

Interactive System インタラクティブ システム特論 (8)

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インタラクティブシステム特論
最終課題について: web参照し準備を
始めましょう

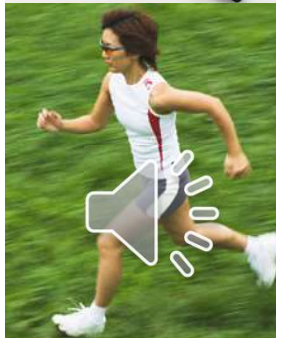
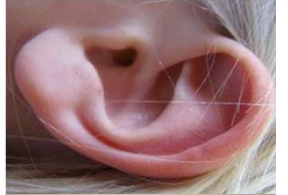
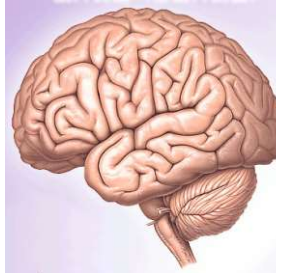
Please see the web for final
presentation-style report, and
start preparation.

<https://kaji-lab.jp/ja/index.php?plugin=attach&refer=people%2Fkaji%2Finteractive&openfile=InteractiveSystemFinalPresentation.pdf>



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2 / Tactile Interface
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

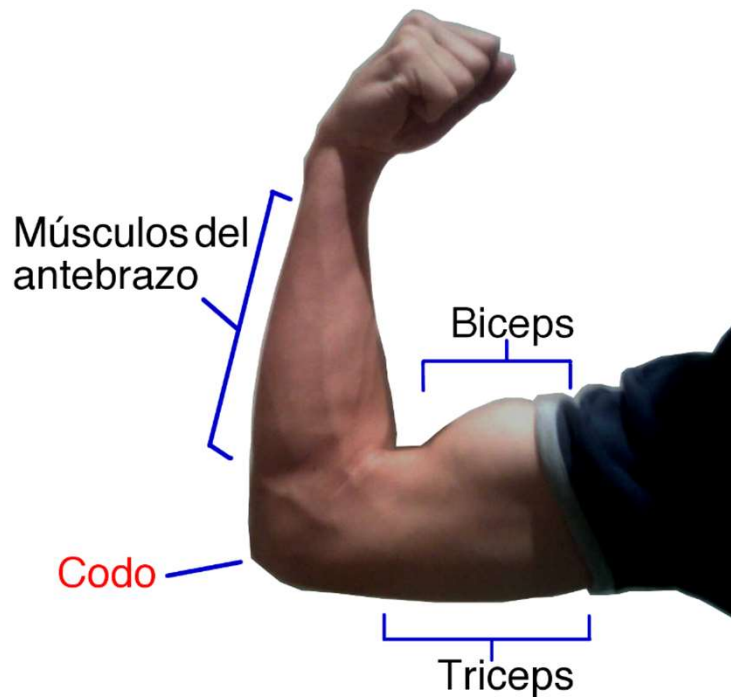


TODAY's TOPIC

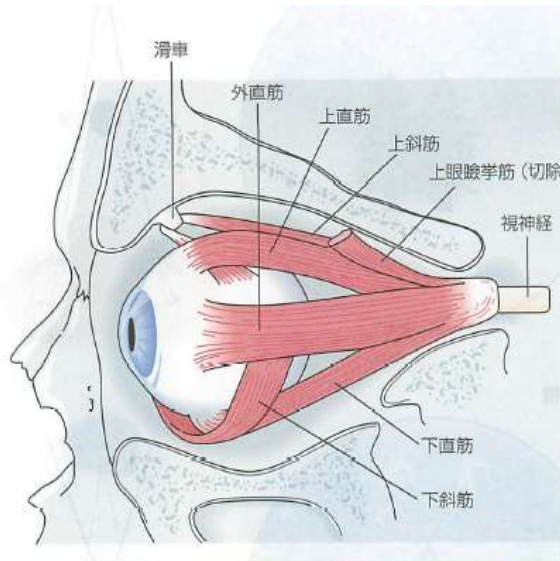
1. 力覚関連のメカニズム Haptic Perception Mechanism
2. 力覚ディスプレイの分類 Classifying Haptic Displays
3. 力覚ディスプレイの応用 Application of Haptic Interface



Antagonistic muscle pairs 拮抗筋

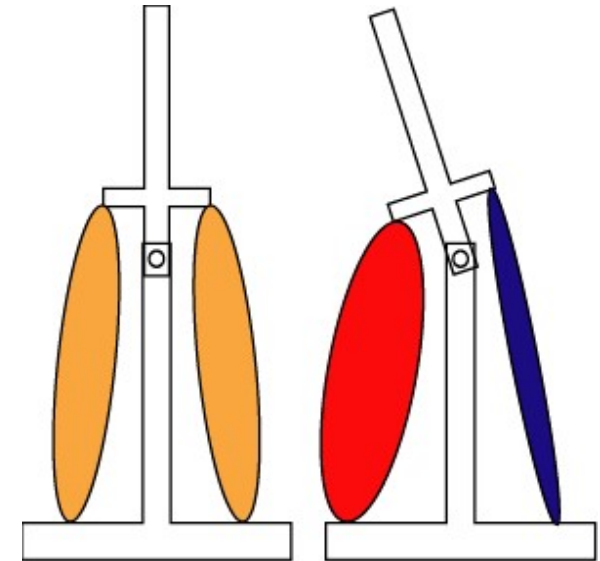


https://en.wikipedia.org/wiki/Anatomical_terms_of_muscle



カandel神経科学 (Principles of Neural Science)

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



• 2つの拮抗筋ペアが一つの関節で協調動作

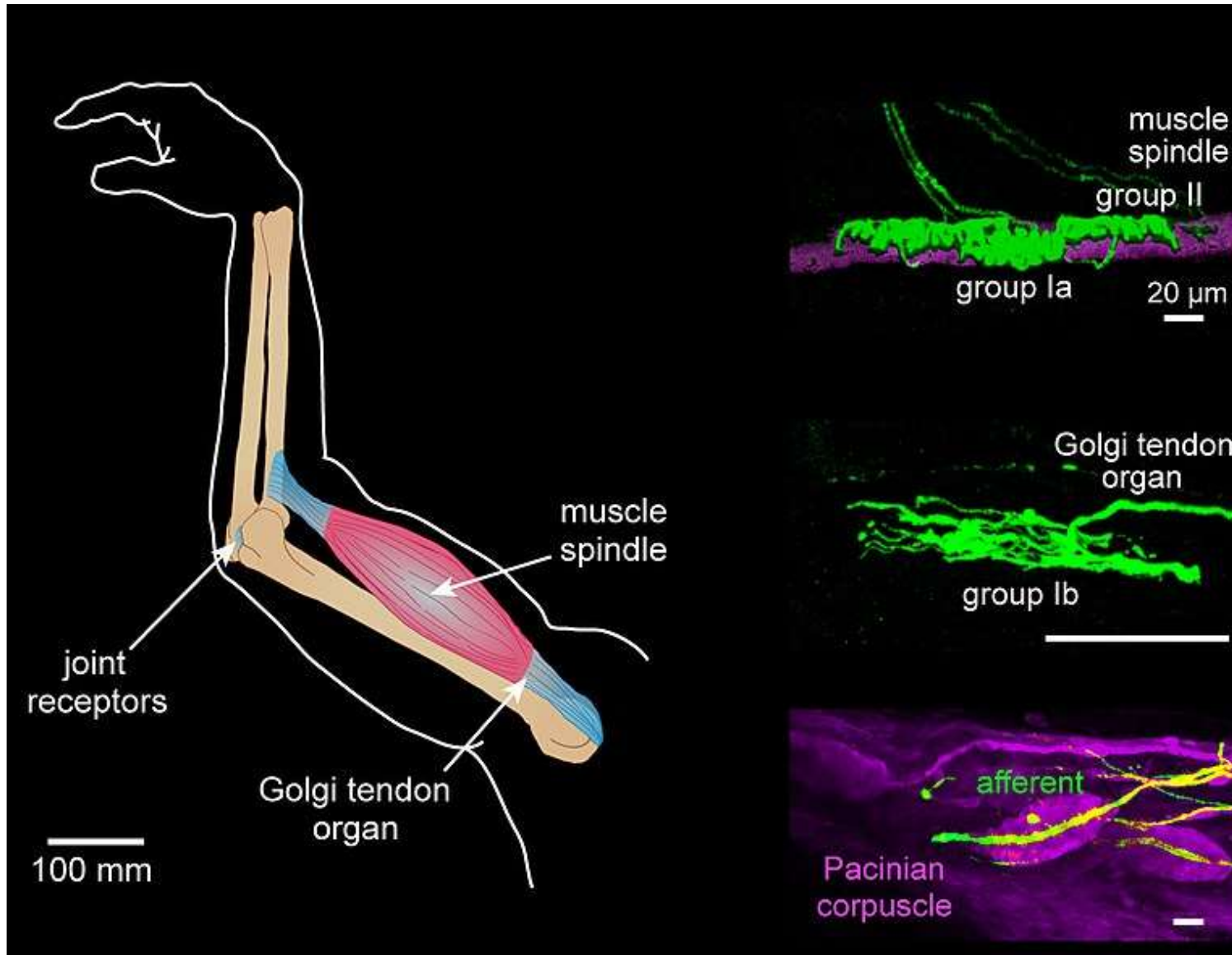
- 筋は収縮側でしか力を発揮できないため
- 制御自由度が2あることで、固さ(インピーダンス)と外力の2パラメータを決定できる
- 主働筋の動作時に拮抗筋が弛緩する(相反神経支配)

• Two muscles are responsible for one joint.

- Muscle can only exert force when it shrinks.
- By Two muscles, “Force” and “Impedance(softness)” is independently presented.



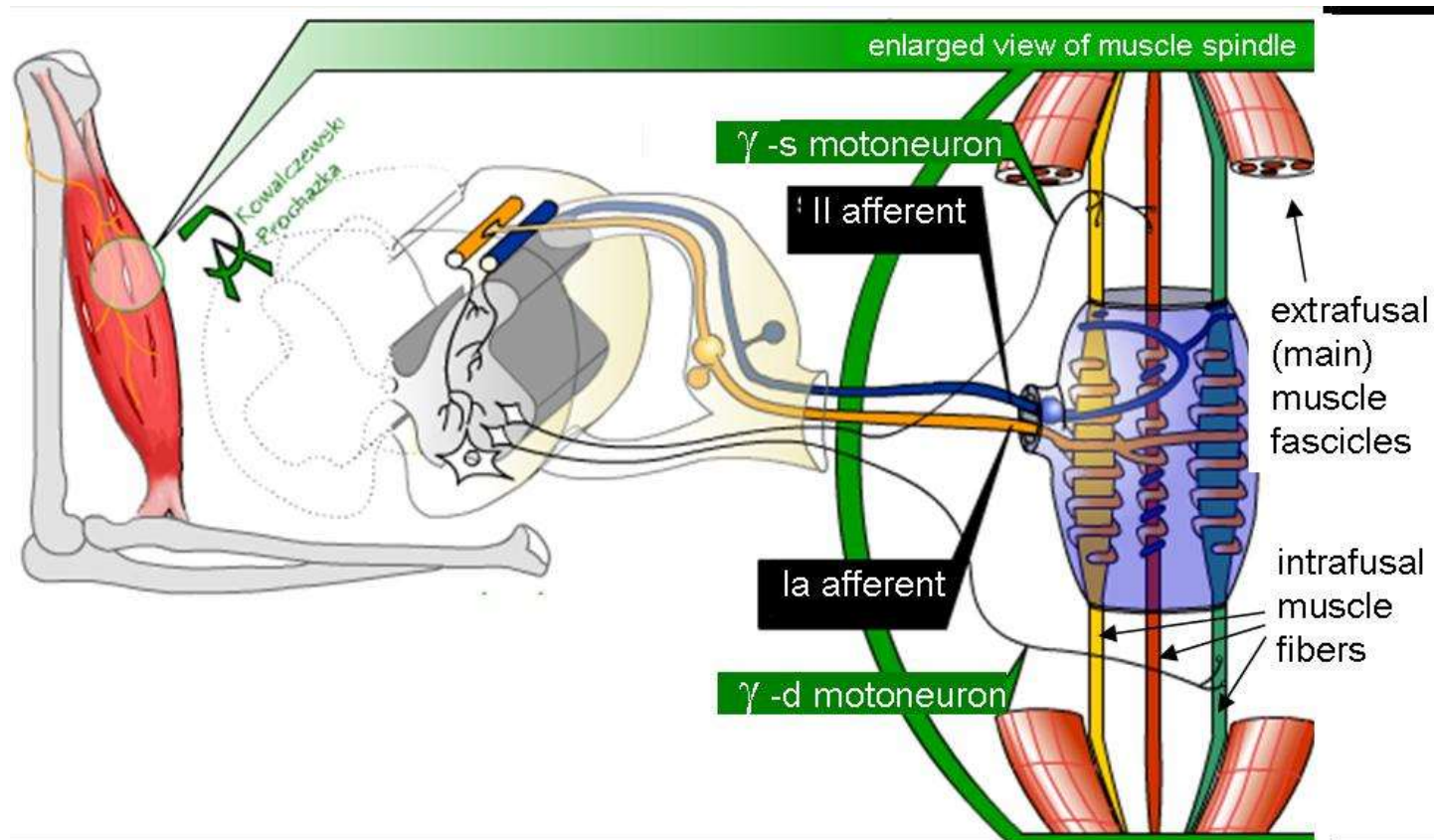
Receptors around Muscle and Joint



- 筋紡錘
Muscle Spindle
 - Inside Muscle
- ゴルジ腱器官
Golgi Tendon Organ
 - At the Tendon
(Muscle-Bone Connection)
- 関節受容器
Joint Mechanoreceptor
 - Inside Joint



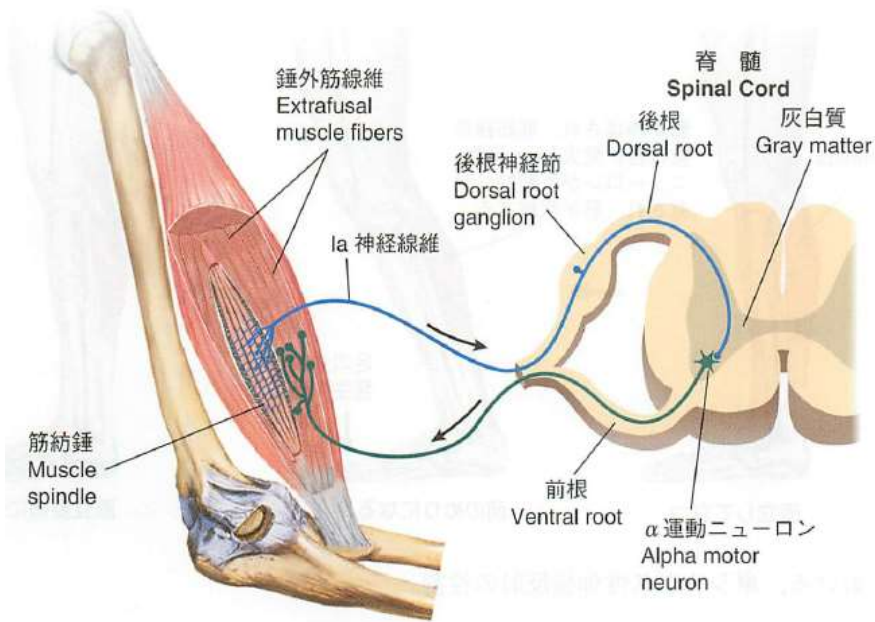
筋紡錘 Muscle Spindle



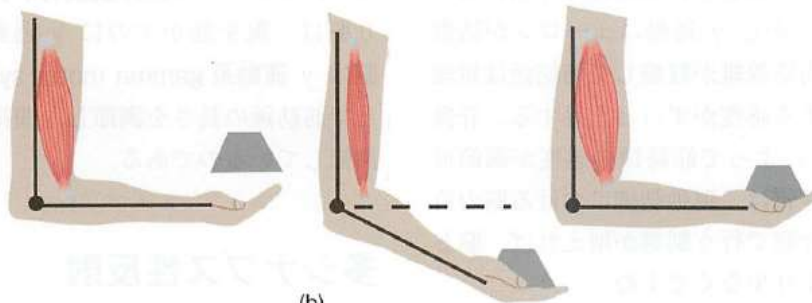
https://en.wikipedia.org/wiki/Muscle_spindle

- 筋肉の伸長→筋内繊維の伸長→感覚神経末端の物理的変形→活動
 - Ia繊維（直径12-20um）：伸びた長さおよび速度に反応（位置と速度。文献によっては速度）
 - II繊維（直径5-12um）：伸ばされた筋が伸び続けている場合に反応（文献によっては位置）
 - γ 運動ニューロン。筋伸縮のさいの筋内繊維の「ゆるみ」を防止する調整役（ α - γ 連関）
 - Ia afferent mainly detects length and velocity. II afferent is for static length.

伸長反射 Stretch Reflex



(a)



(b)

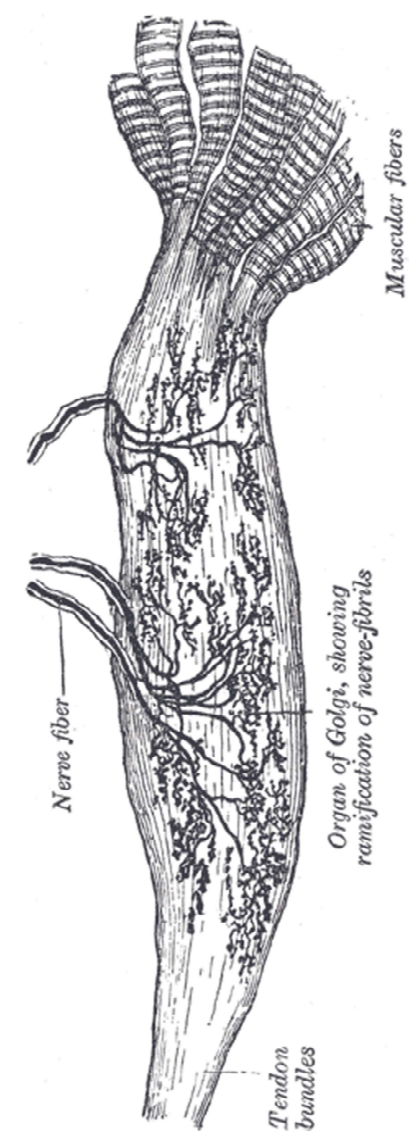
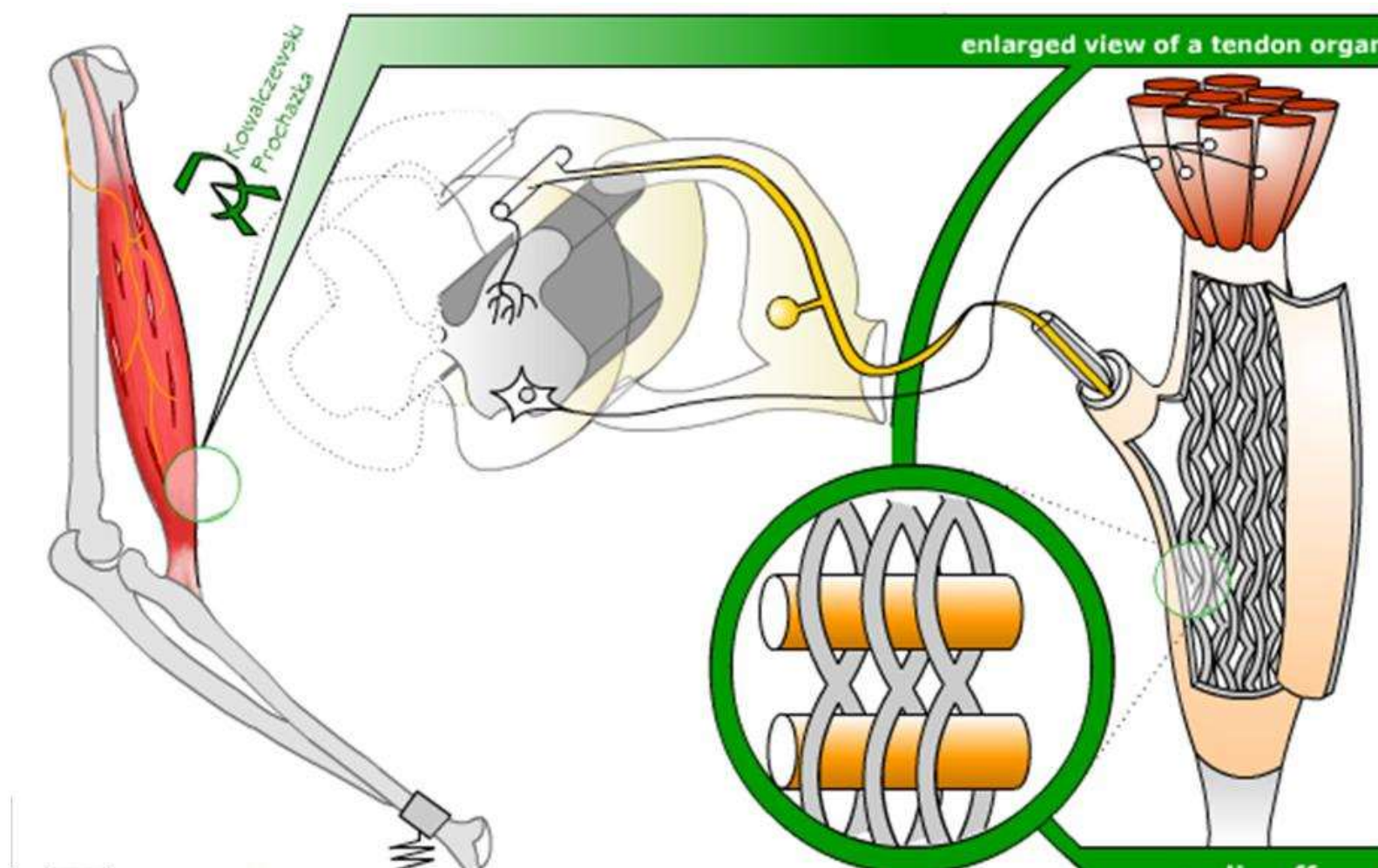


カールソン神経科学テキスト (Physiology of Behavior)
<https://www.maruzen-publishing.co.jp/item/b294439.html>

- 筋が受動的に引き伸ばされた際にその筋が収縮する反射。
 - 唯一の単シナプス反射。
 - いわゆる膝蓋腱反射もこの一種。
 - 姿勢の維持に貢献
 - 同時に拮抗筋の活動が抑制される(1a抑制反射)



ゴルジ腱器官 Golgi Tendon Organ

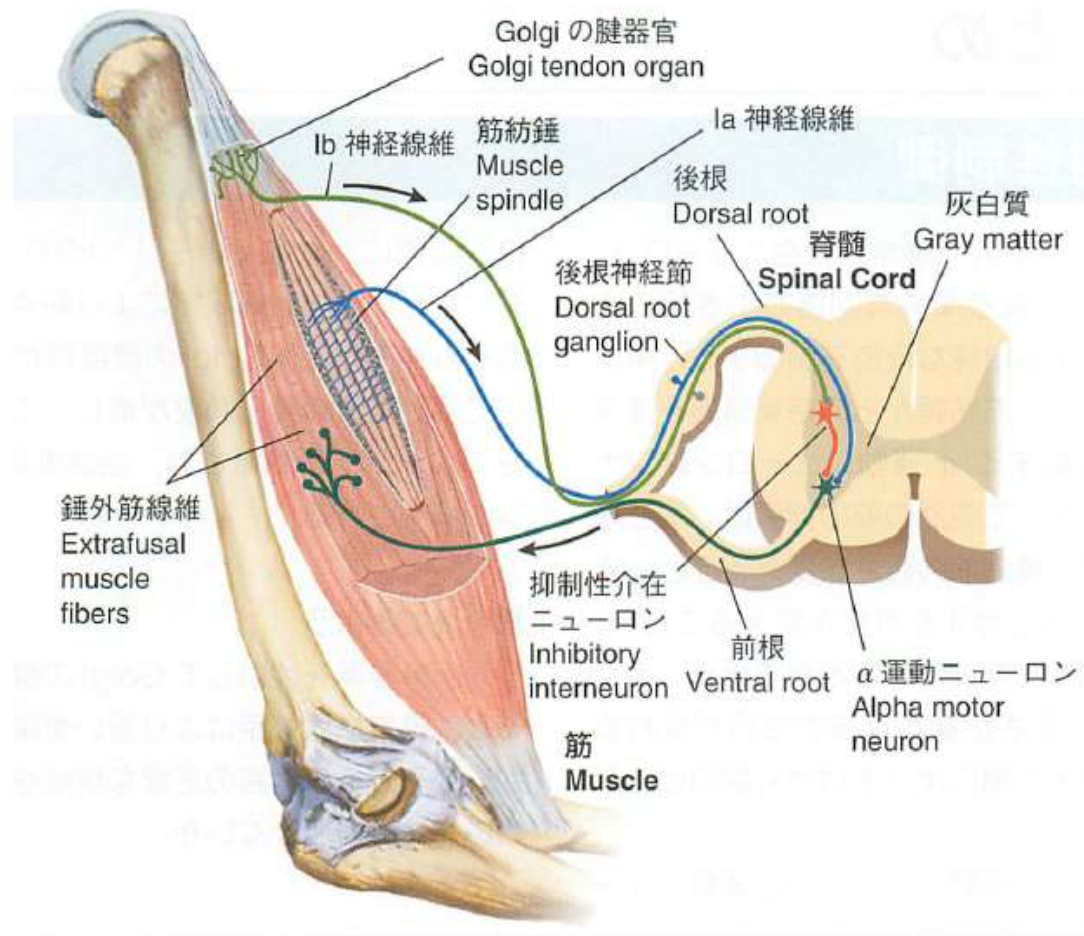


https://en.wikipedia.org/wiki/Golgi_tendon_organ

- 骨格筋と腱の移行部に存在。筋の力に応じて活動。
 - Ib繊維(直径12-20um)
 - 腱反射のような殴打する刺激に対しては筋紡錘のみ活動。
 - 筋張力を一定に保つ。



Ib抑制反射 Golgi tendon reflex



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>

- ゴルジ腱器官に伸張刺激が加わると刺激が加わった筋の緊張が低下する
- 同時に拮抗筋の活動も生じる
- When a stretching stimulus is applied to the Golgi tendon organ, the tension in the stimulated muscle is reduced. Antagonistic muscle activity occurs simultaneously.



錯触（皮膚感覚に対する錯触のぞく）の一部 Haptic Illusions (other than purely cutaneous illusion)

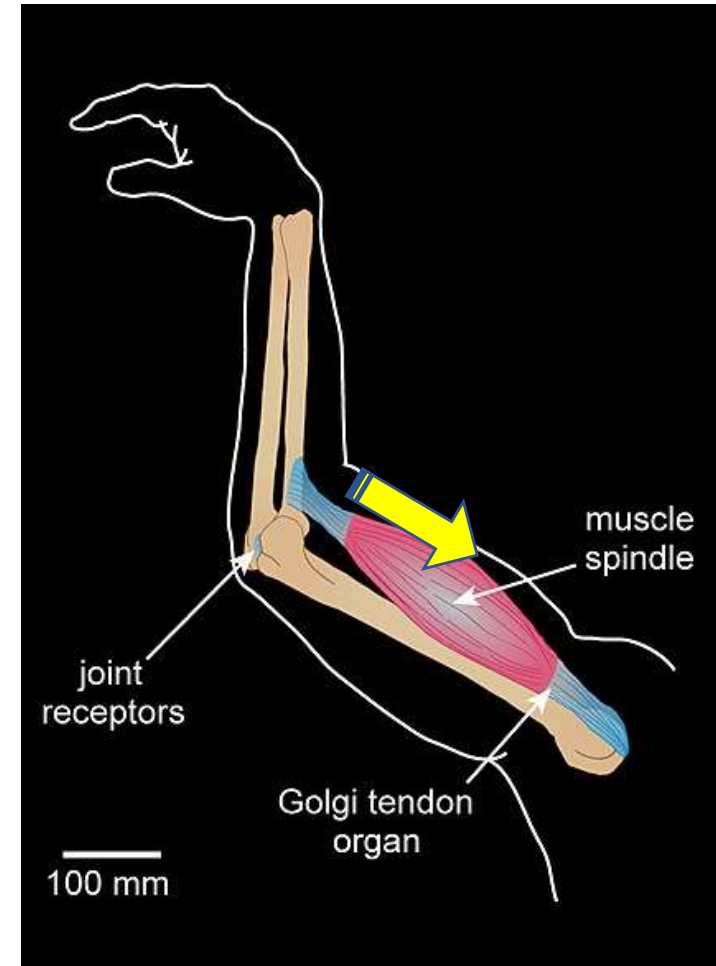
1. 深部受容器自体の刺激
2. 視覚 + 深部感覚 Vision + Haptics
3. 皮膚感覚 + 深部感覚 Cutaneous + Haptics



腱振動による運動錯覚 kinetic illusion by tendon vibration



Leonardis, Haptics Symposium, 2012














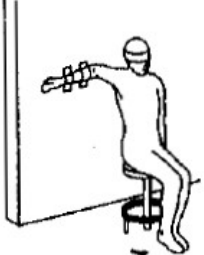




- 腱に80Hzの振動を打ち込むと関節が曲がって感じられる (Goodwin 1972)
- 振動伝播により筋紡錘を刺激していると考えられている (Burke 1976 他)
- インタフェースとしての提案多 (友田 2009, Roll 2009, Leonardis 2012)
- 強力な振動子が必要 ⇒ 強烈な振動感



運動錯覚による身体変容

Influences of body shape and orientation by

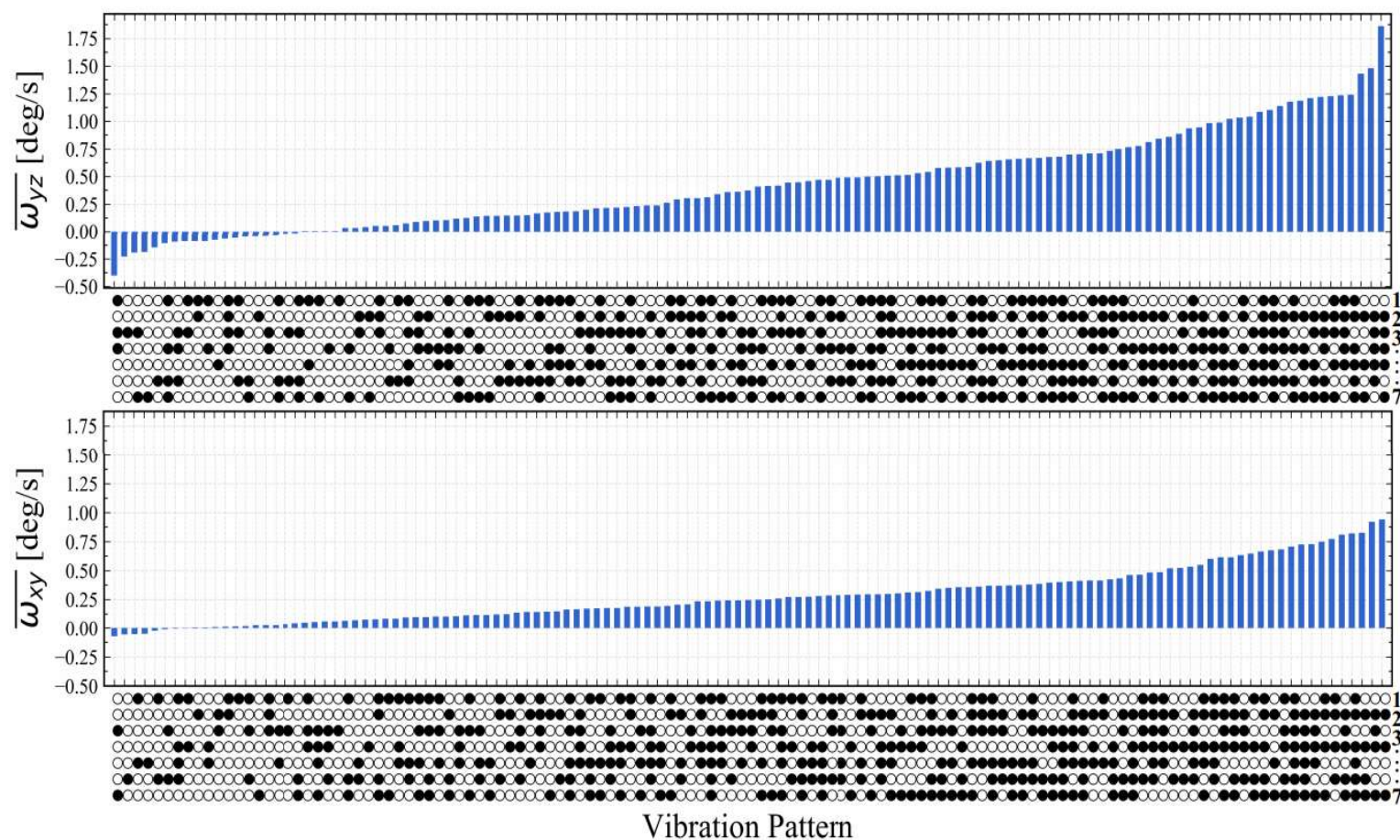
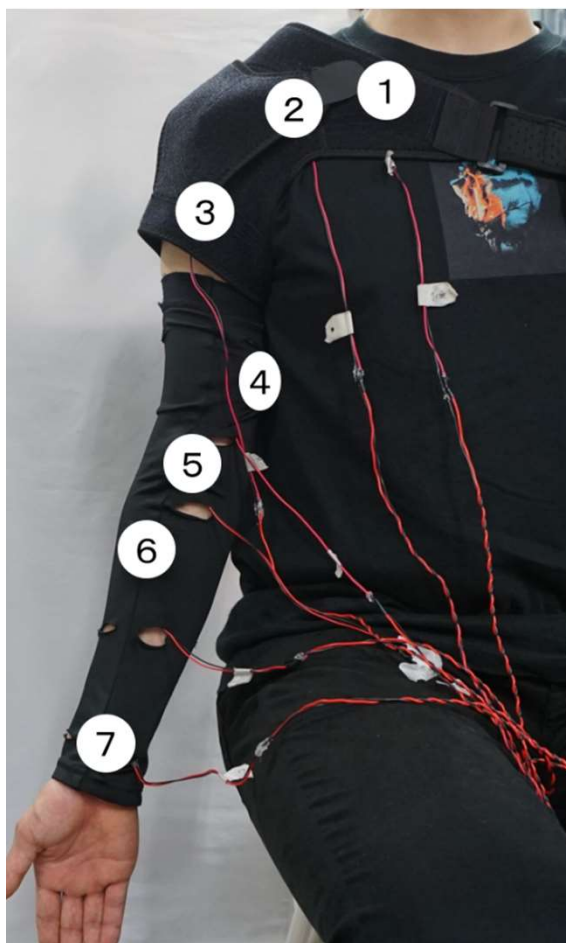
	Test configuration A	Experienced pattern	Test configuration B	Experienced pattern
1				
2				
3				
4				

[Some Proprioceptive Influences on the Perceptual Representation of Body Shape and Orientation," J. R. Lackner, 1988, Brain](#)

- 例えば鼻先をつまんだ状態で振動刺激を加えて肘伸展の運動錯覚を引き起こすと、鼻が物理的に伸びたに違いないと解釈する。
- If a vibrating stimulus is applied to the nose while the tip of the nose is pinched to induce the kinetic illusion of elbow extension, the nasal sensation is interpreted that the nose must have been physically stretched



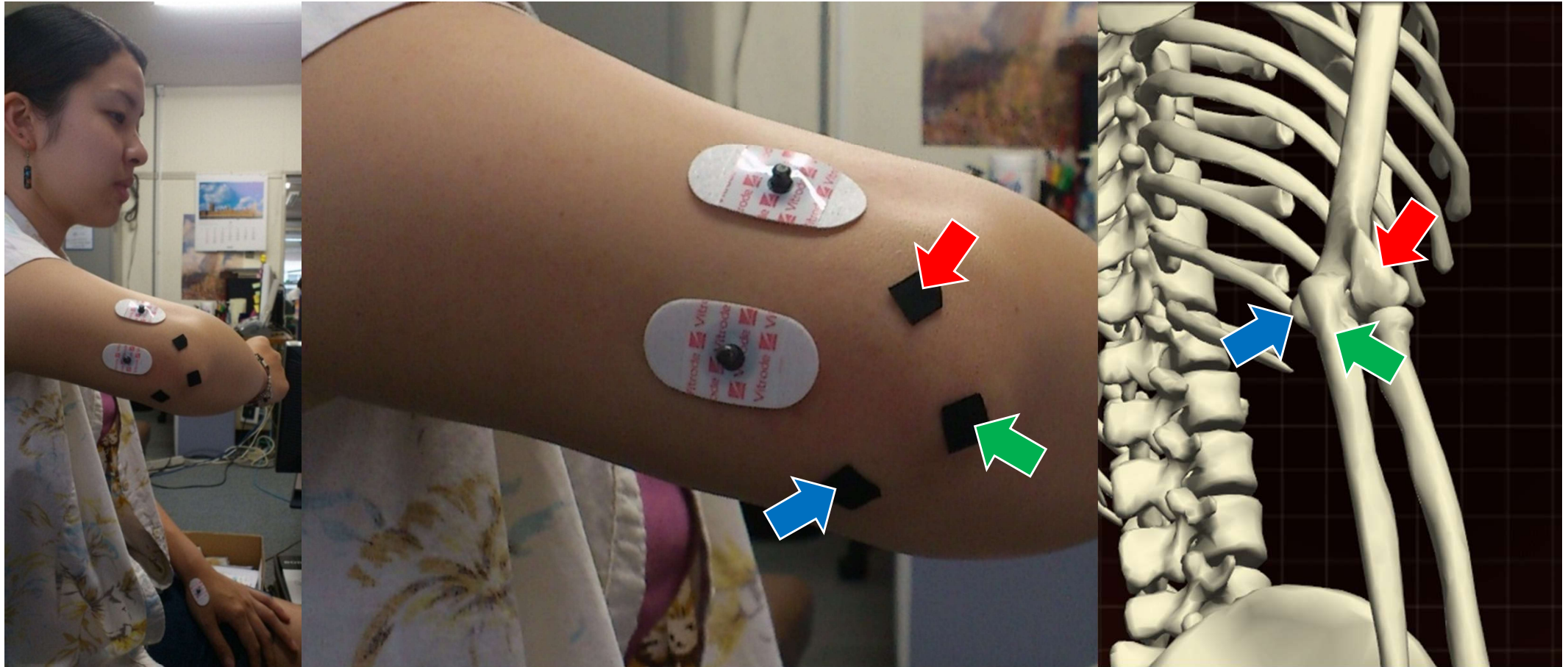
Keigo Ushiyama, Satoshi Tanaka, Akifumi Takahashi, and Hiroyuki Kajimoto.
The Effects of Simultaneous Multi-Point Vibratory Stimulation on Kinesthetic Illusion. Eurohaptics 2020



- 運動には多数の協働筋あり。複数の筋で同時に運動錯覚を生じさせることで運動錯覚をより増強させることができる。
- THERE ARE MANY COOPERATING MUSCLES IN MOTION. THE ILLUSION OF MOVEMENT CAN BE ENHANCED BY STIMULATING MULTIPLE MUSCLES SIMULTANEOUSLY.

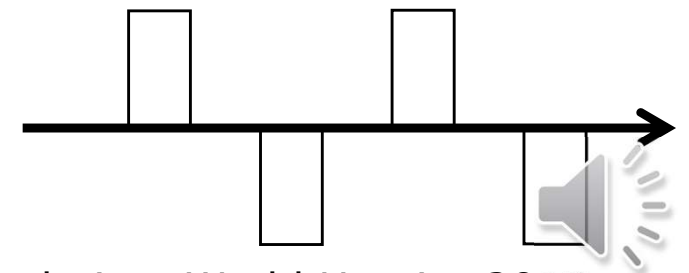


電気刺激による運動錯覚 Electrical stimulation to tendon part also induce kinesthetic illusion



- 上腕三頭筋の肘側の**腱**を電気刺激

- ✓ 100Hz、500usの両極性パルス
- ✓ 電流値は被験者自身が調整。最大10mA
- ✓ 10秒程度の刺激で腕姿勢を回答



右腕を刺激、左腕で姿勢を模擬（閉眼）



閉眼、右腕腱刺激、なるべく力を抜いて腕を前に突き出す



視覚によるハプティック錯覚 (1) : サイズ-重さ錯覚 Vision Induced Haptics(1): Size-Weight Illusion



同じ重量なら小さいものをより重く感じる (家でやってみましょう)

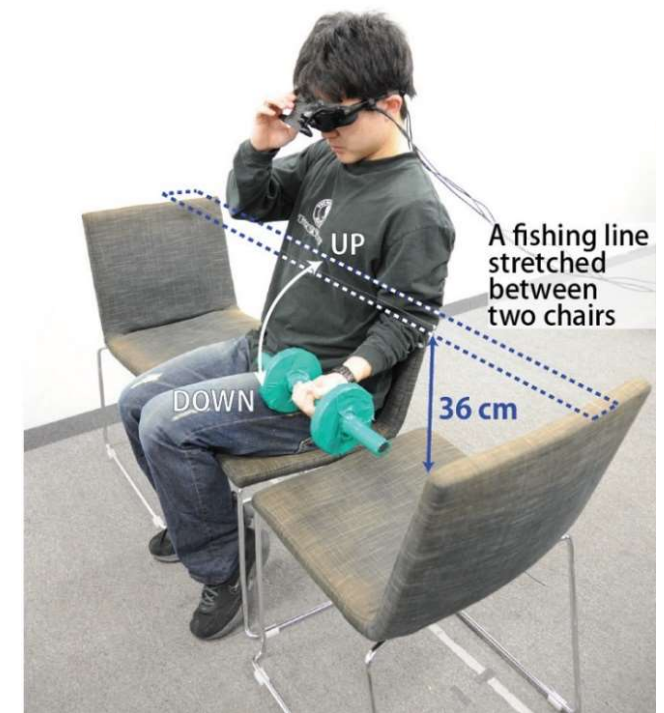
If two objects are the same weight, smaller one felt heavier.



明度 ⇒ 重さ知覚



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



Reducing Brightness Enhancing Brightness



Ban et al.: Augmented Endurance: Controlling Fatigue while Handling Objects by Affecting Weight Perception using Augmented Reality, CHI2013.



視覚によるハプティック錯覚 (2) : シュードハプティクス Vision Induced Haptics(2): Pseudo-Haptics



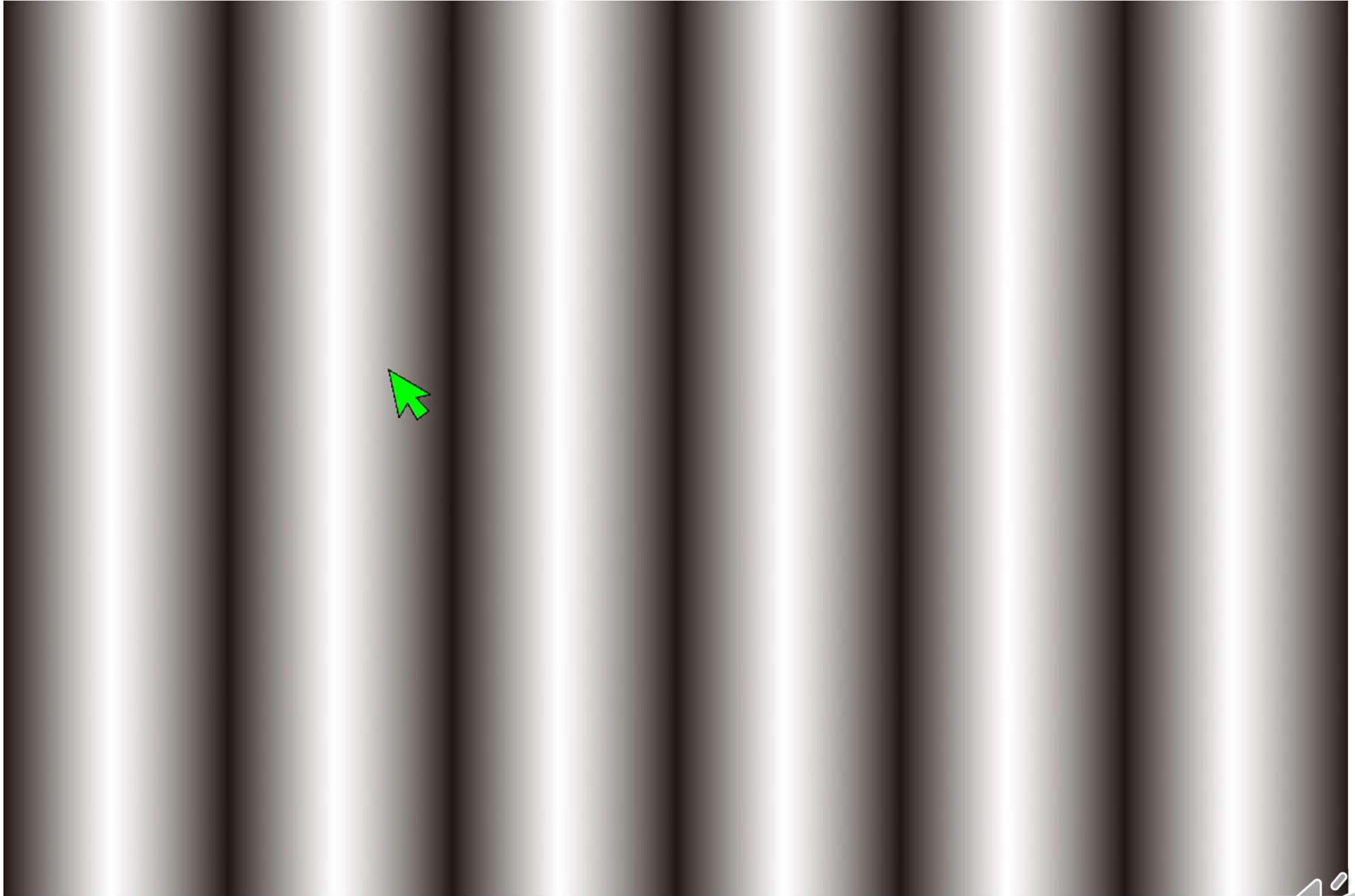
視覚的な動きによって、触覚的な抵抗感を感じる。マウスカーソルの動きを遅くしたときのブレーキ感。

Visual motion induces haptic resistance. (ex) Braking feeling when mouse cursor is suddenly slowed down.

http://www.irisa.fr/bunraku/GENS/alecuyer/projets_textures.html



PseudoHaptics

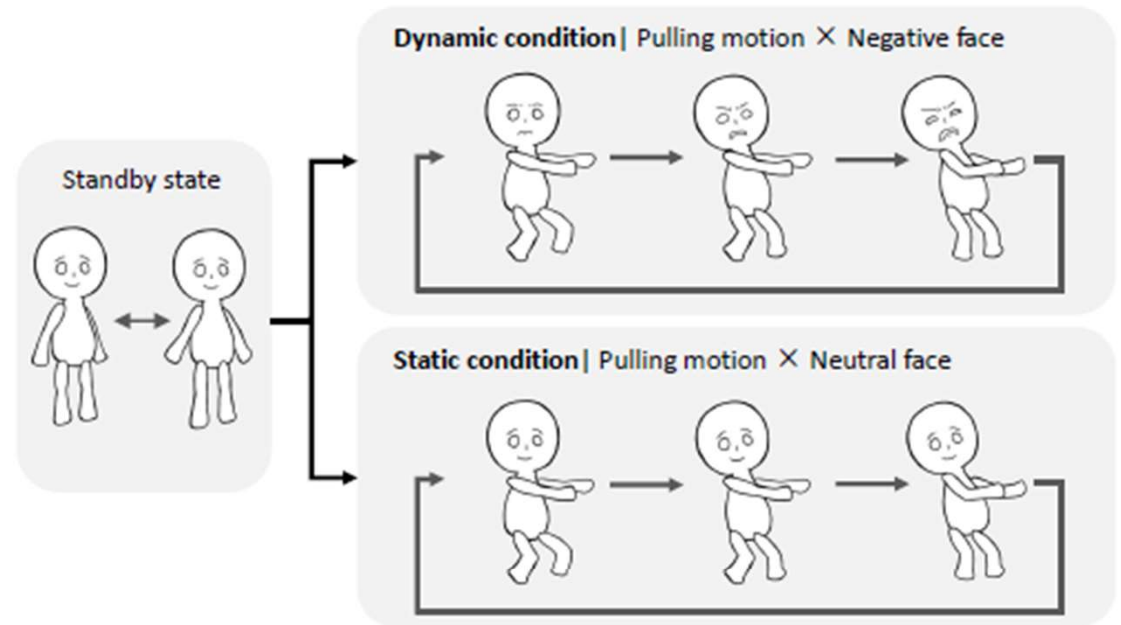
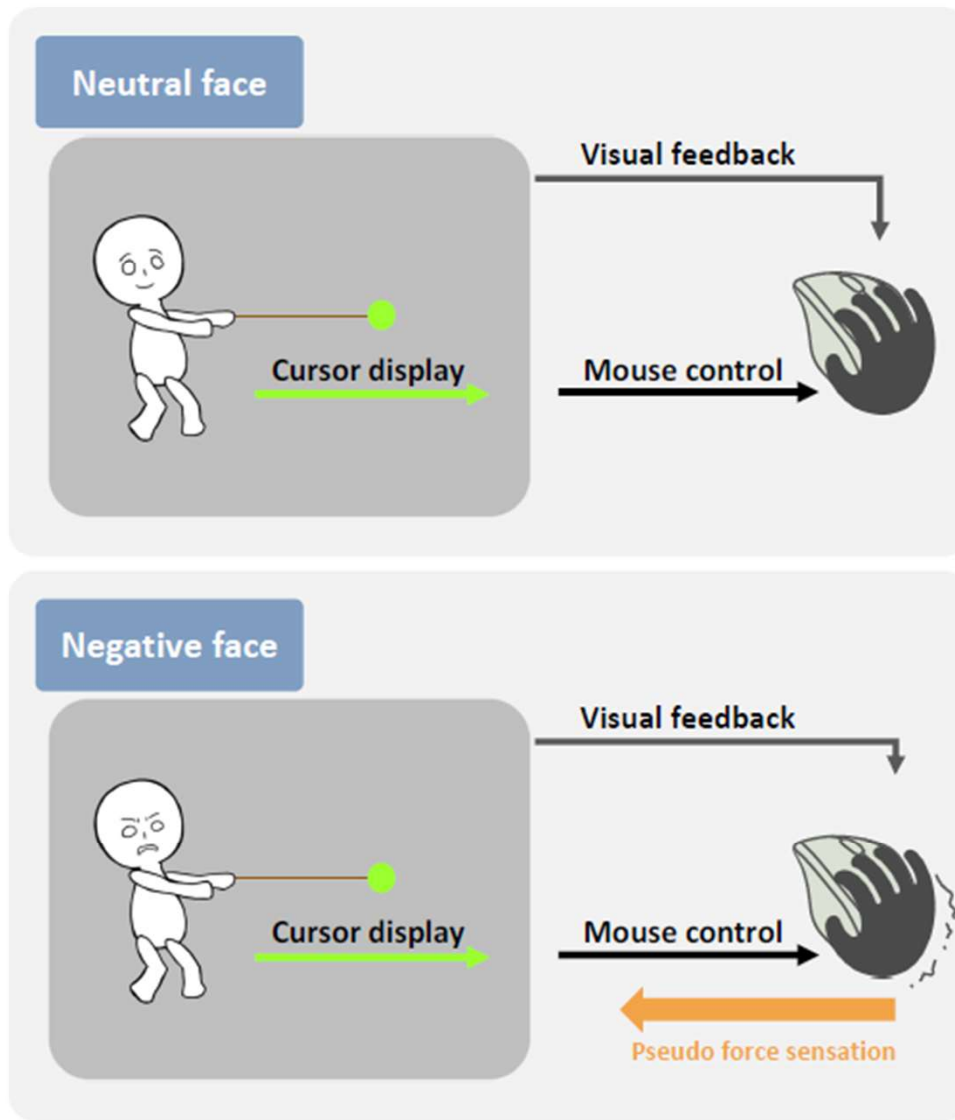


<https://github.com/HiroyukiKajimoto/PseudoHaptics>

(家でやりましょう)



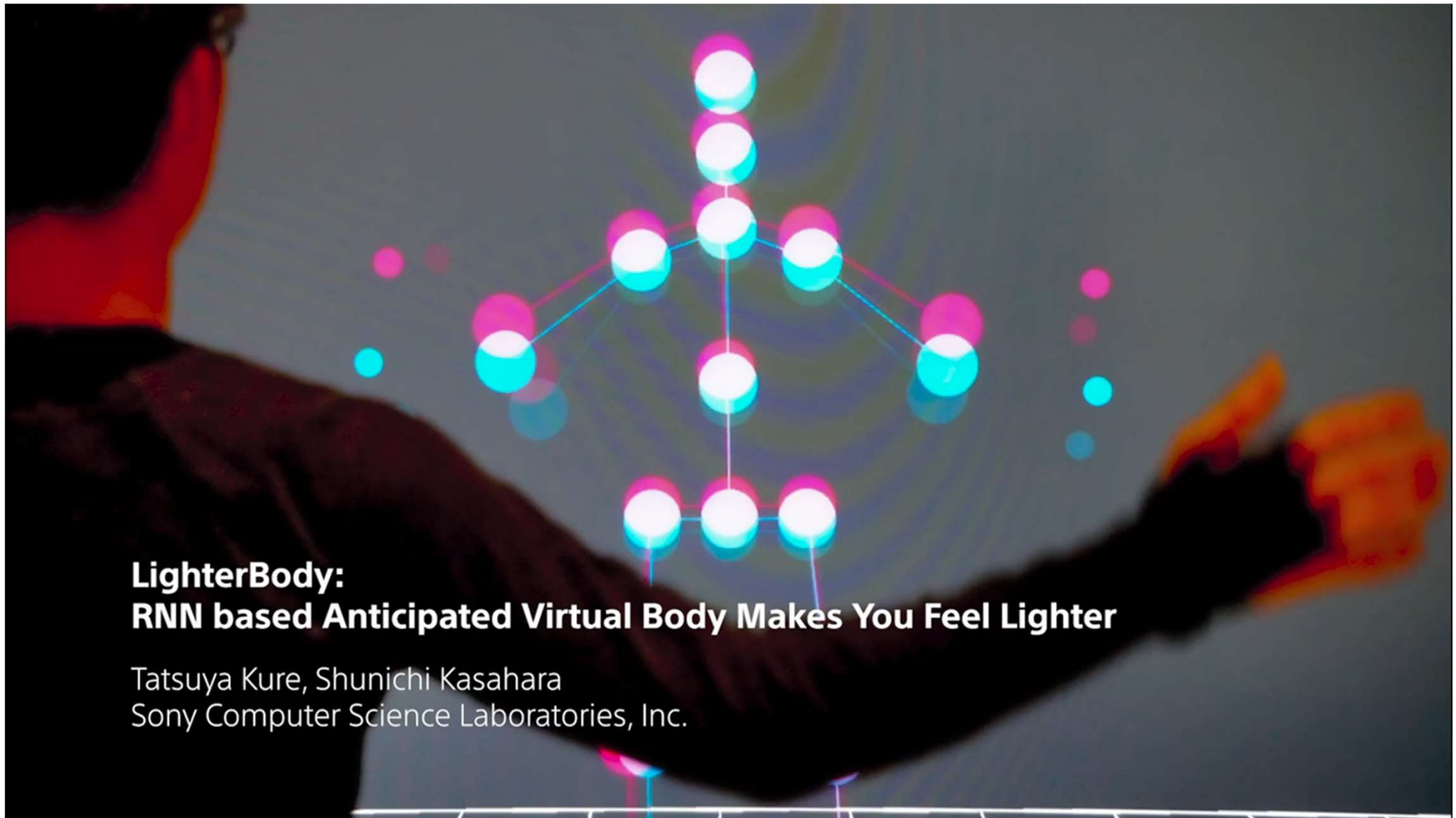
「共感」と PseudoHaptics/ Sympathy and PseudoHaptics



- 「カーソルを引っ張るキャラクタ」を描画する。キャラクタの表情を変化させることで力覚を生起する。
- この生起強度はコミュニケーション及び社会的スキルに相関がある。



(IEEEVR2021 Poster) Tatsuya Kure, Shunichi Kasahara
LighterBody: RNN based Anticipated Virtual Body Makes You Feel Lighter



**LighterBody:
RNN based Anticipated Virtual Body Makes You Feel Lighter**

Tatsuya Kure, Shunichi Kasahara
Sony Computer Science Laboratories, Inc.

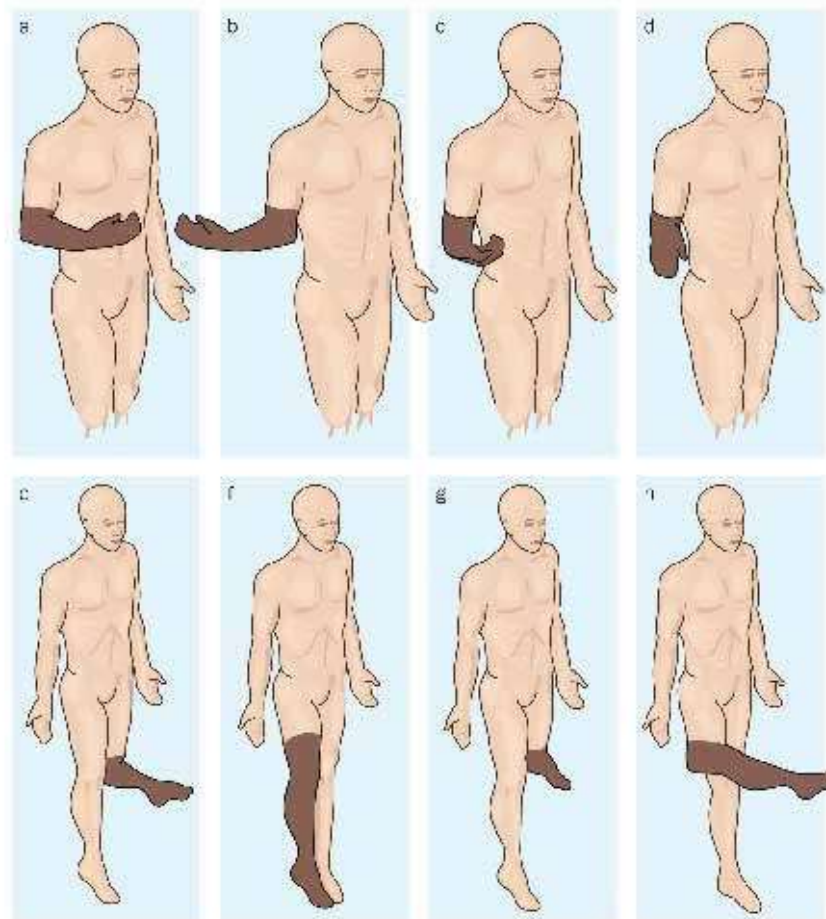
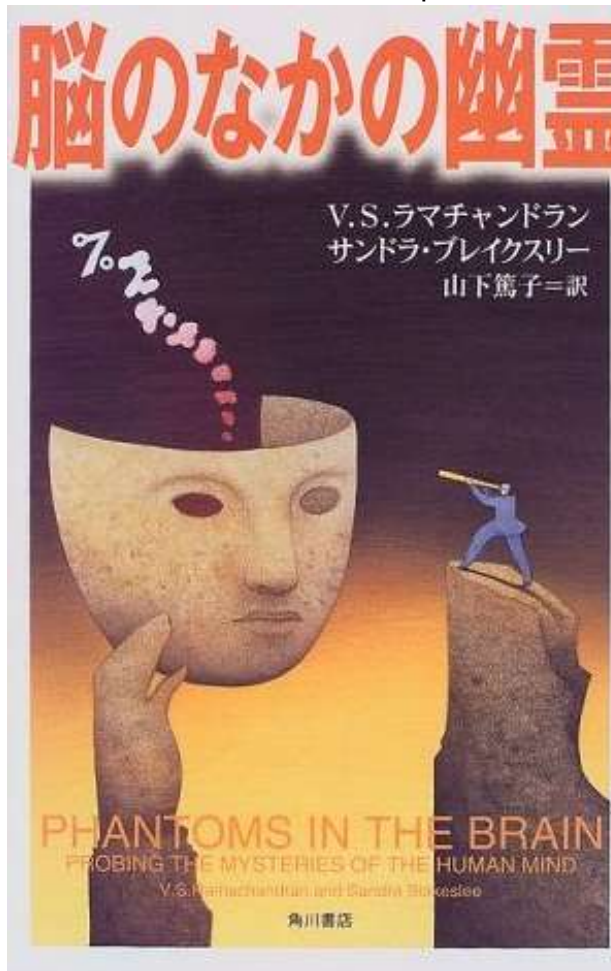
<https://www.youtube.com/watch?v=Dnzxbyhz3o4>

- 自分の身体の動きをRNNで予測させ、100ms早く描画すると身体が軽くなったように感じる。
- If you let the RNN predict your body's movement and draw it 100ms earlier, you will feel like your body is lighter.



視覚によるハプティック錯覚 (4) : ミラーボックスによる幻肢痛緩和

Reduction of phantom pain by mirror box



<https://www.amazon.co.jp/dp/4042982115>

幻肢痛：手足を失った後に、切断部位は問題ないのに激しい痛みを感じる現象。
ひとつの仮説：失った手足の脳内座標(ボディマップ)が狂い、体内に「食い込む」
ことで脳内で痛みシグナルが発生。姿勢をもとに戻せないために痛みを生じ続ける。

Phantom pain: After one's hand/arm/leg was removed, pain seems to occur from the removed site. One hypo.: Removed limb's body map in the brain comes wrong, and the brain generates pain signal.



ミラーボックスセラピー Mirror box therapy



ミラーボックスを使い、両手を使っていることをイメージさせることで、脳内で無いはずの手を動かすことができる。これにより幻肢痛を劇的に低減できる。
Using mirror box, patients can “move” their lost limb in their brain, so that the phantom pain is dramatically reduced.



視覚による痛みの低減

Pain is reduced by visually making it small



反転させた双眼鏡を使って痛みの患部を観察すると痛みが減る。

Observing the pain region with reverted binocular, the pain is reduced.

- Moseley GL, Parsons TJ, Spence C. s. *Curr Biol.* 2008;18(22):R1047-R1048.
- Mancini F, Longo MR, Kammers MP, Haggard P. Visual distortion of body size modulates pain perception. *Psychol Sci.* 2011;22(3):325-330.



視覚+触覚によるハプティック錯覚：Rubber Hand Illusion



http://www.youtube.com/watch?v=nzF_DfOafKw

見えていない実際の手に触覚的な刺激を与え、同時にゴムの手に視覚的な刺激を与える。しばらくするとゴムの手が自分の手であるように感じる

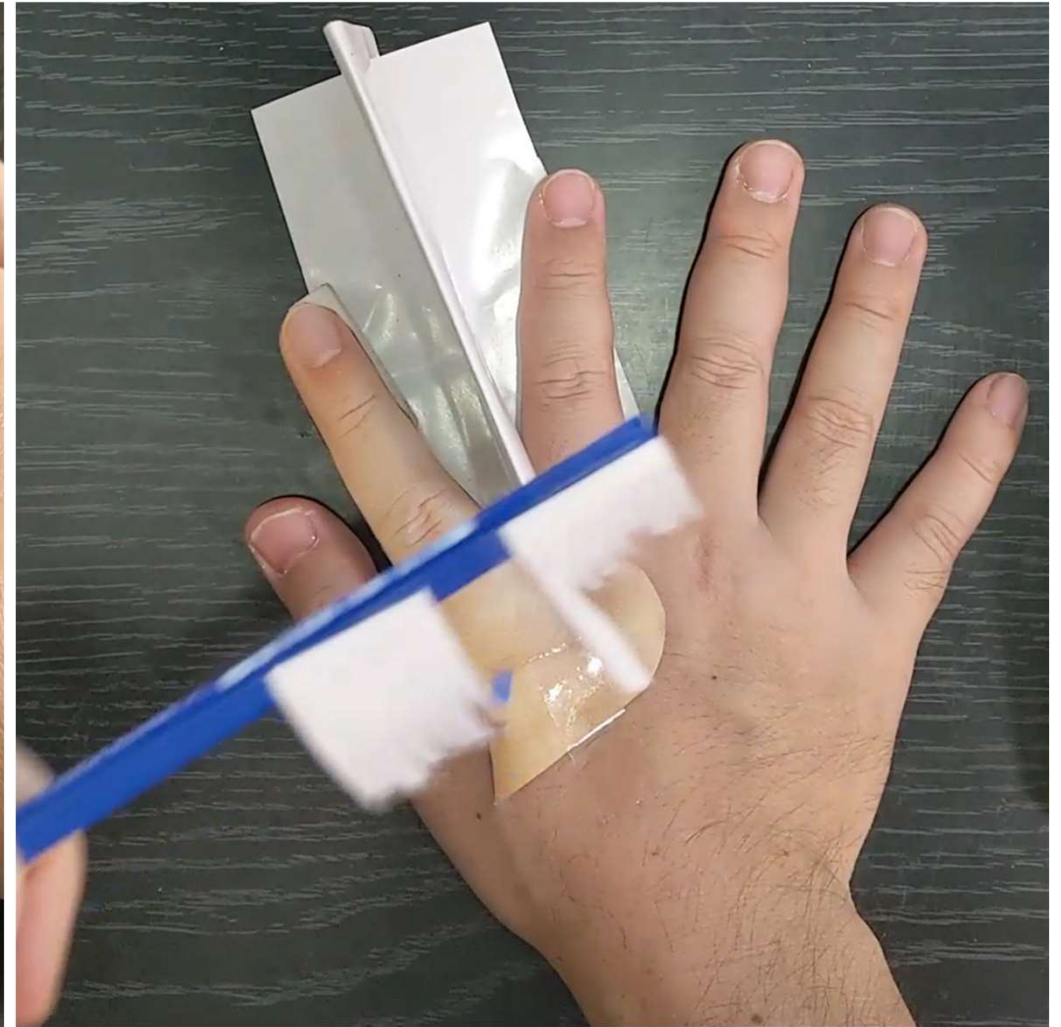
Watching a rubber hand being stroked synchronously with one's own unseen hand causes the rubber hand to be attributed to one's own body, to "feel like it's my hand."

Botvinick, M., & Cohen, J.: Rubber hands "feel" touch that eyes see, *Nature*, 391, 756 (1998)

Armel, K. C., & Ramachandran, V. S.: Projecting sensations to external objects: evidence from skin conductance response, *Proc R Soc Lond B Biol Sci*, 270, 1499-1506 (2003)



指バージョンヨン：Rubber Hand Illusion (finger version)

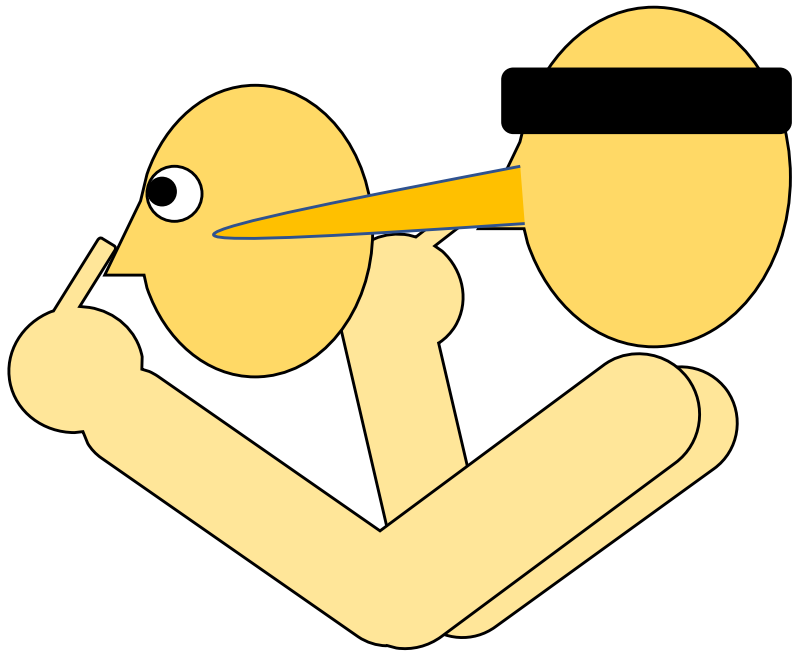


自分の手の写真を印刷すれば簡単にできます (家でやってみましょう)

You can try the rubber hand illusion using your finger. Take a photo of your hand and make a simple setup as shown.



皮膚感覚によるハプティック錯覚 Cutaneous Induced Haptics : ピノキオ錯覚 Pinocchio Illusion



自分の前の人の鼻を撫でつつ、自分の鼻も撫でると、1分程度で半分程度の人が自分の鼻が伸びたように感じる。



(IEEEVR2021 Poster) Ryota Kondo:
The Onset Time of the Dynamic and Static Invisible Body Illusion



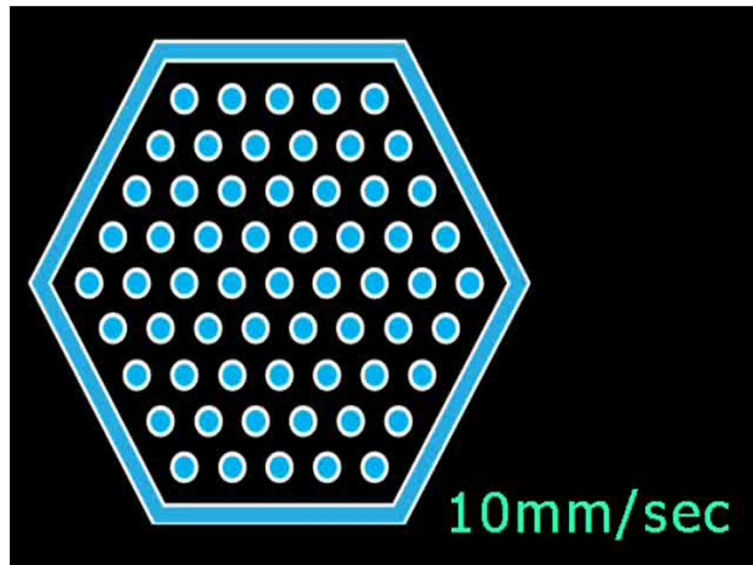
<https://www.youtube.com/watch?v=u3DKAz8DqPk>

Kondo, R., Sugimoto, M., Minamizawa, K., Hoshi, T., Inami, M., and Kitazaki, M. (2018). Illusory body ownership of an invisible body interpolated between virtual hands and feet via visual-motor synchronicity, *Scientific Reports*, 8:7541 DOI:10.1038/s41598-018-25951-2 www.nature.com/articles/s41598-018-25951-2
https://www.ist.go.jp/erato/inami/project_3.html

- Invisible Body Illusion: VR空間で手と足だけを描画する。動きとのシンクロによって透明な身体があるように感じられる。
- Invisible Body Illusion: Draw only the tips of your hands and feet in VR space. By synchronizing with the movement, the user feels as if there is a transparent body.



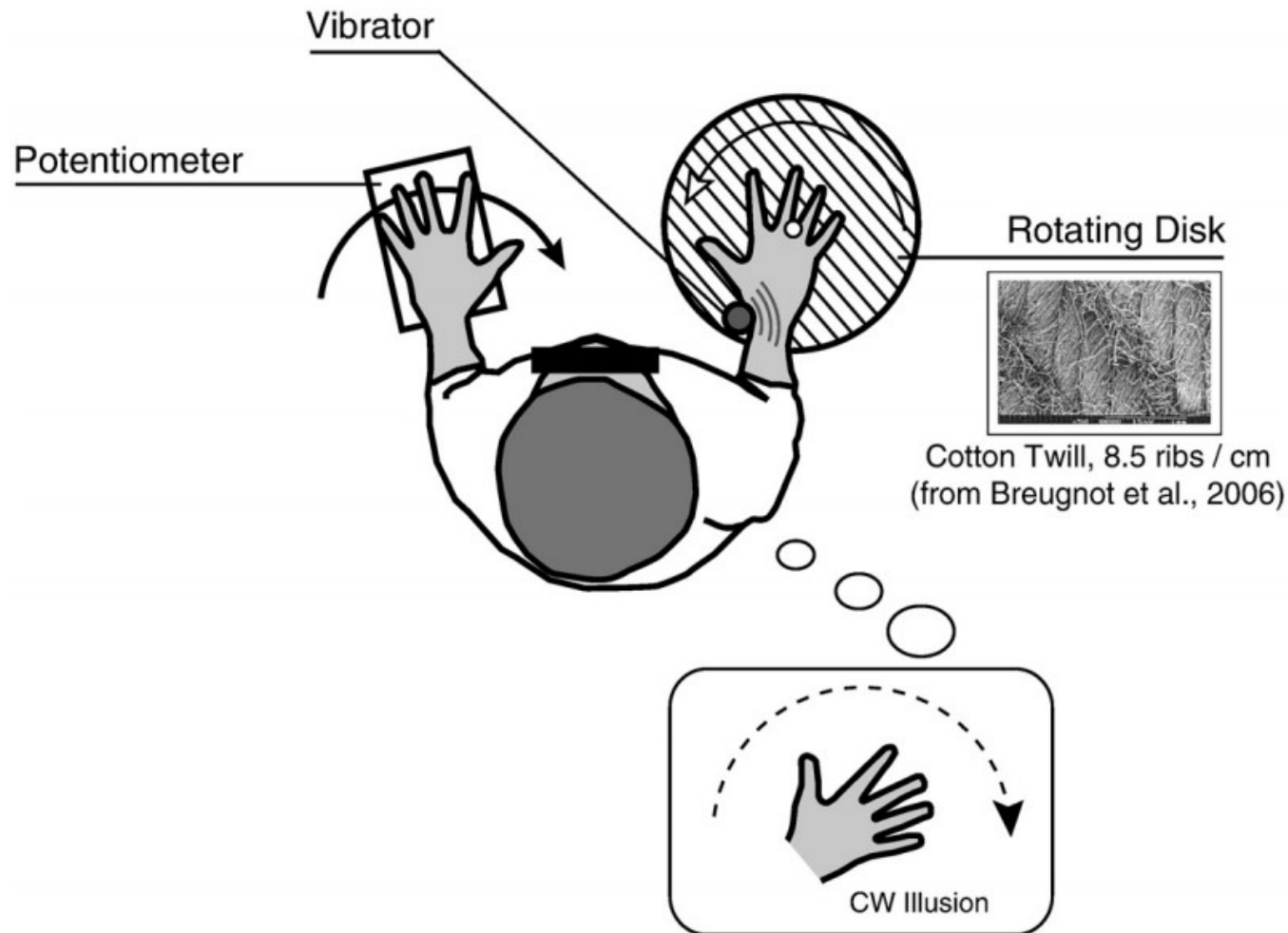
皮膚感覚によるハプティック錯覚 Cutaneous Induced Haptics : 動きの錯覚 Illusion of motion



力と同時に触覚的な「流れ場」を提示すると、指の「運動(ぬめり・滑り)」を感じる
Okabe et al., Fingertip Slip Illusion with an Electrocutaneous Display, ICAT2011



皮膚感覚によるハプティック錯覚 Cutaneous Induced Haptics : 動きの錯覚 Illusion of motion

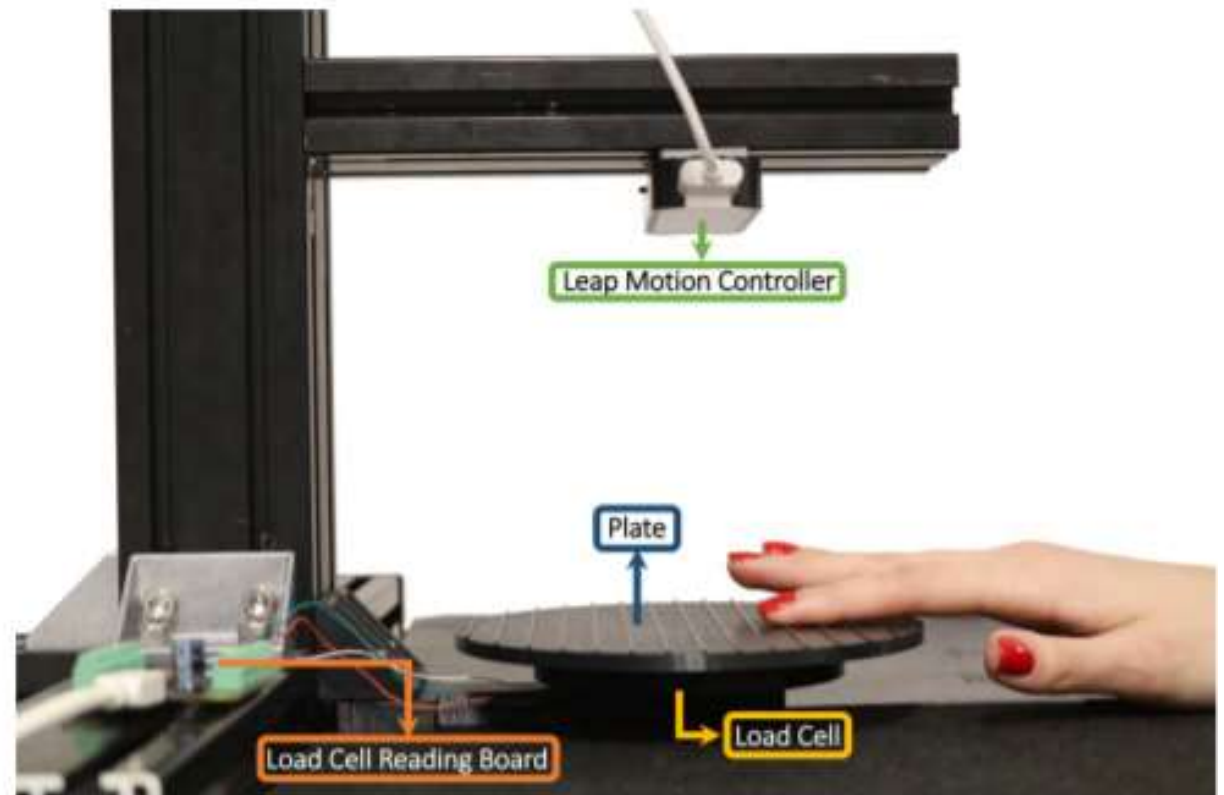
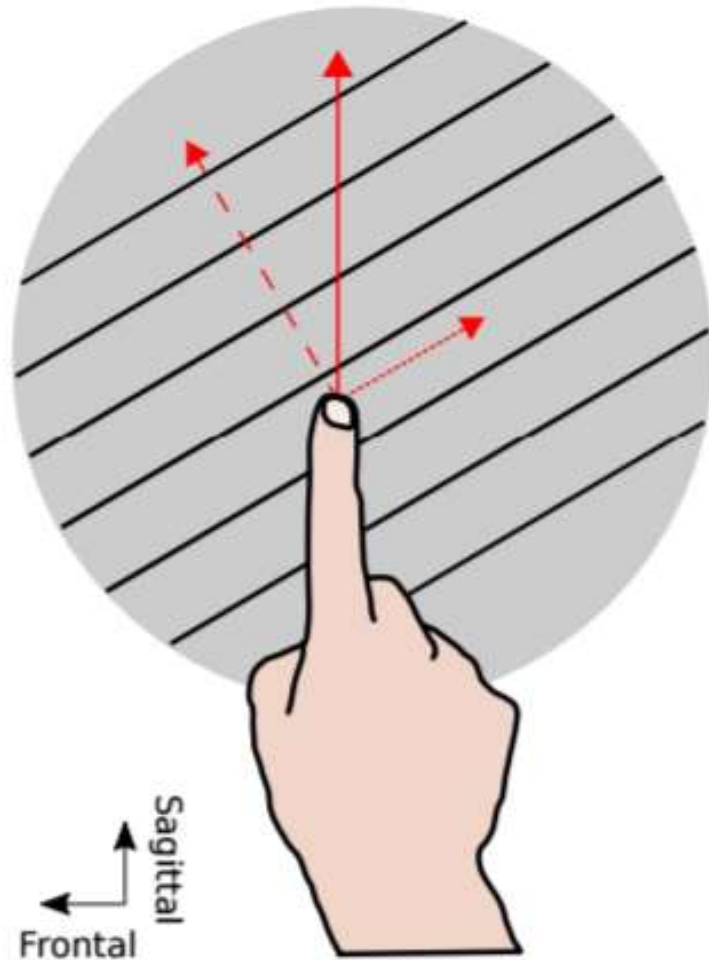


- 手のひらへの回転状触刺激＋振動による筋活動⇒手首が「回転し続ける」錯覚。

Blanchard et al., Combined contribution of tactile and proprioceptive feedback to hand movement perception, Brain Res. 2011.



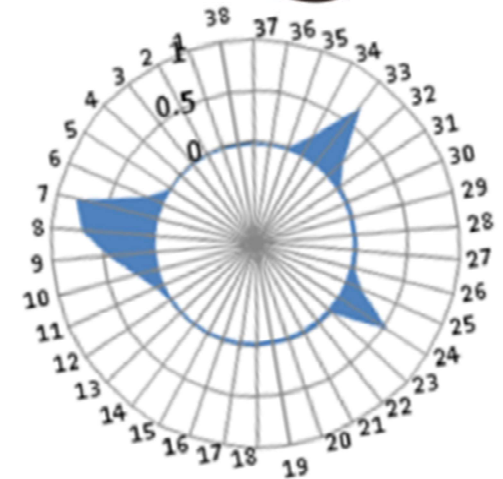
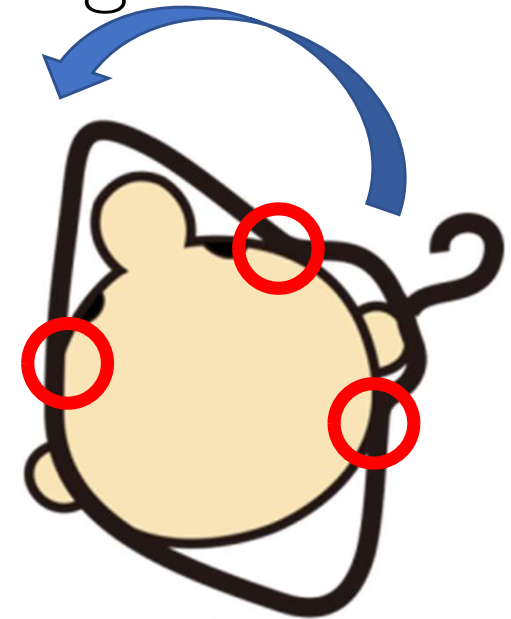
[WorldHaptics2017] Haptic Feedback of Membrane Puncture with an MR-Compatible Instrumented Needle and Electroactive Polymer Display* | Supplemental Material
Jung Hwa Bae, Amy Kyungwon Han, Christopher J. Ploch, Bruce L. Daniel, Mark R. Cutkosky



- シマシマの凸凹は皮膚上での触覚の運動を引き起こす。これが実際の指の運動と一致しない場合、指の動きの方向の誤認が生じ、結果的に動きの方向も変化。指先版 Redirected Walking。



皮膚感覚によるハプティック錯覚 Cutaneous Induced Haptics : ハンガー反射 / Hanger Reflex



- 側頭部圧迫によって外力を知覚
- 頭部の回旋をも誘発 (家でやってみましょう)
- Front temporal pressure induces “rotational” force perception.
- Rotation itself is induced.

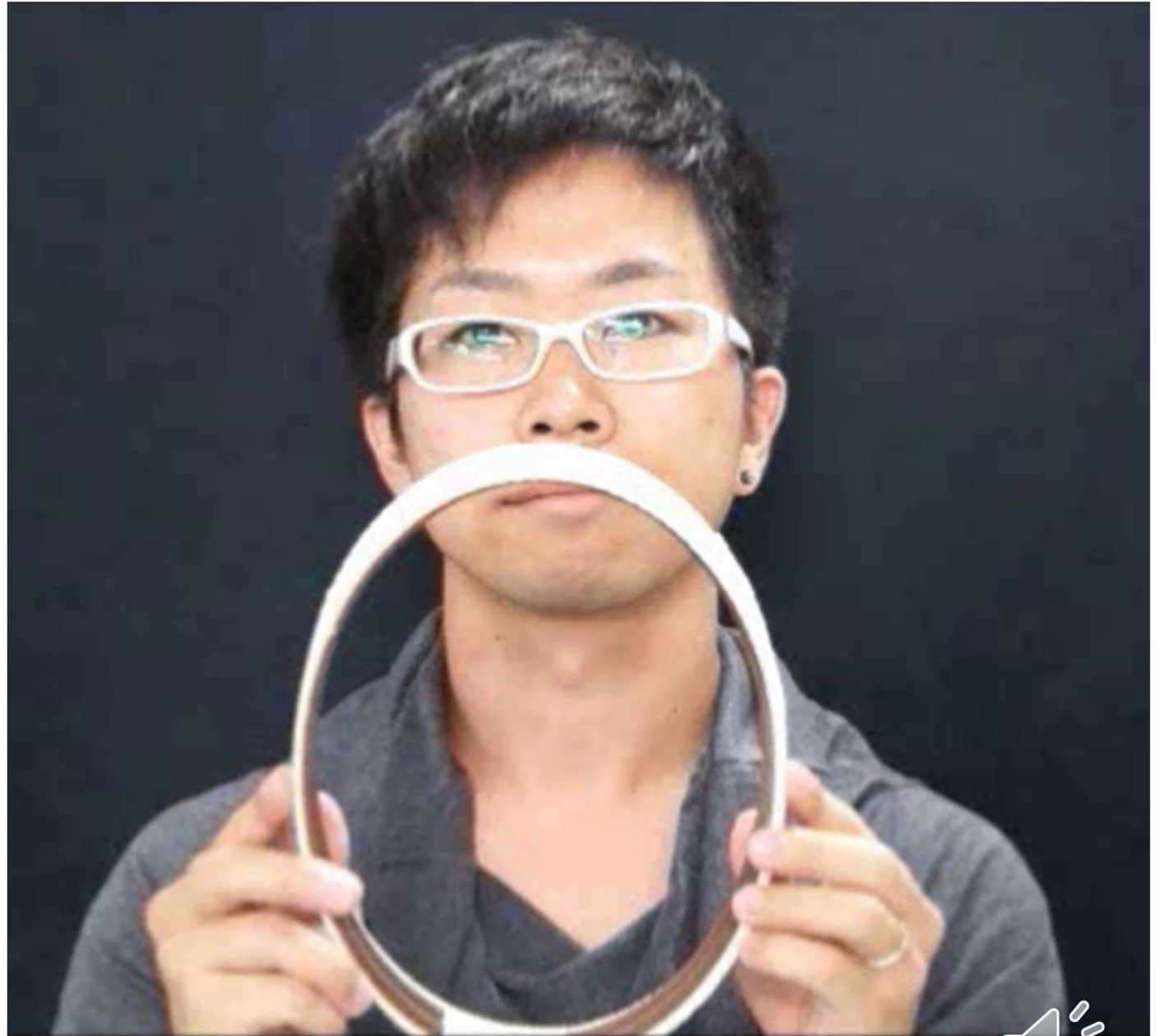
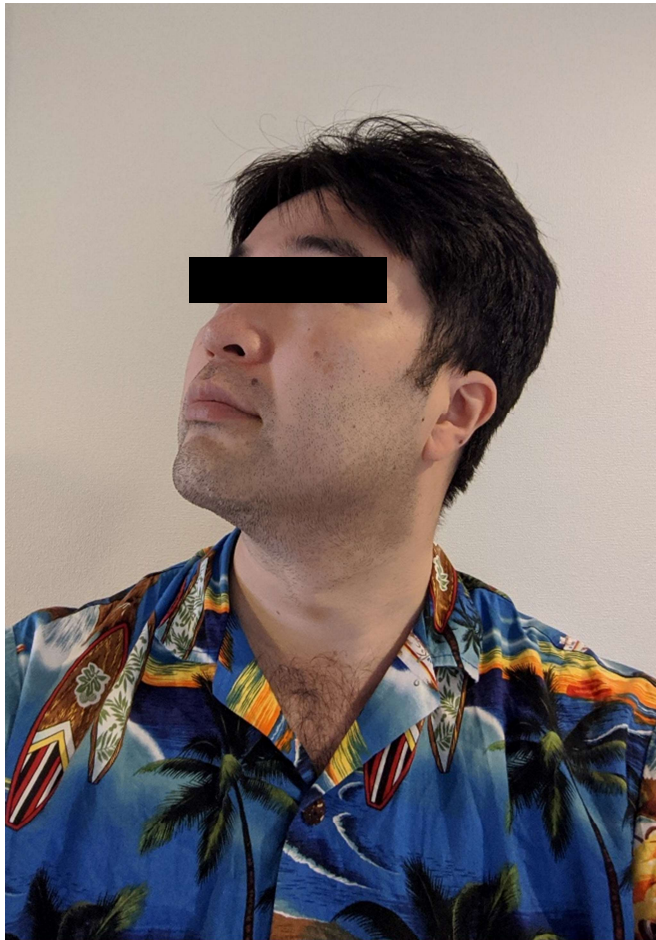


ハンガー反射

To clarify the details of the HR,
we measured pressure distribution
on the head when the reflex took place,



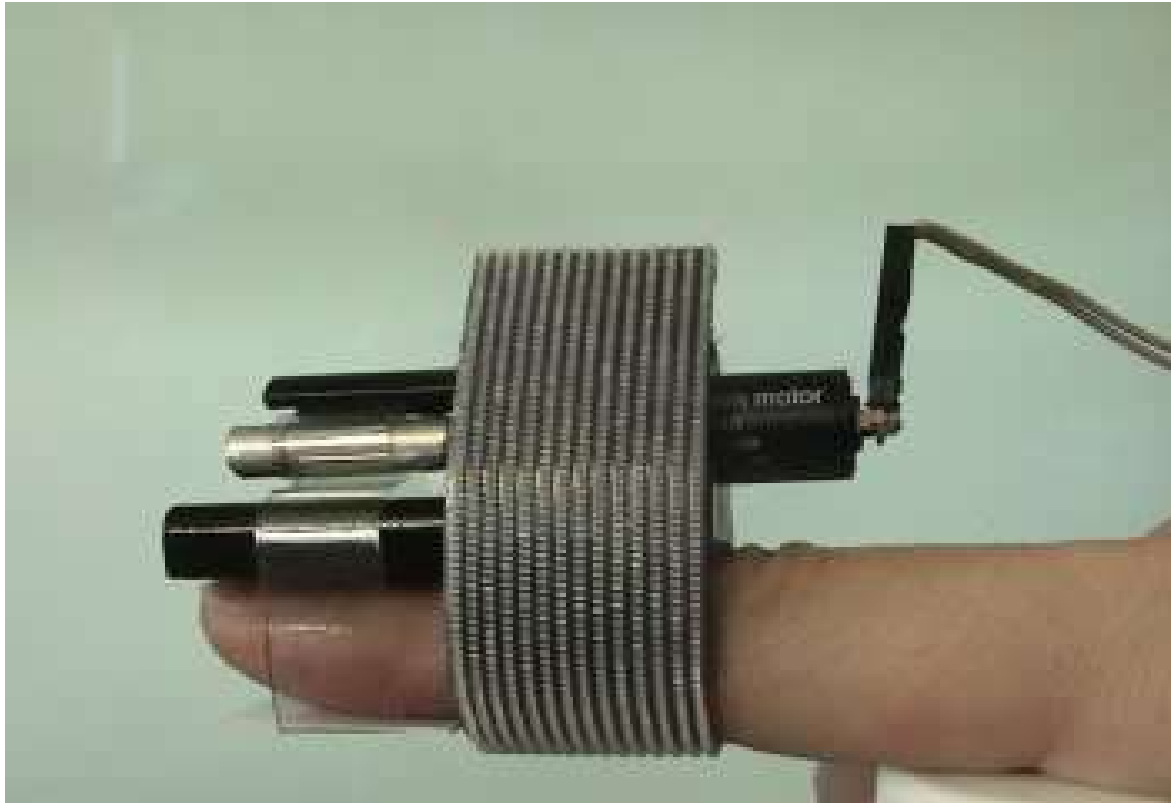
(参考)痙性斜頸への応用



T. Asahi et al. : Pilot Study of a Device to Induce the Hanger Reflex in Patients with Cervical Dystonia, *Neurologia medico-chirurgica*, Vol.58, No.5, pp.206-211, 2018



皮膚感覚によるハプティック錯覚 Cutaneous Induced Haptics : 皮膚圧迫による外力錯覚 Illusory external force by pressure

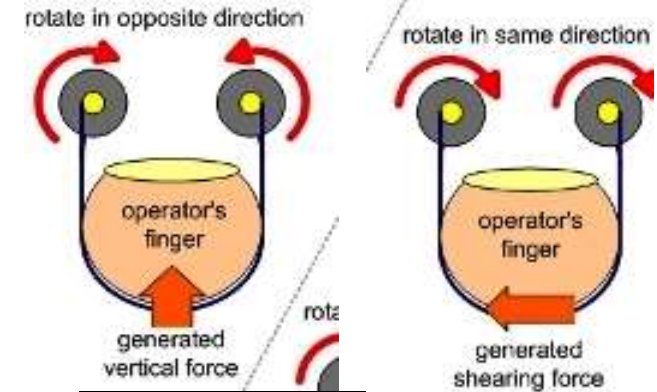


<http://reality.ei.tuat.ac.jp/>

A pseudo-force-feedback device by fingertip tightening for multi-finger object manipulation

G Inaba, EuroHaptics2016

稲葉、藤田：指先圧迫による擬似反力提示装置の提案と試作, 日本VR学会論文誌, 2007.



<https://www.youtube.com/watch?v=oEGBXu-N51w>

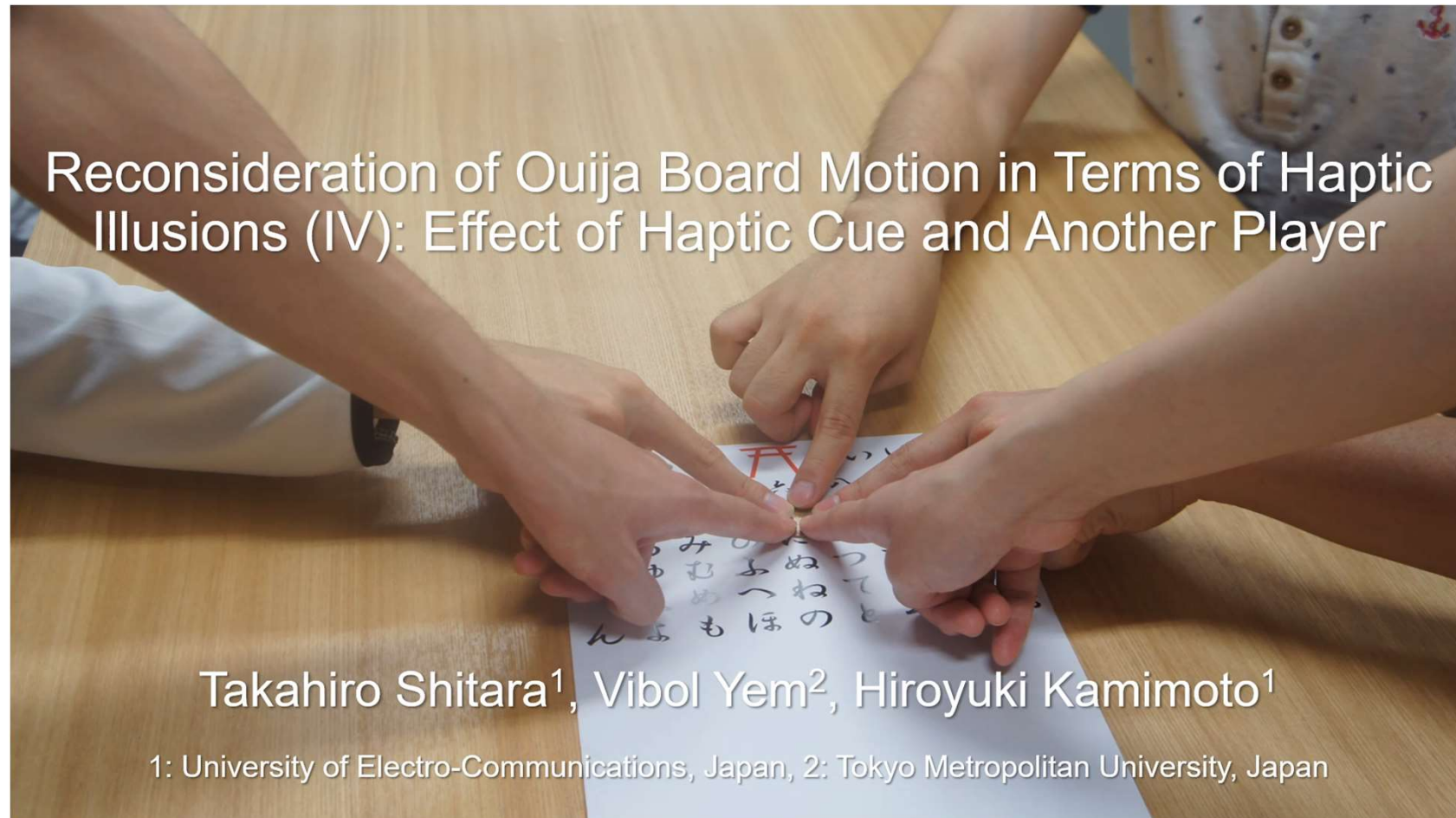
Minamizawa, Haptic Interface for Middle Phalanx Using Dual Motors, EuroHaptics, 2006.

Minamizawa: Wearable Haptic Display to Present Gravity Sensation - Preliminary Observations and Device Design", WorldHaptics 2007

- 皮膚の圧迫により、本来は外力がない状況で外力を感じる
- Simple pressure sensation is perceived as external force.



こっくりさん？ / Ouija-board?



- こっくりさんを皮膚感覚による力覚の錯覚として説明。
- VR環境で複数人が表示される(責任分担がなされる)と動きが増加。
- Explains Oui-ja board as an illusion of force sensation through skin sensation. Movement increases when multiple people are displayed in the VR environment (responsibilities are shared).



TODAY's TOPIC

1. 力覚関連のメカニズム Haptic Perception Mechanism
2. 力覚ディスプレイの分類 Classifying Haptic Displays
3. 力覚ディスプレイの応用 Application of Haptic Interface



力覚ディスプレイの形態 Grounded and Wearable Haptic Display



CAVE automatic virtual environment (Wikipedia)

https://en.wikipedia.org/wiki/Cave_automatic_virtual_environment



Head Mounted Display (wikipedia)

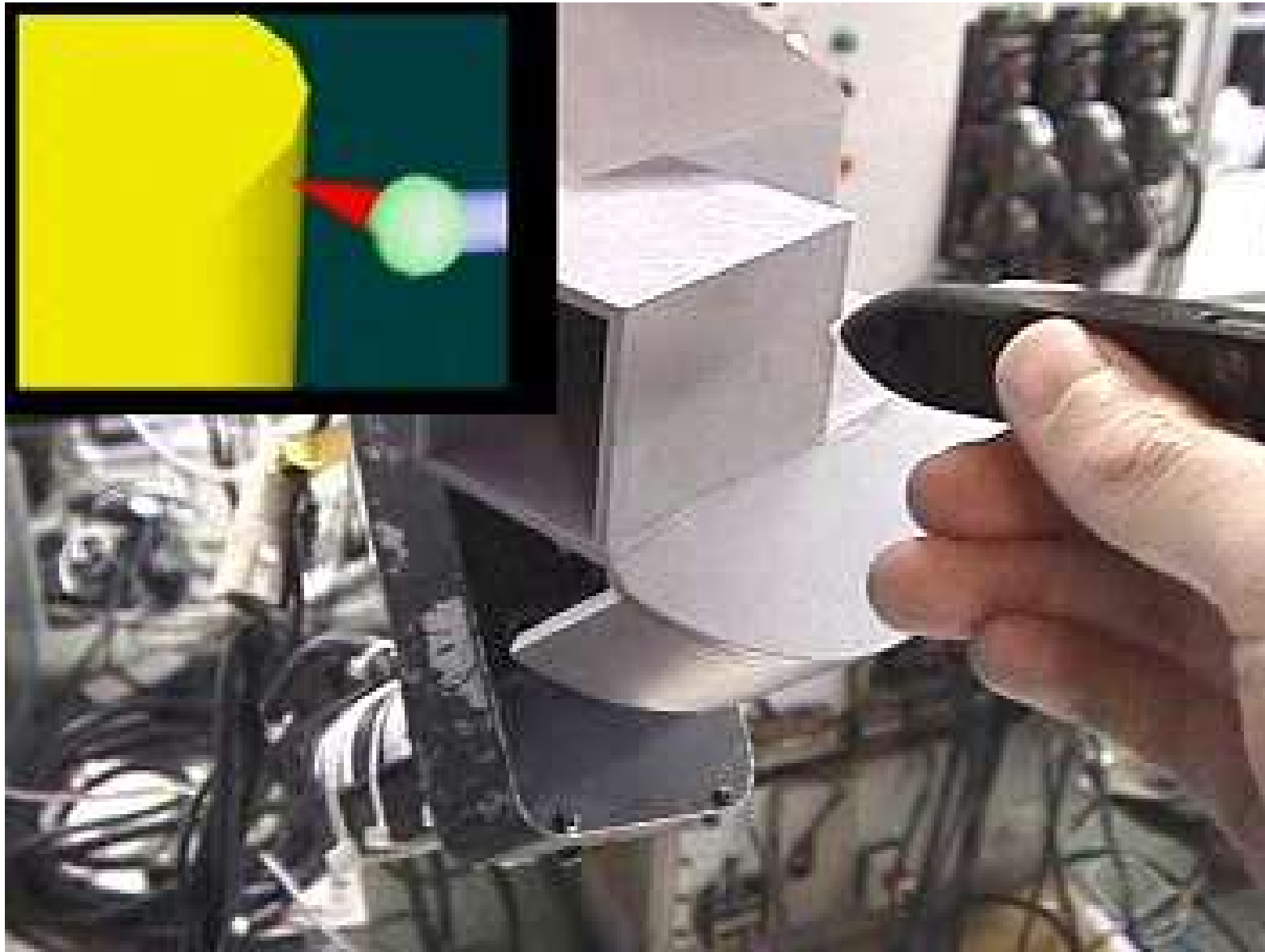
https://en.wikipedia.org/wiki/Head-mounted_display

視聴覚のディスプレイと同様、環境型と非環境型に分類可能？

Like visual and auditory displays, there are environmental type and non-environmental type.



環境型 ≡ 遭遇型 / Environment type ~ Encounter type
Active Environment Display (Tachi et al., 1994)



<http://tachilab.org/modules/projects/aed.html>

S. Tachi, T. Maeda, R. Hirata and H. Hoshino: A Construction Method of Virtual Haptic Space, Proceedings of the 4th International Conference on Artificial Reality and Tele-Existence (ICAT '94), pp.131-138, Tokyo, Japan (1994.7)

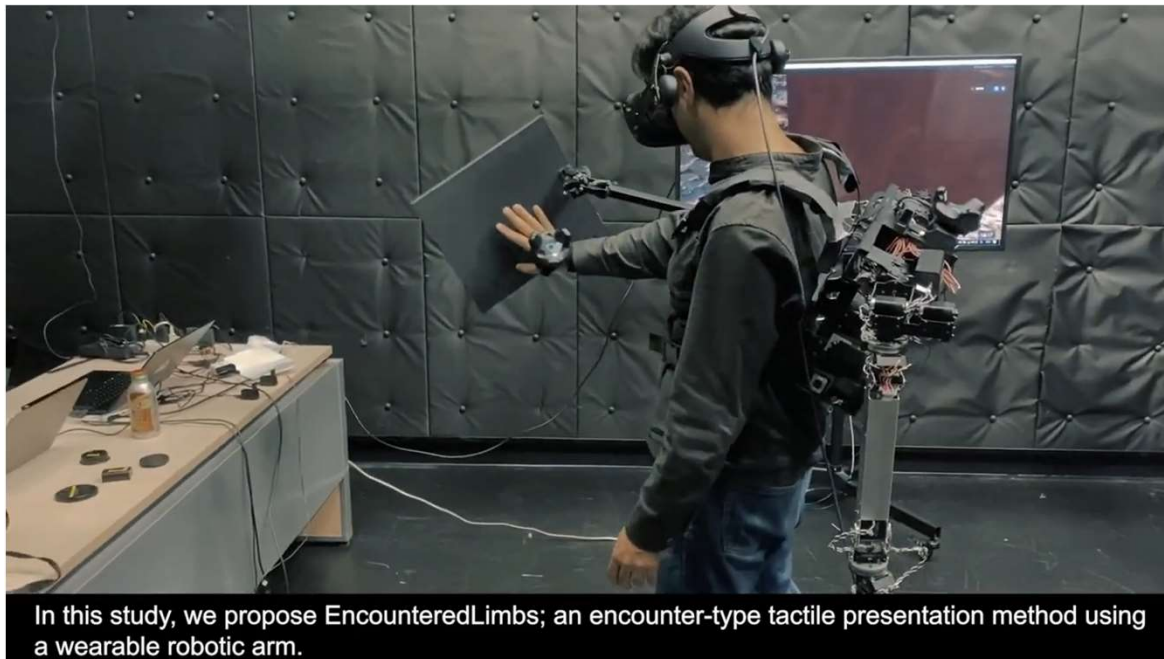


ウェアラブルな遭遇型 Encounter type + Wearable



(UIST2020) Haptic PIVOT: On-Demand Handhelds in VR
Robert Kovacs, Eyal Ofek, Mar Gonzalez Franco, Alexa Fay Siu, Sebastian Marwecki, Christian Holz, Mike Sinclair

<https://www.youtube.com/watch?v=uOhxQ5nKO6U>

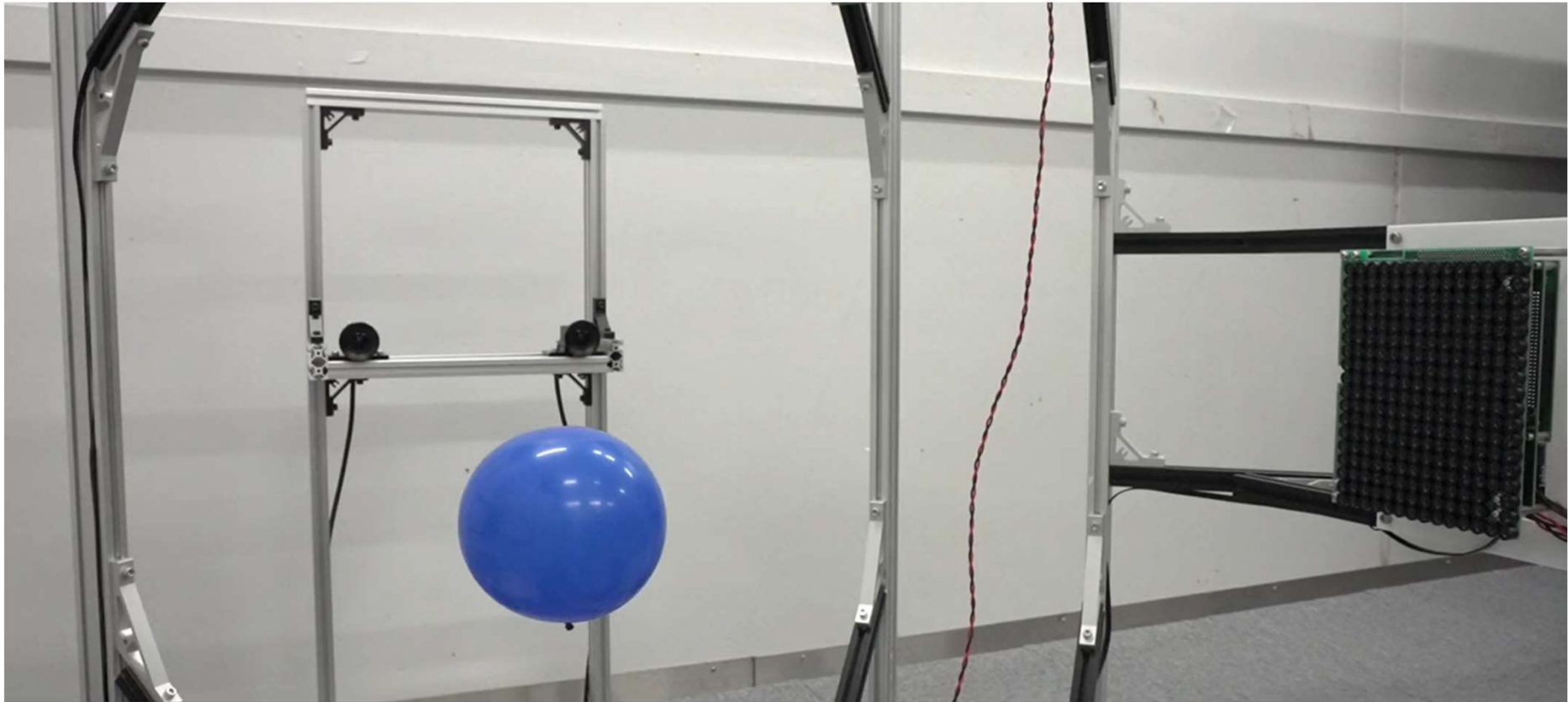


(IEEEVR2021) Arata Horie, Mhd Yamen Saraiji, Zendai Kashino, Masahiko Inami:
EncounteredLimbs: A Room-scale Encountered-type Haptic Presentation using Wearable Robotic Arms

<https://www.youtube.com/watch?v=pLEdvauF40g>



(UIST2021) Midair Balloon Interface: A Soft and Lightweight Midair Object for Proximate Interactions Takuro Furumoto, Takumi Kasai, Masahiro Fujiwara, Yasutoshi Makino, Hiroyuki Shinoda



Midair Balloon Interface :

A Soft and Lightweight Midair Object for Proximate Interactions

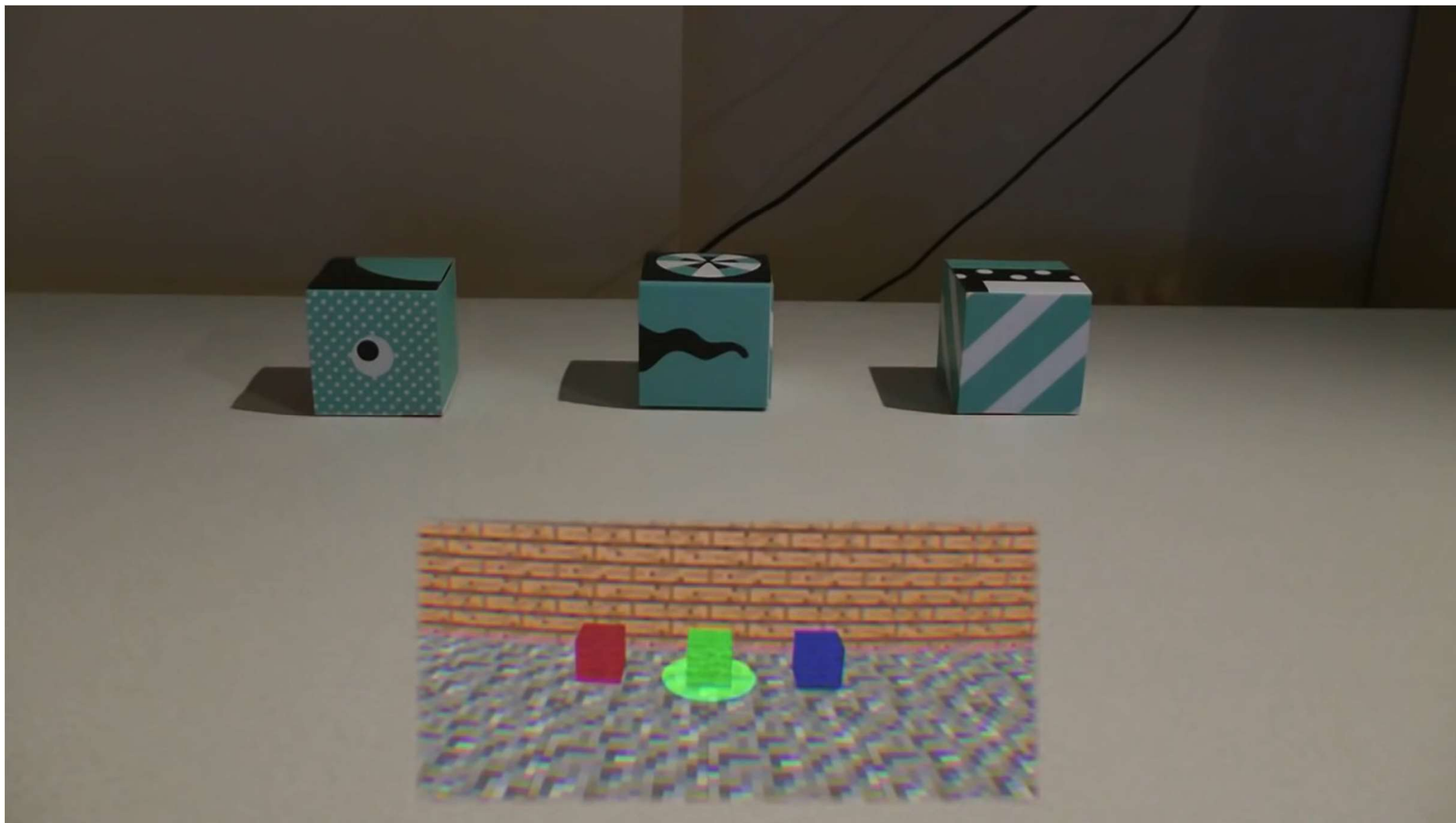
Takuro Furumoto, Takumi Kasai, Masahiro Fujiwara, Yasutoshi Makino, Hiroyuki Shinoda The University of Tokyo

空中超音波でバルーンを移動させ触覚提示。

Using floating balloon that is controlled by ultrasound for encounter-type haptic display.

<https://www.youtube.com/watch?v=HPYi-YWVaeY&list=PLqhXYFYmZ-VeKUIuttbQWomTQ-oXF6PLf&index=95>

(CHI2016) Haptic Retargeting: Dynamic Repurposing of Passive Haptics for Enhanced Virtual Reality Experiences, Mahdi Azmandian, Mark Hancock, Hrvoje Benko, Eyal Ofek, Andrew D. Wilson

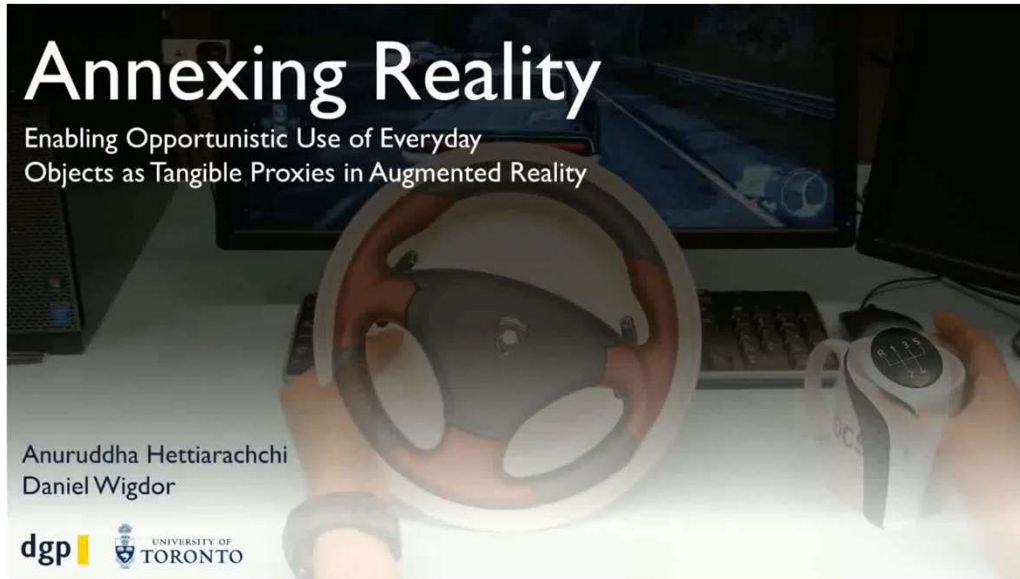


https://www.youtube.com/watch?v=v-5u0z4zA_8

HMDによる視覚誘導によって、現実の物体を異なる場所で触っているように感じさせる。

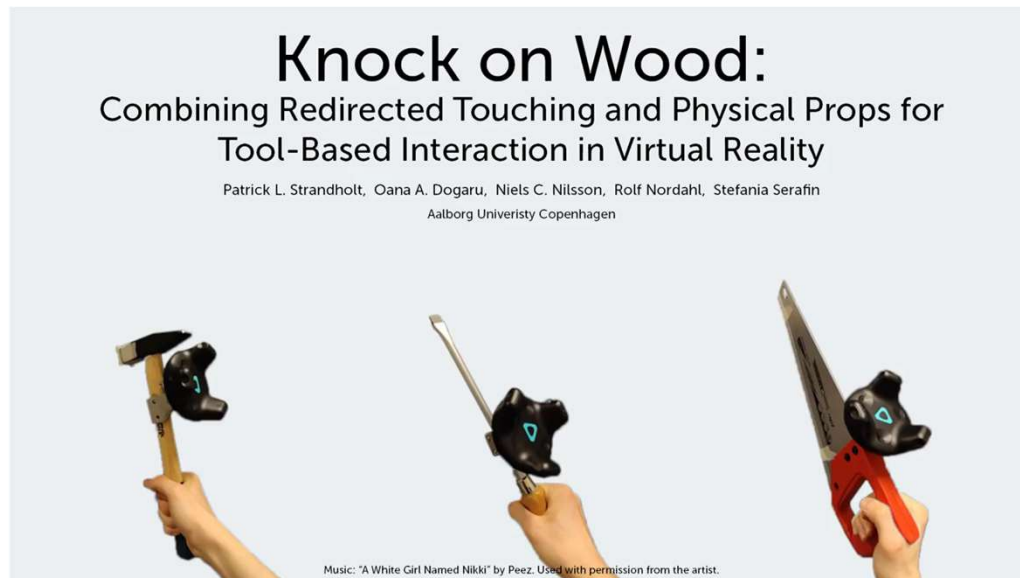


Haptic Retargeting的な研究



<https://www.youtube.com/watch?v=xL3WJQuyZil>

(CHI2016) Annexing Reality: Enabling Opportunistic Use of Everyday Objects as Tangible Proxies in Augmented Reality, Anuruddha Lakmal Hettiarachchi, Daniel Wigdor 現実空間の物体をVR空間の物体として触らせることで触覚を提示



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

(CHI2020) Knock on Wood: Combining Redirected Touching and Physical Props for Tool-Based Interaction in Virtual Reality, Patrick L. Strandholt; Oana A. Dogaru; Niels C. Nilsson; Rolf Nordahl; Stefania Serafin

実物を使ったHapticsで、視覚的なずらしのテクニックを使う。釘が沈んでいく。
Use visual shifting techniques in haptics with real objects, the nails are sinking.



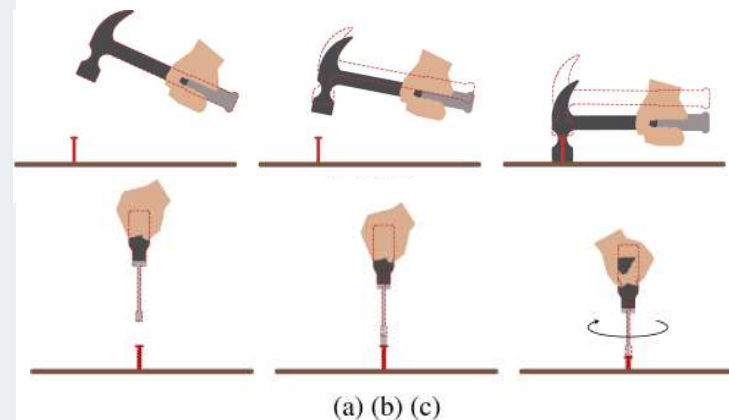
<https://www.youtube.com/watch?v=gNE83EZ9Bcg>

(IEEEVR2021) André Zenner, Kora Persephone Regitz, Antonio Krüger

Blink-Suppressed Hand Redirection

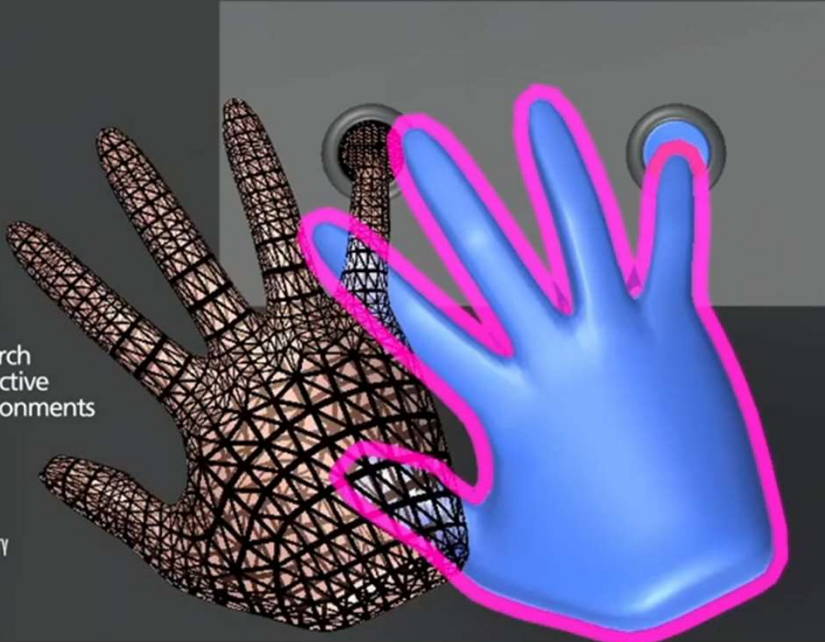
Haptic Retargetingを、瞬きの瞬間に行う。歩行の研究(Redirected Walking)で行われたことを手の運動でもやったもの。

Haptic Retargeting is performed at the moment of blinking. Similar technique from Redirected Walking.



(IEEEVR2022) Shape Aware Haptic Retargeting for Accurate Hand Interactions
Brandon J. Matthews, Bruce H. Thomas, Stewart von Itzstein, Ross Smith


Shape Aware Haptic Retargeting for Accurate Hand Interactions



Brandon J Matthews
Prof. Bruce H Thomas
As.Prof. G Stewart Von Itzstein
As.Prof. Ross T Smith

University of South Australia
Australian Research Centre for Interactive and Virtual Environments

IEEE VR 2022
IEEE CONFERENCE ON VIRTUAL REALITY + 3D USER INTERFACES
12-16 MARCH 2022 | VIRTUAL EVENT

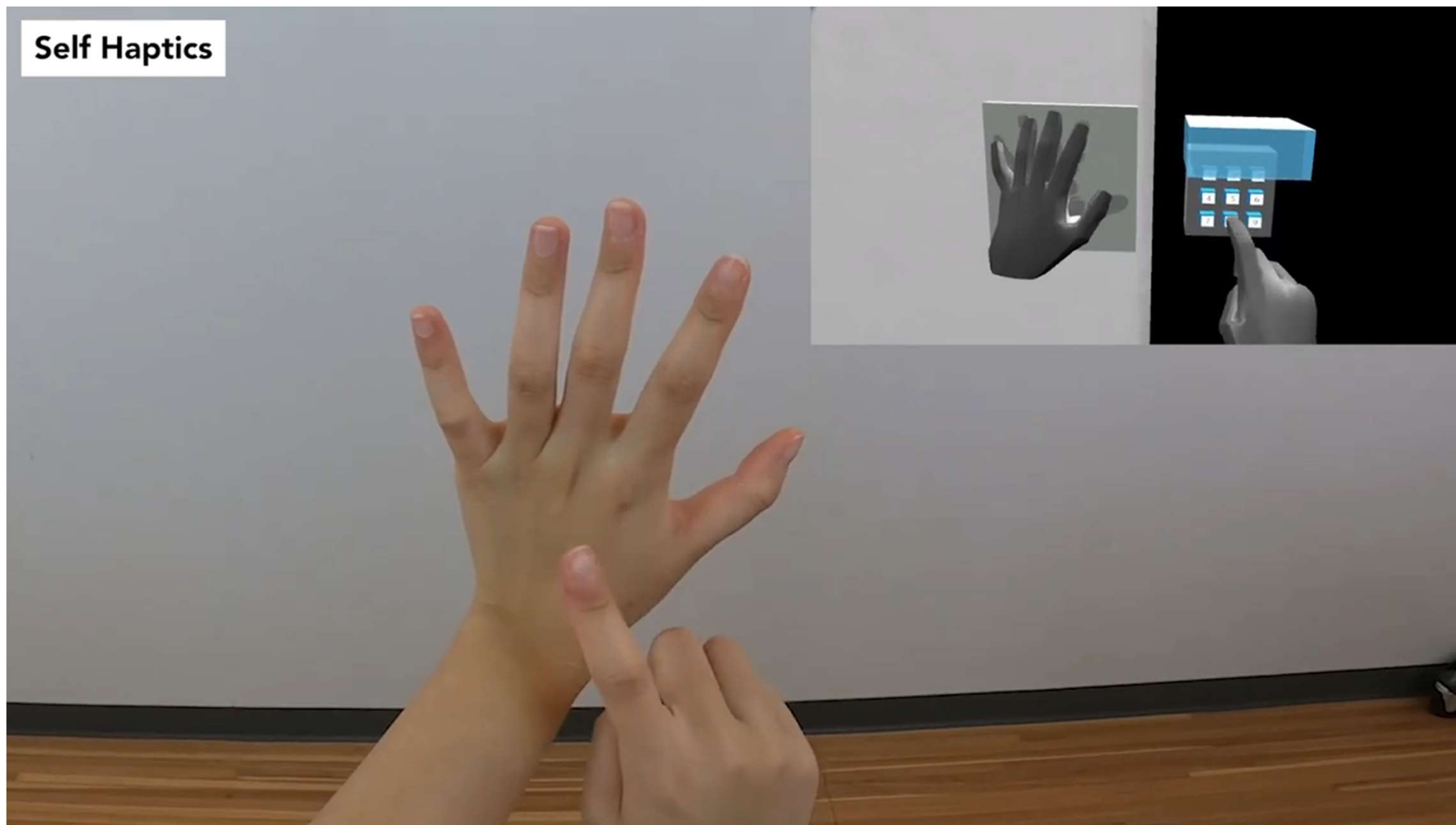


Haptic Retargetingをより精緻化。手指メッシュ形状と対象物メッシュ形状を考えてそのあいだの距離を取ることで、エッジ形状まで表現可能なretargetingが出来る

More sophisticated Haptic Retargeting. By considering the hand mesh shape and the object mesh shape and taking the distance between them, retargeting that can represent even the edge shape can be performed.

<https://www.youtube.com/watch?v=m2mb0dkPeN0>

(UIST2021) Retargeted Self-Haptics for Increased Immersion in VR without Hand Instrumentation Cathy Mengying Fang, Chris Harrison

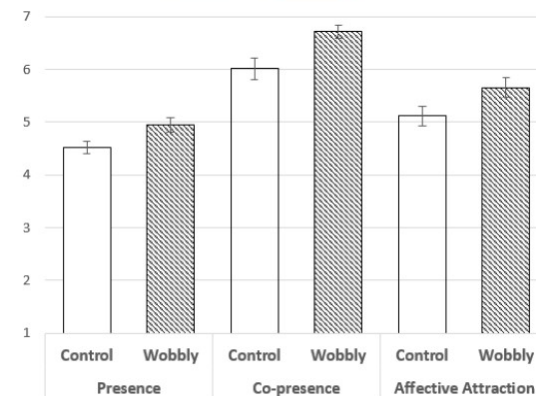
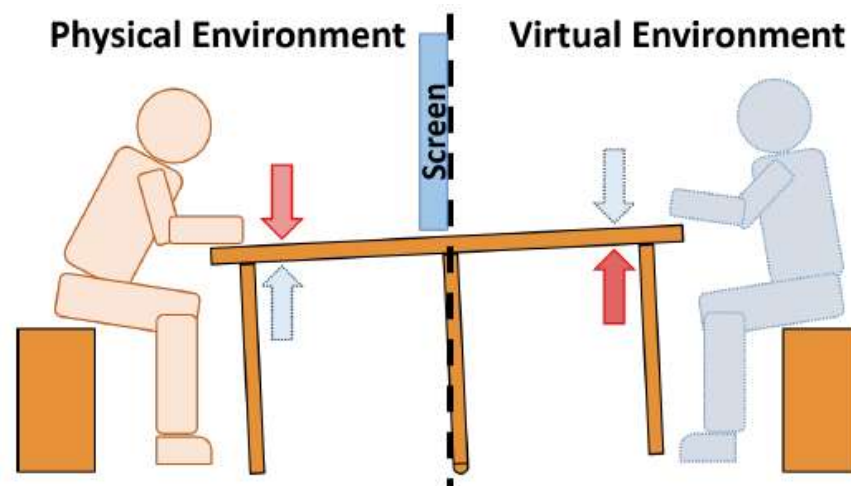


自分の非利き手をHaptic Retargetingの対象にする

Make your non-dominant hand the target of Haptic Retargeting

<https://www.youtube.com/watch?v=6dOVmh4LXk&list=PLqhXYFYmZ-VeKUIuttbQWomTQ-oXF6PLf&index=9>

(IEEEVR2016) The Wobbly Table: Increased Social Presence via Subtle Incidental Movement of a Real-Virtual Table, Myungho Lee, Kangsoo Kimy, Salam Daherz, Andrew Raji



対面VR環境で机に微細なガタつきを設ける。VR側にもこのガタつきが反映される。VR内のVirtual Humanはこのガタつきに微かに応答する（机の下を覗きこむなど）。すると臨場感、空間共有感などが強調される。現実のものを使ったちょっとしたHapticsが現実感を底上げする好例。

In the face-to-face VR environment, the desk wobbles, and this is reflected in the VR. The sense of presence and the sense of shared space are emphasized.



Drone based haptics (encounter-type).



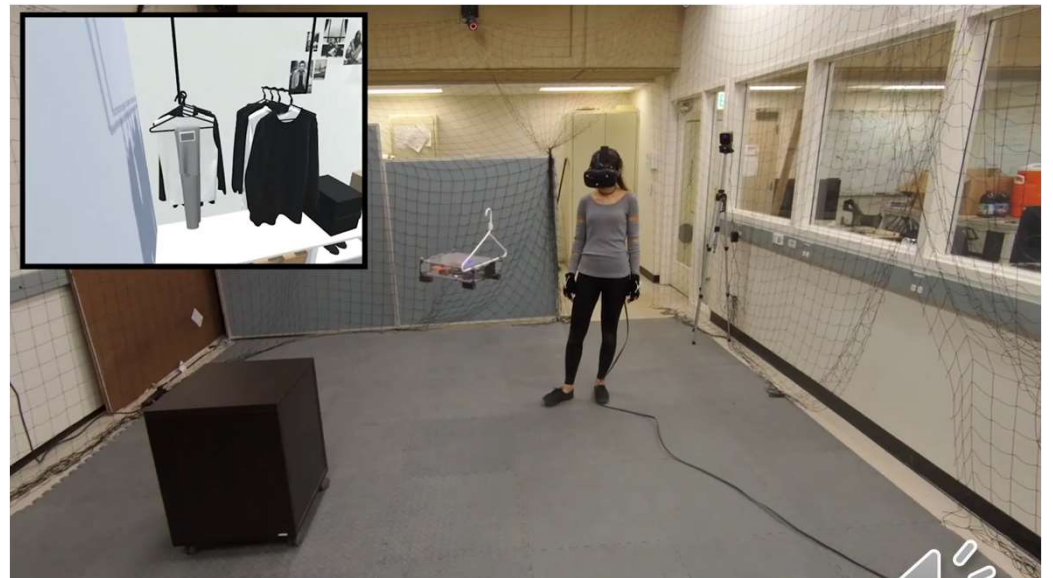
<https://www.youtube.com/watch?v=7MRCRywAQpA>
(SUI2016) A Non-grounded and Encountered-type Haptic Display Using a Drone, Yamaguchi et al.



<https://dl.acm.org/doi/abs/10.1145/3027063.3050426>
(CHI2017) Tactile Drones - Providing Immersive Tactile Feedback in Virtual Reality through Quadcopters, Knierim et al.



<https://dl.acm.org/doi/abs/10.1145/3282894.3282898>
(MUM2018) VRHapticDrones: Providing Haptics in Virtual Reality through Quadcopters, Hoppe et al.



<https://www.youtube.com/watch?v=JJV6fbCqm6g>
(CHI2019) Beyond The Force: Using Quadcopters to Appropriately Interact with Objects and the Environment for Haptics in Virtual Reality, Abtahi et al.

(CHI2020) Haptic-go-round: A Surrounding Platform for Encounter-type Haptics in Virtual Reality Experiences, Hsin-Yu Huang;Chih-Wei Ning;Po-Yao Wang;Jen-Hao Cheng;Lung-Pan Cheng



Haptic-go-round

A Surrounding Platform for Encounter-type Haptics in Virtual Reality Experiences

Hsin-Yu Huang*, Chih-Wei Ning*, Po-Yao Wang,
Jen-Hao Cheng, Lung-Pan Cheng

*Both authors contributed equally to this work

- <https://www.youtube.com/watch?v=AvB4rxwzbnE>
- Haptics用のデバイスが周りに多数配置されている。



壁を作る、部屋を作る Room or Wall Haptics



(CHI2020) RoomShift: Room-scale Dynamic Haptics for VR with Furniture-moving Swarm Robots

Ryo Suzuki;Hooman Hedayati;Clement Zheng;James L. Bohn;Daniel Szafir;Ellen Yi-Luen Do;Mark D. Gross;Daniel Leithinger

<https://www.youtube.com/watch?v=4OWU60gTOFE>

部屋が動的に変化するVRHaptics環境



(UIST2020) ZoomWalls: Dynamic Walls that Simulate Haptic Infrastructure for Room-scale VR World

YAN YIXIAN, Kazuki Takashima, Anthony Tang, Takayuki Tanno, Kazuyuki Fujita, Yoshifumi Kitamura

<https://www.youtube.com/watch?v=t6J65a1S1y0>

Motivation

Natural haptic feedback in VE using Cobot

Haptics for mechanical quantities of virtual structures

Support Walkable VR in large spaces

Autonomous safe behavior

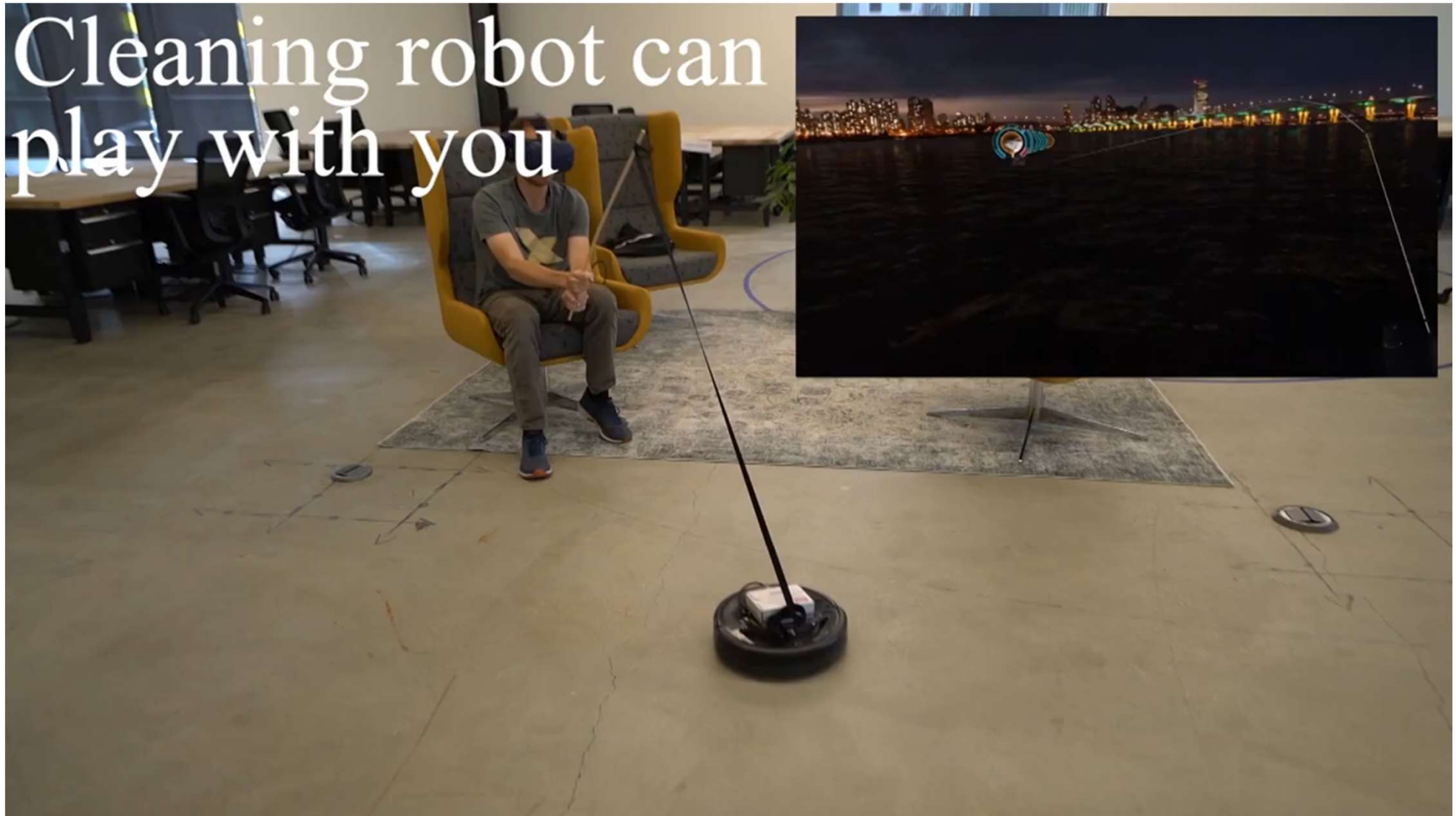


(IEEEVR2023) CoboDeck: A Large-Scale Haptic VR System using a Collaborative Mobile Robot

Soroosh Mortezaipoor, Khrystyna Vasylevska, Emanuel Vonach, Hannes Kaufmann

可動運台にのったロボットアームで板を動かし、「壁」を提示する。大型の「遭遇型」ディスプレイ

(CHI2020) MoveVR: Enabling Multiform Force Feedback in Virtual Reality using Household Cleaning Robot, Yuntao Wang;Zichao (Tyson) Chen;Hanchuan Li;Zhengyi Cao;Huiyi Luo;Tengxiang Zhang;Ke Ou;John Raiti;Chun Yu;Shwetak Patel;Yuanchun Shi



- <https://www.youtube.com/watch?v=JejpEtvHxeY>
- 家用掃除ロボットをハプティックデバイスとして利用する



(再) 力覚ディスプレイの形態 Grounded and Wearable Haptic Display



CAVE automatic virtual environment (Wikipedia)

https://en.wikipedia.org/wiki/Cave_automatic_virtual_environment



Head Mounted Display (wikipedia)

https://en.wikipedia.org/wiki/Head-mounted_display

視聴覚のディスプレイと同様、環境型と非環境型に分類可能。

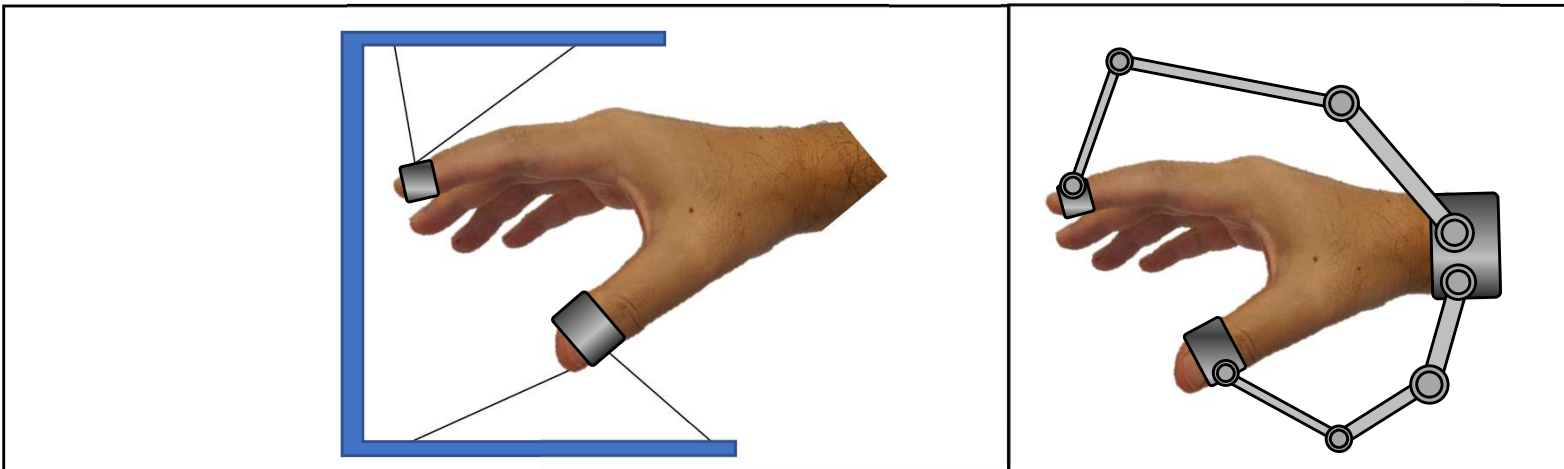
Like visual and auditory displays, there are environmental type and non-environmental type.



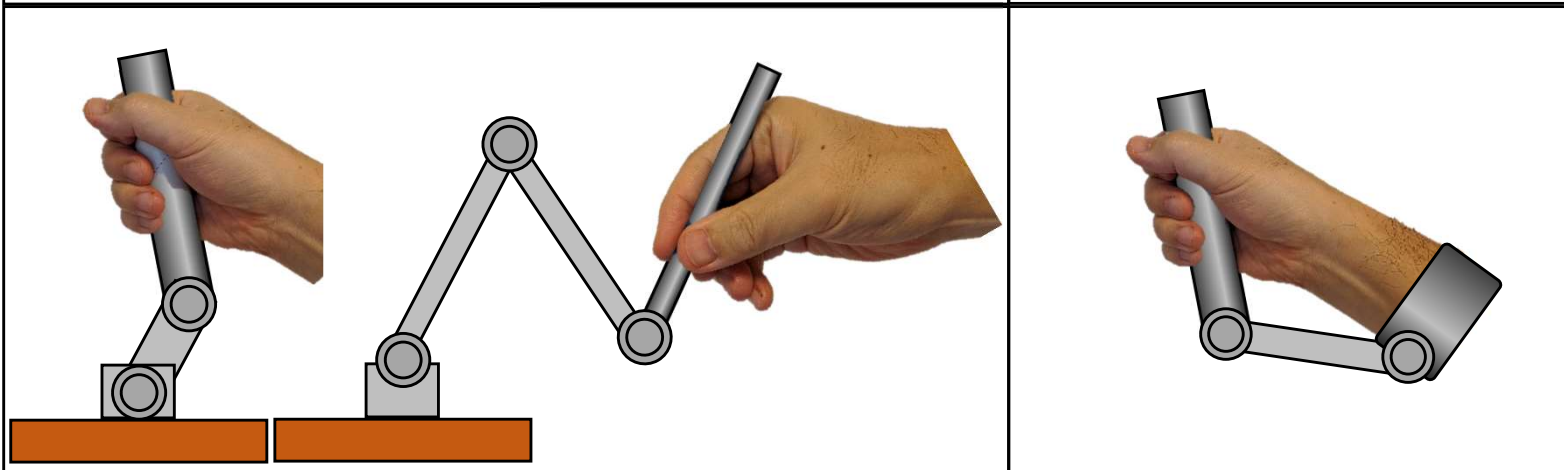
非環境型の力覚ディスプレイの形態

Configurations of non-environmental haptic displays

装着
Wear



把持
Hold



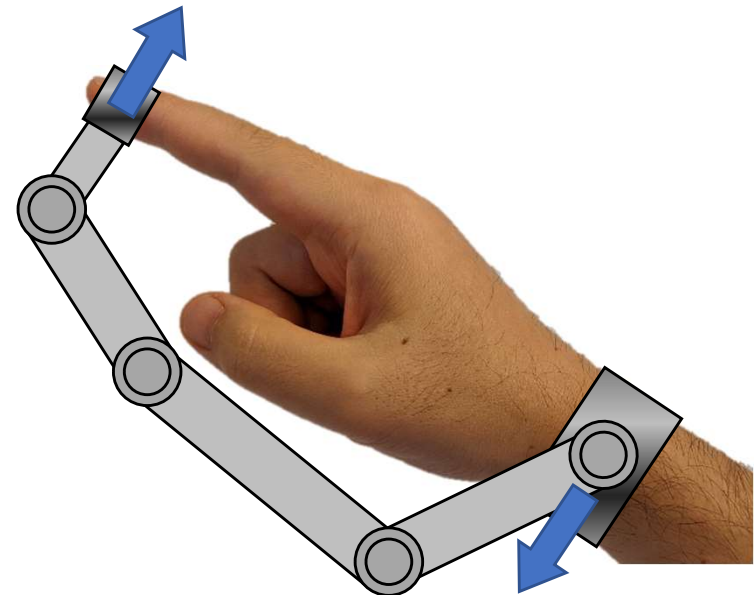
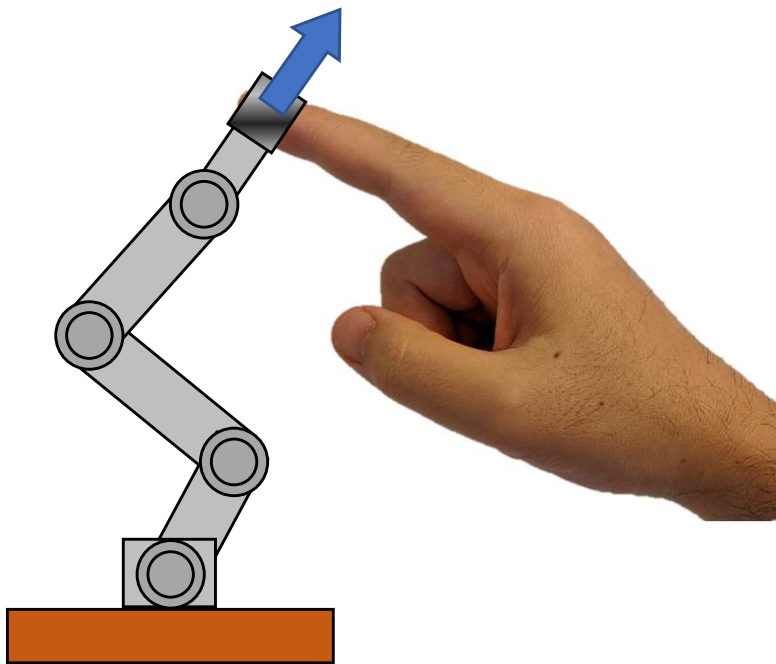
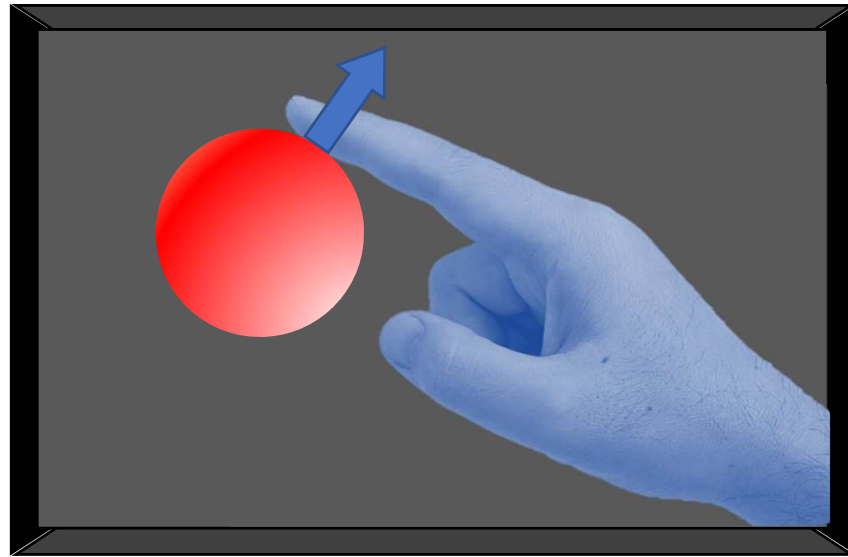
環境接地 Environment Grounded

身体接地 Body Grounded

- 装着型か、把持型か / Wear or Hold
 - 装着型：手の振る舞いの再現 Wear type presents “hand, finger” behavior.
 - 把持型：ツールの振る舞いの再現 Hold type presents “tool” behavior.
- 環境接地か、身体接地か / How it is grounded
 - 環境接地：外界に対して力を発揮 Force is applied from environment.
 - 身体接地：別の身体部位との間に力を発揮 Force is exerted in between body parts.



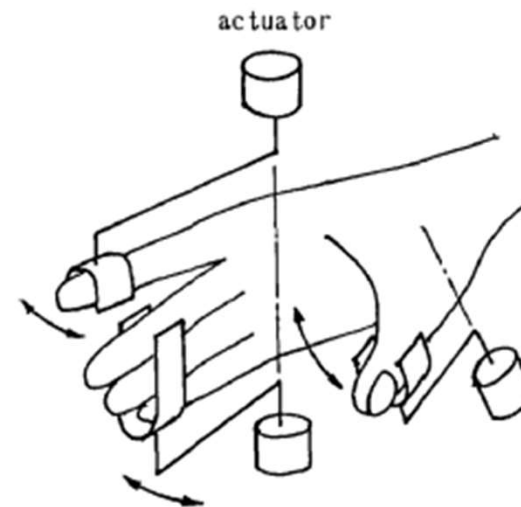
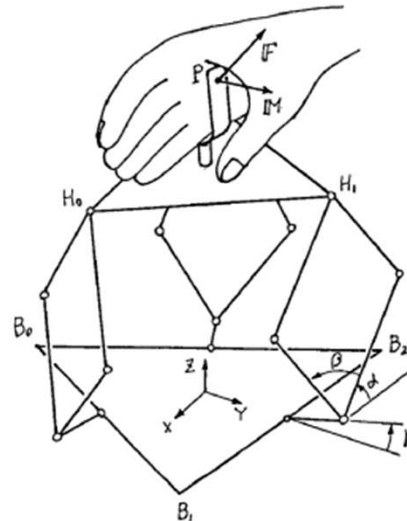
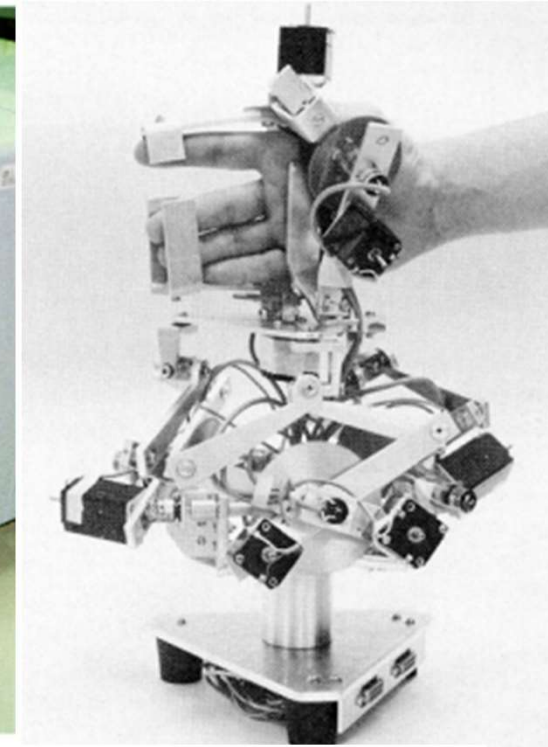
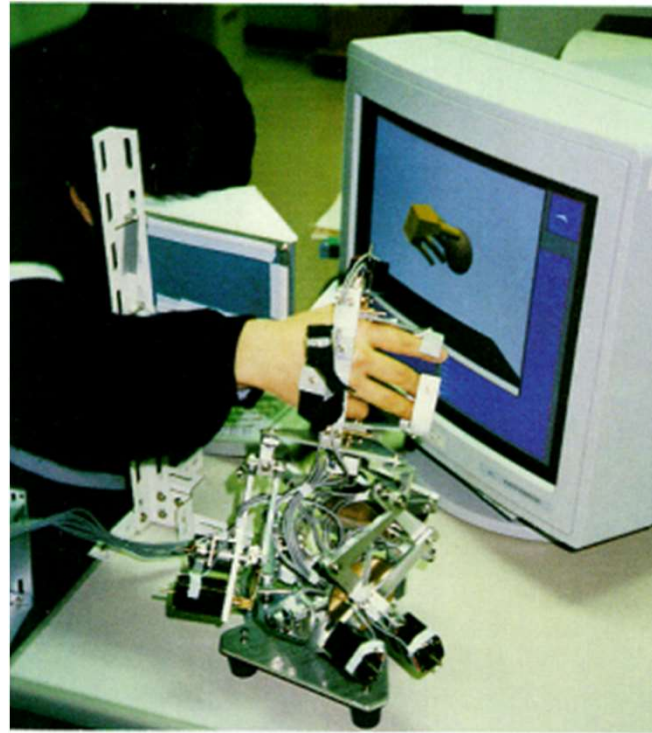
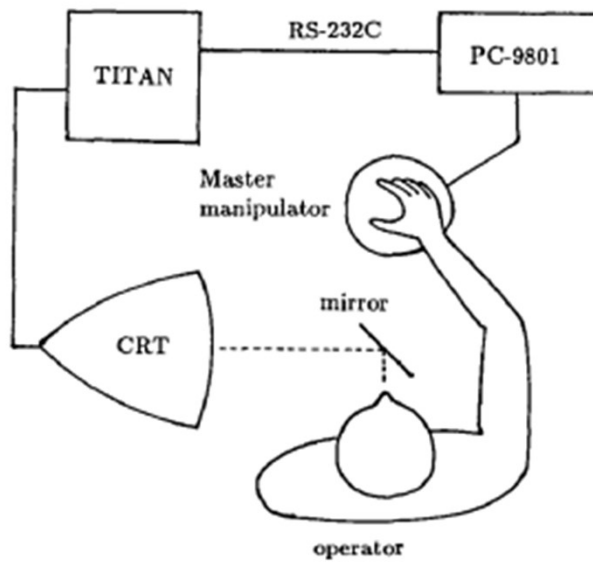
接地はなぜ重要か Why grounding matters?



環境に接地すると所望の力のみ提示可能。身体に接地すると作用反作用で他の力が発生する。
When grounded to the environment, the desired force can be presented. When grounded to the body, the action-reaction generates other forces.



Desktop Force Display (1989)



黎明期の力覚ディスプレイ。掌部、指部への力覚提示を実現

Hiroo Iwata: Artificial reality with force-feedback: development of desktop virtual space with compact master manipulator (1990, SIGGRAPH) <https://dl.acm.org/doi/10.1145/97879.97897>

CyberGrasp/CyberForce

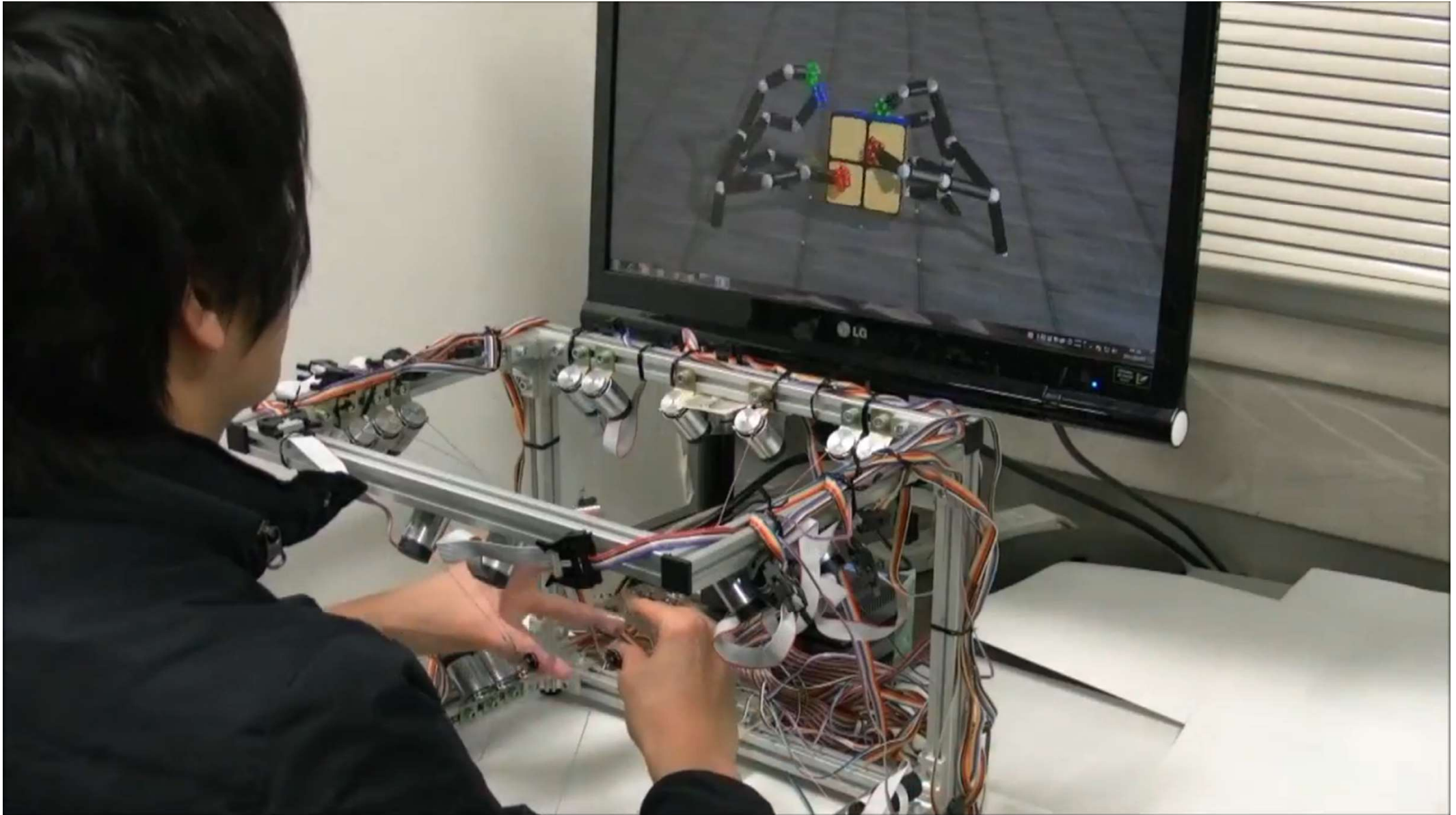


<http://www.youtube.com/watch?v=Td7QcAgCtWE&feature=fvw>

装着型。腕全体は環境接地、各指は身体接地。

Wear type. The whole arm is environmental grounded, whereas each finger is body grounded.

SPIDAR-8

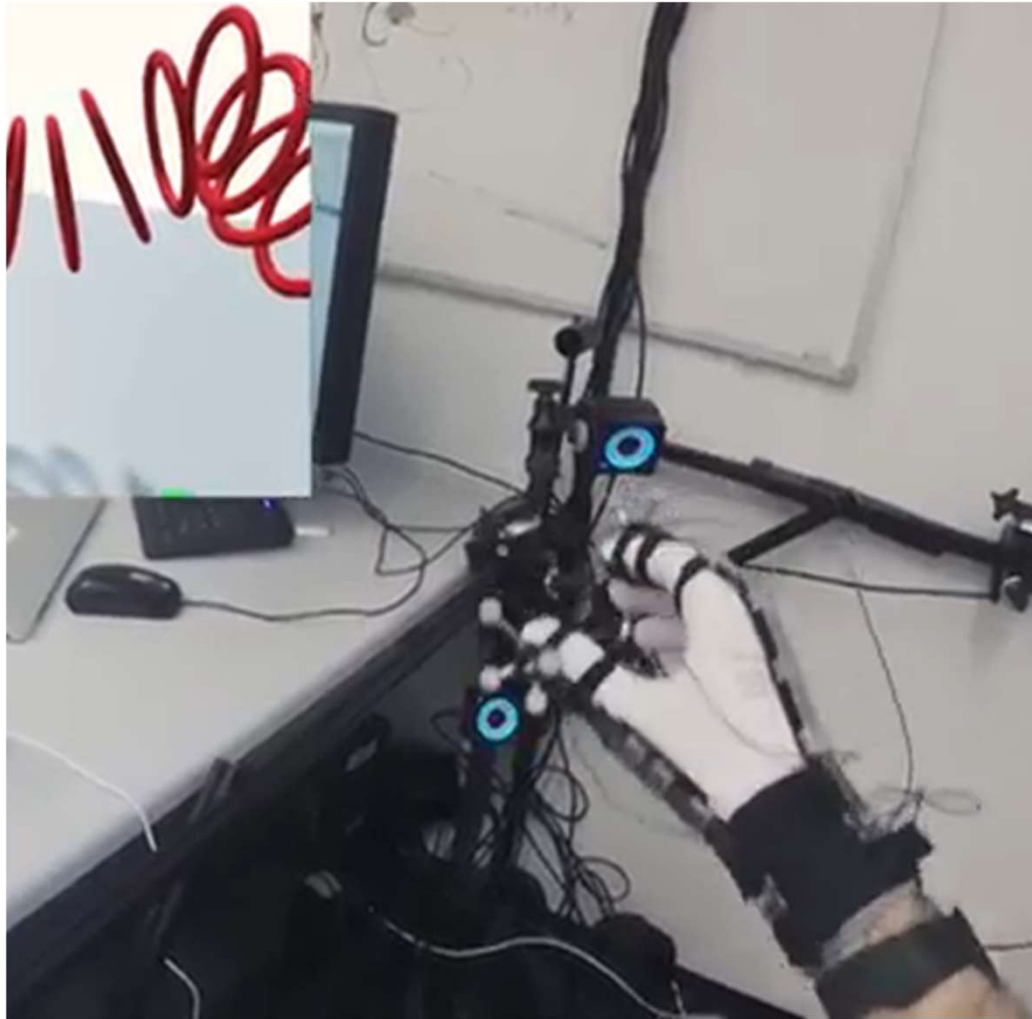


- Wear type. Environment grounded.
- (left) 4 finger, (right) 4 finger
- One finger is pulled by 3 wires

<https://www.youtube.com/watch?v=ZUb4-g8J93k>

Somsak WALAIRACHT, Yasuharu KOIKE, Makoto SATO: A New Haptic Display for Both-Hands-Operation: SPIDAR-8, ISPACS'99

手首、手の甲を接地部位とする
Grounded to wrist, back of the hand, or palm



<https://www.youtube.com/watch?v=fgRaw9k-Eu8>
(CHI2018) DextrES: Wearable Haptic Feedback for Grasping in VR via a Thin Form-Factor Electrostatic Brake, Hinchet et al.

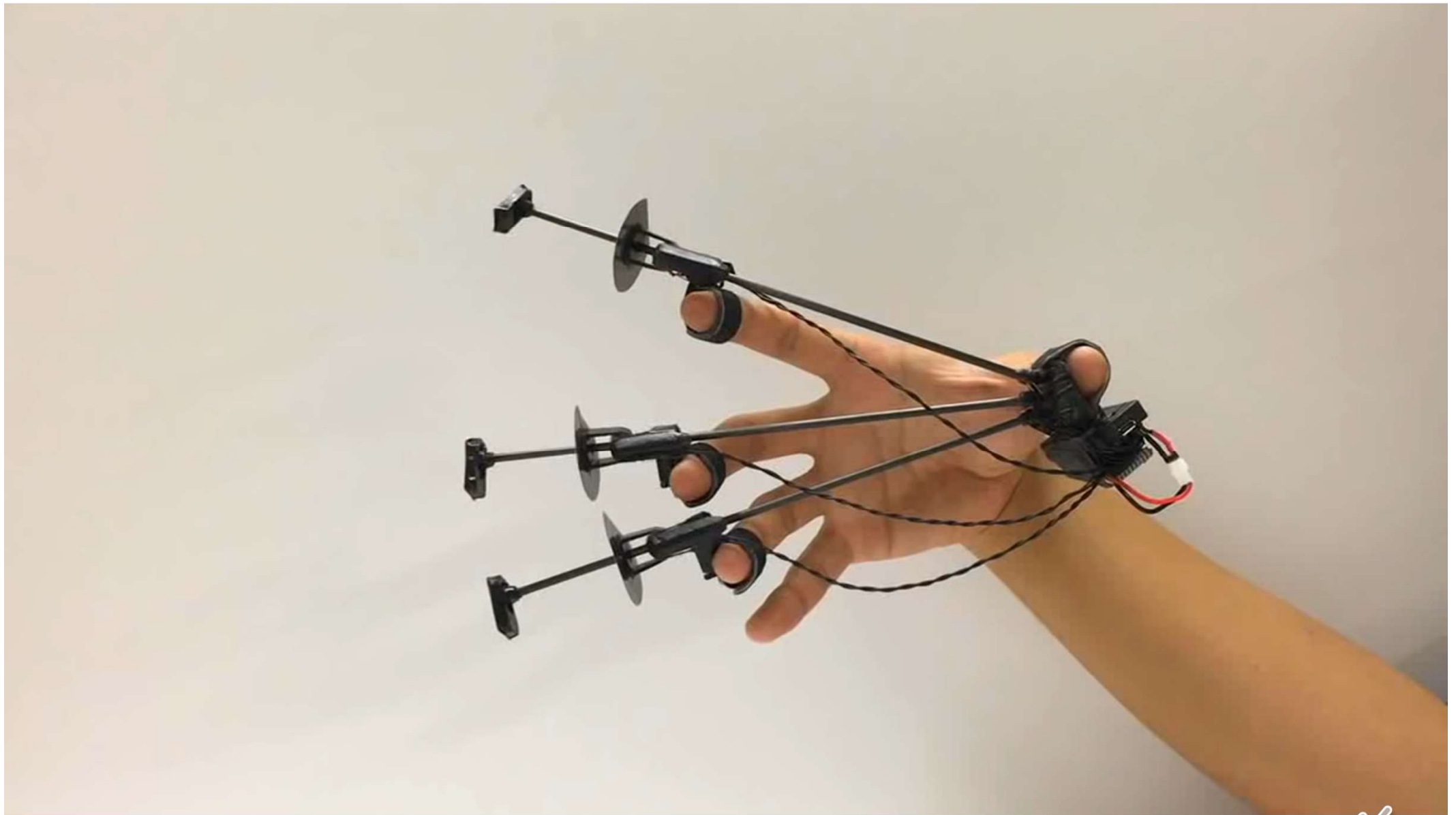
静電気力によるブレーキで力覚提示グローブ。手首部分に接地



<https://www.youtube.com/watch?v=yt1QNW08mqg>
(CHI2018) CLAW: A Multifunctional Handheld Haptic Controller for Grasping, Touching, and Triggering in Virtual Reality, Choi et al.

二本指の間の力覚で幅広いウェアラブル力覚を提供。手掌部にハンドルとして接地。

指同士で接地する Mutual grounding to fingers



<https://www.youtube.com/watch?v=kgE7JwlUuX4>

Choi, I., Hawkes, E. W., Christensen, D. L., Ploch, C. J., and Follmer, S. Wolverine: A wearable haptic interface for grasping in virtual reality. In Intelligent Robots and Systems (IROS), 2016



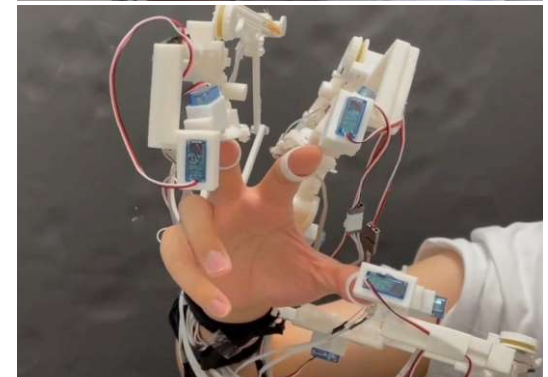
(UIST2022) ELAXO : Rendering Versatile Resistive Force Feedback for Fingers Grasping and Twisting

Zhong-Yi Zhang, Hong-Xian Chen, Shih-Hao Wang, Hsin-Ruey Tsai

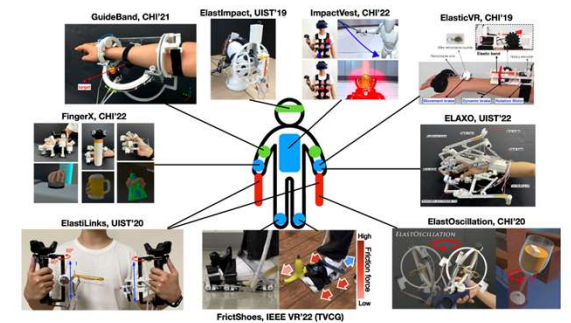
ELAXO :

Rendering Versatile Resistive Force Feedback for Fingers Grasping and Twisting

Zhong-Yi Zhang, Hong-Xian Chen, Shih-Hao Wang, Hsin-Ruey Tsai
National Chengchi University



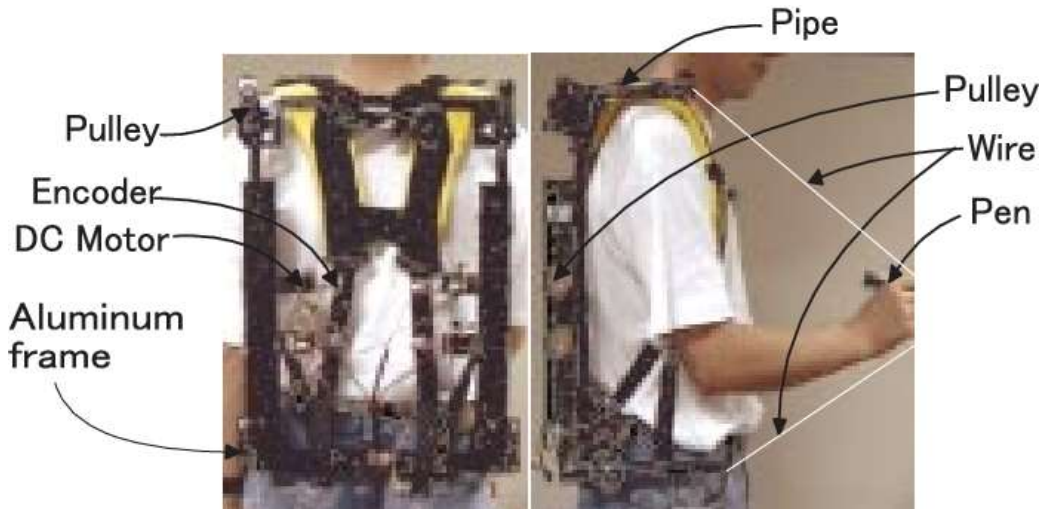
VR/AR Haptics Works (Selected)



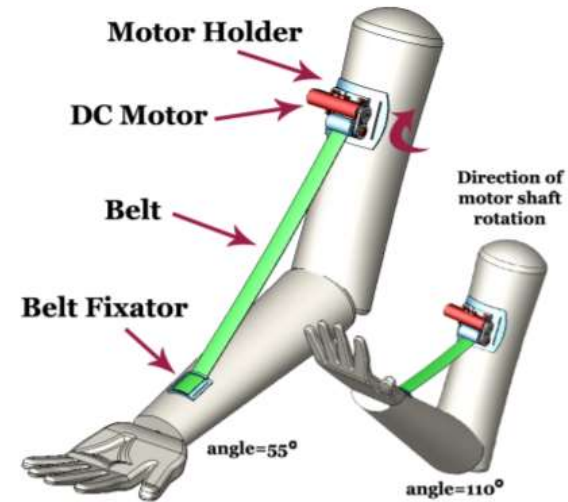
<https://www.youtube.com/watch?v=TlyaZPgD390&list=PLqhXYFYmZ-VdaPIMTFVH5K5brMDJClfAn&index=17>

3本指用ウェアラブル力覚ディスプレイ。指による「ねじり」まで対応している
Wearable haptic display for three fingers. Even "twisting" by fingers is supported.

Grounded to the other body parts (String or belt based)



(IEEEVR2001) HapticGEAR: The development of a wearable force display system for immersive projection displays. Hirose et al.



(AH2010) ExoInterfaces: novel exoskeleton haptic interfaces for virtual reality, augmented sport and rehabilitation, Tsetserukou et al.

HapticSphere:

Physical Support to Enable Precision Touch Interaction in Mobile Mixed-Reality

Chiu-Hsuan Wang, Chen-Yuan Hsieh, Neng-Hao Yu¹, Andrea Bianchi², Liwei Chan

Industrial Design, NTUST, Taiwan¹
Industrial Design, KAIST, Korea²
Computer Science, NCTU, Taiwan



<https://www.youtube.com/watch?v=VAvPfq4rrNc>

(IEEEVR2019) HapticSphere: Physical Support To Enable Precision Touch Interaction in Mobile Mixed-Reality, Wang et al.

WIREALITY

Enabling Complex Tangible Geometries in Virtual Reality with Worn Multi-String Haptics

Cathy Fang Yang Zhang Matthew Dworman Chris Harrison



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

(CHI2020) Wireality: Enabling Complex Tangible Geometries in Virtual Reality with Worn Multi-String Haptics, Fang et al.

(IEEEVR2022) STROE: An Ungrounded String-Based Weight Simulation Device

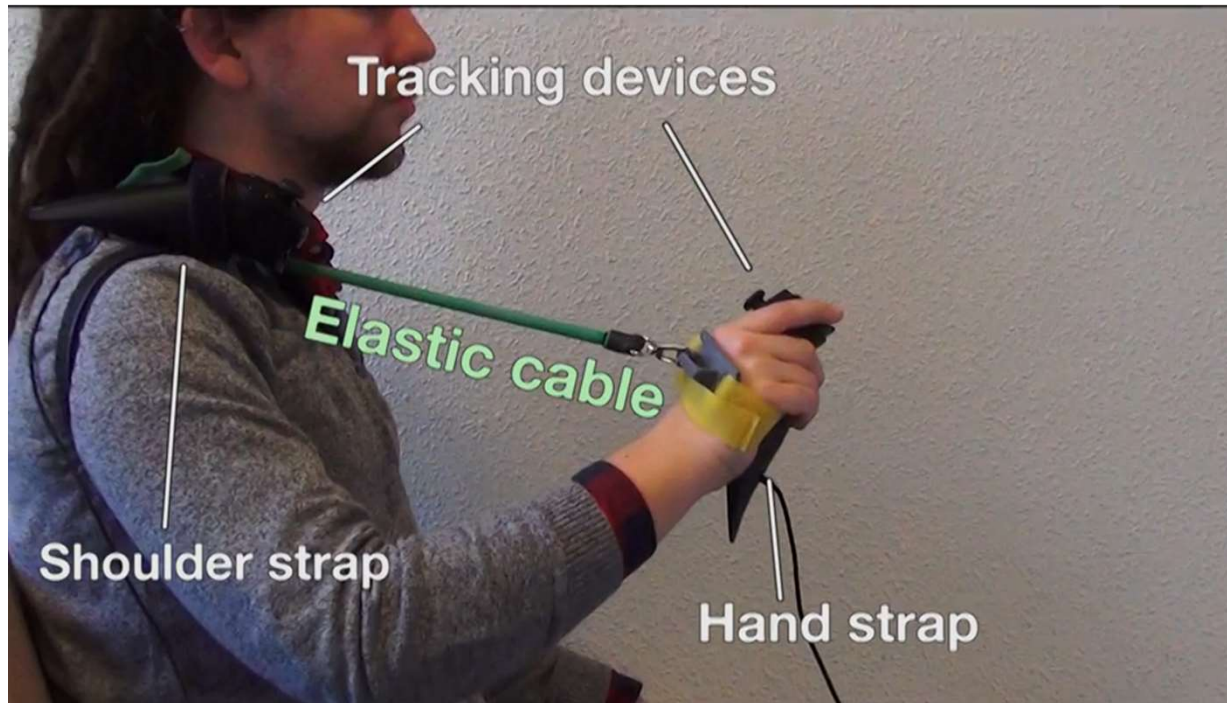
Alexander Achberger, Pirathipan Arulrajah, Kresimir Vidackovic, Michael Sedlmair



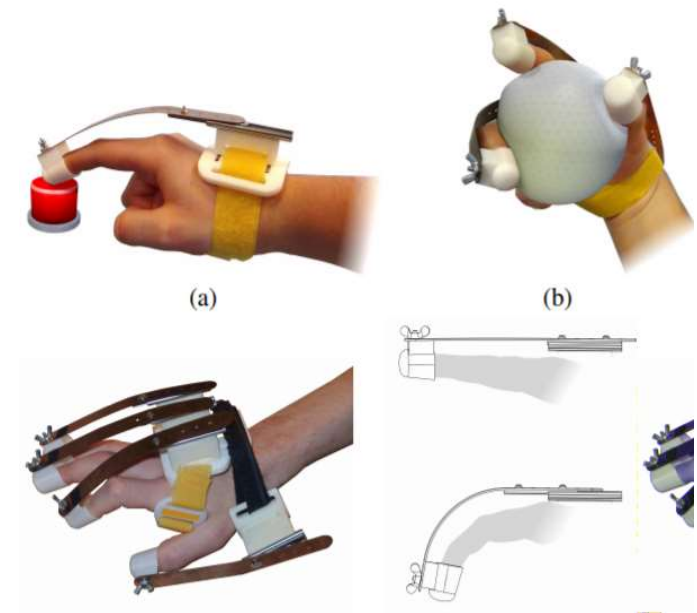
Ungroundedワイヤベースで重さ感を知覚させる。足とハンドヘルドコントローラの間で力を提示する Grounded to the user's foot.

<https://youtu.be/DigYL9eHDGQ?t=545>

パッシブ弾性要素 + 身体接地 Passive elastic elements + body grounded



https://www.youtube.com/watch?v=ub7pz5_TXX8
(IEEEVR2015) Elastic-Arm: Human-Scale Passive Haptic Feedback for Augmenting Interaction and Perception in Ves, Merwan Achibet et al.



(3DUI2017) FlexiFingers: Multi-finger Interaction in VR Combining Passive Haptics and Pseudo-Haptics
Merwan Achibet et al.

- 手・指に対してパッシブな弾性力を提示することで、VR空間での力覚の納得感を高める。
- A passive elastic plate enhances realism of force perception in VR space.



パッシブ+他者

(UIST2022) DigituSync: A Dual-User Passive Exoskeleton Glove That Adaptively Shares Hand Gestures

Jun Nishida, Yudai Tanaka, Romain Nith, Pedro Lopes



<https://www.youtube.com/watch?v=XpOKhXOXnt8&list=PLqhXYFYmZ-VdaPIMTFVH5K5brMDJClfAn&index=98>

二つの手を物理的につなぎ、リアルタイムで指の動きを伝達するパッシブ型外骨格

Passive exoskeleton that physically connects two hands and transmits finger movements in real time

筋電気刺激とVR / EMS and VR



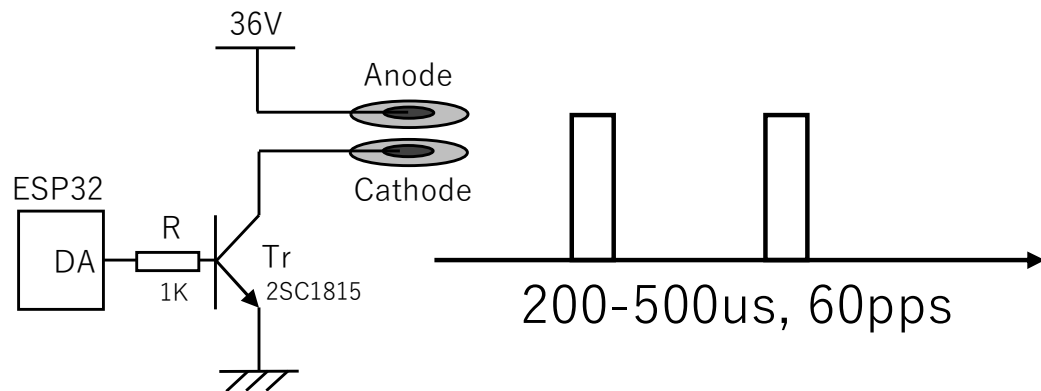
稲見, 川上: 仮想体感装置, 特開平7-20978

IVRC1993

<https://www.youtube.com/watch?v=9QVd45N1j00>

- 拮抗筋の電気刺激で抵抗力を提示。軽量。ただし刺激場所での触覚も生じる。
- 接地部位は身体。機能的電気刺激の分野では古くから利用
- Antagonist Muscle is electrically stimulated. Light weight, but strong tactile sensation also. Grounded to joint. Used in the field of Functional Electrical Stimulation (FES).



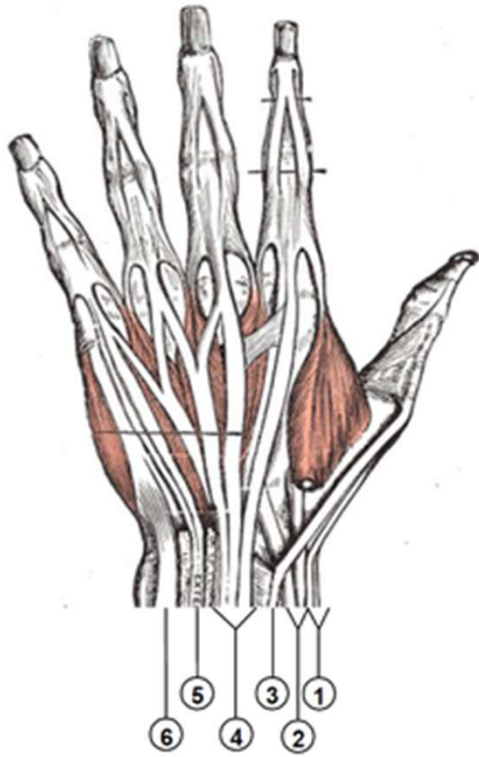


(この回路は安全ではないので非推奨です。
必要なら問い合わせてください。)

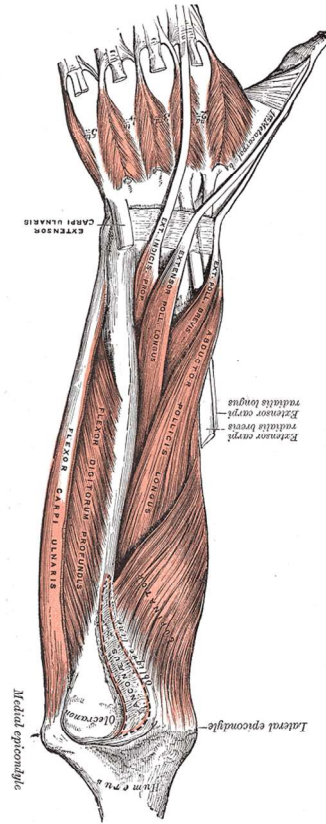
This circuit is not safe and not recommended.



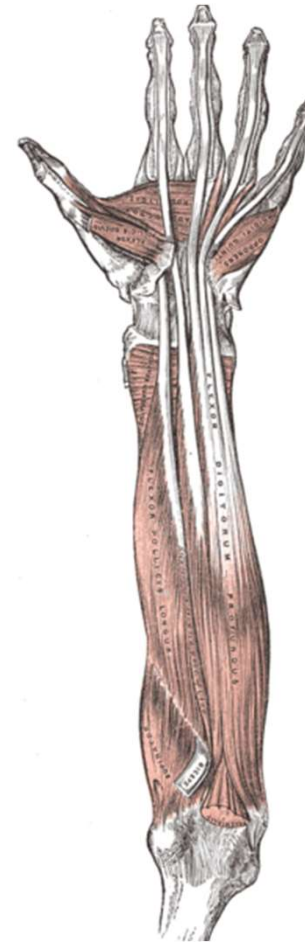
(参考) 指を動かす筋肉 / Muscles for fingers



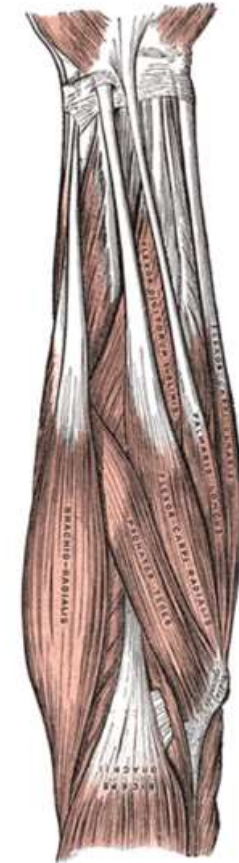
https://en.wikipedia.org/wiki/Muscles_of_the_hand



Deep muscles of the posterior forearm (背側)



Deep muscles of the anterior forearm (腹側)



Superficial muscles of the forearm

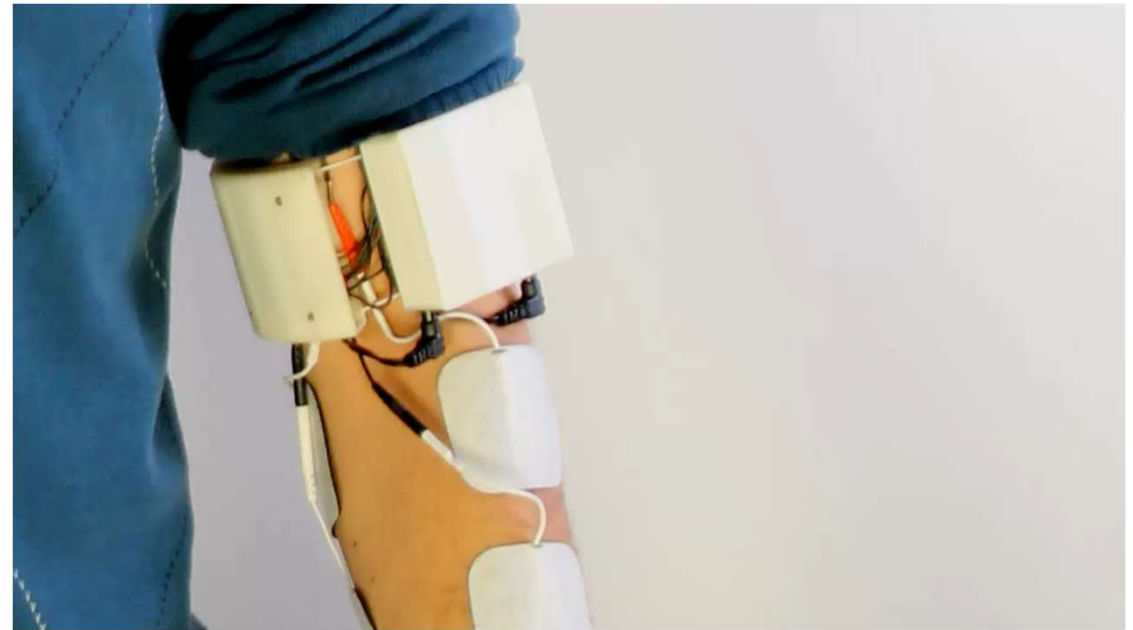
<https://en.wikipedia.org/wiki/Forearm>

- 非常に多くの筋が担当。多くが前腕に存在。
- 手外筋：前腕中にあり大まかな動きを担当 Extrinsic hand muscles: Large & coarse finger motion
- 手内筋：掌中にあり細かな動きを担当 Intrinsic hand muscles: Small & fine finger motion.

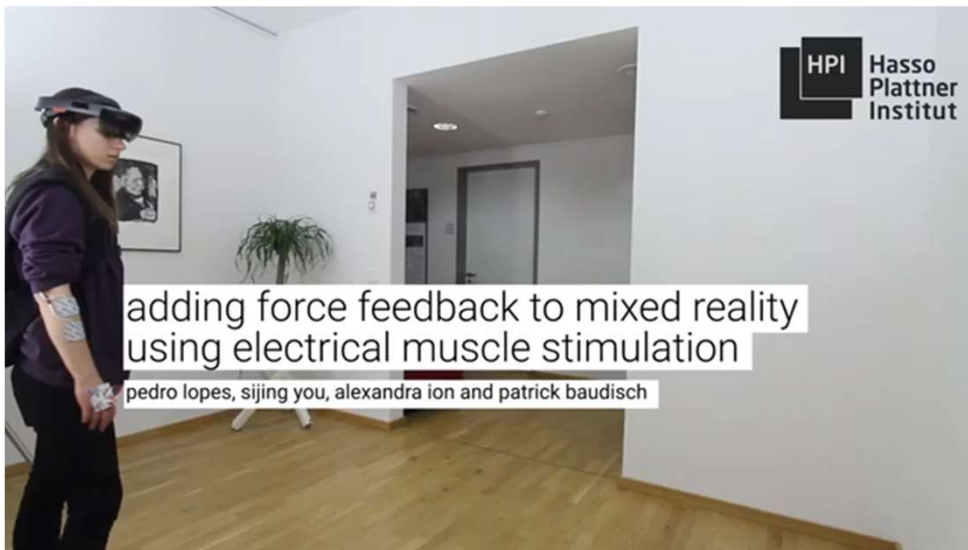
EMS for HCI



<https://www.youtube.com/watch?v=9XBoZyfB8hY>
(CHI2011) PossessedHand: Techniques for controlling human hands using electrical muscles stimuli, Tamaki et al.



<https://www.youtube.com/watch?v=KMxlfj7zhlw>
(CHI2015) Proprioceptive Interaction, Lopes et al.



<https://www.youtube.com/watch?v=qHRn05Kmwew>
(CHI2018) Adding Force Feedback to Mixed Reality Experiences and Games using Electrical Muscle Stimulation, Lopes et al.

EMS for HCI



<https://www.youtube.com/watch?v=R1DDTgT5X04>

(CHI2018) Controlling Maximal Voluntary Contraction of the Upper Limb Muscles by Facial Electrical Stimulation, Niijima et al.

<https://www.youtube.com/watch?v=xQk2MuAGhDM>

(CHI2022) Electrical Head Actuation: Enabling Interactive Systems to Directly Manipulate Head Orientation Yudai Tanaka, Jun Nishida, Pedro Lopes
首の電気刺激で頭を直接動かす



<https://www.youtube.com/watch?v=7h2JzBmoiGk&list=PLqhXYFYmZ-VdaPIMTFVH5K5brMDJClfAn&index=54>

(UIST2022) Muscle Synergies Learning with Electrical Muscle Stimulation for Playing the Piano
Arinobu Niijima, Toki Takeda, Ryosuke Aoki, Shinji Miyahara
筋電気刺激（EMS）を使用し、初心者がピアノのスケール演奏中の筋シナジーを向上させる方法を学ぶことを支援

Arinobu Niijima, Toki Takeda, Ryosuke Aoki, Shinji Miyahara
(NTT Human Informatics Laboratories, NTT Corporation)



these fingers are actuated
independently by electrical
muscle stimulation (EMS)

<https://www.youtube.com/watch?v=Sp8Eo9t90A8>

- 手の甲側から、指を曲げ下ろす側の筋を駆動する。
- Drive the finger muscles from the back of the hand.



(UIST2021) DextrEMS: Achieving Dexterity in Electrical Muscle Stimulation by Combining it with Brakes Romain Nith, Shan-Yuan Teng, Pengyu Li, Yujie Tao, Pedro Lopes



指先の機械的ブレーキと筋電気刺激を組み合わせることでより正確な指姿勢指定が出来る

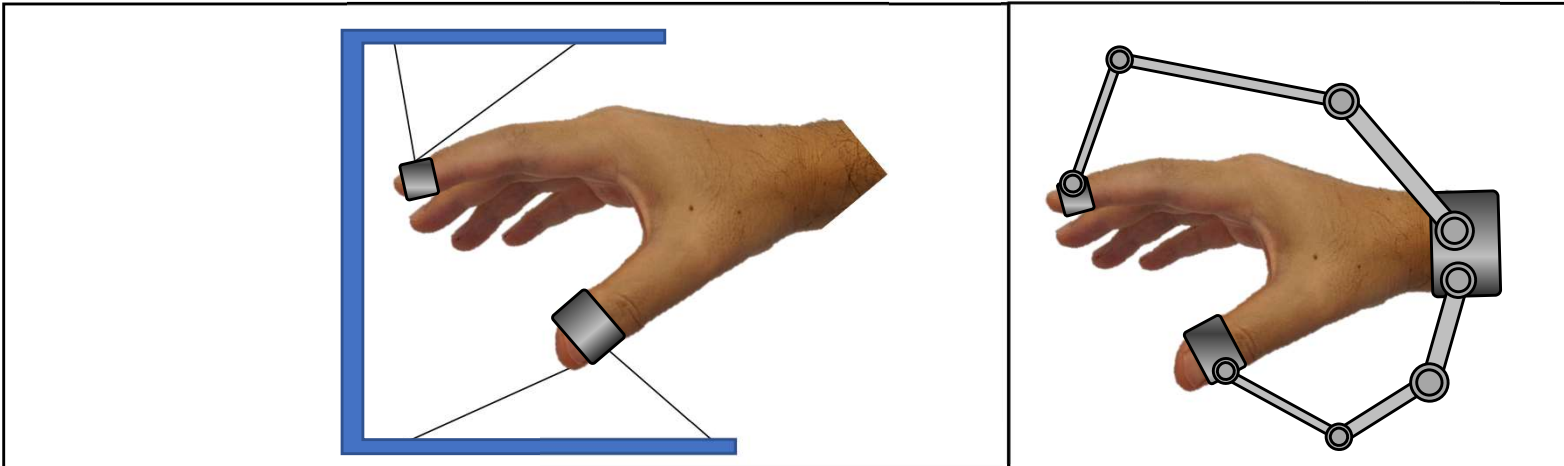
More precise finger posture specification by combining mechanical braking of the fingertips with myoelectrical stimulation.

<https://www.youtube.com/watch?v=arxlyor4Hq4&list=PLqhXYFYmZ-VeKUIuttbQWomTQ-oXF6PLf&index=54>

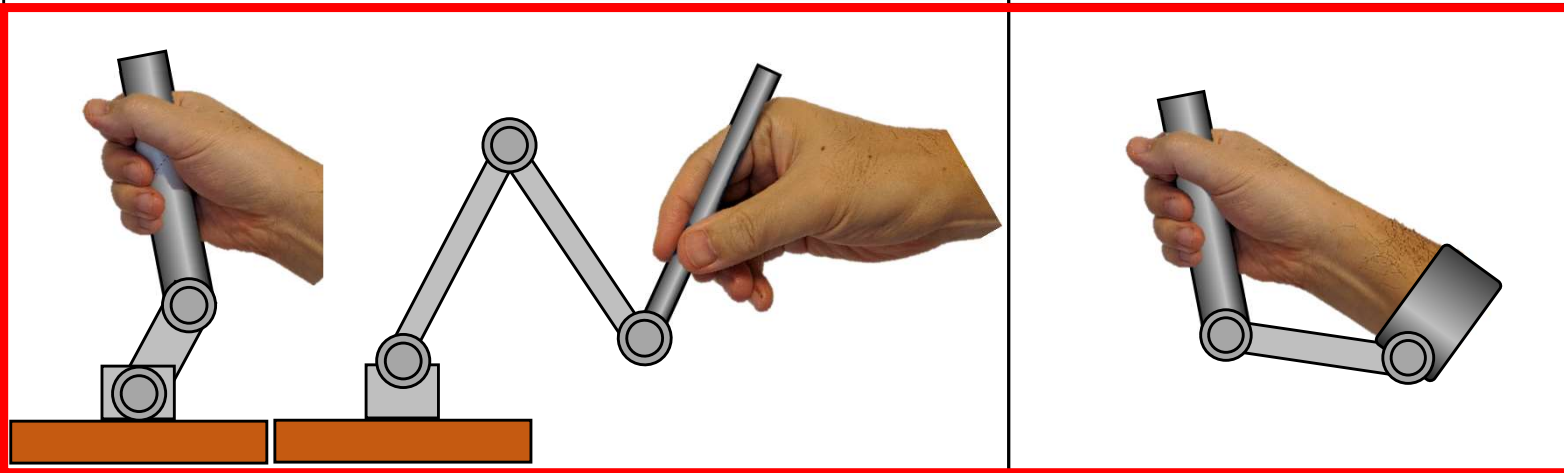
非環境型のカ覚ディスプレイの形態

Configurations of non-environmental haptic displays

装着
Wear



把持
Hold



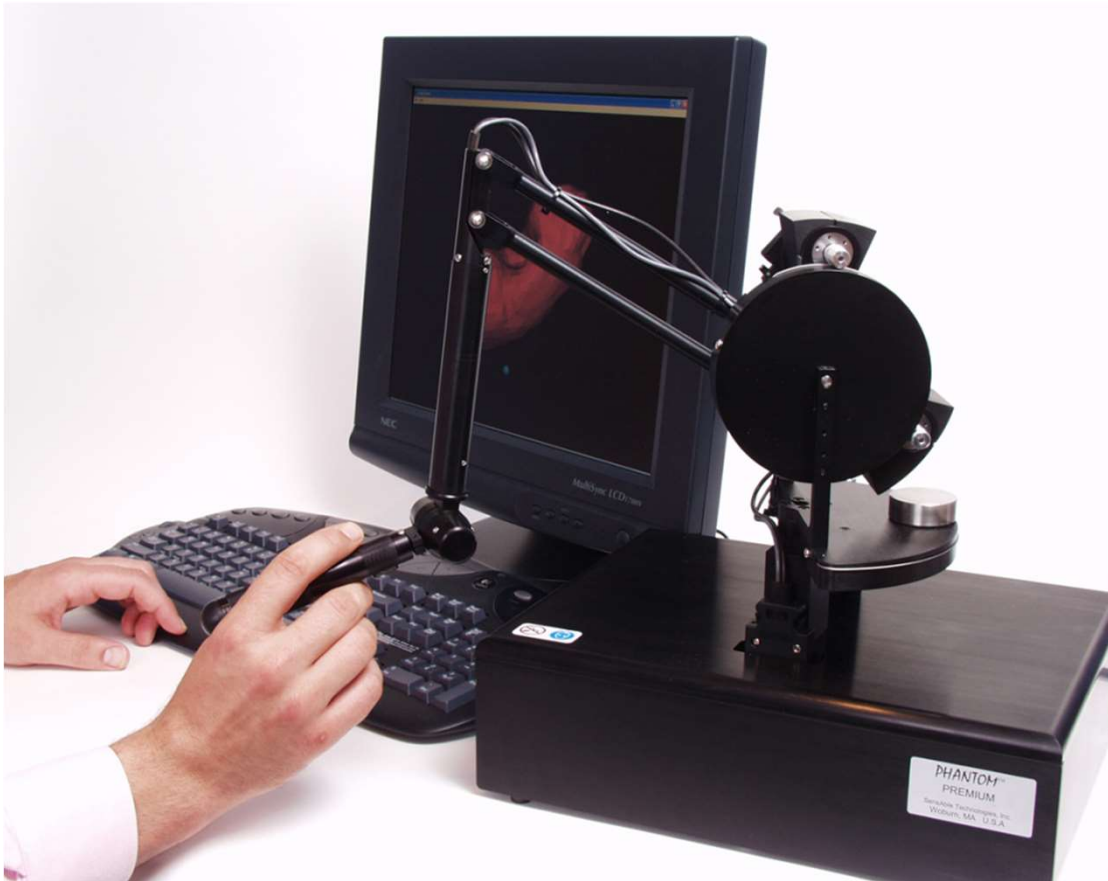
環境接地 Environment Grounded

身体接地 Body Grounded

- 装着型か、把持型か / Wear or Hold
 - 装着型：手の振る舞いの再現 Wear type presents “hand, finger” behavior.
 - 把持型：ツールの振る舞いの再現 Hold type presents “tool” behavior.
- 環境接地か、身体接地か / How it is grounded
 - 環境接地：外界に対して力を発揮 Force is applied from environment.
 - 身体接地：別の身体部位との間に力を発揮 Force is exerted in between body parts.



PHANToM (SensAble)



https://en.wikipedia.org/wiki/Thomas_Massie

- 最も有名なハプティックデバイス。6自由度をサポート
- 指サックタイプも開発されたが多くはペングリップタイプ
- Most Famous Haptic Interface with 6DOF
- Fingerstall type was developed, but most are pen-grip type

Massie T. H., Salisbury J. K., "The PHANTOM Haptic Interface: A Device for Probing Virtual Objects," Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems, 1994.



PHANToM, PHANToM Omni (SensAble)



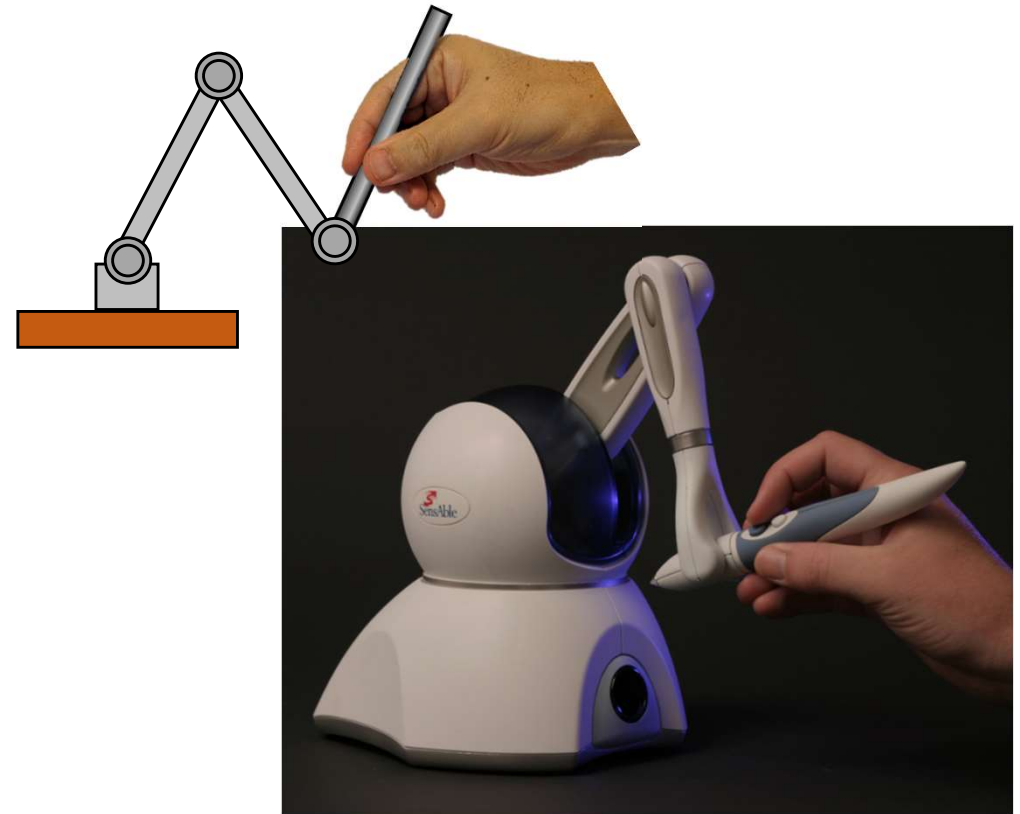
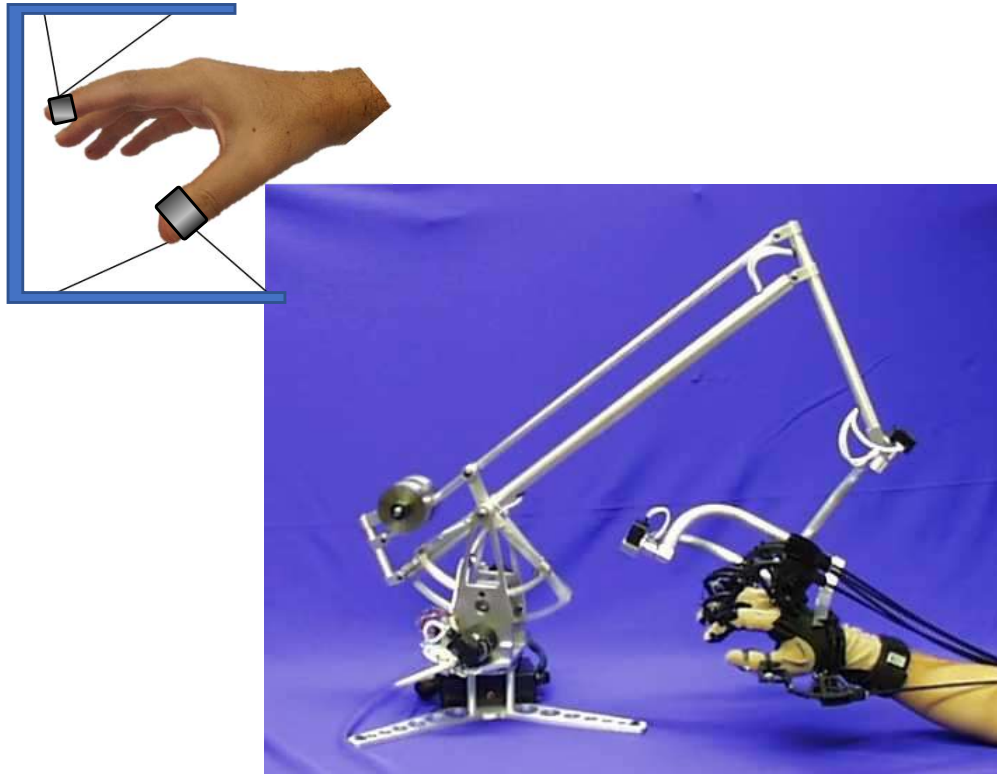
<http://www.youtube.com/watch?v=u9jdhUvOmMw&feature=related>

<http://www.youtube.com/watch?v=REA97hRX0WQ>



装着型と把持型の小さくて大きな違い

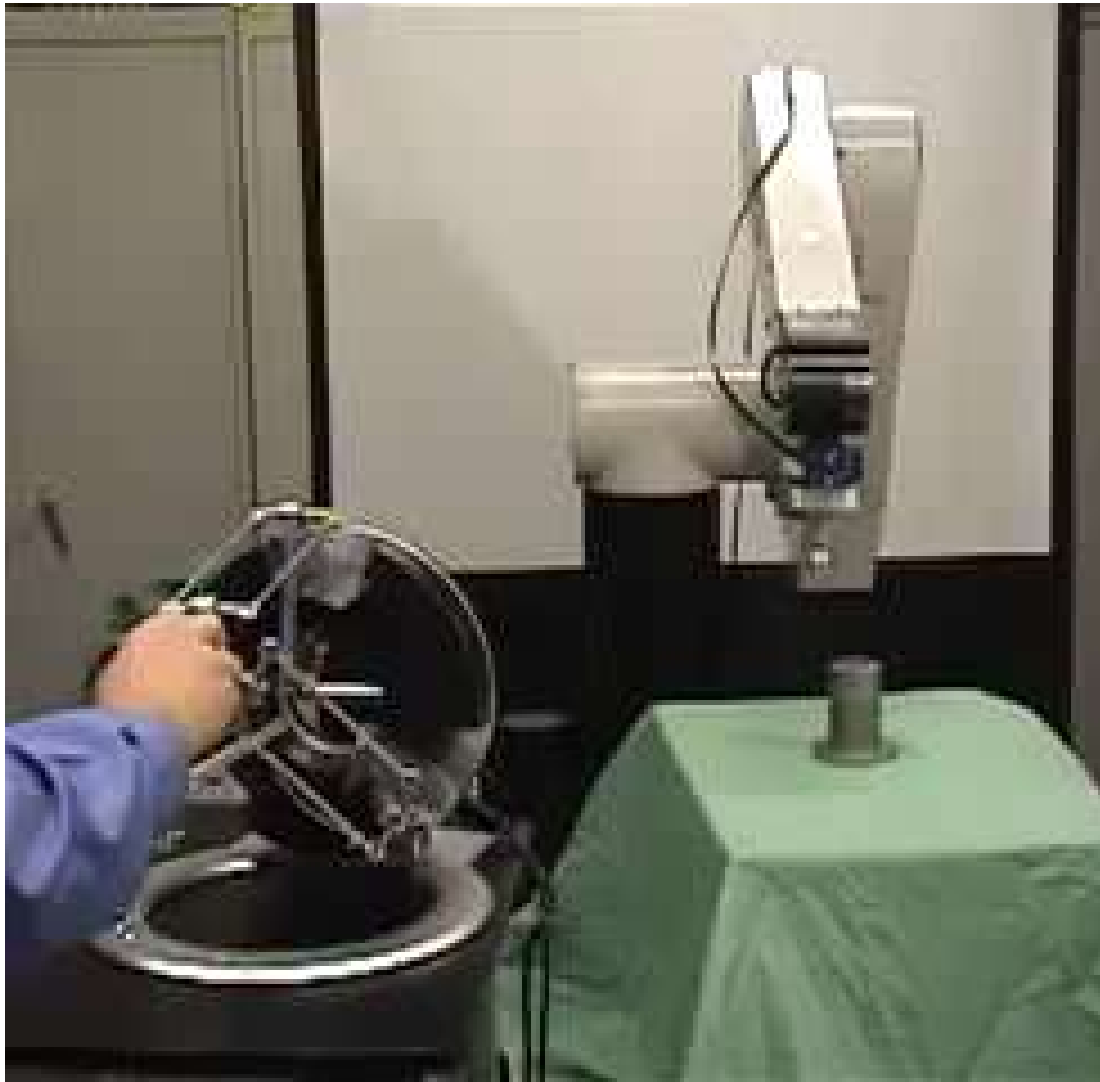
Small but significant difference between wear type and grip type



- 装着型／Wear type :
 - 指ごとにサポートする必要 Each finger must be supported
 - VR世界を手で直接触るには必須/ Direct touch in VR is possible
- 把持型／Grip type :
 - 「ペン」等の類推の利く **道具** に対して力提示（道具再現型）． 指への力提示は間接的 Force is presented to “Tool”, and presentation to hand is indirect.
 - 多くの応用で現実的解/Practical solution for many applications



パラレルリンクタイプ Parallel link type



<http://www.youtube.com/watch?v=Oh7saN3hI68>

Omega (force dimension)



<http://www.youtube.com/watch?v=mW70eIK9Yrs>

Falcon (Novint)



把持型SPIDAR



<https://www.youtube.com/watch?v=ZUb4-g8J93k>



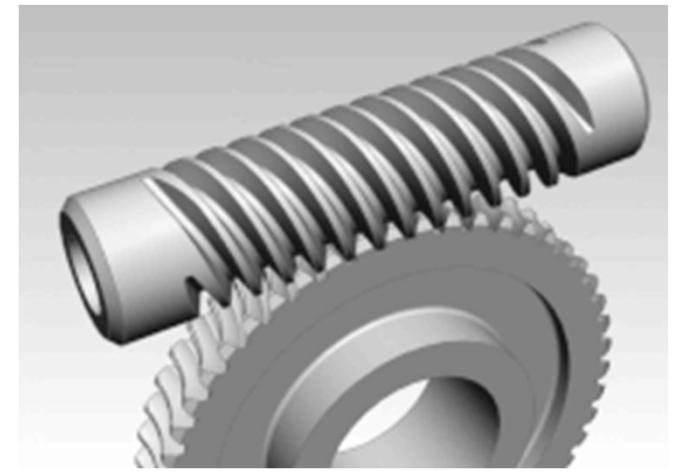
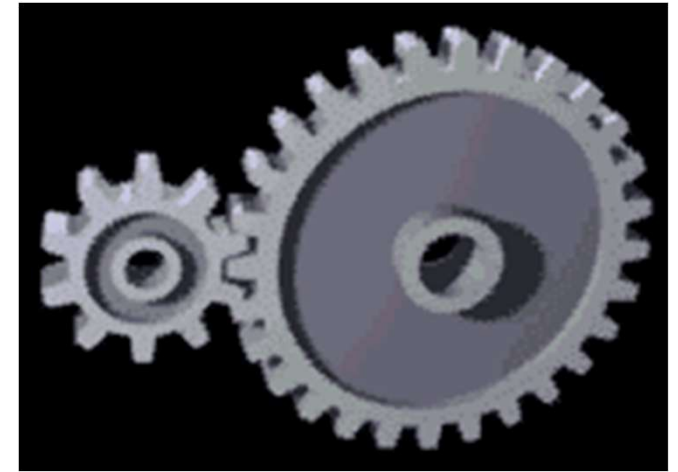
HapticMaster (MOOG FCS)



<http://www.youtube.com/watch?v=tgGEcE1VS6I>

- 産業用ロボットの的なバックドライバビリティのない剛構造+力センサ
- Rigid structure without back-drivability, like industrial robot. With force sensor

軽く作るかしっかりつくるか? Make it light, or make it rigid?



- バックドライバビリティ / back-drivability = 出力軸を直接動かせるかどうか
Whether output shaft can be moved directly
- 通常の歯車 / Ordinary gear : バックドライバビリティ有. ただしギア比が大きいほど減少 (1:50程度) Back-drivable, but reduced if gear ratio is higher.
- ウォームギア / Worm gear : バックドライバビリティ無 Not back-drivable.

出力軸を直接接触するため、バックドライバブルかどうかで制御が変わる。

As Human handles output shaft directly, control method is closely related to back-drivability

軽く作るかしっかりつくるか? Make it **light**, or make it **rigid**?



- 「軽い」装置：
 - ワイヤ駆動等. 低ギア比.
 - バックドライバビリティ有)

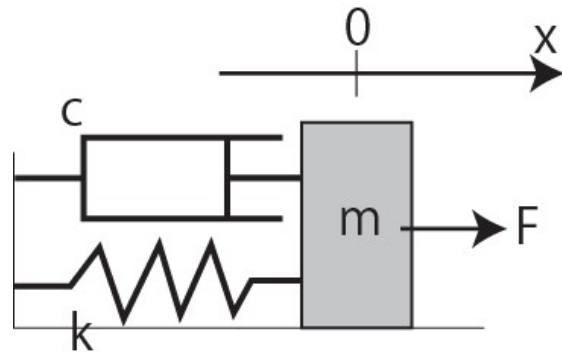


- 「固い」装置：
 - 産業用ロボットなど.
 - 高ギア比. ユーザは動かせない.
 - ハンドル先端の力センサに応答.



「軽い」装置の制御方法

How to control “light” haptic interface?



$$m\ddot{x} = f - c\dot{x} - kx$$



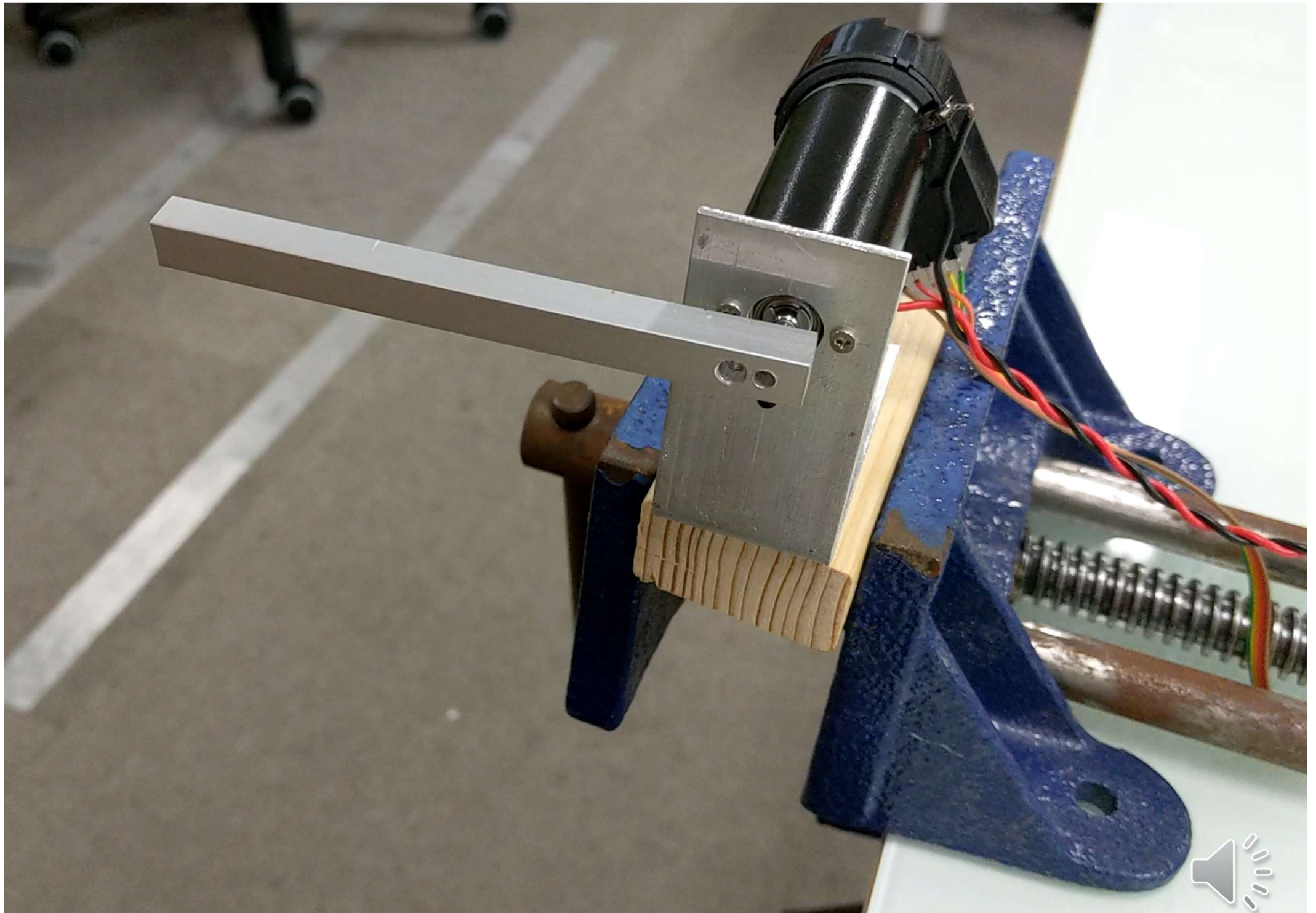
インピーダンス型のシミュレート手法

- 手先の位置を計測.
- 位置や速度に応じた力を出力.
- 手先が壁にめり込むところから開始するから、力覚ディスプレイは操作者の力だけで動かせる必要 = バックドライバビリティ有

Impedance based method

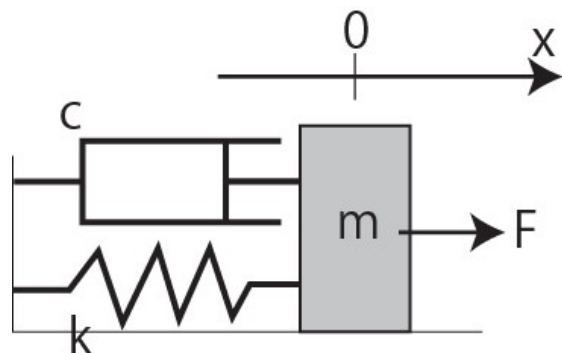
- Measure grip position.
- Output force according to the position and velocity.
- As in the first step, position must be changed by the user, the haptic interface must be back-drivable.





「堅い」装置の制御方法

How to control “rigid” haptic interface?



$$m\ddot{x} = f - c\dot{x} - kx$$

アドミッタンス型のシミュレート手法

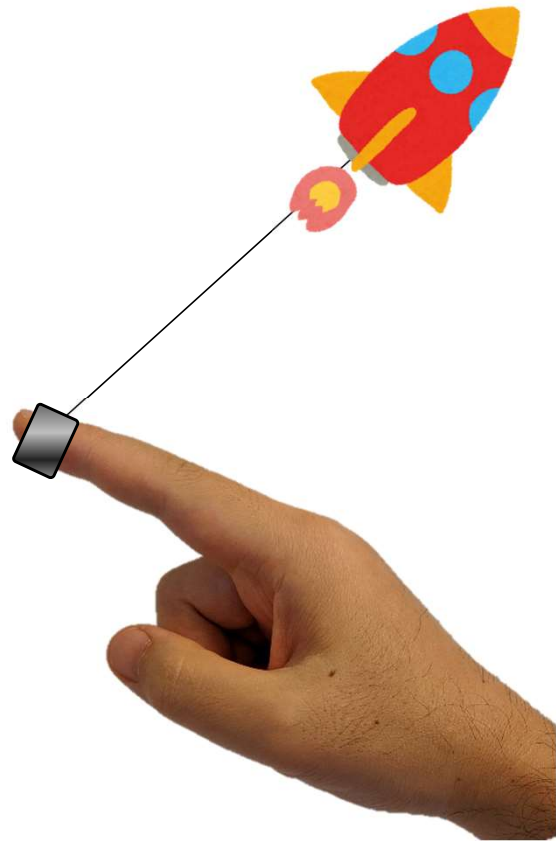
- 操縦者の力を計測
- その力に基づき、手先がどう動くか計算。その軌道を出力。
- 手先に力センサ必須だが、バックドライバビリティは不要、産業用ロボット等の固い装置を利用可能

Admittance based method

- Measure operator's force
- Calculate world's behavior according to the force, and change position of the grip.
- Force sensor is necessary, but back-drivability is not. Rigid robot can be used such as industrial robot.



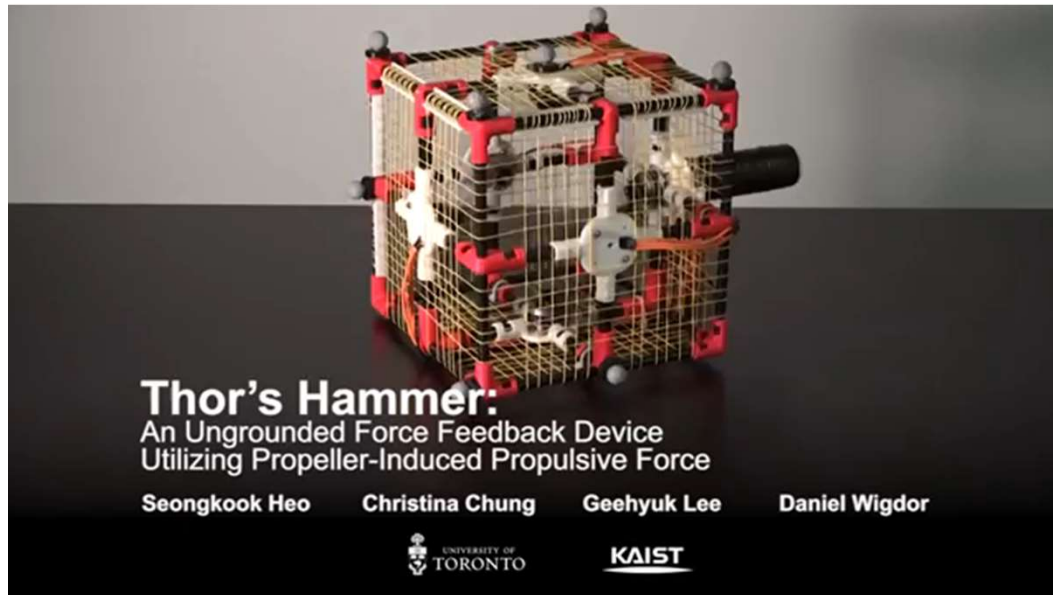
非接地の力覚提示装置は可能か Is non-grounded haptic display possible?



- なんとか力を出す。 Somehow exert physical force.
- 何らかのトルクを出す。 Exert torque.
- 皮膚感覚や錯覚を利用。 Substitute with cutaneous cue or use illusion.



風（ドローン）を利用した力覚提示 Haptic display using wind (or drone)



<https://www.youtube.com/watch?v=Y3hs2RUM4ZQ>

(CHI2018) Thor's Hammer: An Ungrounded Force Feedback Device Utilizing Propeller-Induced Propulsive Force, Seongkook Heo, Christina Chung, Geehyuk Lee, Daniel Wigdor

プロペラによる力覚提示



https://www.youtube.com/watch?v=Qh3SDRaOR_4

(Siggraph2018) LevioPole: Mid-Air Haptic Interactions Using Multirotor, Tomoya Sasaki Richard Sahala Hartanto Kao-Hua Liu Keitarou Tsuchiya Atsushi Hiyama Masahiko Inami

ドローンによる力覚提示



(CHI2022) AirRacket: Perceptual Design of Ungrounded, Directional Force Feedback to Improve Virtual Racket Sports Experiences Ching-Yi Tsai, I-Lun Tsai, Chao-Jung Lai, Derrek Chow, Lauren Wei, Lung-Pan Cheng, Mike Y. Chen

AirRacket

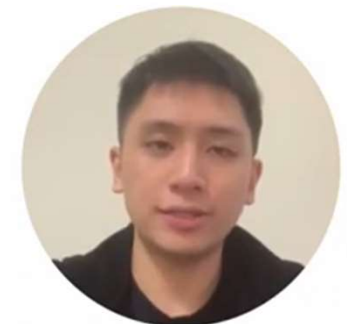


National
Taiwan
University



Perceptual Design of Ungrounded, Directional Force Feedback to Improve Virtual Racket Sports Experiences

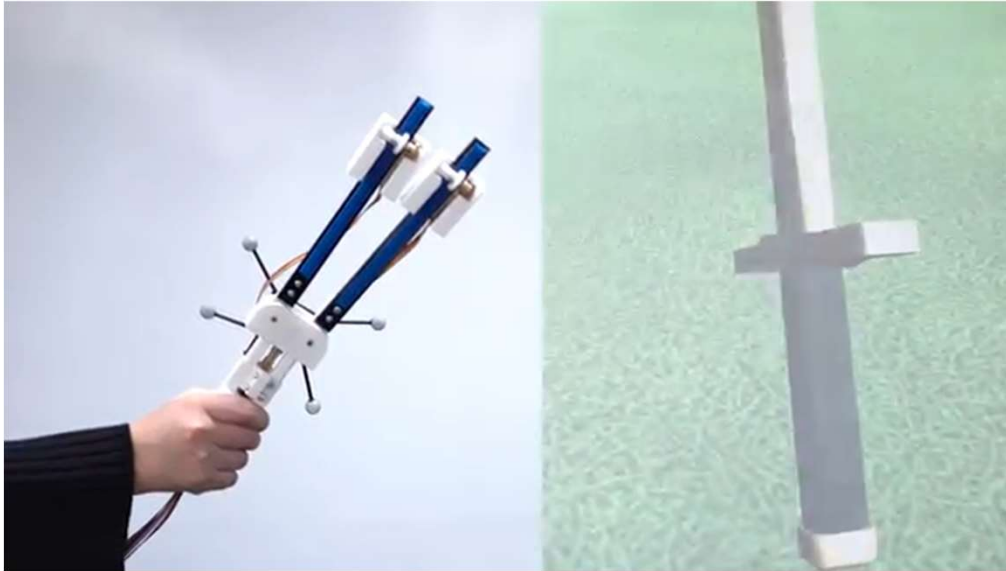
Ching-Yi Tsai I-Lun Tsai Chao-Jung Lai Derrek Chow Lauren Wei Lung-Pan Cheng Mike Y. Chen



エアジェットでラケットの触覚。Racket feeling by airjet.

<https://www.youtube.com/watch?v=INXk8tT5H3U&list=PLqhXYFYmZ-VcAoFsLTdH9hF26jsFkvs2B&index=142>

物性（重心、抵抗力、etc）を変える / Change physical properties



<https://www.youtube.com/watch?v=TJA7psWM8sY>

(SIGGRAPH2018) Transcalibur: Weight Moving VR Controller for Dynamic Rendering of 2D Shape Using Haptic Shape Illusion, Jotaro Shigeyama Takeru Hashimoto Shigeo Yoshida Taiju Aoki Takuji Narumi Tomohiro Tanikawa Michitaka Hirose
重心位置を変化させる + ビジュアルの組み合わせで様々な武器を再現。

ElastOscillation:

3D Multilevel Force Feedback for Damped Oscillation on VR Controllers

Hsin-Ruey Tsai, Ching-Wen Hung,
Tzu-Chun Wu, Bing-Yu Chen
National Chengchi University
National Taiwan University





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

(CHI2020) ElastOscillation: 3D Multilevel Force Feedback for Damped Oscillation on VR Controllers, Hsin-Ruey Tsai;Ching-Wen Hung;Tzu-Chun Wu;Bing-Yu Chen
ゴム紐 + おもりで、張力を変えることで特性を変える



<https://www.youtube.com/watch?v=bNRKsab2y6c>

(IEEEVR2021) Shuntaro Shimizu, Takeru Hashimoto, Shigeo Yoshida, Reo Matsumura, Takuji Narumi, Hideaki Kuzuoka Unident: Providing Impact Sensations on Handheld Objects via High-Speed Change of the Rotational Inertia
重心移動によるハンドヘルド力覚提示。インパクト等の表現も

Drag:on

André Zenner
Antonio Krüger

DFKI
Saarland Informatics Campus
Germany



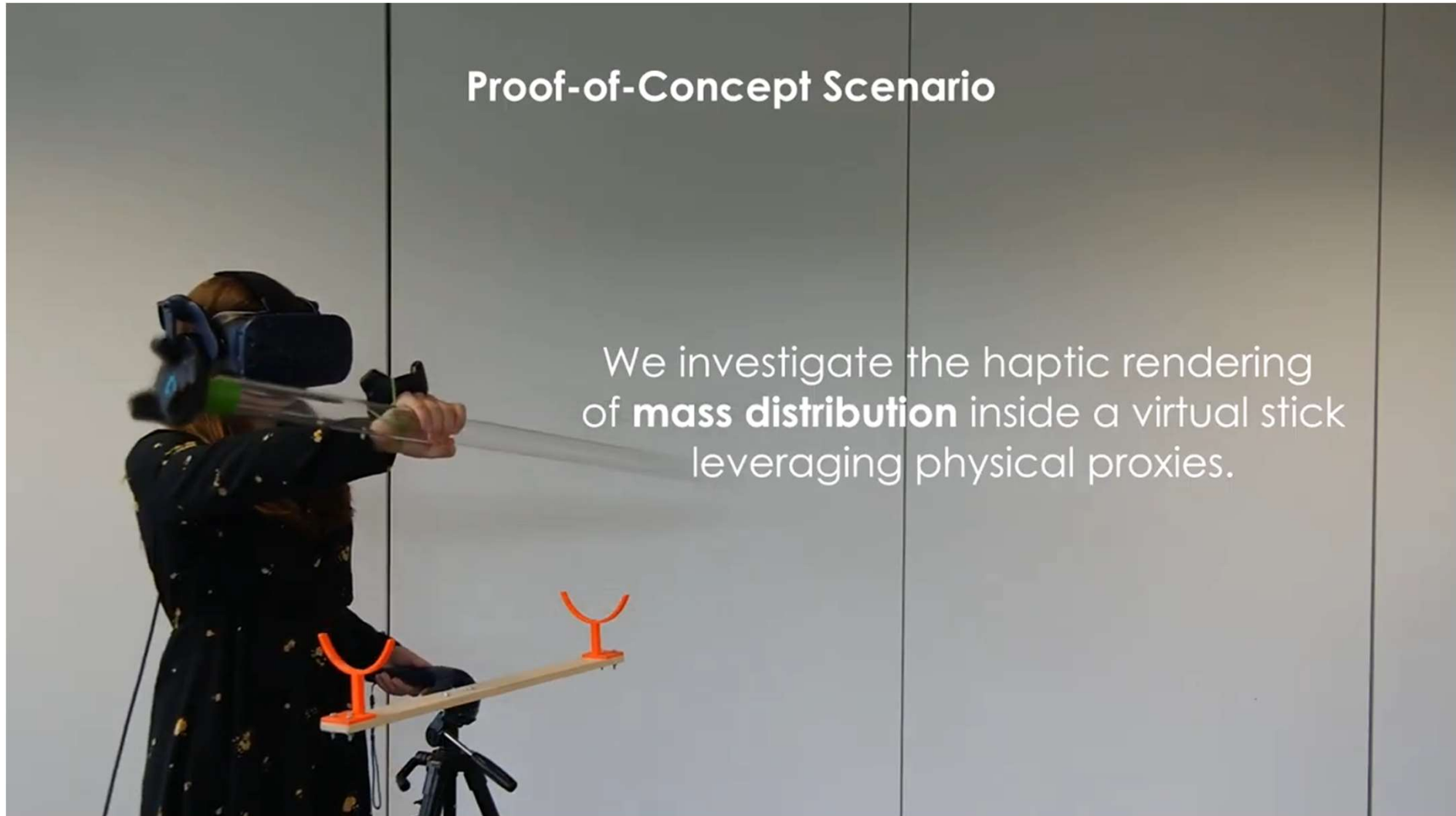
A Virtual Reality Controller Providing Haptic Feedback Based on Drag and Weight Shift

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

(CHI2019) Drag: on - A Virtual Reality Controller Providing Haptic Feedback Based on Drag and Weight Shift, André Zenner, Antonio Krüger
VR環境中での色々な手で持つものを実現する。扇子を使うことで抵抗感を出す。



(IEEEVR2021) André Zenner, Kristin Ullmann, Antonio Krüger
Combining Dynamic Passive Haptics and Haptic Retargeting for Enhanced Haptic Feedback in Virtual Reality

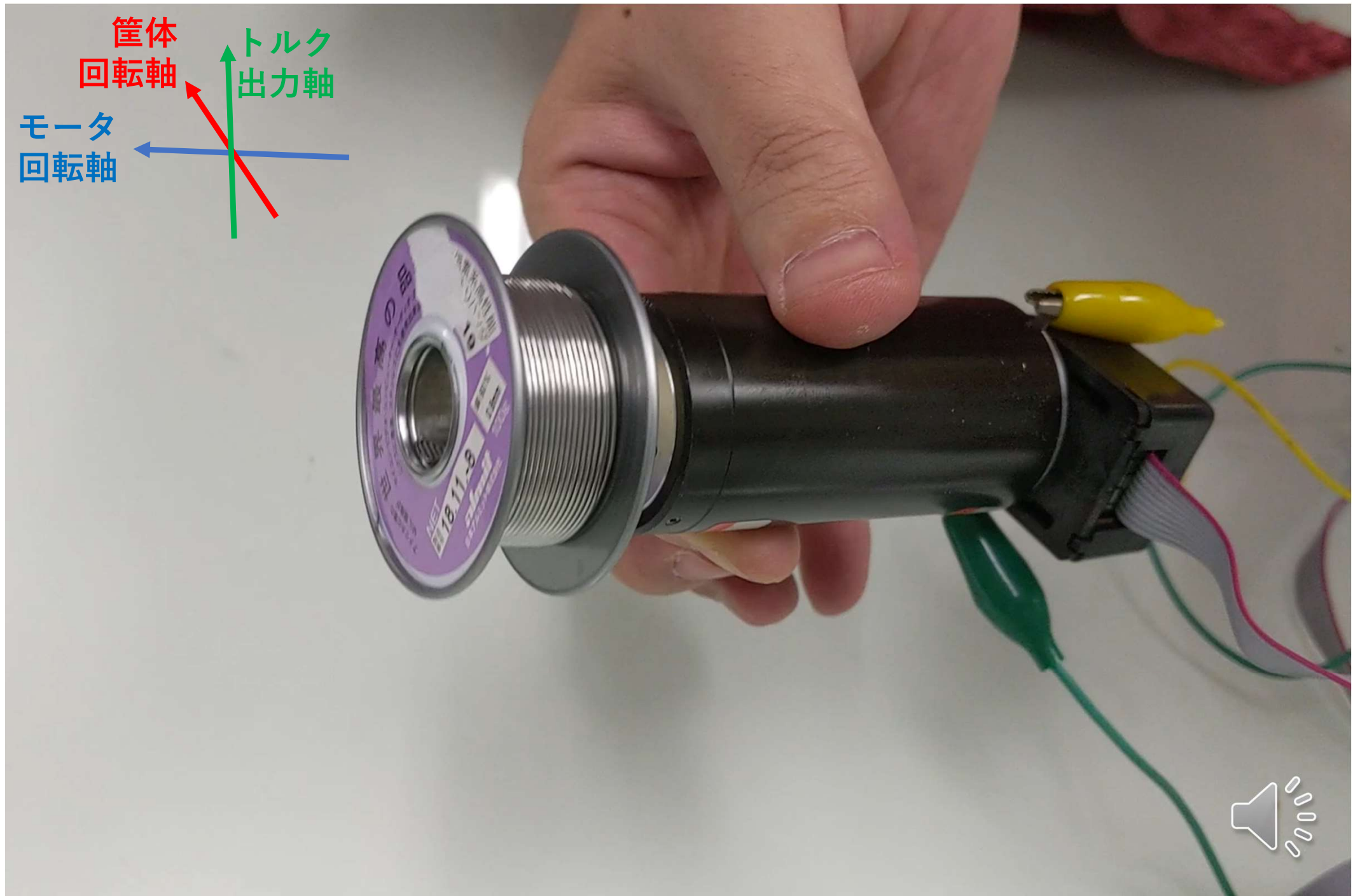


<https://www.youtube.com/watch?v=C2zprVoPEzs>

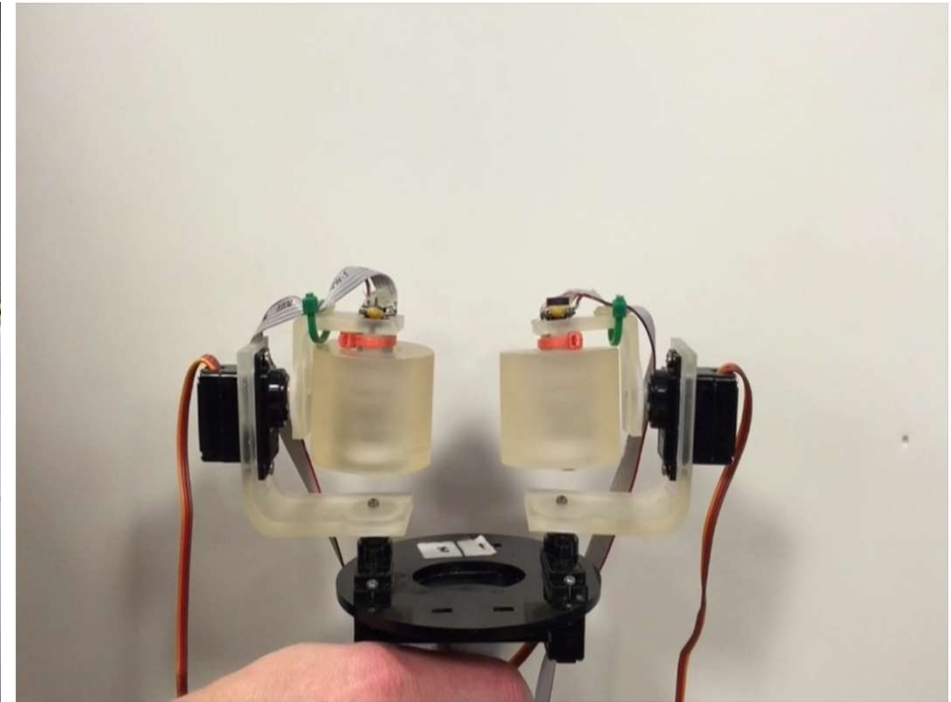
- 棒の中の重りの重心移動と、視覚映像の手の位置ずらし (Retargeting)を組み合わせ、所望の重心位置の棒を表現する。
- Combining the center-of-gravity shift of the weight in the stick and the hand displacement (retargeting) of the visual image, the stick with the desired center-of-gravity position is represented.



ジャイロ効果の利用 / Using gyro effect

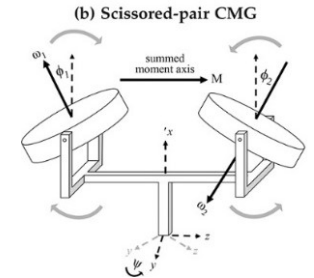
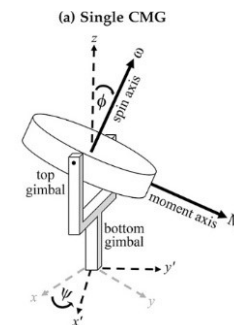
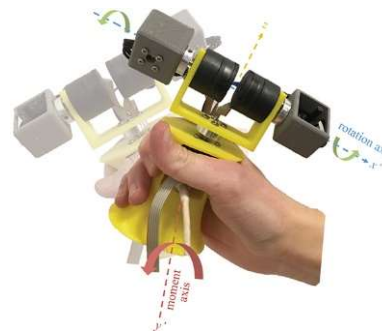


ジャイロ効果の利用：定速回転→回転軸変動 Using gyro effect: Rotation axis is turned



吉江 将之、矢野博明、岩田 洋夫：ジャイロモーメントを用いた力覚呈示装置、日本VR学会論文誌Vol.7 No.3 (2002)

http://intron.kz.tsukuba.ac.jp/gyro/gyro_j.html



<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6078422/>

(HapticsSympo2016) A Dual-Flywheel Ungrounded Haptic Feedback System Provides Single-Axis Moment Pulses for Clear Direction Signals
Julie M. Walker, Michael Raitor, Heather Culbertson, Philipp Stolka, Allison Okamura

単一のジャイロでジャイロ効果によるトルク提示を行うと、回転軸が傾いていくため所望外の軸のトルクも発生してしまう。これを2つのフライホイールによってキャンセル。

When a single gyro is used to provide torque by the gyroscopic effect, an undesired axis of torque is also generated. This is cancelled by the two flywheels.

•<https://www.youtube.com/watch?v=s26bmD8wR28>

•(UIST2017) GyroVR: Simulating Inertia in Virtual Reality using Head Worn Flywheels, Jan Gugenheimer, Dennis Wolf, Eythor R. Eiriksson, Pattie Maes, Enrico Rukzio

•ハードディスク回転+頭を振った際のジャイロ効果で抵抗感と感じさせる。「HMDに組み込まれた触覚」のさきがけの研究。The hard disk is rotated and the gyroscopic effect generates torque, which is made to feel like resistance.

(UIST2022) MetamorphX: An Ungrounded 3-DoF Moment Display that Changes its Physical Properties through Rotational Impedance Control
Takeru Hashimoto, Shigeo Yoshida, Takuji Narumi



<https://www.youtube.com/watch?v=jq xv95YCnhs&list=PLqhXYFYmZ-VdaPIMTFVH5K5brMDJClfAn&index=47>

持ち物の性質（慣性や粘性）を推定することを目的に、3自由度モーメントフィードバックを生成
能動的に力を出すのではなく、回転に対するインピーダンスを変えることで、把持物の重さ等を表現
Generate 3-DOF moment feedback for the purpose of estimating the properties (inertia and viscosity) of the
handheld objects.

回転速度変化/ Change of rotation speed



<https://youtu.be/J8YvKlxFmTs?t=492>

Daijiro Koga et al., Virtual Chanbara, Siggraph2002

<http://www.siggraph.org/s2002/conference/etch/virtual.html>



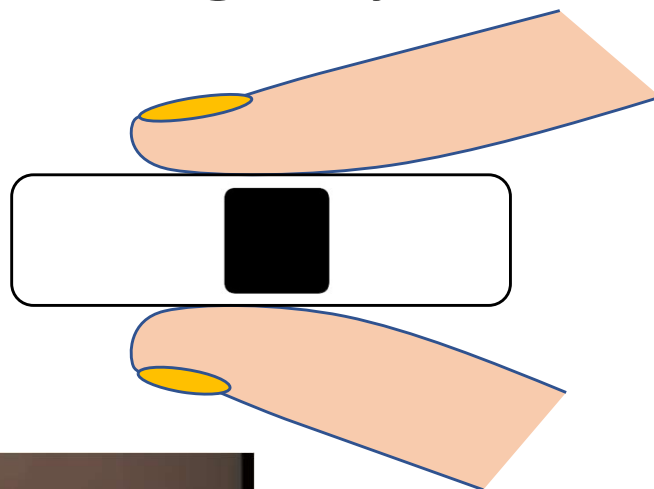
<http://staff.aist.go.jp/n-nakamura/HapticNavi/movie.html>

仲田他, 角運動量変化を利用した力覚提示デバイス, 日本バーチャルリアリティ会論文誌, 6-2, pp.115-120, 2001

中村, 福井, "GyroCubeを用いたHapticCompassの提案", 感覚代行シンポジウム, 2002



偏加速度の利用 / Using Asymmetric Acceleration



Buru-Navi (Amemiya et al. 2004~)

http://www.youtube.com/watch?v=Yj_WnNwV8F4

<http://www.kecl.ntt.co.jp/human/burunavi/>



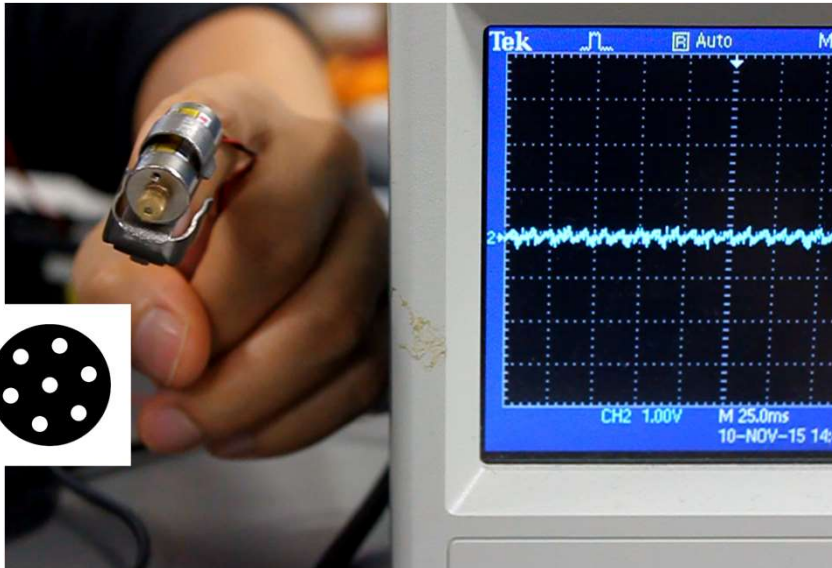
Traxion (Rekimoto et al. 2013~)

<https://vimeo.com/84665437>

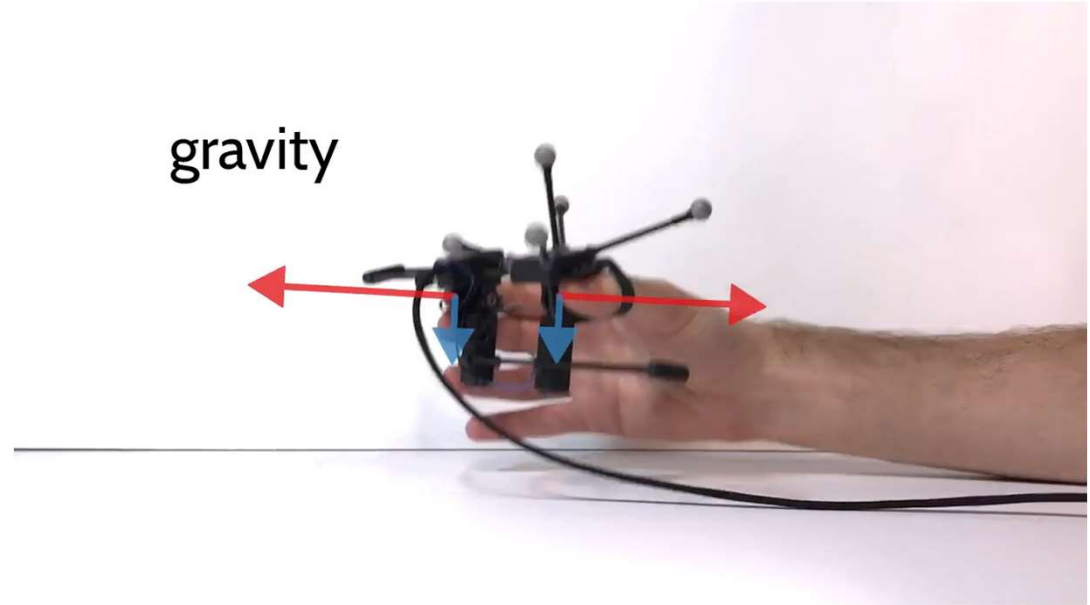
<https://lab.rekimoto.org/projects/traxion/>



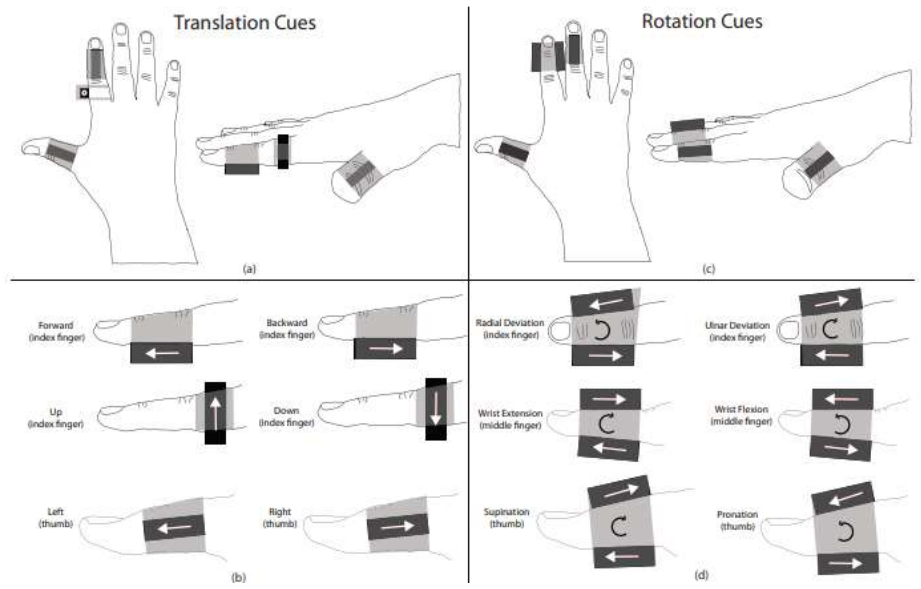
回転も含めた多自由度提示：Multi-DoF presentation



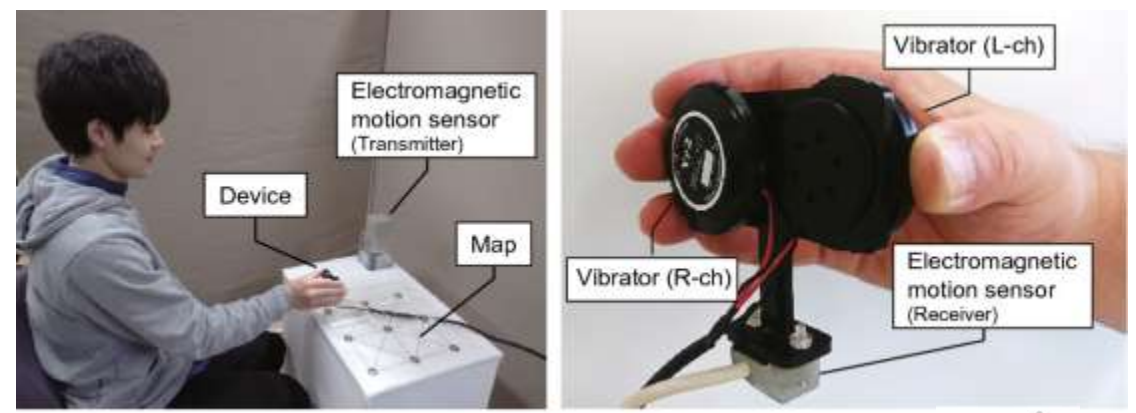
V. Yem, R. Okazaki and H. Kajimoto, "Vibrotactile and Pseudo Force Presentation using Motor Rotational Acceleration." Proc. of IEEE HapticsSymposium 2016.



Choi (UIST2017) Grability: A Wearable Haptic Interface for Simulating Weight and Grasping in Virtual Reality <https://www.youtube.com/watch?v=Vj79OLcxnDk>
 把持力は親指と人差指の間で出し、2つの上下振動子で上下重量感とトルク感を提示。



Culbertson (CHI2017) WAVES: A Wearable Asymmetric Vibration Excitation System for Presenting Three-Dimensional Translation and Rotation Cues <http://library.usc.edu/ph/ACM/CHI%202017/1proc/p4972.pdf>

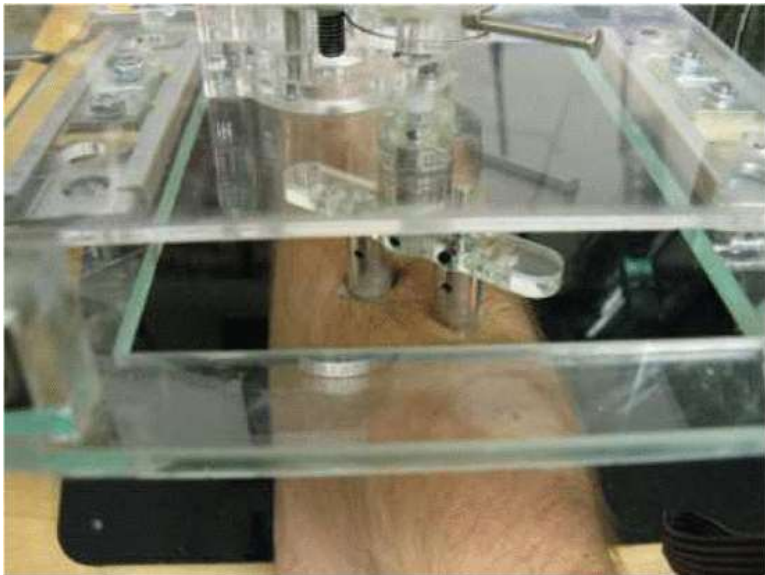


Tanabe (EuroHaptics2020) Motion Guidance Using Translational Force and Torque Feedback by Induced Pulling Illusion https://link.springer.com/chapter/10.1007/978-3-030-58147-3_52

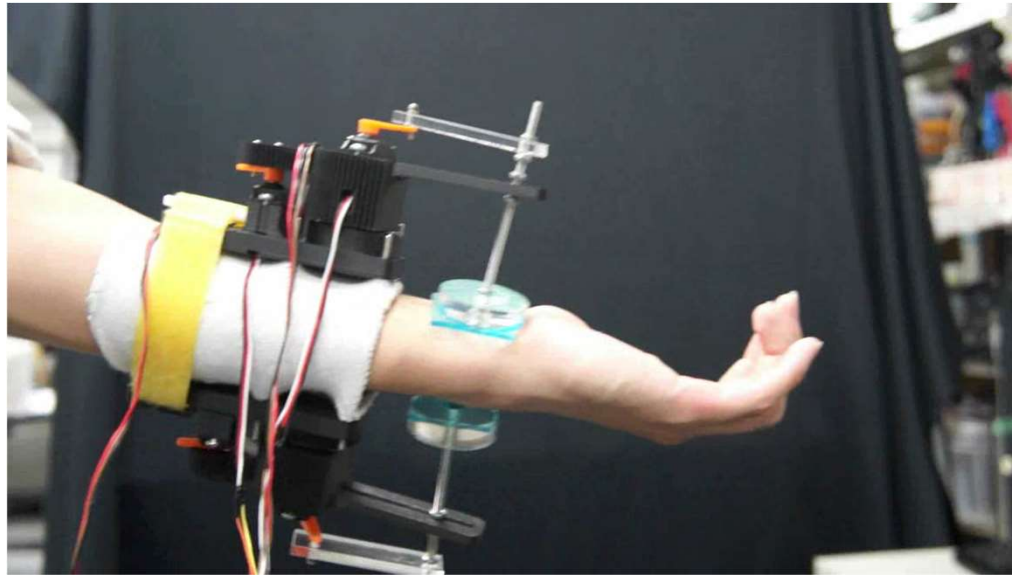
ハンガー反射の身体の他の部位への適用(前腕, 腰)



Several skin drag type displays (1/2)



<https://ieeexplore.ieee.org/document/5444675>
(HS2010) Skin nonlinearities and their effect on user perception for rotational skin stretch, Shull et al.



<https://dl.acm.org/doi/10.1145/2160125.2160141>
(AH2010) Transmission of forearm motion by tangential deformation of the skin. Kuniyasu et al.

Springlets: Expressive, Flexible and Silent
On-Skin Tactile Interfaces

Nur Al-huda Hamdan - Adrian Wagner - Simon Völker
Jürgen Steimle - Jan Borchers



ACM CHI 2019

 **RWTH AACHEN** UNIVERSITY
 SAARLAND UNIVERSITY
COMPUTER SCIENCE

hci.rwth-aachen.de/Springlets

<https://www.youtube.com/watch?v=HsC4gcziDJ0>
(CHI2019) Springlets: Expressive, Flexible and Silent On-Skin Tactile Interfaces, Hamdan et al.

Skin Drag Displays



<https://www.youtube.com/watch?v=H-megrNfqDo>
(CHI2015) Skin Drag Displays: Dragging a Physical Factor across the User's Skin Produces a Stronger Tactile Stimulus than Vibrotactile, Ion et al.




Several skin drag type displays (2/2)



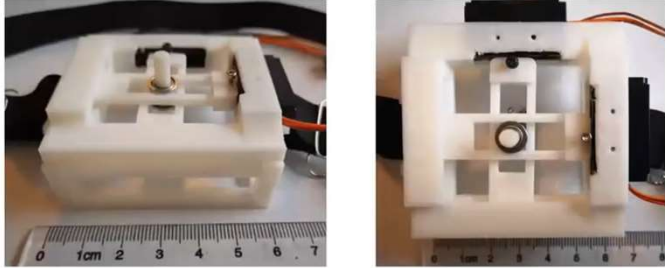
https://www.youtube.com/watch?v=9gRQG_QzbPg

CHI2021) GuideBand: Intuitive 3D Multilevel Force Guidance on a Wristband in Virtual Reality


Hsin-Ruey Tsai, Yuan-Chia Chang, Tzu-Yun Wei, Chih-An Tsao, Xander Koo, Hao-Chuan Wang, Bing-Yu Chen



Device design and actuation



- 3D printed, light-weighted, 25 g
- Low power consumption
- Dimension: 60 x 60 x 20 mm



inria CITS INSA RENNES IRISA

https://www.youtube.com/watch?v=A_L8dVo9nkQ&list=PLXRBbyxY9IBW4kMSsuq1KzEhzlkBKmUWj&index=6

(HS2022) L. Kuang, M. Aggravi, P. Robuffo Giordano, C. Pacchierotti, Wearable Cutaneous Device for Applying Position/Location Haptic Feedback in Navigation Applications



運動錯覚の利用 Application of Kinesthesia

K. Ushiyama, A. Takahashi, and H. Kajimoto: Increasing Perceived Weight and Resistance by Applying Vibration to Tendons During Active Arm Movements. Eurohaptics (2022)

TODAY's TOPIC

1. 力覚関連のメカニズム Haptic Perception Mechanism
2. 力覚ディスプレイの分類 Classifying Haptic Displays
3. 力覚ディスプレイの応用 Application of Haptic Interface



(再) 触覚ディスプレイの応用分野の方向性

Elements of application for tactile display

- **Touch Panel & Mobile**

- 市場が巨大。差別化要素としての触覚

- **Emotion, Affection**

- 触覚は驚きから愛情まで、幅広い情動へ働きかけることが出来る

- **Navigation, Instruction**

- 触覚は身体座標に直接提示できる。また無意識の運動も誘導できる

- **Reality, Multimodal**

- 触覚が視聴覚に加わることで存在感、現実感を上げることが出来る

- **The Whole Body**

- 身体全体への触覚提示により、触覚にも臨場感を生じる

- **Tactile AR**

- 触覚を現実世界で使うことでAR化する



力覚ディスプレイの応用分野の方向性

Elements of application for tactile display

- **Mobile**

- 市場が巨大。差別化要素としての触覚

- **Emotion, Affection, Communication**

- 力覚は皮膚感覚とともにコミュニケーションの要素となる

- **Navigation, Instruction**

- 力覚は身体座標に直接提示でき、皮膚感覚に比べ実際に正確に動かすこともできる。

- **Reality, Multimodal**

- 力覚は皮膚感覚とともに、存在感、現実感を上げることが出来る

- **The Whole Body**

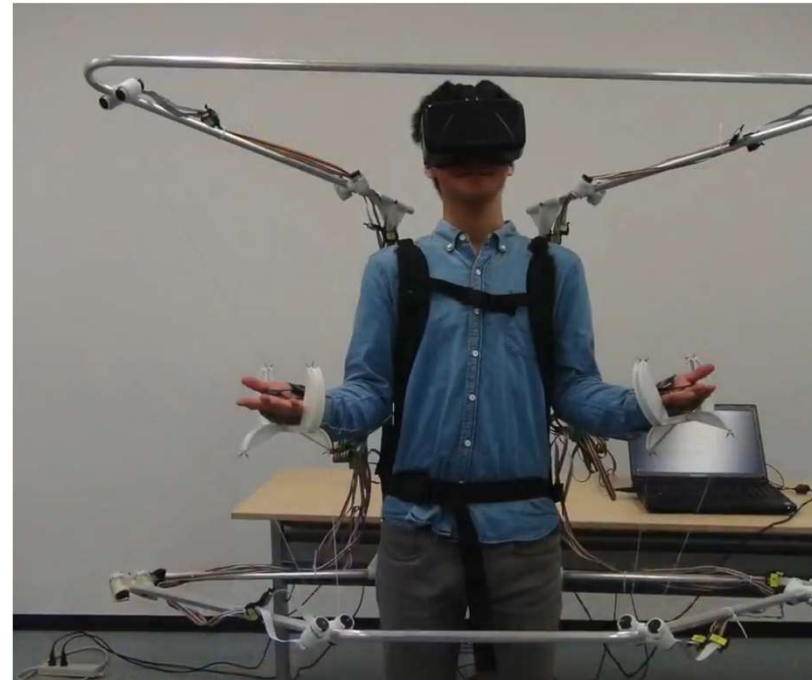
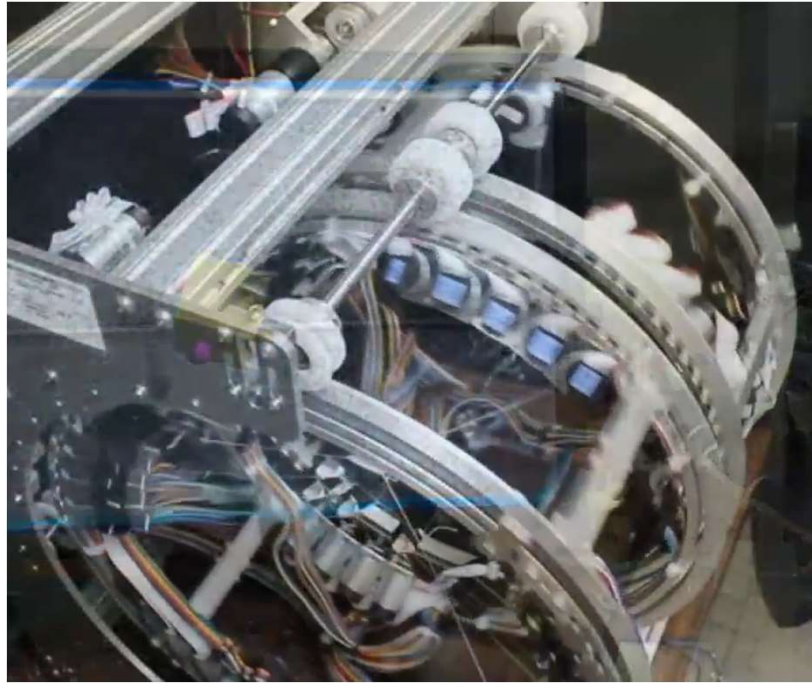
- 身体全体への力覚提示により、臨場感を生じる

- **Haptic AR**

- 力覚を現実世界で使うことでAR化する



全指・全身・モバイルSPIDAR



The Whole
Body

Navigation
Instruction

Mobile



<https://www.youtube.com/watch?v=ZUb4-g8J93k>

Remote mutual communication Robotic User Interface

Emotion, Affection, Communication



<http://files.tachilab.org/publications/intconf2000/Sekiguchi200412ICAT.pdf>
(ICAT2004) The Design of Internet-Based RobotPHONE, Sekiguchi et al.



inTouch: A Medium for Haptic Interpersonal Communication CHI 1997

<https://tangible.media.mit.edu/project/intouch/>



https://www.youtube.com/watch?v=qygCh35_oBA
(CHI2012) PINOKY: a ring that animates your plush toys. Sugiura et al.



<https://www.youtube.com/watch?v=gVkJL-G2biE>
(AsiaHaptics2014) Force Control of Stuffed Toy Robot for Intention Expression, Kleawsirikul et al.



内視鏡手術シミュレータ Laparoscopic Surgery Simulator

Navigation,
Instruction



ロボット遠隔手術／Robotic Tele-Surgery: da Vinci



<https://www.youtube.com/watch?v=QksAVT0YMEo>

da Vinci: 製品としては力の提示なし。人の入力から振動を除く等のサポートはあり。
研究としては力覚提示各種あり。

daVinci: No force presentation. Low pass filtering of human input to eliminate vibration.



指を駆動して情報提示 Display by actuation

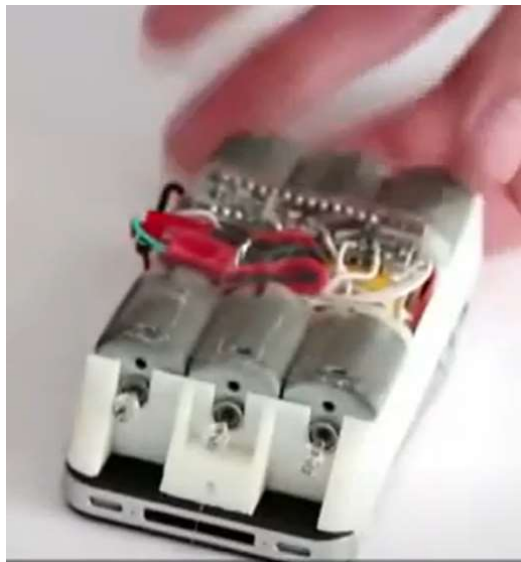
Navigation
Instruction
Mobile



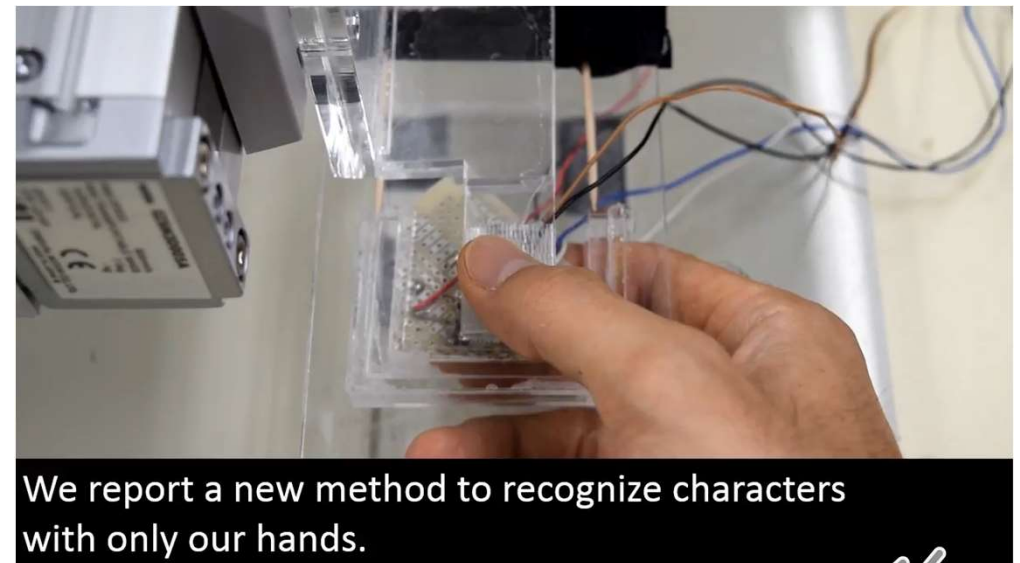
<https://www.youtube.com/watch?v=xxA08dxP-zl>



Hasegawa et al., Character Reading via Stylus Reproducing Normal Handwriting Motion, IEEE Trans. On Haptics, 2016.



A. Roudaut et al., "Gesture output: Eyes-free output using a force feedback touch surface", CHI2013



<https://www.youtube.com/watch?v=Nu7n5EcZkMs>
Yoshida et al. Character Recognition by Flick Movements Presented on Fingers, AsiaHaptics2016.

ロボットトレーニング：ゴルフ Robot Golf Training

Navigation,
Instruction



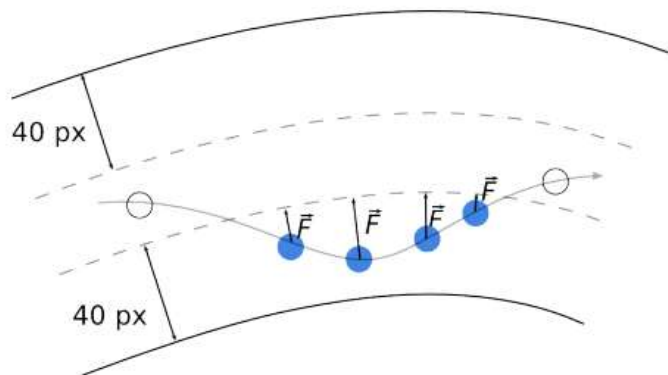
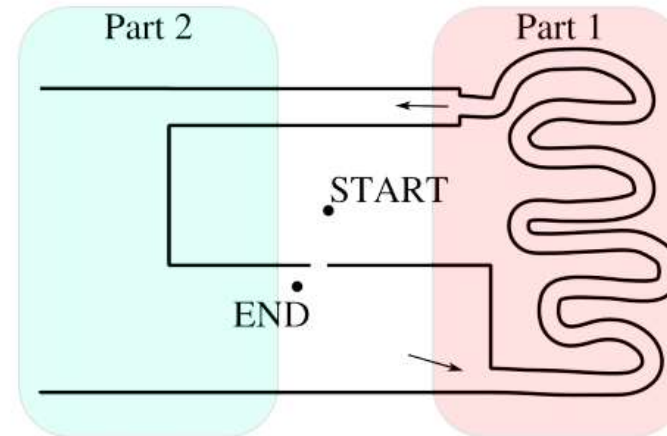
<http://robogolfpro.com/>



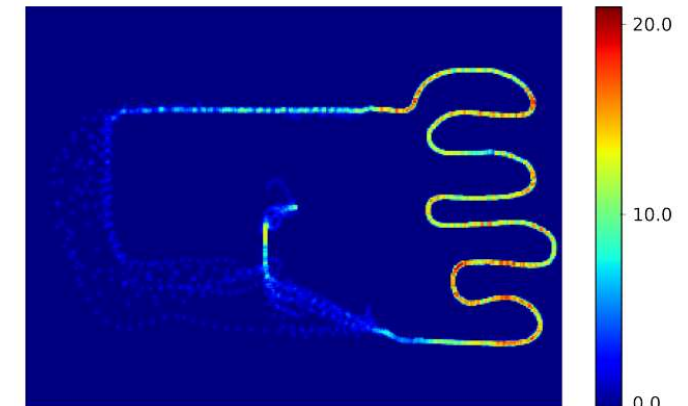
難易度の自動調整

Adjustment of difficulty

Navigation,
Instruction



○	Cursor (assistance disabled)
●	Cursor (assistance enabled)
\vec{F}	Assistance force (repulsive)
- - -	Min distance for assistance
—	Border



- 触覚ガイドの強さを、脳活動に応じて変化させる。
- 難しい所にさしかかると自動的に重くなる。



(CHI2021) Preserving Agency During Electrical Muscle Stimulation Training Speeds up Reaction Time Directly After Removing EMS

Shunichi Kasahara, Kazuma Takada, Jun Nishida, Kazuhisa Shibata, Shinsuke Shimojo, Pedro Lopes

Navigation,
Instruction



<https://www.youtube.com/watch?v=cPa71vVQBxs>

- 筋電気刺激で応答速度を早める際に、自己主体感 (Agency) を維持して早めた (参加者自身の反応速度より少しだけ早める) 場合にトレーニング効果があった。



触れない物を触る

Touching the non-touchable by sensory conversion



<https://youtu.be/GaOtiDuvngE>

野嶋 琢也, 関口 大陸, 稲見 昌彦, 舘 暲: 力覚提示を利用した実時間実環境作業支援システムの提案, 日本バーチャルリアリティ学会論文誌, Vol.7, No.2, pp.193-200 (2002.5)



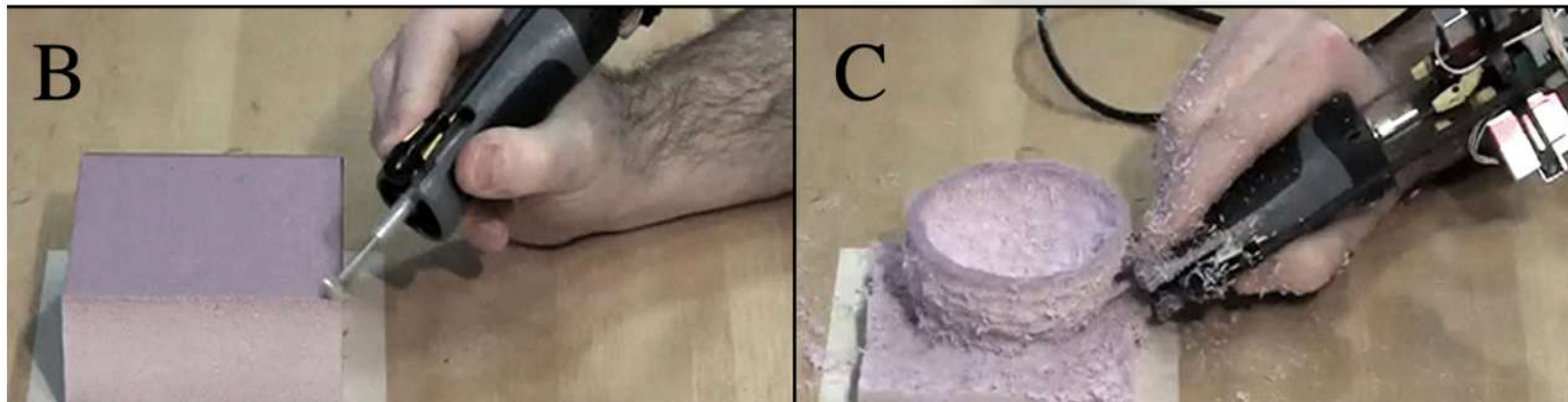
Haptic AR(2): カセンサと制御により柔らかさを劇的に変える

Stiffness Modulation by using force sensor and impedance control

Haptic AR



定規（自由度拘束）としてのHaptic AR Haptic AR as a ruler (reducing DoF)



http://web.media.mit.edu/~amitz/Research/Entries/2011/11/15_FREE-D.html

Zoran et al.: FreeD – A Freehand Digital Sculpting Tool, CHI2013

運慶は今太い眉を一寸の高さに横へ彫り抜いて、鑿の齒を豎に返すや否や斜に、上から槌を打下した。堅い木を一刻に削って、厚い木屑が槌の声に応じて飛んだと思ったら、小鼻のおっ開びらいた怒り鼻の側面がたちまち浮き上がって来た。その刀の入れ方がいかにも無遠慮であった。そして少しも疑念を挟しはさんでおらんように見えた。

「よくああ無造作に鑿を使って、思うような眉や鼻ができるものだな」と自分はいあまり感心したから独言のように言った。するとさっきの若い男が、「なに、あれは眉や鼻を鑿で作るんじゃない。あの通りの眉や鼻が木の中に埋まっているのを、鑿と槌の力で掘り出すまでだ。まるで土の中から石を掘り出すようなものだからけっして間違はずはない」と云った。

自分はこの時始めて彫刻とはそんなものかと思ひ出した。はたしてそうなら誰にでもできる事だと思ひ出した。それで急に自分も仁王が彫ってみたくなくなったから見物をやめてさっそく家へ帰った。（夏目漱石「夢十夜」第六夜より抜粋）

(UIST2020) HandMorph: a Passive Exoskeleton that Miniaturizes Grasp
Jun Nishida, Soichiro Matsuda, Hiroshi Matsui, Shan-Yuan Teng, ziwei Liu,
Kenji Suzuki, Pedro Lopes

Haptic AR

HandMorph: a Passive Exoskeleton that Miniaturizes Grasp

Jun Nishida | Soichiro Matsuda
Hiroshi Matsui | Shan-Yuan Teng
Ziwei Liu | Kenji Suzuki | Pedro Lopes



x1.5 speed



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

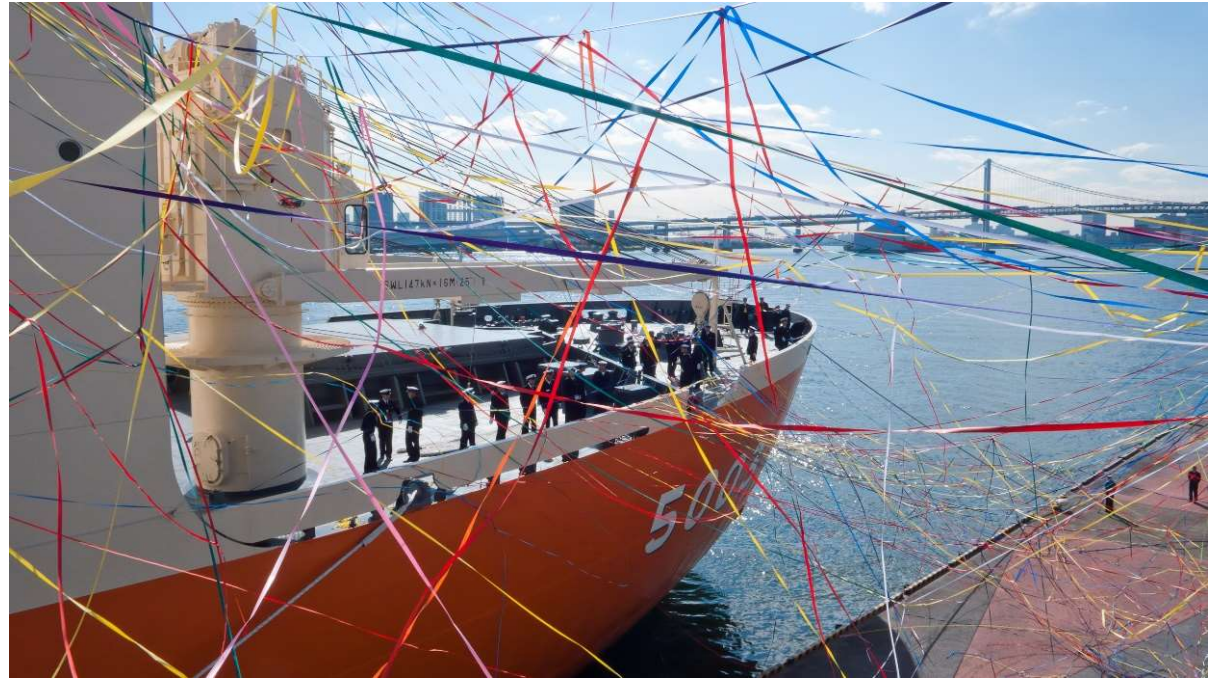
- IVRC発の作品。手を小さくするパッシブデバイス。



(参考) 触覚VR事始め？
When people really need haptics.



国宝 山越阿弥陀図



<https://ja.wikipedia.org/wiki/%E7%B4%99%E3%83%86%E3%83%BC%E3%83%97>



コロナ患者の手握る「神の手」 ブ
ラジル発のケアに注目
<https://www.asahi.com/articles/ASP4K3RC9P4KUHBI00M.html>

平安時代、極楽往生を願う者が臨終の際、横たわりながら、仏像や仏画の手から伸びた五色の糸を手にした。

In the Heian period, when people were on their deathbed, they would lie down and hold in their hands a five-colored thread that extended from the hand of a Buddhist statue or painting.



小テスト：一週間以内に提出

Mini Test: Submit in one week

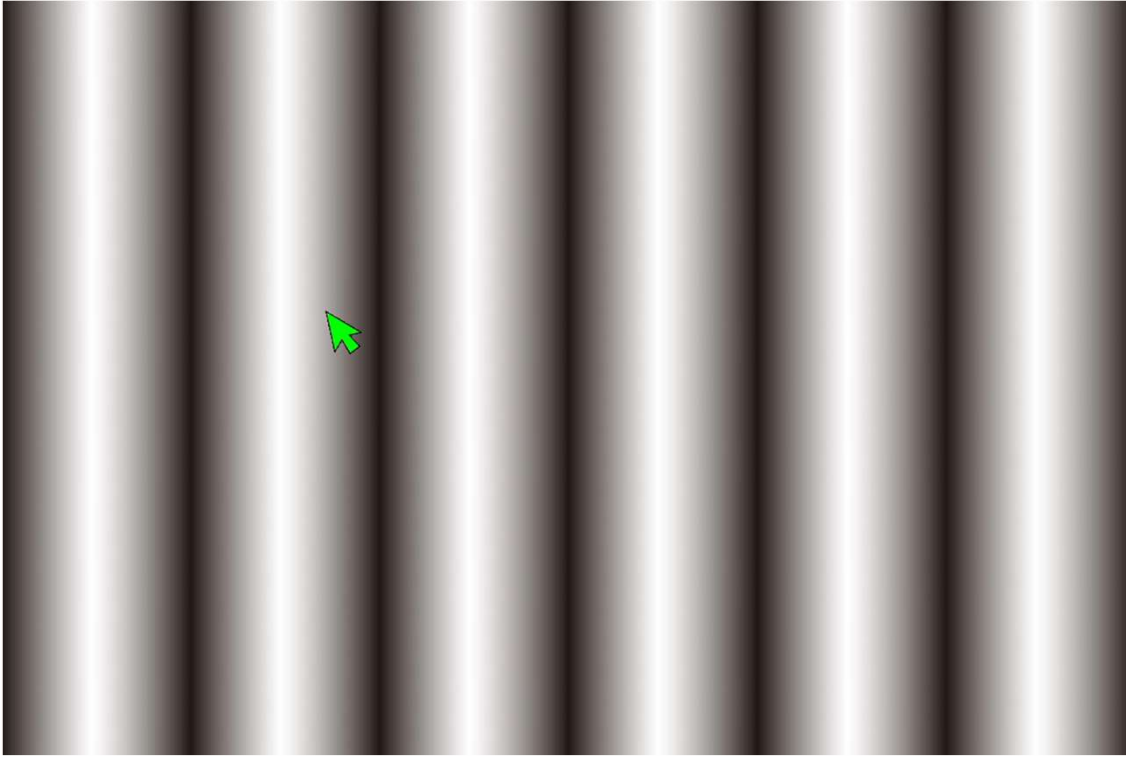
以下の全てに100字以内程度で解答せよ / Answer all questions within 50 words

- 1.拮抗筋構造の利点について説明せよ Explain merit of antagonistic muscle structure.
- 2.筋紡錘の役割について説明せよ Explain role of muscle spindle
- 3.ゴルジ腱器官の役割について説明せよ Explain role of Golgi tendon organ.
- 4.サイズ-重さ錯覚について説明せよ Explain size-weight illusion.
- 5.シュードハプティクスについて説明せよ Explain pseudo-haptics illusion
- 6.ラバーバンドイリュージョンについて説明せよ Explain rubber-hand illusion
- 7.幻肢痛について説明せよ Explain phantom pain.
- 8.ハンガー反射について説明せよ Explain hanger reflex
- 9.遭遇型ハプティックデバイスについて説明せよ Explain encounter type haptic device.
- 10.装着型ハプティックデバイスについて説明せよ Explain wear type haptic device.
- 11.装着型と把持型のハプティックデバイスの違いについて説明せよ Explain difference between wear type and grip type haptic device.
- 12.バックドライバビリティについて説明せよ Explain back-drivability



実験レポート：錯覚の体験

Report: Try some haptic 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。
 - Pseudo Haptics：サンプルコードを使ってよい。使わなくてもよい。時間があれば写真を変えてみる。マウスを使うのが本来だがタッチパッドだとどうか。
 - Rubber Hand (finger) illusion
- Experience the following illusions introduced in class. In your report, you will include pictures of your experience and describe the results.
 - Pseudo Haptics: You can use the sample code (or may write your own code) . Change photos if you have time. Mouse is recommended but how about touchpad?
 - Rubber Hand (finger) illusion

