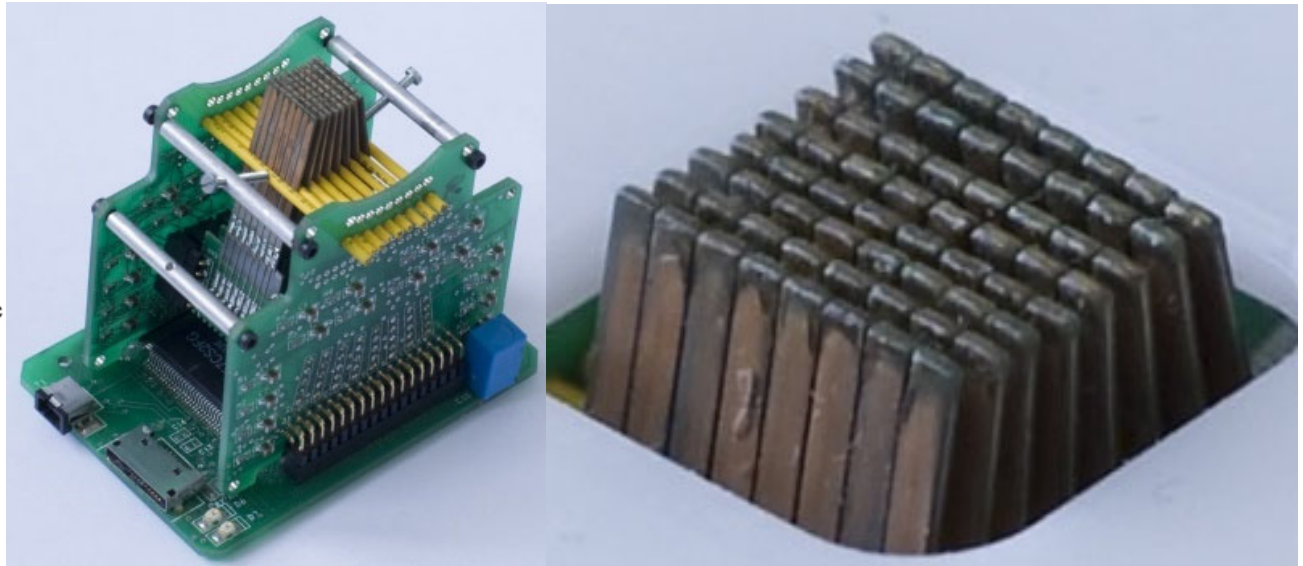
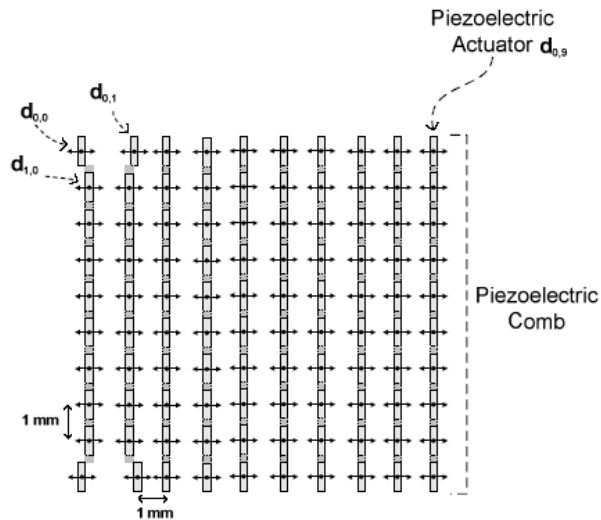
<https://www.youtube.com/watch?v=ghsXhqu8FCY>



<https://en.wikipedia.org/wiki/Optacon>



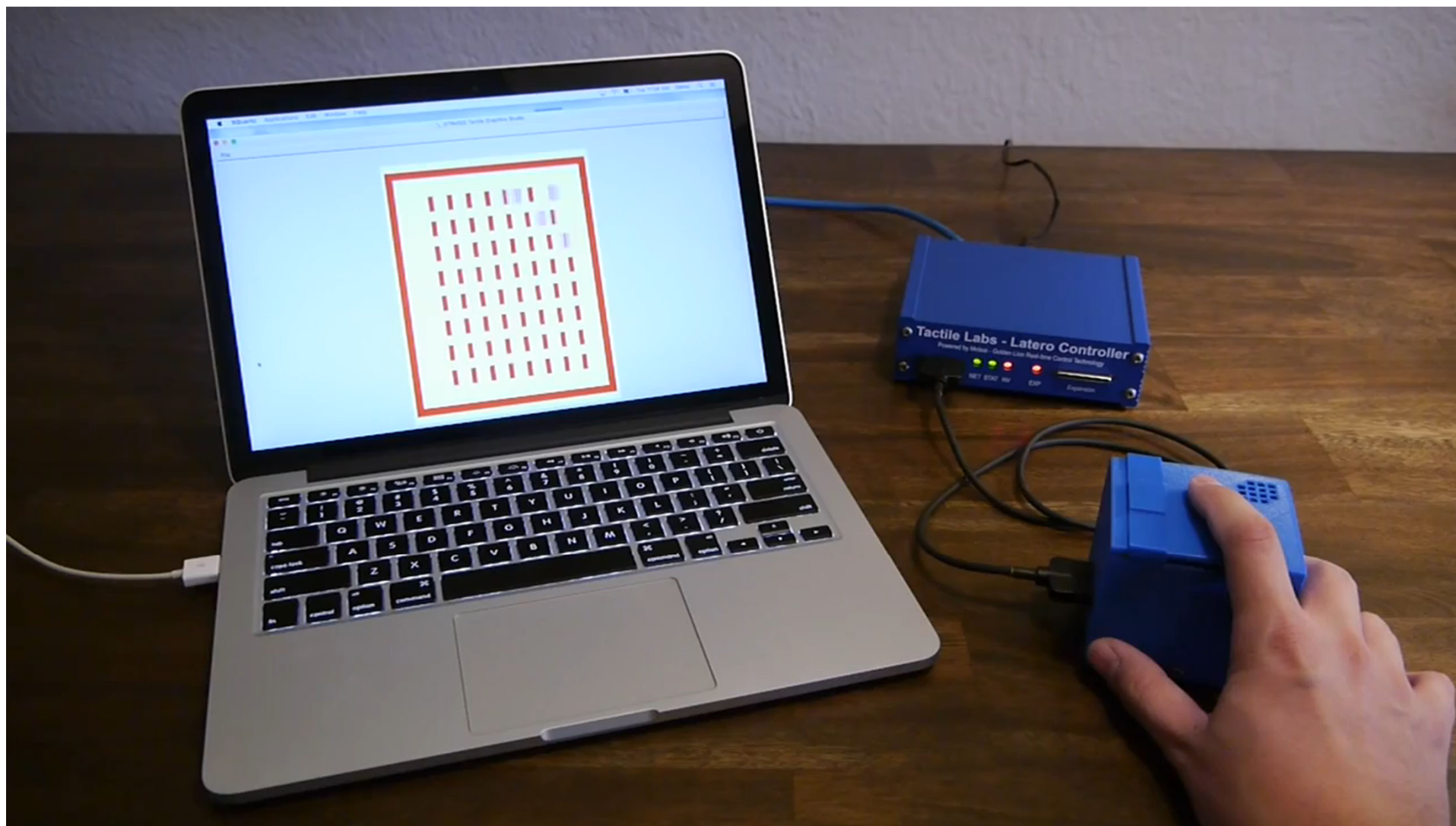
製品として入手可能な高分解能, 広帯域触覚ディスプレイ



- 皮膚の水平駆動の重要性に着目して作成されたもの。
- 結果としてシンプルなピエゾアクチュエータの配置が可能となり, 高密度化も可能に。
- Horizontal Vibration is achieved by piezo drive. High density and compact system is achieved by this simple structure.



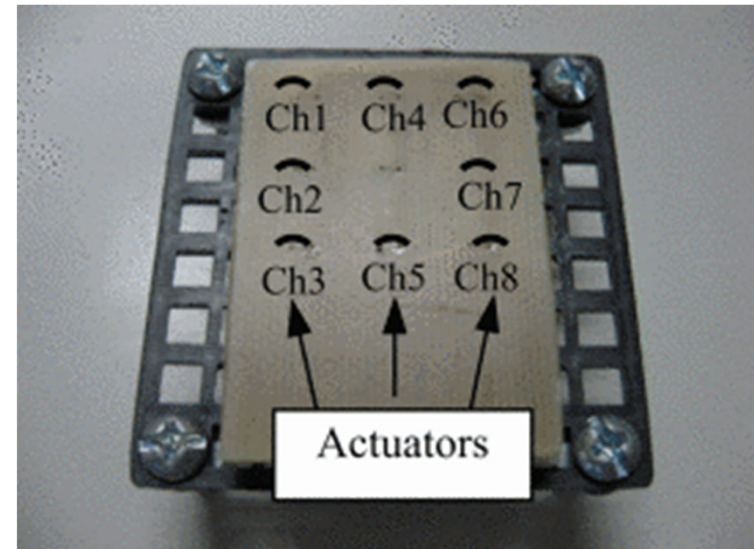
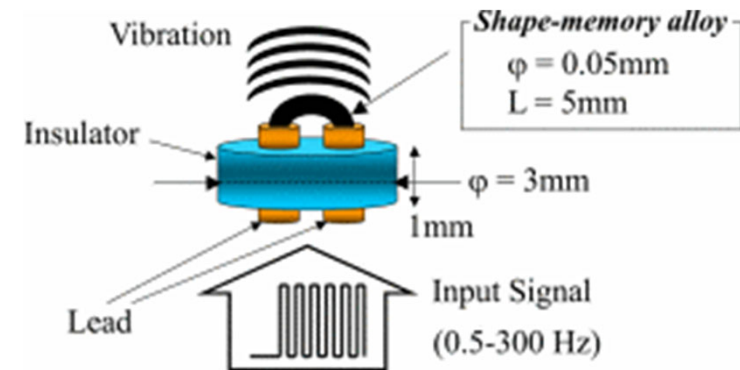
Hayward, "Tactile display device using distributed lateral skin stretch," ASME, DSC, 2000.



<https://www.youtube.com/watch?v=AVsD1Gy0sHg>



Simple Actuation by Heating Wire

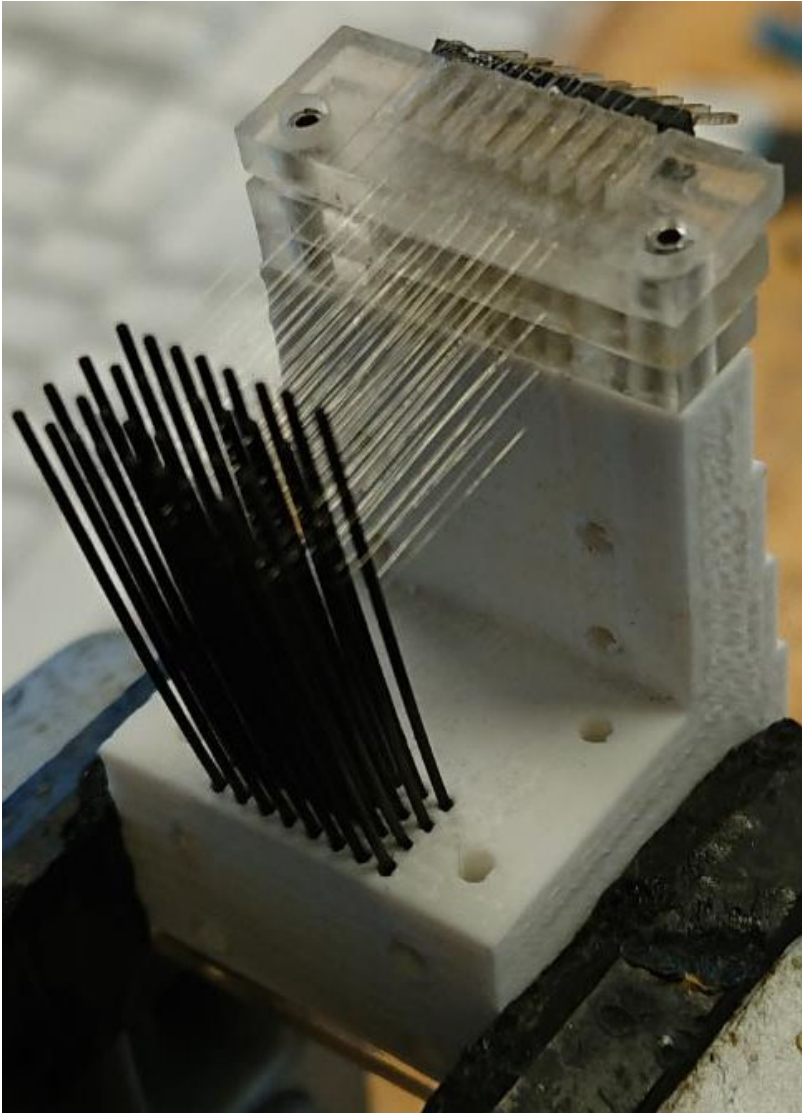


Fukuyama (2009) Tactile display using the vibration of SMA wires and the evaluation of perceived sensations

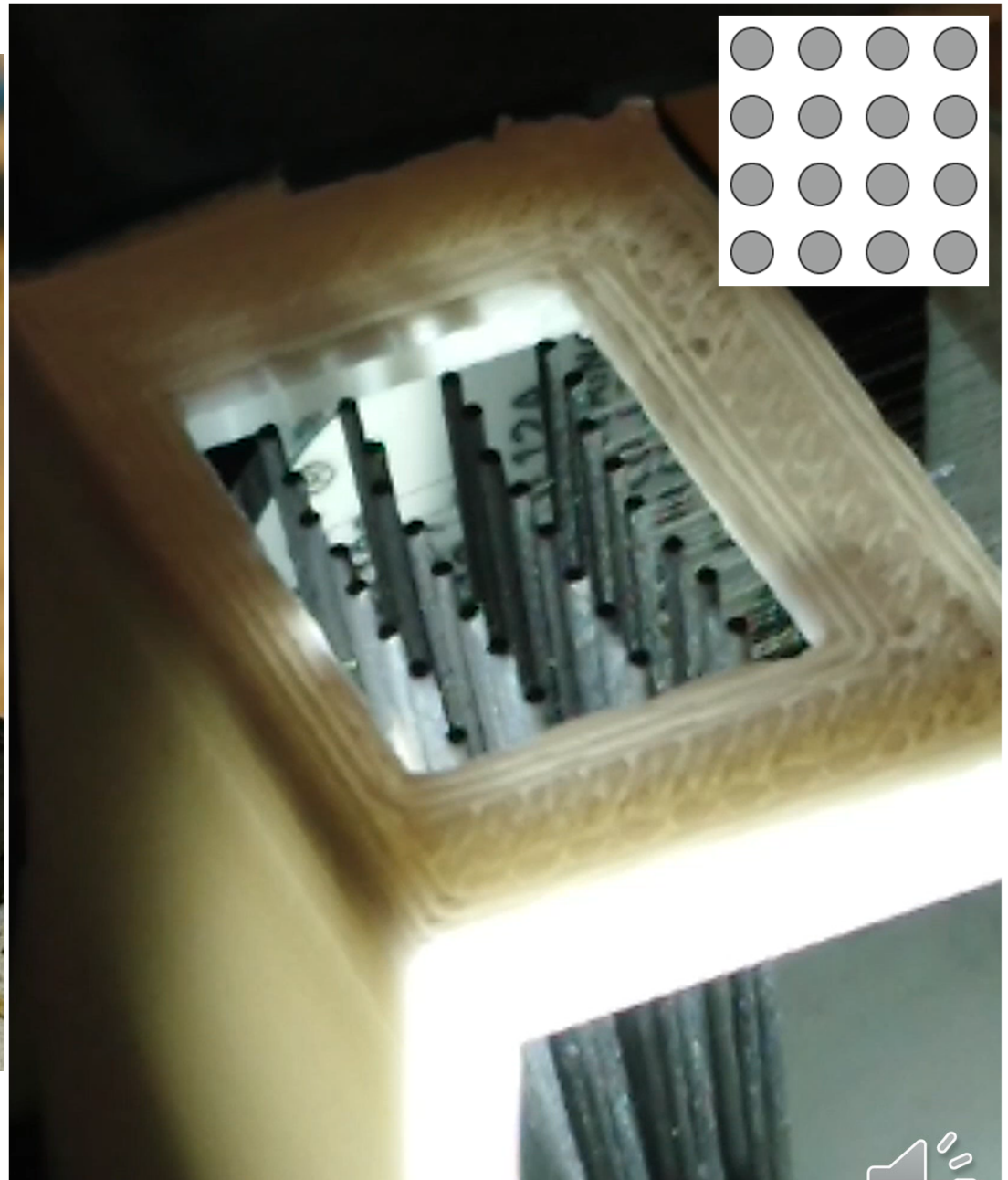
- Very thin Nichrome wire can be elongated by heating. Can also quickly shrink.
- Similar phenomenon observed by SMA wire, but not necessarily SMA.
- Heating phenomenon = Smaller the quicker. Good for small tactile display



2D Matrix



Hiroyuki Kajimoto, Lynette Jones: Wearable Tactile Display Based on Thermal Expansion of Nichrome Wire, IEEE Transaction on Haptics, pp.257-268, 2019.



8 by 4, 1.2mm interval. Up to 320 Hz vibration.

(CHI2023) Flat Panel Haptics: Embedded Electroosmotic Pumps for Scalable Shape Displays
Craig Shultz, Chris Harrison

Flat Panel Haptics

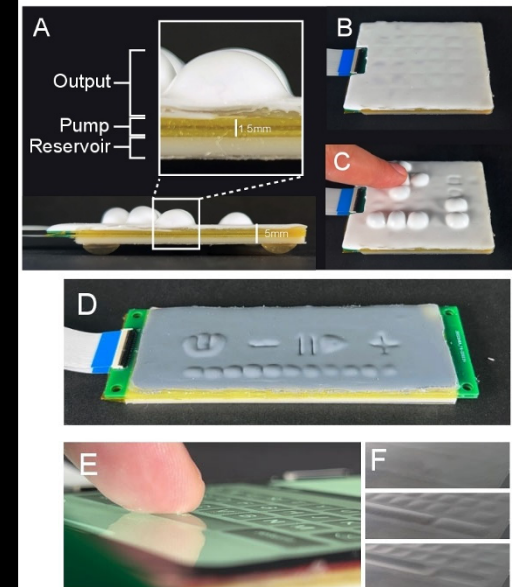
Embedded Electroosmotic Pumps
for Scalable Shape Displays

Craig Shultz

Chris Harrison



Carnegie Mellon University



高電圧による流体現象を利用し、300V程度の電圧の印加で細かなピンの駆動を可能とする。

<https://dl.acm.org/doi/fullHtml/10.1145/3544548.3581547>

https://www.youtube.com/watch?v=j_rErbhxNFM

Fluid Reality

High-Resolution, Untethered Haptic Gloves Using Electroosmotic Pump Arrays

Vivian Shen

Tucker Rae-Grant

Joe Mullenbach

Chris Harrison

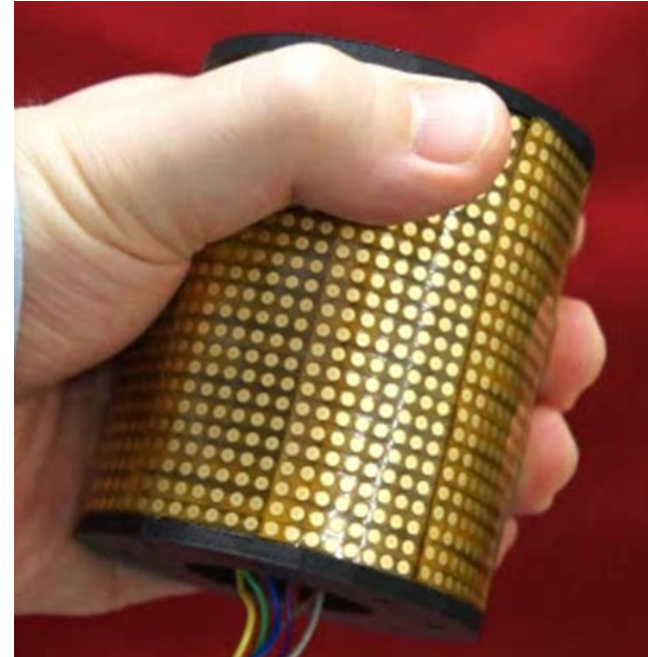
Craig Shultz



前述の原理でVR用グローブ化したもの

<https://www.fluidreality.com/>

電気刺激：高時空間分解能，省スペース，低コスト/ Electrotactile display can be high-resolution at low cost



- でも電気といえばビリビリ.
- その理由は物理的相互作用による計算プロセス(皮膚が接触で変形して感覚受容器が活動)を飛ばして受容器活動を生じさせているため.
- 逆に言えば，電気刺激を自然な触感とするためには，物理的な相互作用をすべて理解，モデル化している必要があり，研究課題として魅力的.
- Small, robust, no mechanical resonance, no noise, low power.
- Yet, many consider *Electrical Shock* not appropriate for daily use.



(UIST2023) Double-Sided Tactile Interactions for Grasping in Virtual Reality

Arata Jingu, Anusha Withana, Jürgen Steimle

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

Double-Sided Tactile Interactions for Grasping in Virtual Reality

Arata Jingu, Anusha Withana, Jürgen Steimle



THE UNIVERSITY OF
SYDNEY



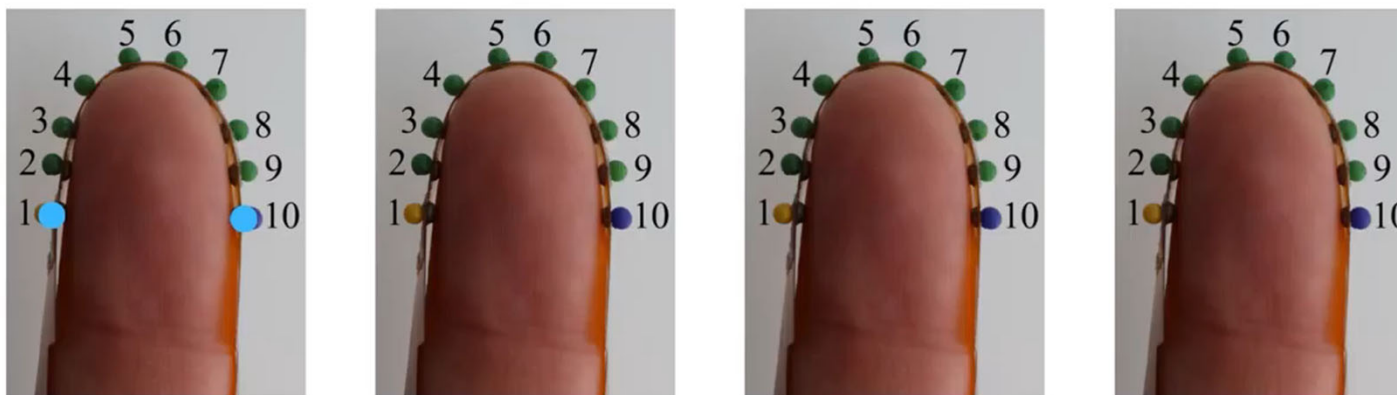
電気触覚を両面に行うことで親指でも電気触覚ができる
Double-sided electrotactile achieves index-finger and thumb stimulation.

(CHI2024) Designing Unobtrusive Modulated Electrotactile Feedback on Fingertip Edge to Assist Blind and Low Vision (BLV) People in Comprehending Charts

Chutian Jiang, Yinan FAN, Junan Xie, Emily Kuang, Kaihao Zhang, Mingming Fan

<https://www.youtube.com/watch?v=-Nfjll338g8>

Direction Perception



- 指の腹の周囲に電気刺激をすることによって指腹を阻害せずに情報提示
- Presentation of directional information by finger-side electrotactile stimulation.

現実的アプローチ：実物を使う Practical Approach using Real Objects



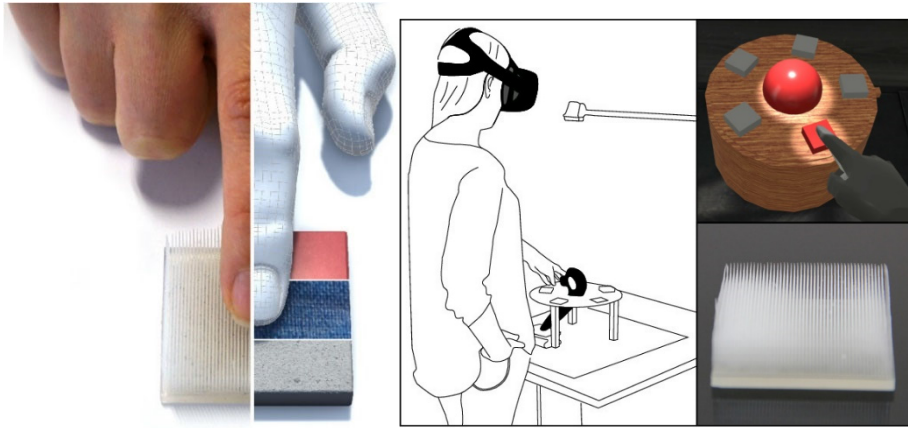
(CHI2018) Haptic Revolver: Touch, Shear, Texture, and Shape Rendering on a Reconfigurable Virtual Reality Controller, Eric Whitmire, Hrvoje Benko, Christian Holz, Eyal Ofek, Mike Sinclair
<https://www.youtube.com/watch?v=Qld0dN0p8P4&list=PLqhXYFYmZ-VcAoFsLTdH9hF26jsFkvs2B&index=153>

- ・ 円筒、円盤を使う「遭遇型触覚提示」。実物を使うことでリアルな触感を提示。
- ・ Encounter-type tactile presentation using cylinders and disks. Realistic tactile sensations are presented by using actual objects.



(CHI2022) SpinOcchio: Understanding Haptic-Visual Congruency of Skin-Slip in VR with a Dynamic Grip Controller Myung Jin Kim, Neung Ryu, Wooje Chang, Michel Pahud, Mike Sinclair, Andrea Bianchi
<https://www.youtube.com/watch?v=kp0IcDULqpI>

実物のテクスチャを使う / Using real textures



(CHI2019) Enhancing Texture Perception in Virtual Reality Using 3D-Printed Hair Structures, Donald Degraen André Zenner Antonio Krüger

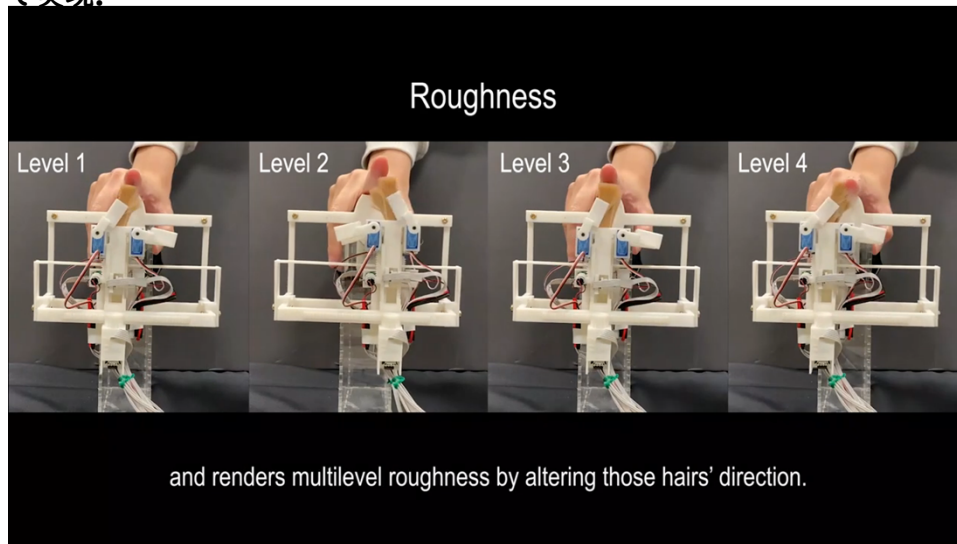
多数の布テクスチャの感触を、限られた本物のテクスチャ+VR視覚で実現。



(CHI2021) TexelBlocks: Dynamic Surfaces For Physical Interactions, Chan et al.

<https://www.youtube.com/watch?v=KYI8OgbFcIc>

ベルトコンベア方式でテクスチャを変える。



(CHI2021) HairTouch: Providing Stiffness, Roughness and Surface Height Differences Using Reconfigurable Brush Hairs on a VR Controller, Chi-Jung Lee, Hsin-Ruey Tsai, Bing-Yu Chen

<https://www.youtube.com/watch?v=4ItO-zszrfY>

細い毛のブラシの基部を変化させて異なる粗さ等を表現。



(CHI2022) Smooth as Steel Wool: Effects of Visual Stimuli on the Haptic Perception of Roughness in Virtual Reality Sebastian, Günther et al.

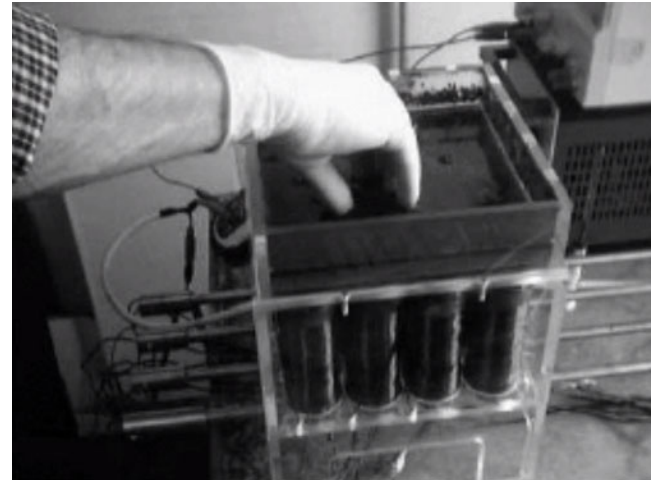
視覚との融合状態では、リアルな錯覚を伝えるには、2段階の粗さがあれば十分との結果。

<https://www.youtube.com/watch?v=h0FQZQ26uoU&list=PLqhXYFYmZ-VcAoFsLTdH9hF26jsFkvs2B&index=136>

実物の柔軟物を使う/ Using real soft material



S. Follmer et al., Jamming user interfaces: programmable particle stiffness and sensing for malleable and shape-changing devices, UIST2012
<https://vimeo.com/108409013>



Haptic displays based on magnetorheological fluids: design, realization and psychophysical validation (2003)

<https://ieeexplore.ieee.org/document/1191217>



The surface is able to present the gradual dynamic transration of its properties from soft to hard and vice versa.
<https://www.youtube.com/watch?v=C5yHoyS1zY>

Matoba et al. : ClaytricSurface: An Interactive Surface With Dynamic Softness Control Capability, ACM SIGGRAPH Emerging Technologies, 2012.



Pinning nodes allows greater shape output variability
<http://www.youtube.com/watch?v=2x4x0v12x00>

Stanley et al. Haptic jamming: A deformable geometry, variable stiffness tactile display using pneumatics and particle jamming, World Haptics Conference 2013.

- ・ ジャミング現象や磁性流体を用い、柔らかさを物理的に変化させる



小テスト：一週間以内に提出

Mini Test: Submit in one week

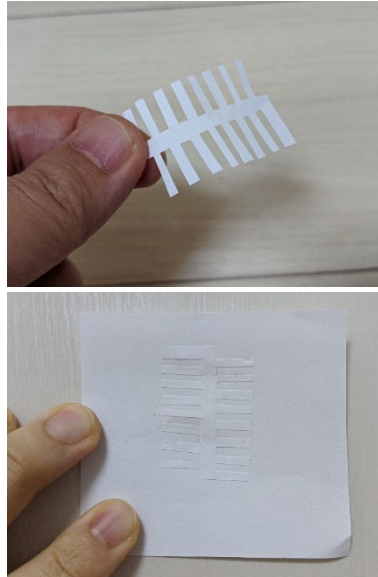
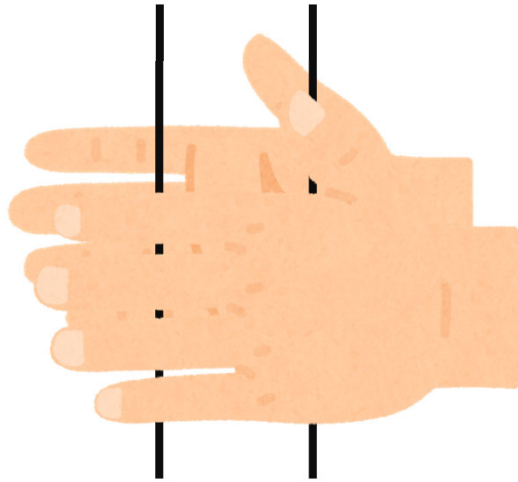
以下の全てに100字以内程度で解答せよ／Answer all questions within 50 words

1. メルケル細胞の役割について説明せよ Explain role of Merkel cell
2. マイスナー小体の役割について説明せよ Explain role of Meissner corpuscle.
3. パチニ小体の役割について説明せよ Explain role of Pacini corpuscle.
4. ルフィニ終末の役割について説明せよ Explain role of Ruffini ending
5. 温度感覚の仕組みについて説明せよ Explain mechanism of thermal sensation.
6. 触覚の仮現運動について説明せよ Explain tactile apparent motion
7. 触覚の跳躍現象について説明せよ Explain cutaneous rabbit.
8. ファントムセンセーションについて説明せよ Explain Phantom Sensation
9. ベルベットイリュージョンについて説明せよ Explain velvet illusion
10. サーマルリファレルについて説明せよ Explain thermal referrel
11. サーマルグリルイリュージョンについて説明せよ Explain thermal grill illusion
12. 触感の5要素について説明せよ Explain five dimension of tactile feeling



実験レポート: 錯触覚の体験

Report: Try some tactile illusions



- ・ 授業で紹介した以下の錯覚現象を実際に体験する。レポートでは体験の様子の写真を載せ、結果を述べる。(例えばどのような条件で錯覚が出やすかったか)
 - ベルベット錯覚(2本の紐でもラケットでも良い)
 - Fishbone錯覚
 - Thermal Referral
- ・ Experience the following illusions introduced in class. In your report, you will include pictures of your experience and describe the results. (For example, under what conditions were the illusions more likely to occur?)
 - Velvet illusion (you may use either two strings or racket)
 - Fishbone illusion
 - Thermal referral

