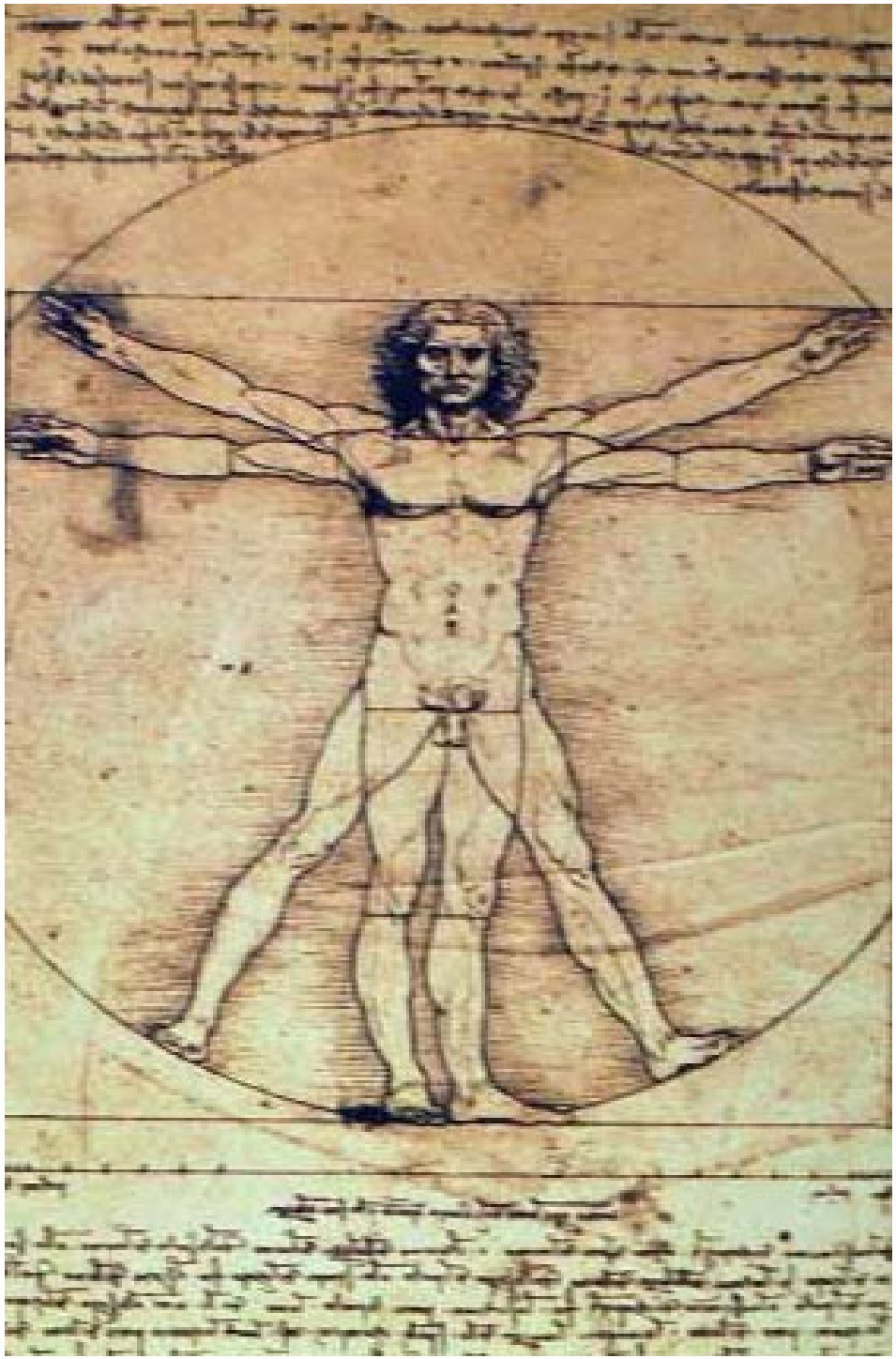

Interactive System
インタラクティブシステム特論 (8)

Hiroyuki Kajimoto
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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

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

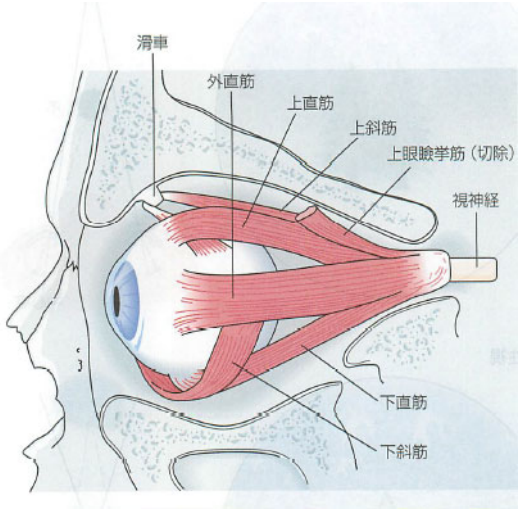
1. 人間計測手法／Measuring Human
2. 視覚／Human Vision System
3. 視覚センシング／Visual Sensing
4. 視覚ディスプレイ／Visual Display
5. 聴覚、聴覚インタフェース／Auditory Interface
6. 触覚、触覚インタフェース／Tactile Interface
7. 触覚、触覚インタフェース2／Tactile Interface
8. 力覚、力覚インタフェース／Haptic Interface
9. 移動感覚インタフェース／Locomotion Interface

TODAY’s TOPIC

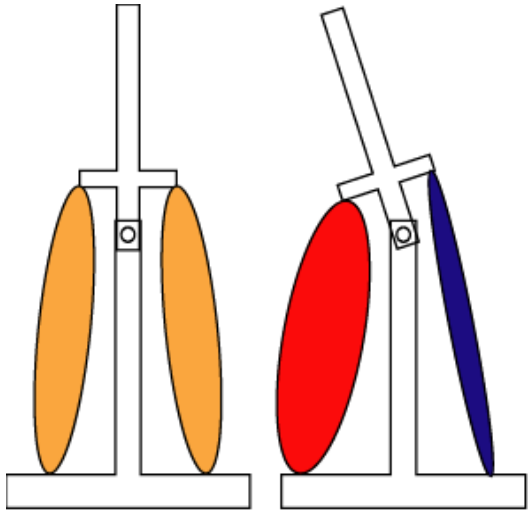
1. 力覚関連のメカニズム Haptic Perception Mechanism
2. 力覚ディスプレイの分類 Classifying Haptic Displays
3. 力覚ディスプレイの応用 Application of Haptic Interface

Antagonistic muscle pairs 拮抗筋

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

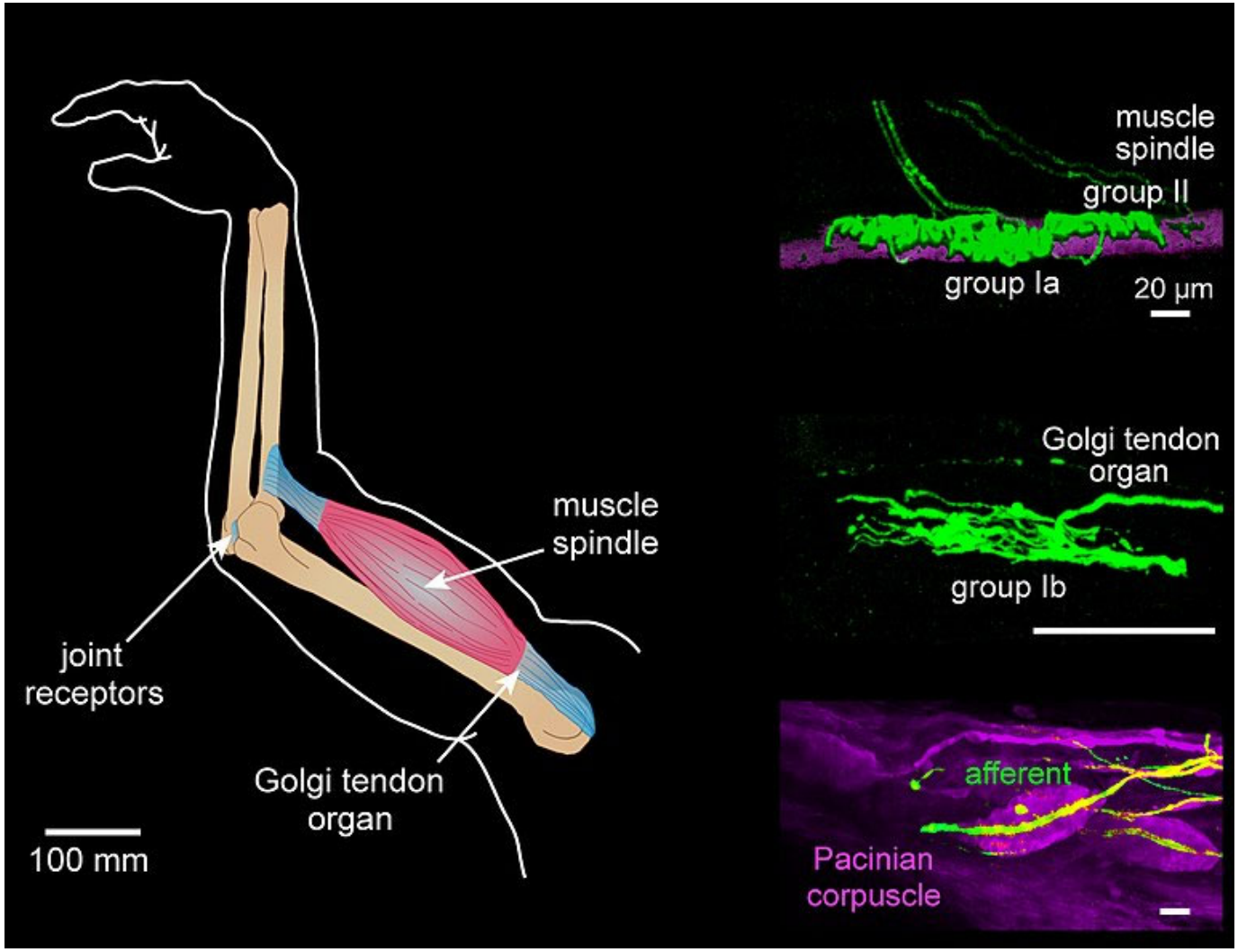


カンデル神経科学(Principles of Neural Science)
https://www.medsi.co.jp/kandel/syousai/index.html



- 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.

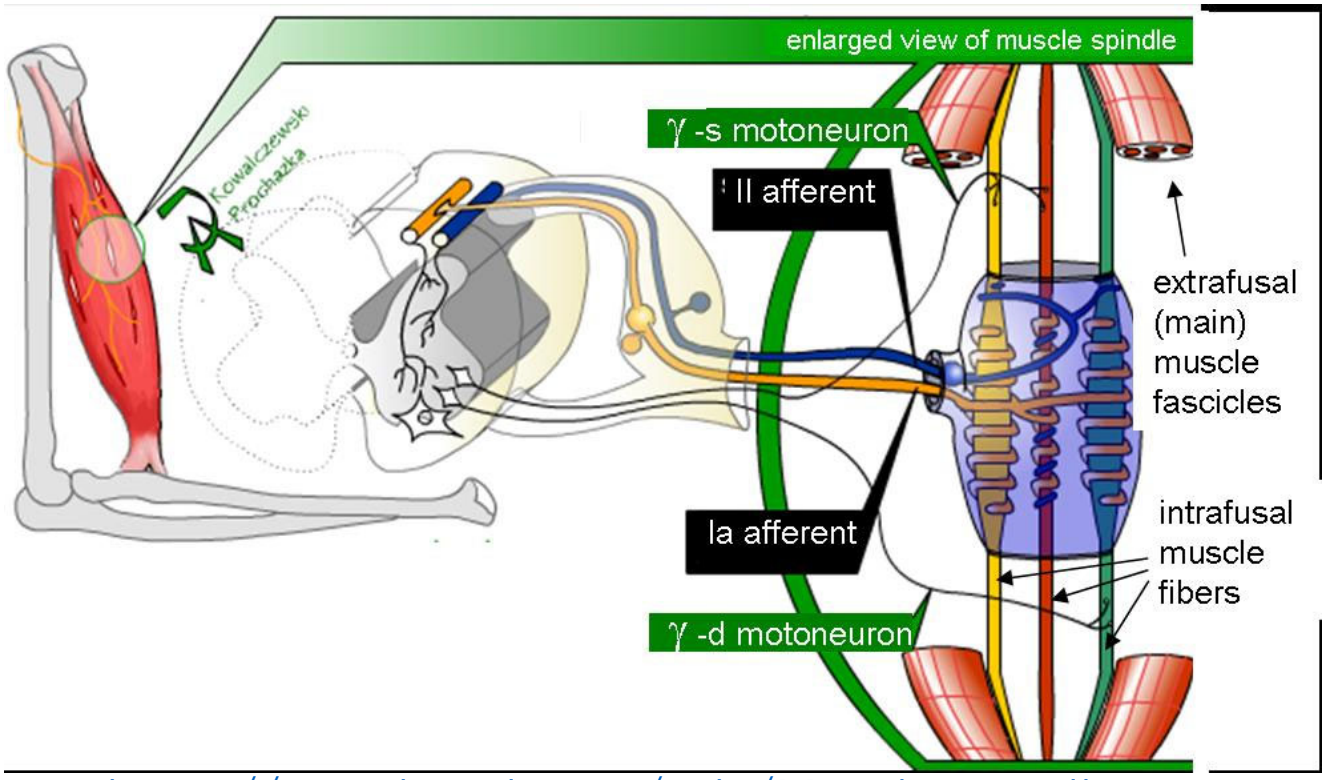
Receptors around Muscle and Joint



- 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

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

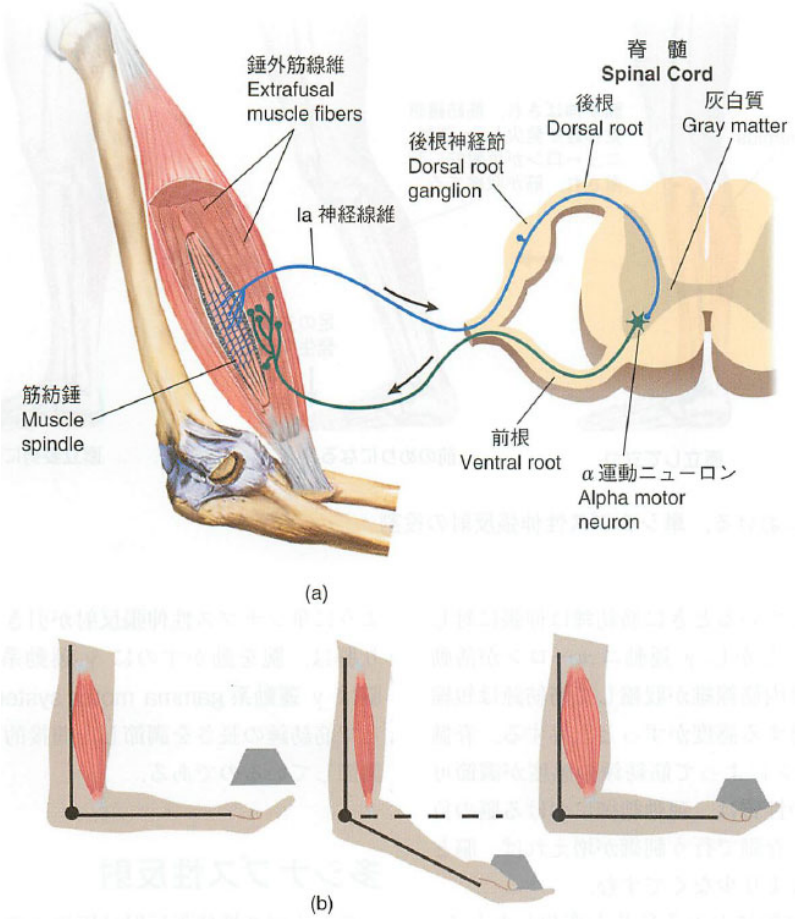
筋紡錘 Muscle Spindle

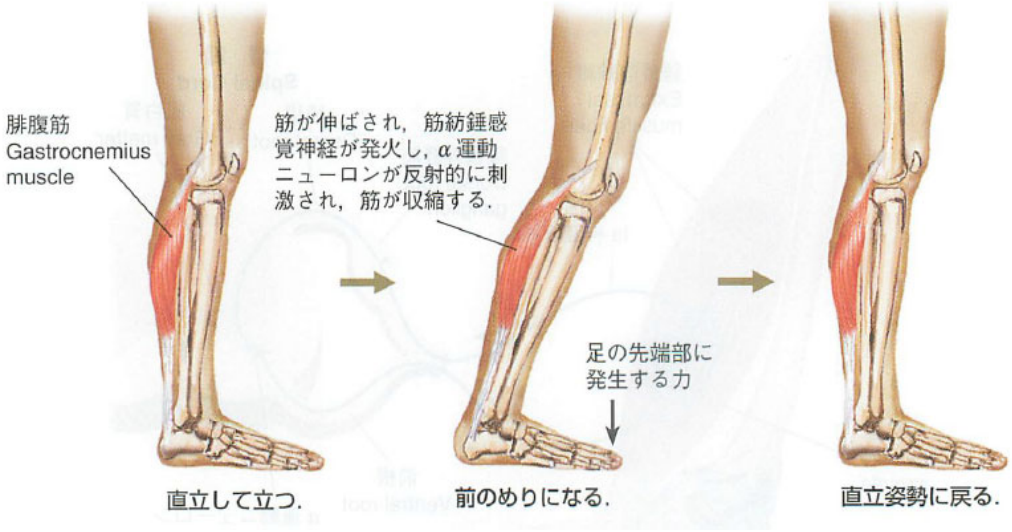


https://en.wikipedia.org/wiki/Muscle_spindle

- 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

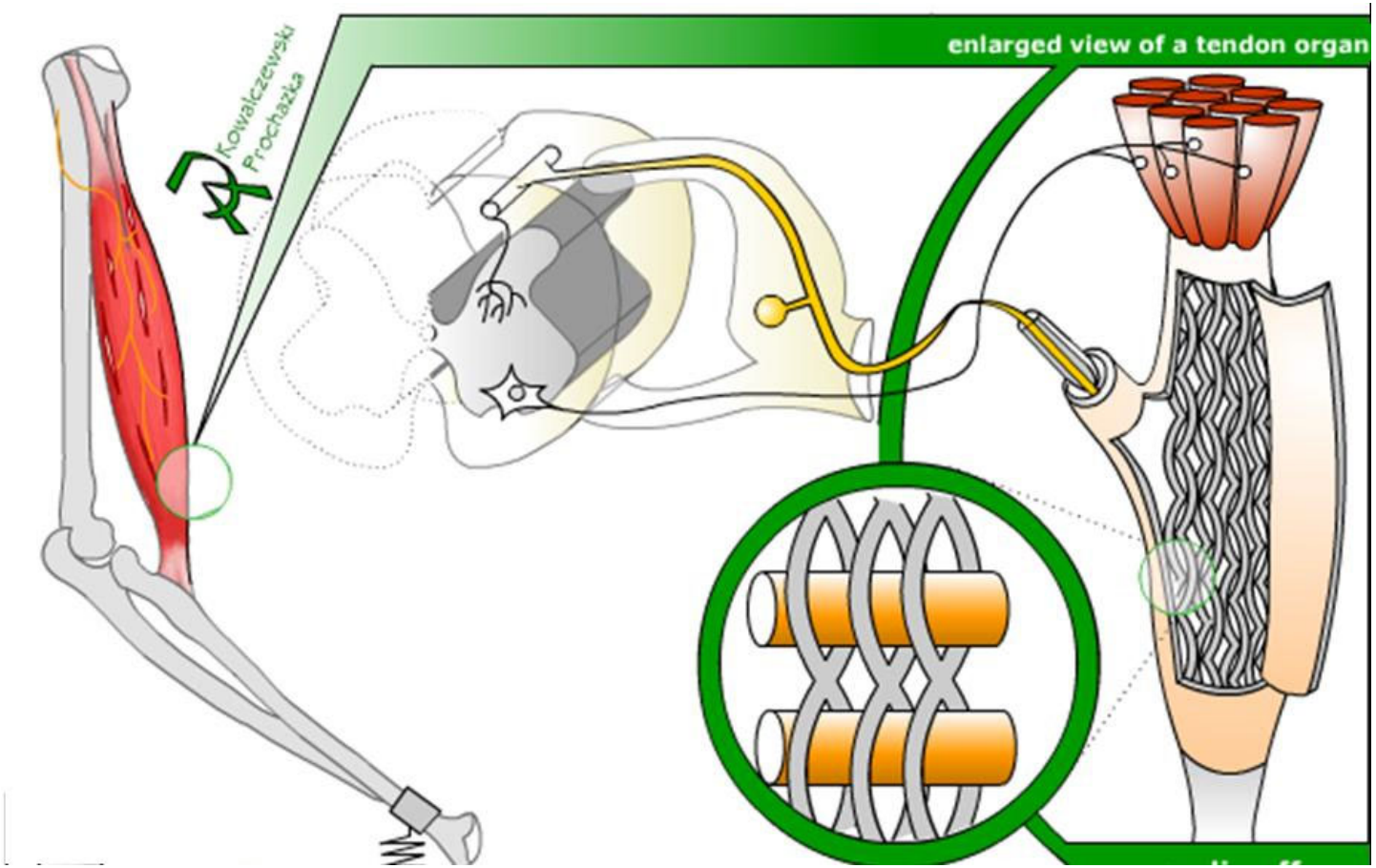


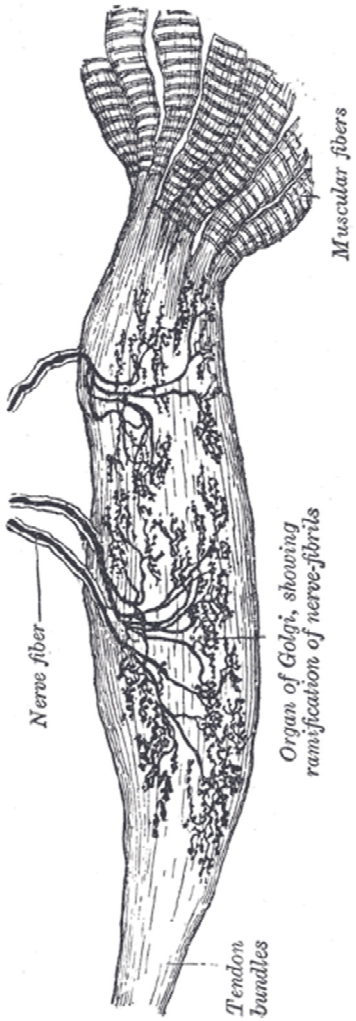


カールソン神経科学テキスト(Physiology of Behavior)
https://www.maruzen-publishing.co.jp/item/b294439.html

- 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

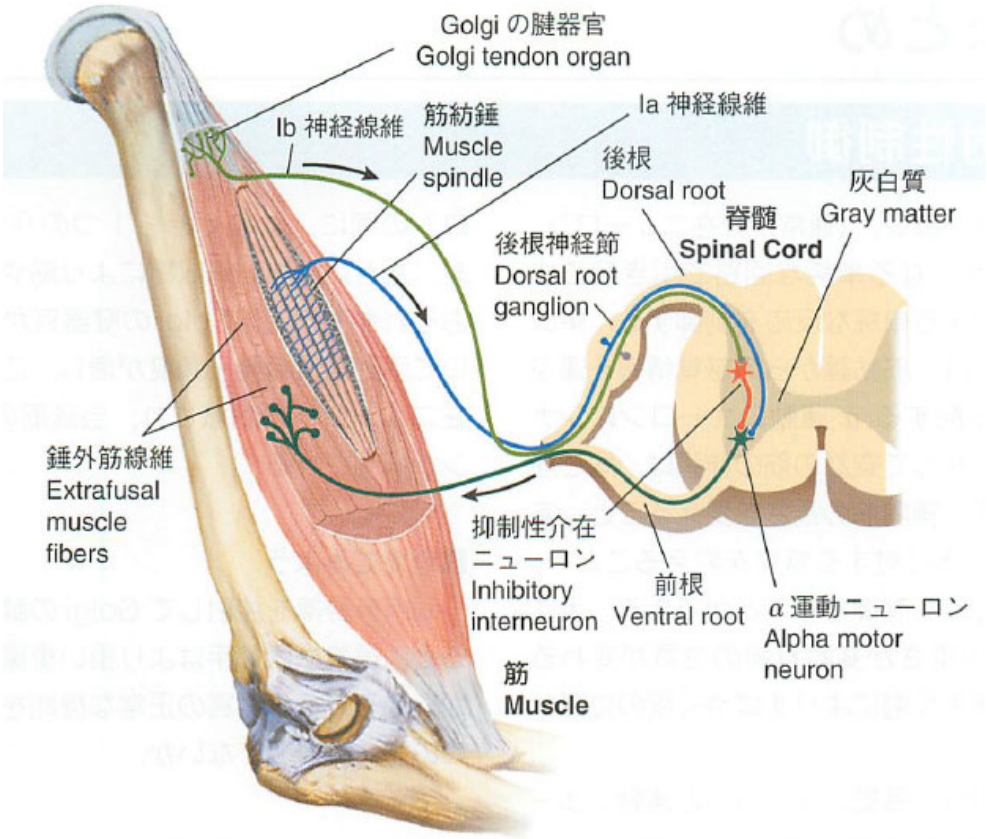




https://en.wikipedia.org/wiki/Golgi_tendon_organ

- 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

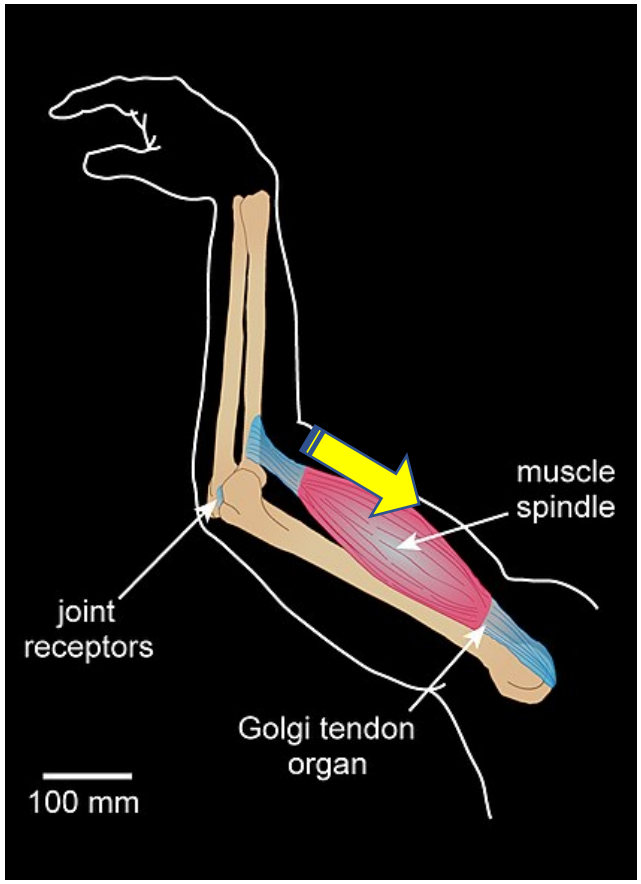
- ゴルジ腱器官に伸張刺激が加わると刺激が加わった筋の緊張が低下する
- 同時に拮抗筋の活動も生じる
- When a stretching stimulus is applied to the Golgi tendon organ, the tension in the stimulated muscle is reduced. Antagonistic muscle activity occurs simultaneously.

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

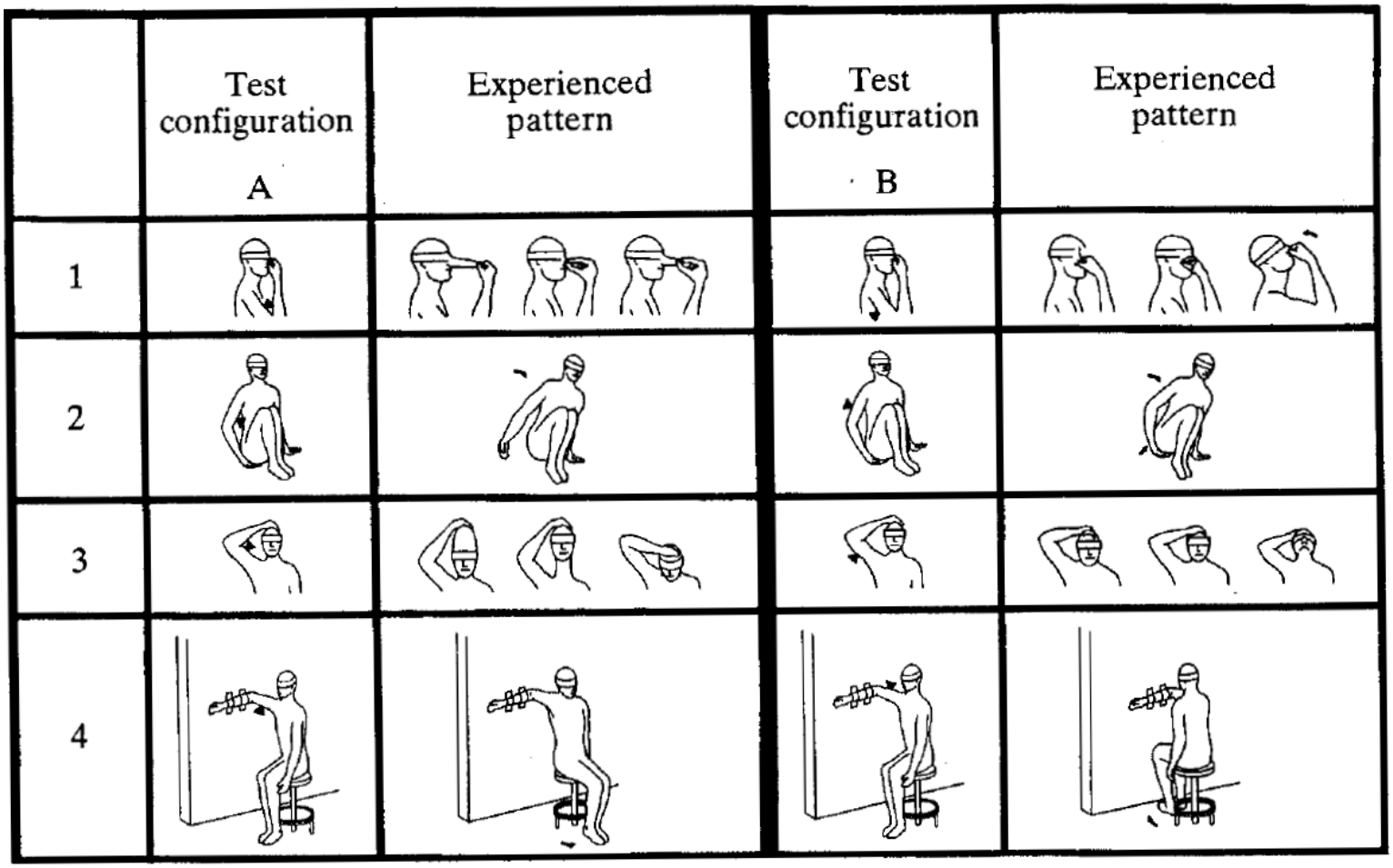
腱振動による運動錯覚 kinetic illusion by tendon vibration

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(Burke1976他)
- インタフェースとしての提案多(友田2009, Roll2009,Leonardis2012)
- 強力な振動子が必要⇒強烈な振動感

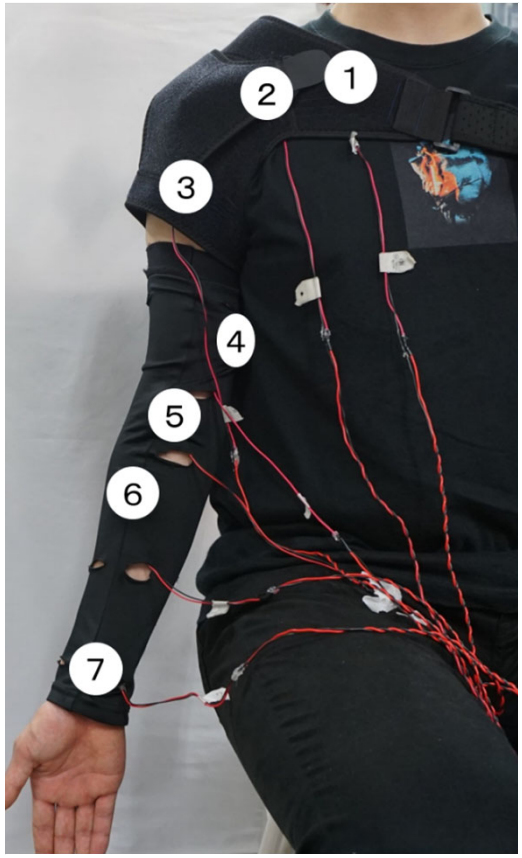
運動錯覚による身体変容
Influences of body shape and orientation by

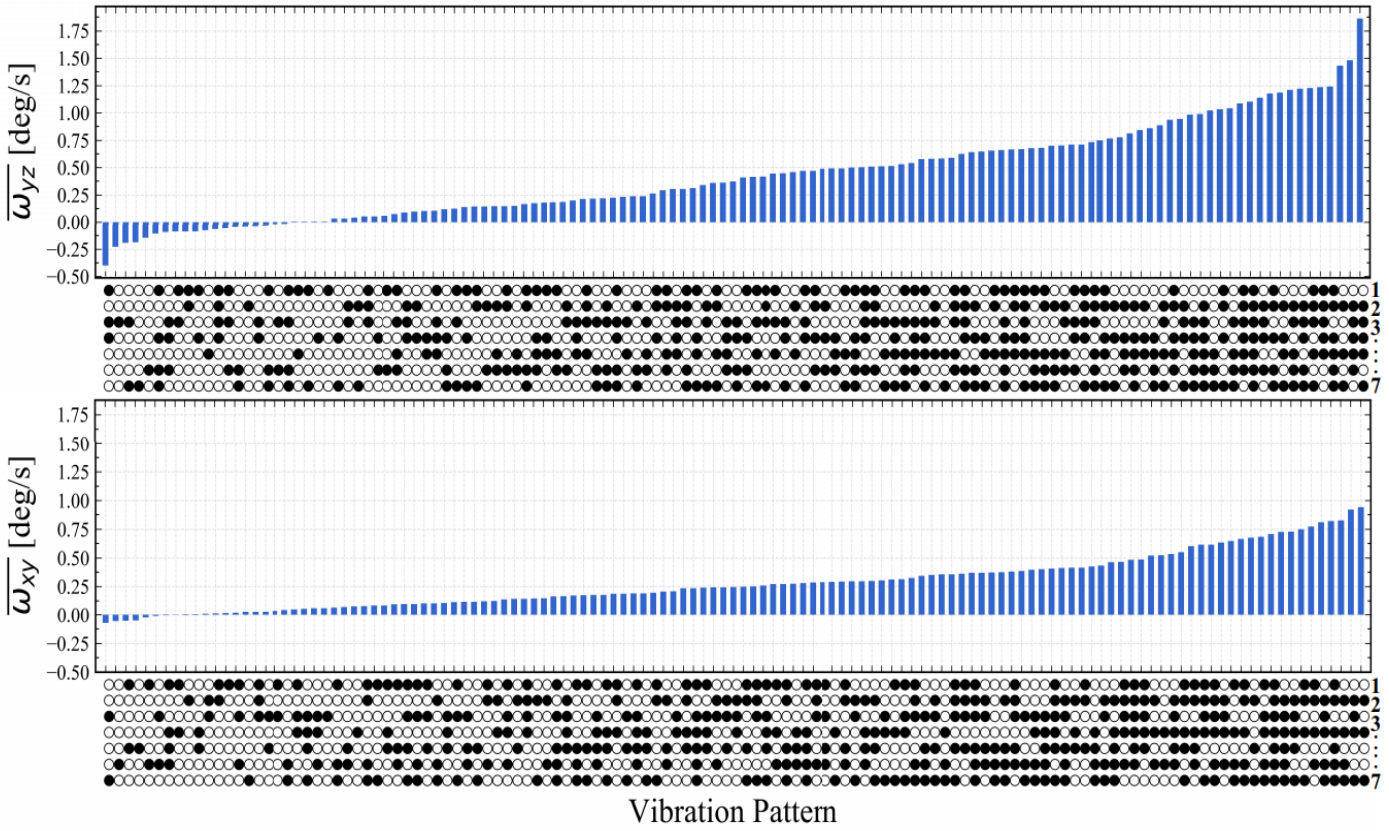


Some Proprioceptive Influences on the Perceptual Representation of Body Shape and Orientation," J. R. Lackner, 1988, Brain

- 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

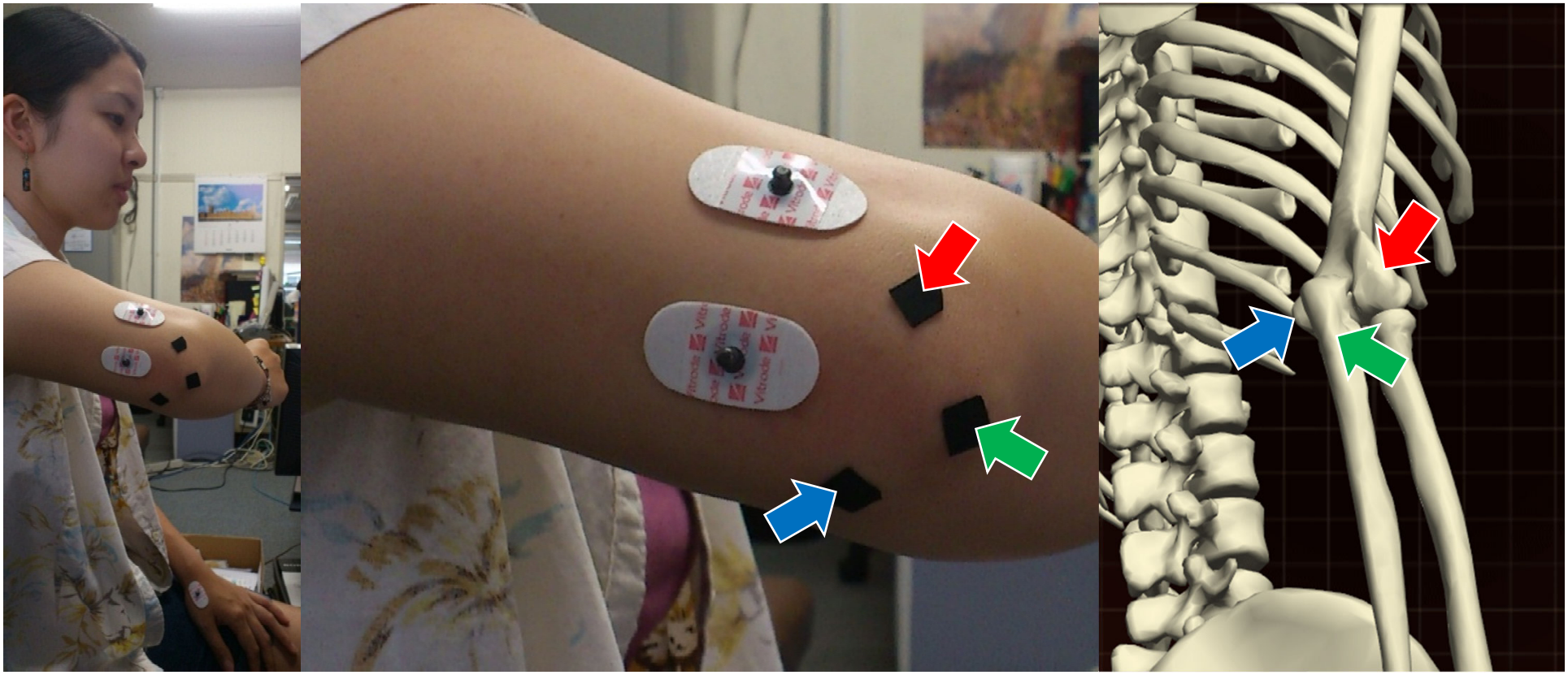
Keigo Ushiyama, Satoshi Tanaka, Akifumi Takahashi, and Hiroyuki Kajimoto. The Effects of Simultaneous Multi-Point Vibratory Stimulation on Kinesthetic Illusion. Eurohaptics 2020



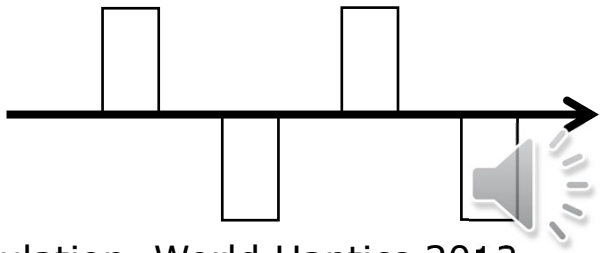


- 運動には多数の協働筋あり。複数の筋で同時に運動錯覚を生じさせることで運動錯覚をより増強させることが出来る。
- THERE ARE MANY COOPERATING MUSCLES IN MOTION. THE ILLUSION OF MOVEMENT CAN BE ENHANCED BY STIMULATING MULTIPLE MUSCLES SIMULTANEOUSLY.

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



Kajimoto: Illusion of Motion Induced by Tendon Electrical Stimulation. World Haptics 2013

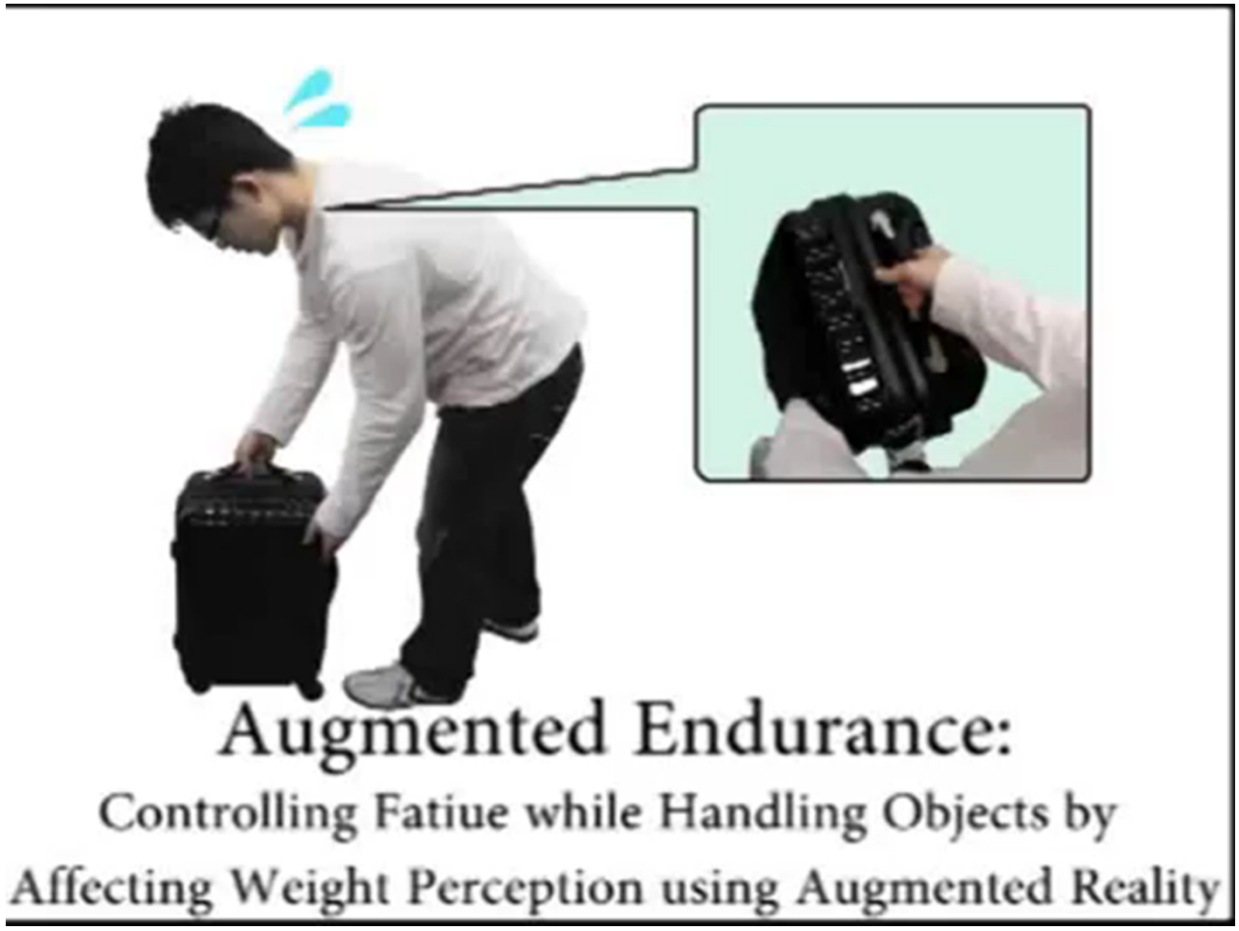
右腕を刺激、左腕で姿勢を模擬（閉眼）

閉眼、右腕腱刺激、なるべく力を抜いて腕を前に突き出す

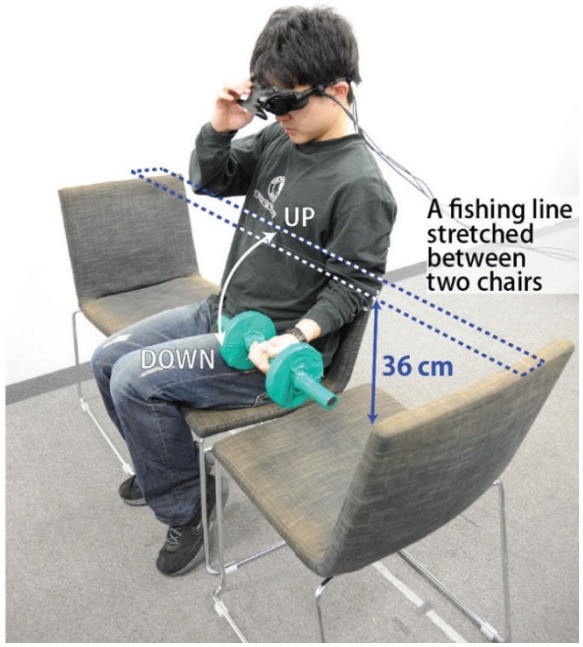
視覚によるハプティック錯覚 (1)：サイズ-重さ錯覚
Vision Induced Haptics(1): Size-Weight Illusion

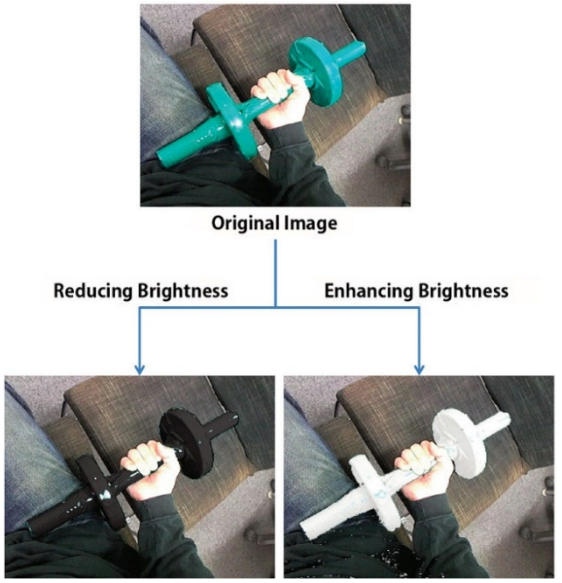
同じ重量なら小さいものをより重く感じる（家でやりましょう）
If two objects are the same weight, smaller one felt heavier.

明度⇒重さ知覚



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





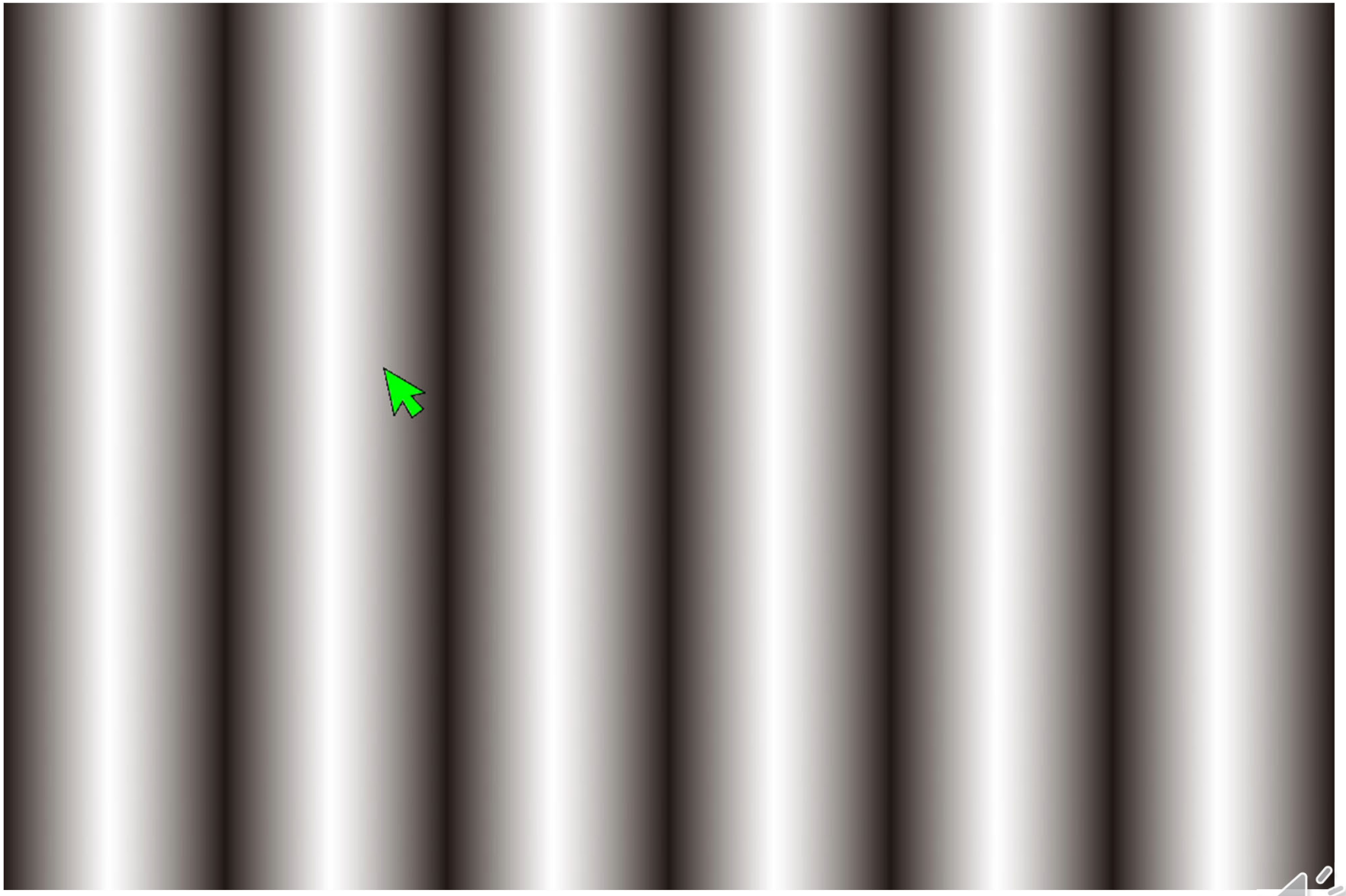
Ban et al.: Augmented Endurance: Controlling Fatigue while Handling Objects by Affecting Weight Perception using Augmented Reality, CHI2013.

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

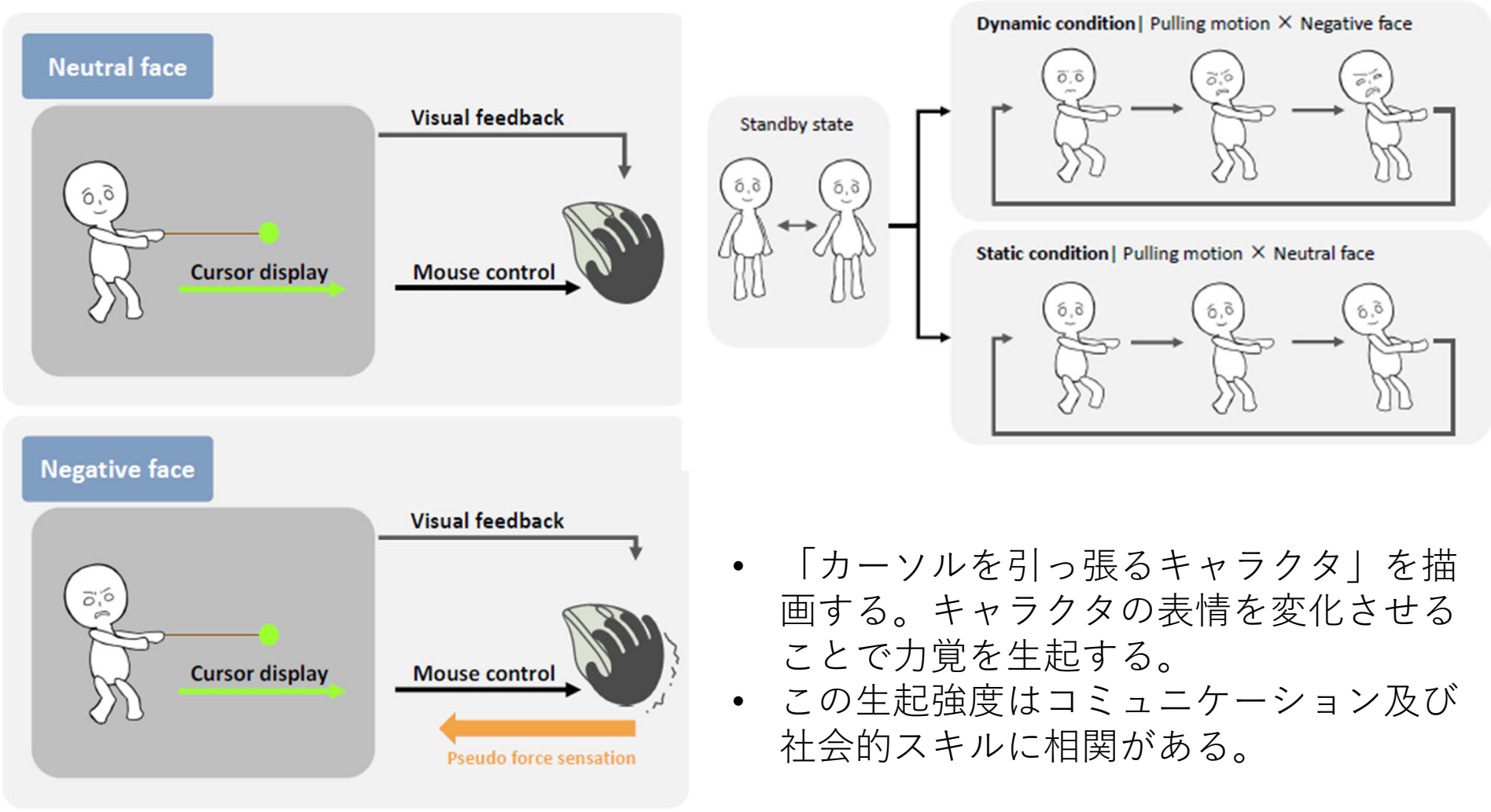
PseudoHaptics



https://github.com/HiroyukiKajimoto/PseudoHaptics

（家でやりましょう）

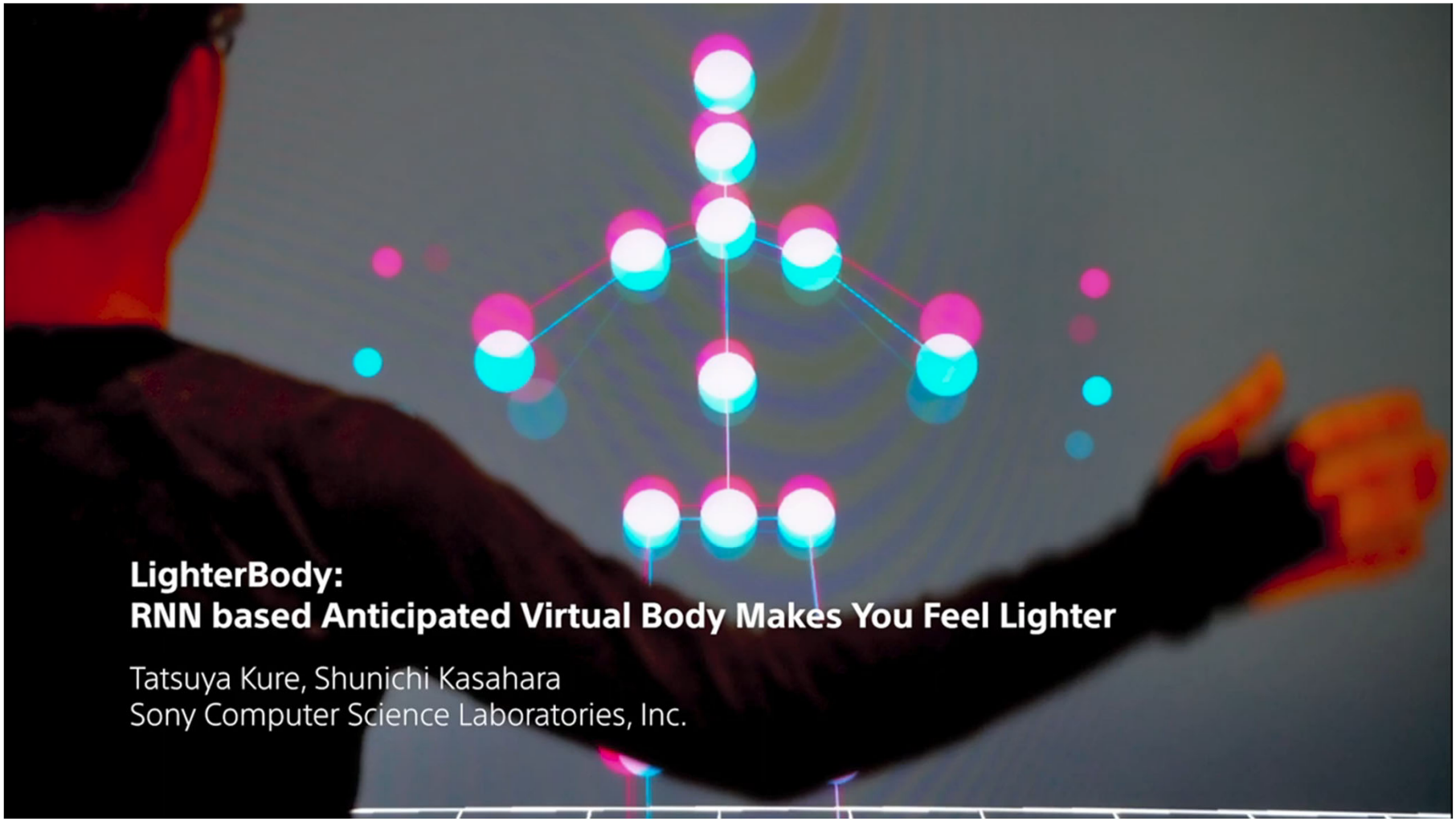
「共感」とPseudoHaptics/ Sympathy and PseudoHaptics



- 「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。

松山他：エージェントの表情変化により生起する力覚の評価, 2022 VRSJ

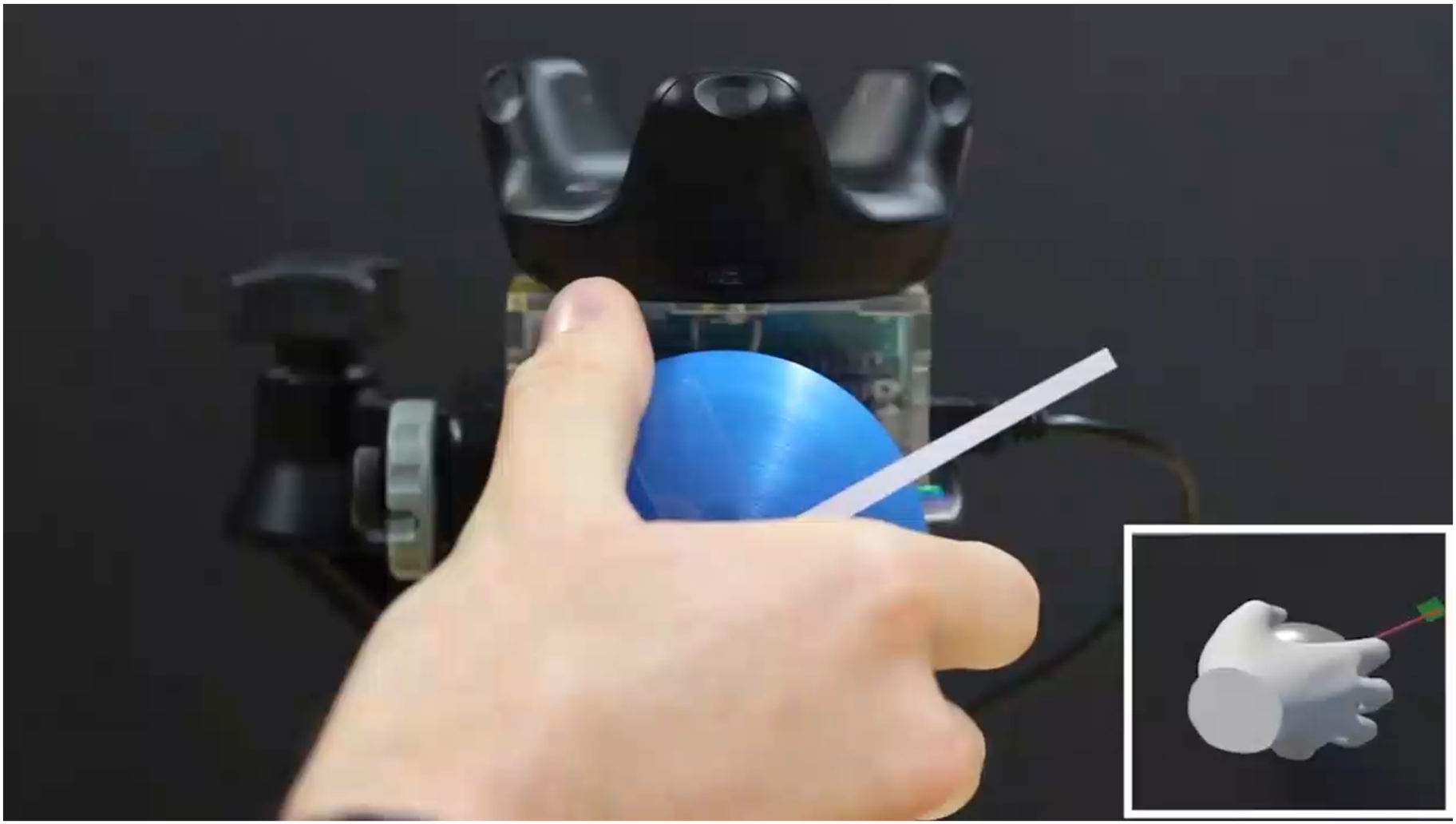
(IEEEVR2021 Poster) Tatsuya Kure, Shunichi Kasahara
LighterBody: RNN based Anticipated Virtual Body Makes You Feel Lighter



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

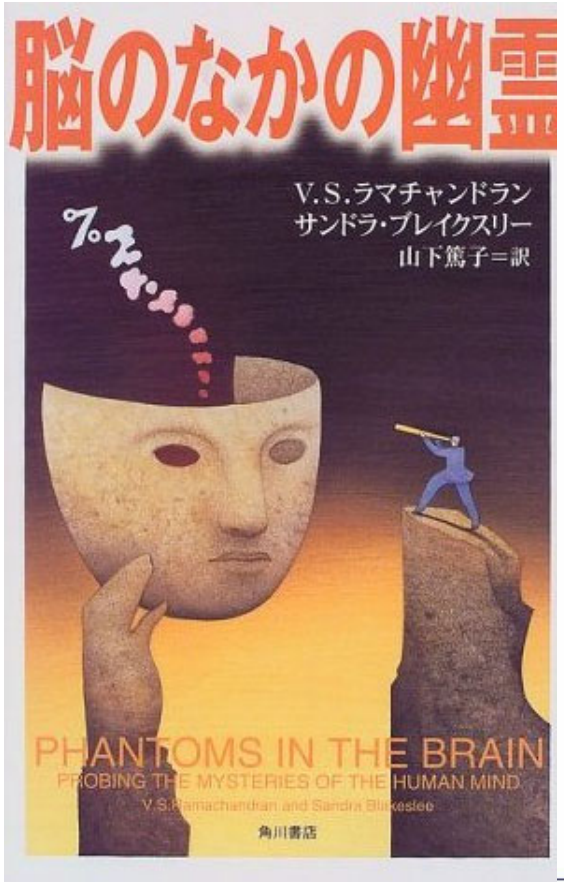
- 自分の身体の動きをRNNで予測させ、100ms早く描画すると身体が軽くなったように感じる。
- If you let the RNN predict your body's movement and draw it 100ms earlier, you will feel like your body is lighter.

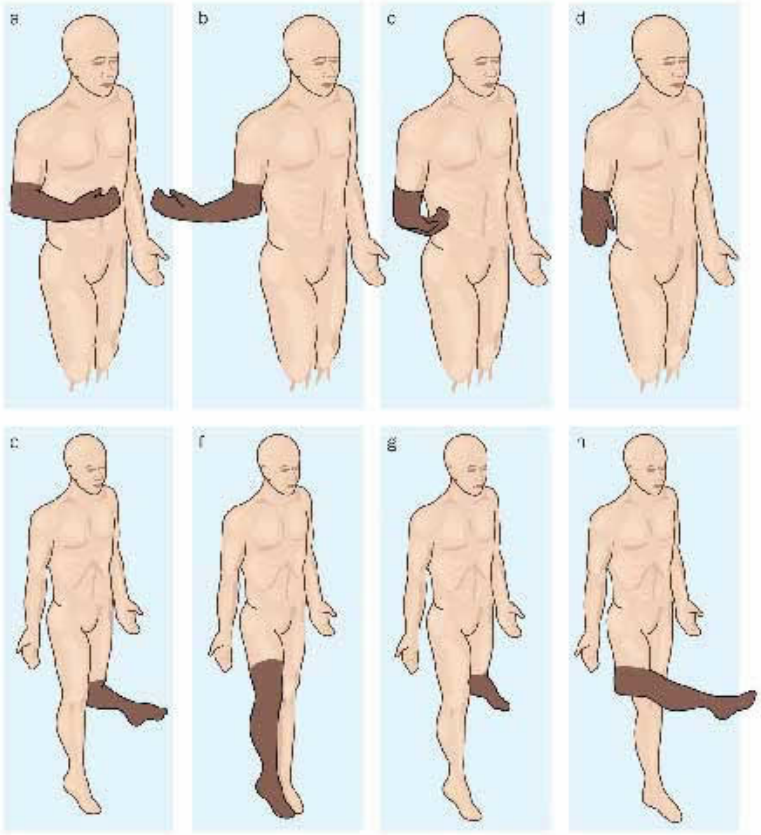
(UIST2023)Turn-It-Up: Rendering Resistance for Knobs in Virtual Reality through Undetectable Pseudo-Haptics
Martin Feick, André Zenner, Oscar Ariza, Anthony Tang, Cihan Biyikli, Antonio Krüger
https://www.youtube.com/watch?v=p9WoxkGJ_10



ノブの感触をPseudoHapticsで提示

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

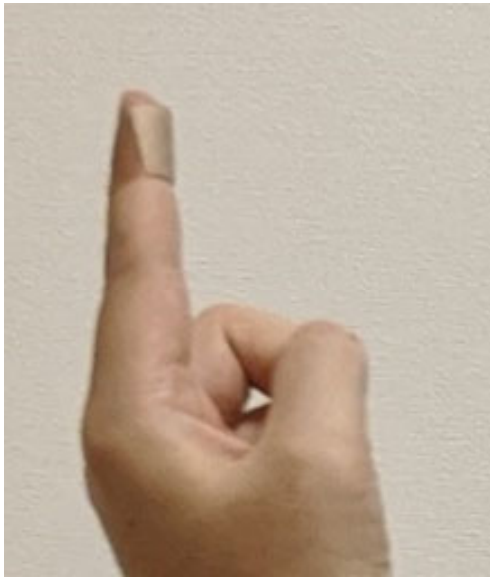
幻肢痛：手足を失った後に、切断部位は問題ないのに激しい痛みを感じる現象。
ひとつの仮説：失った手足の脳内座標(ボディマップ)が狂い、体内に「食い込む」ことで脳内で痛みシグナルが発生。姿勢をもとに戻せないために痛みを生じ続ける。

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

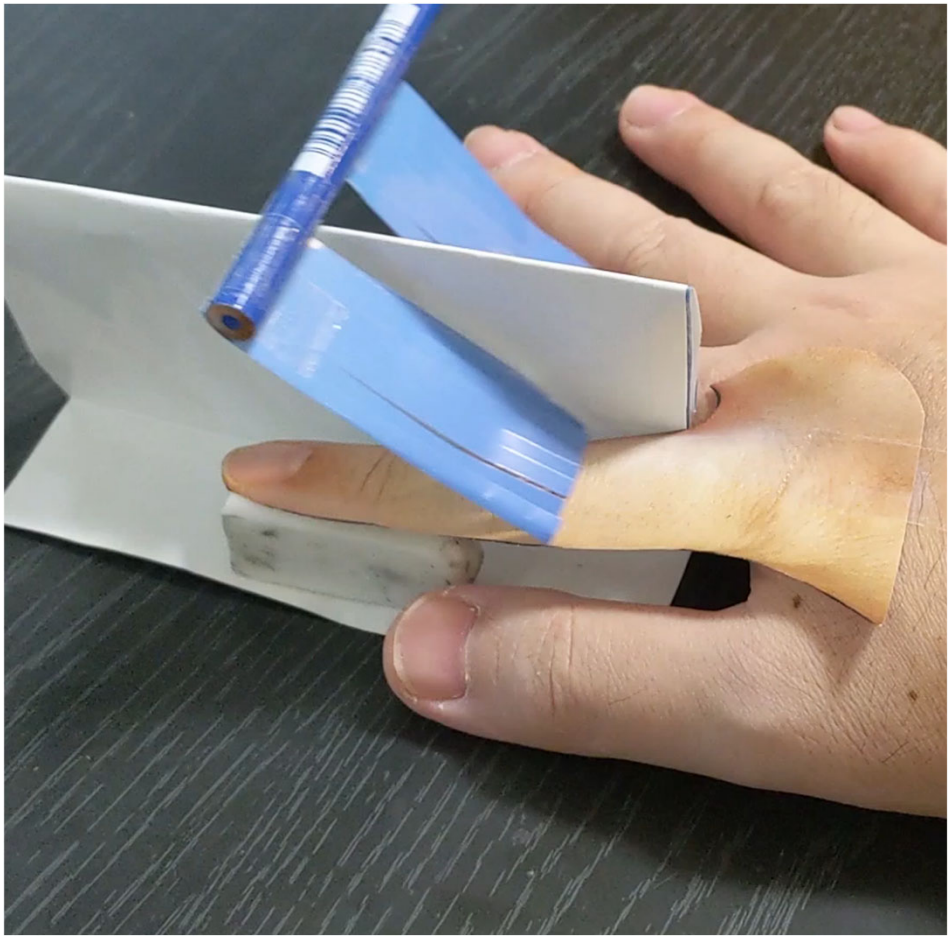
http://www.youtube.com/watch?v=nzF_DfOafKw

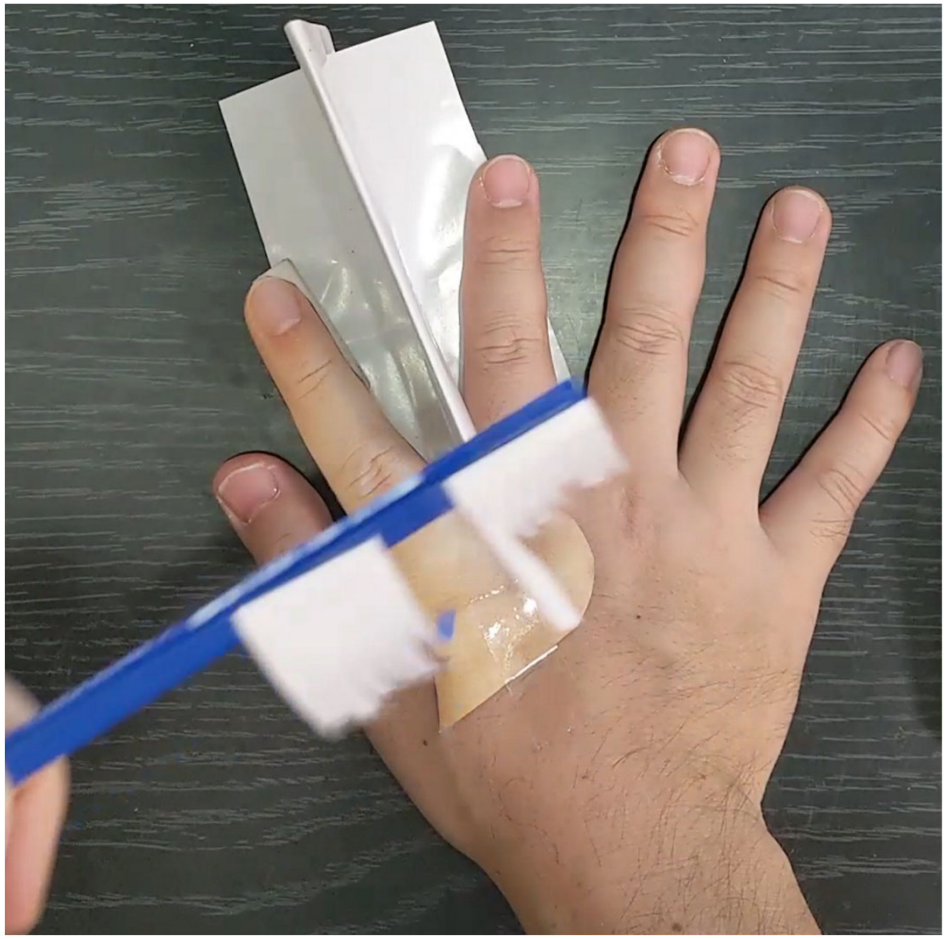
見えていない実際の手に触覚的な刺激を与え、同時にゴムの手に視覚的な刺激を与える。しばらくするとゴムの手が自分の手であるように感じる

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：Rubber Hand Illusion (finger version)

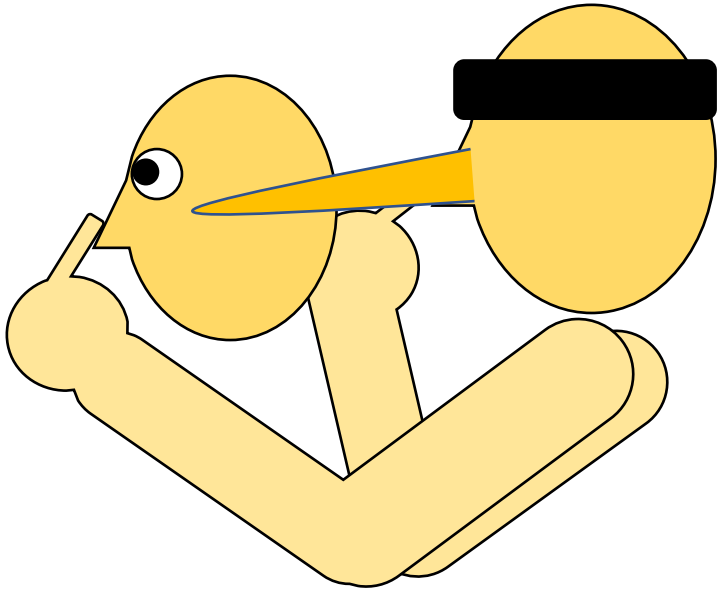




自分の手の写真を印刷すれば簡単にできます（家でやってみましょう）

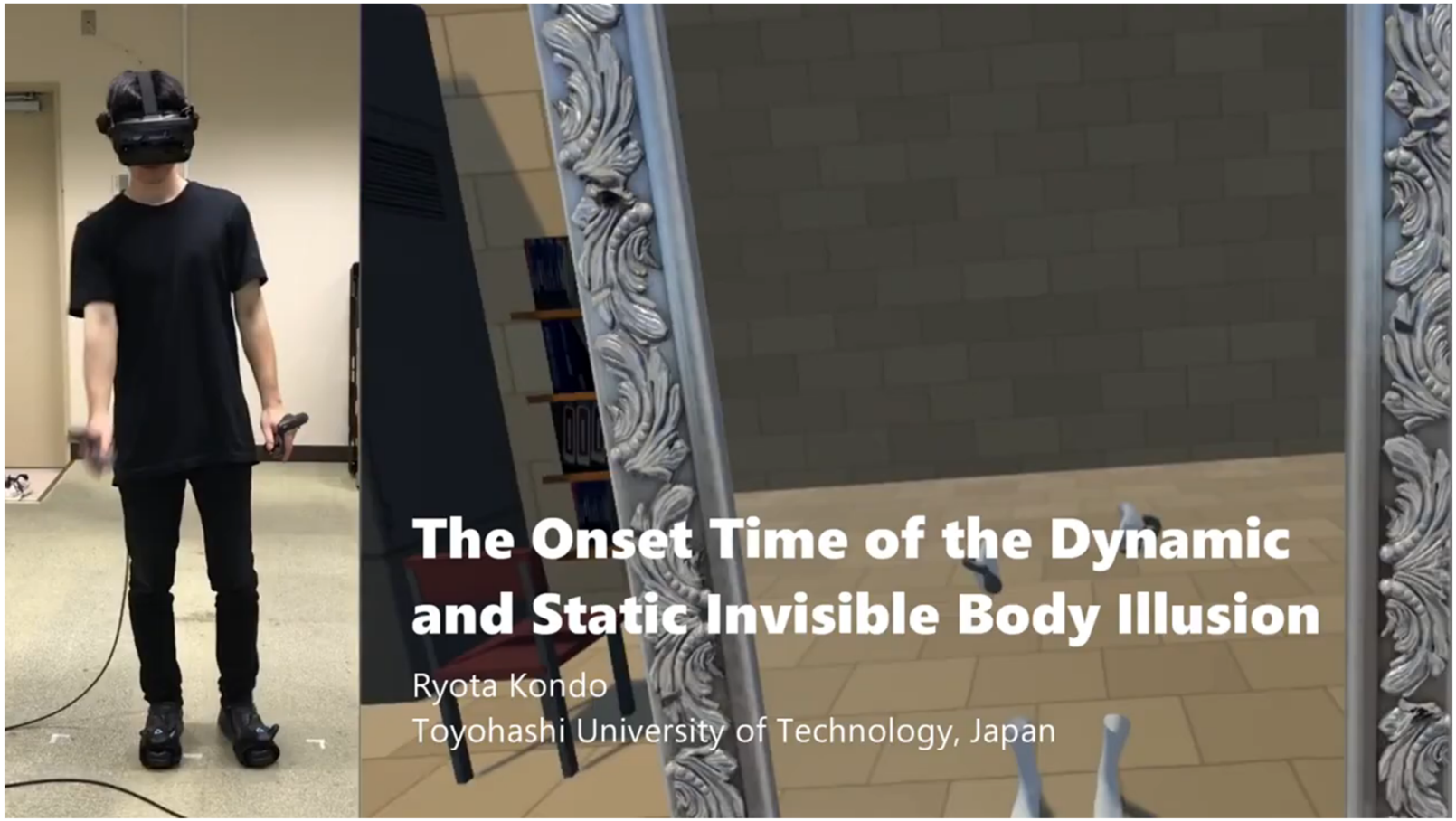
You can try the rubber hand illusion using your finger. Take a photo of your hand and make a simple setup as shown.

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

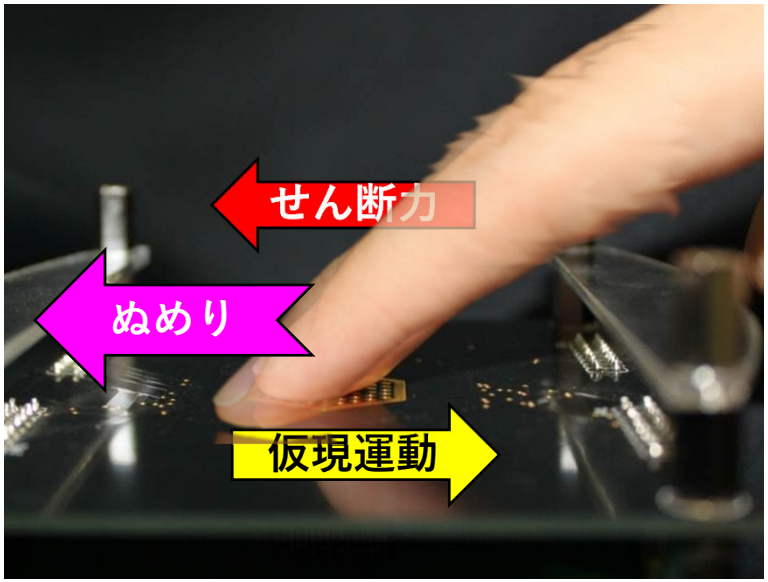


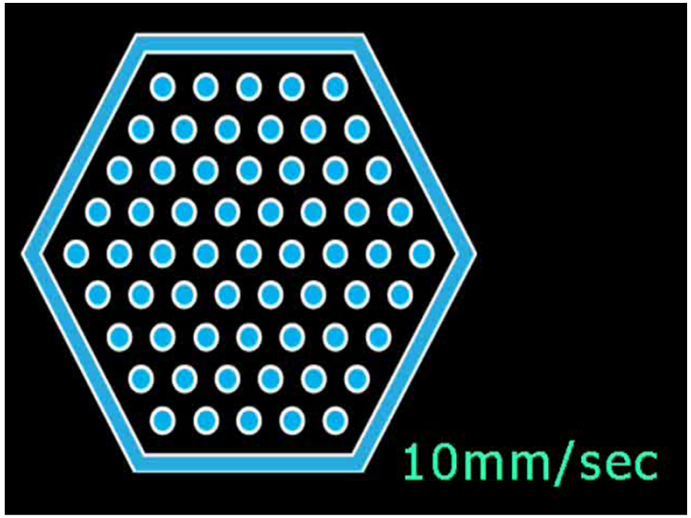
https://www.youtube.com/watch?v=u3DKAz8DqPk

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.jst.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 foots 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

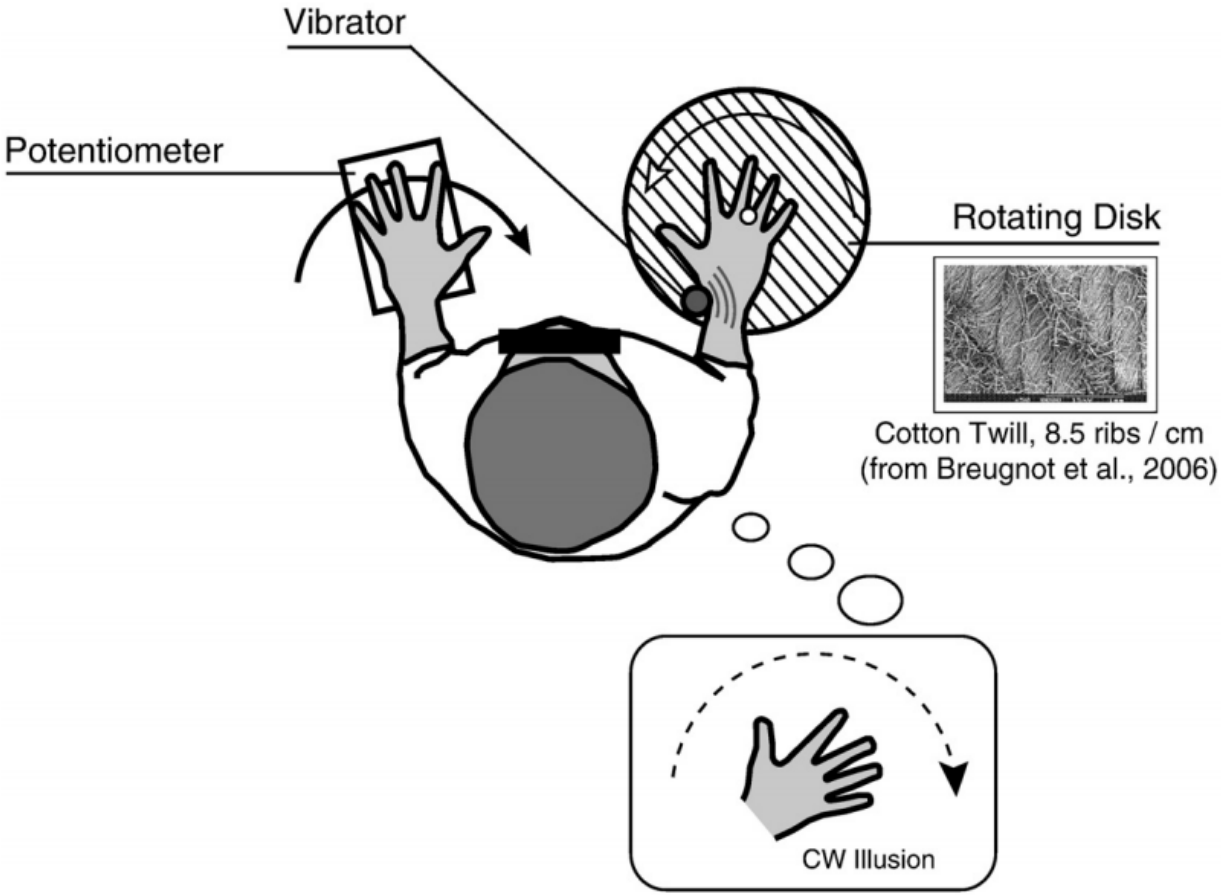




力と同時に触覚的な「流れ場」を提示すると、指の「運動（ぬめり・滑り）」を感じる

Okabe et al., Fingertip Slip Illusion with an Electrocutaneous Display, ICAT2011

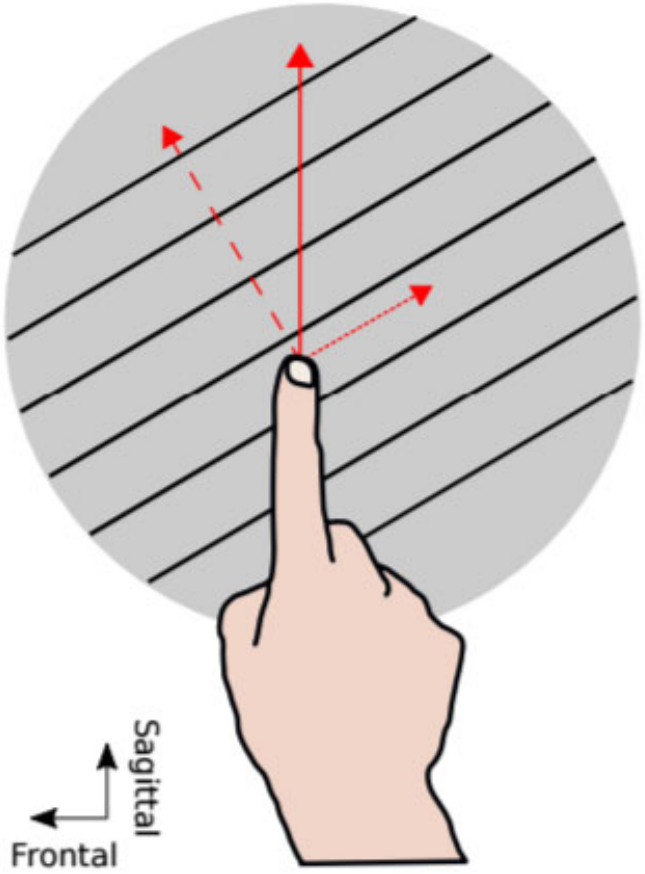
皮膚感覚によるハプティック錯覚 Cutaneous Induced Haptics：動きの錯覚 Illusion of motion

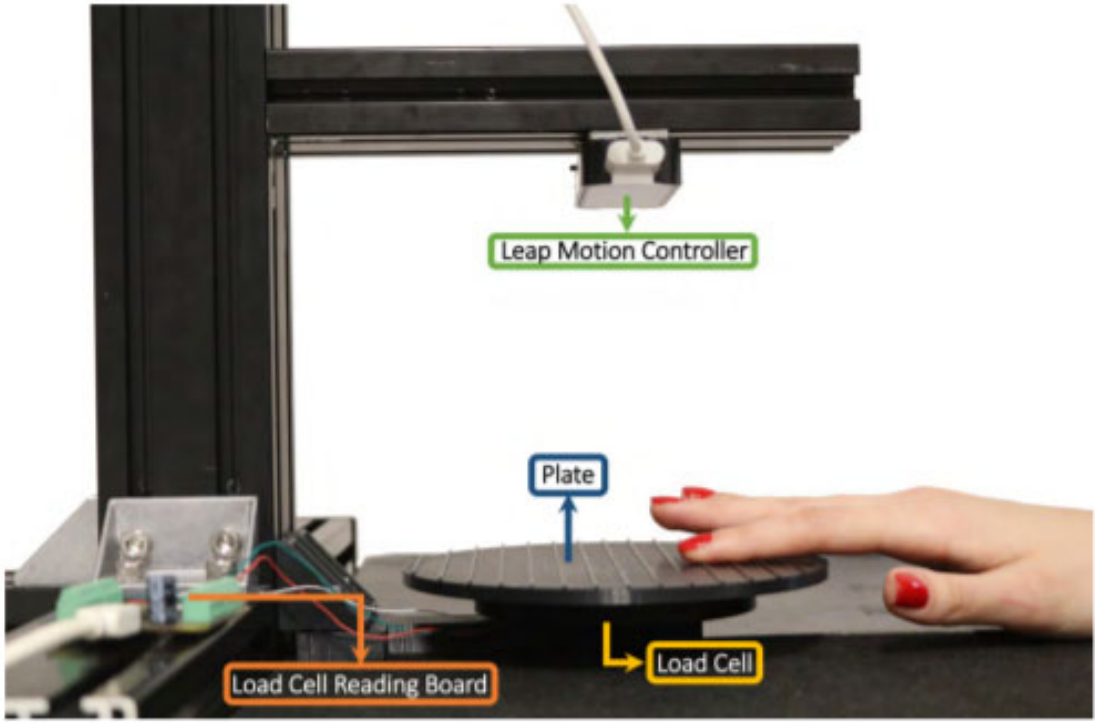


- **手のひらへの回転状触刺激＋振動による筋活動⇒手首が「回転し続ける」錯覚。**

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

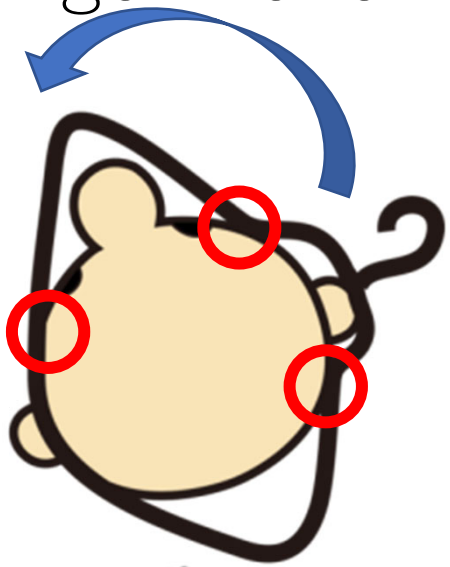
[WorldHaptics2017] Haptic Feedback of Membrane Puncture with an MR-Compatible Instrumented Needle and Electroactive Polymer Display* | Supplemental Material
Jung Hwa Bae, Amy Kyungwon Han, Christopher J. Ploch, Bruce L. Daniel, Mark R. Cutkosky

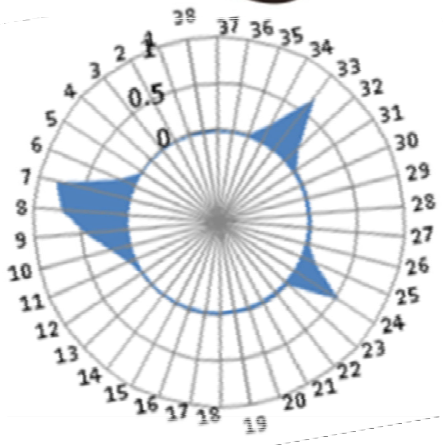




• シマシマの凸凹は皮膚上での触覚の運動を引き起こす。これが実際の指の運動と一致しない場合，指の動きの方向の誤認が生じ、結果的に動きの方向も変化。指先版Redirected Walking。

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



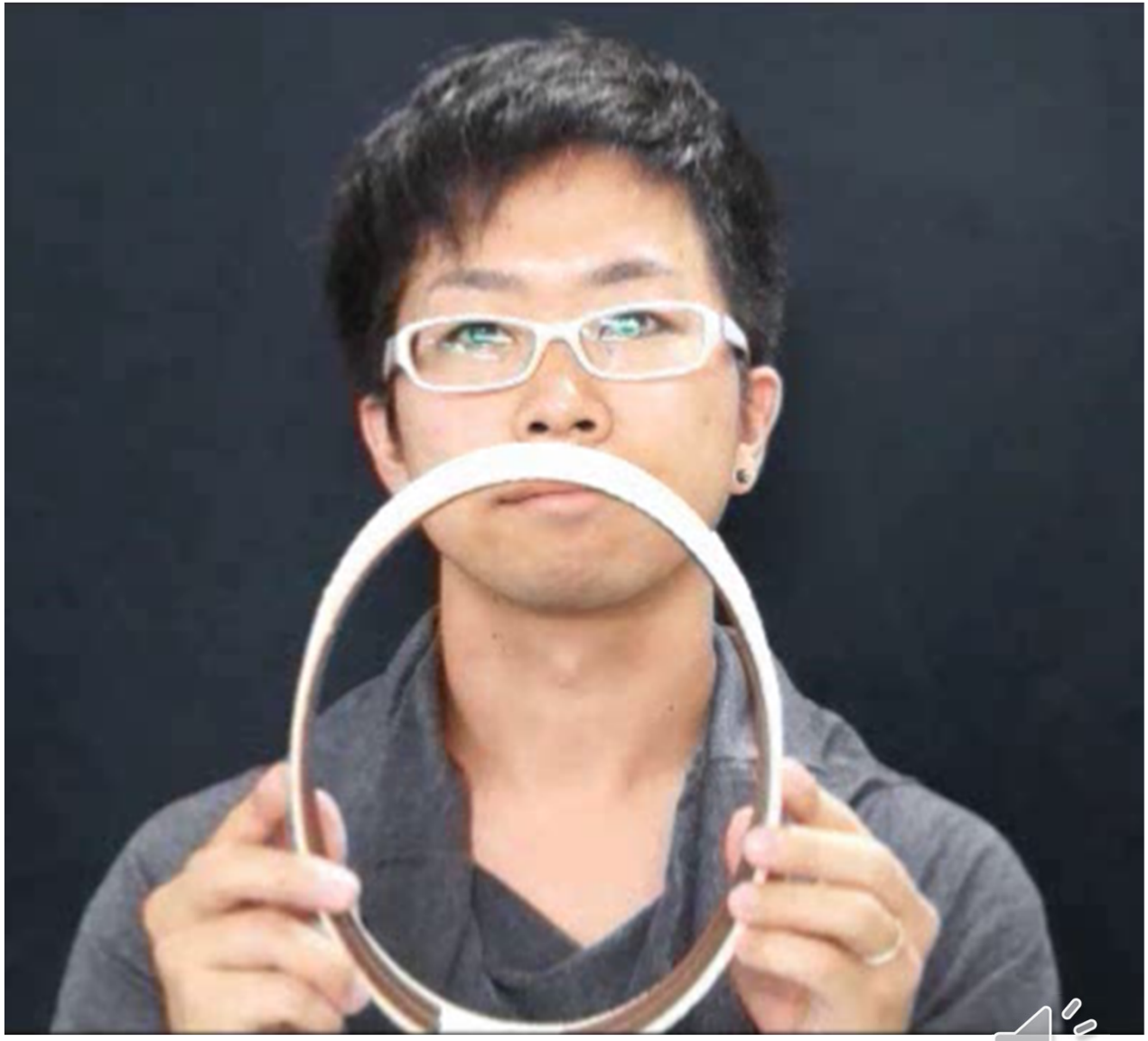


- ●側頭部圧迫によって外力を知覚
- ●頭部の回旋をも誘発（家でやってみましょう）
- ●Front temporal pressure induces “rotational” force perception.
- ●Rotation itself is induced.

ハンガー反射

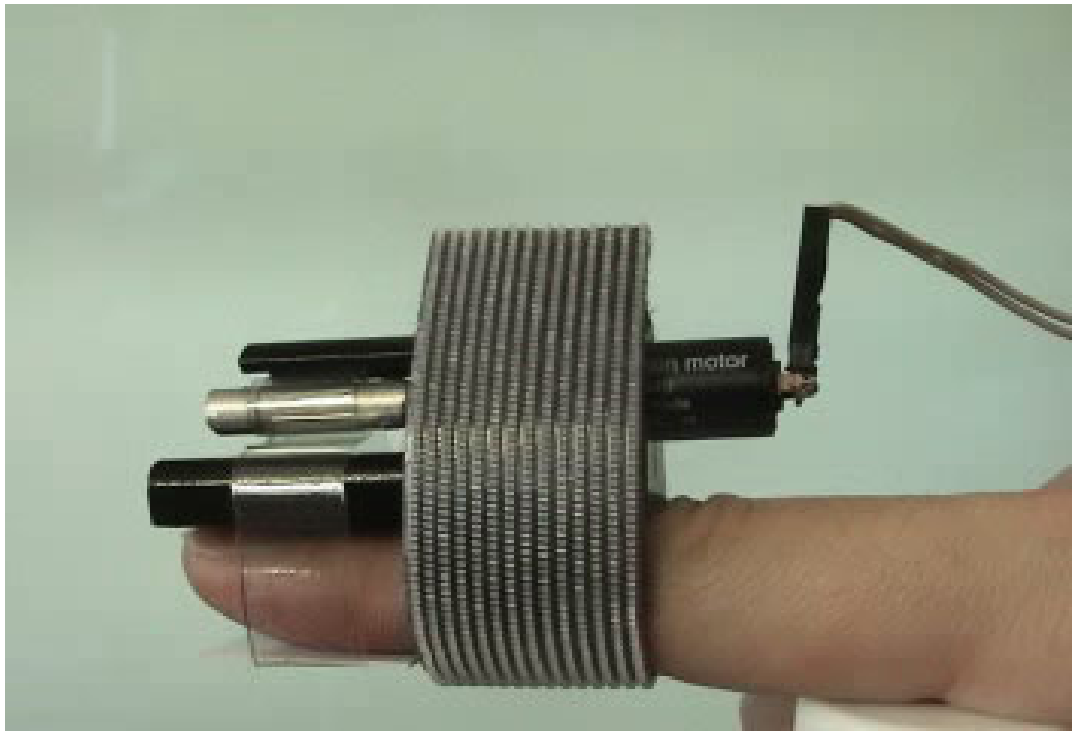

To clarify the details of the HR,
we measured pressure distribution
on the head when the reflex took place.

（参考）痙性斜頸への応用

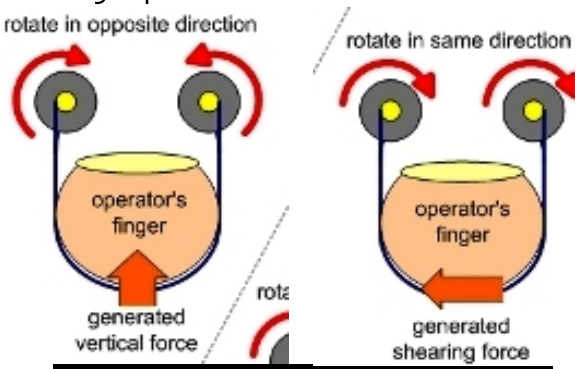


T. Asahi et al.：Pilot Study of a Device to Induce the Hanger Reflex in Patients with Cervical Dystonia, Neurologia medico-chirurgica, Vol.58, No.5, pp.206-211, 2018

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



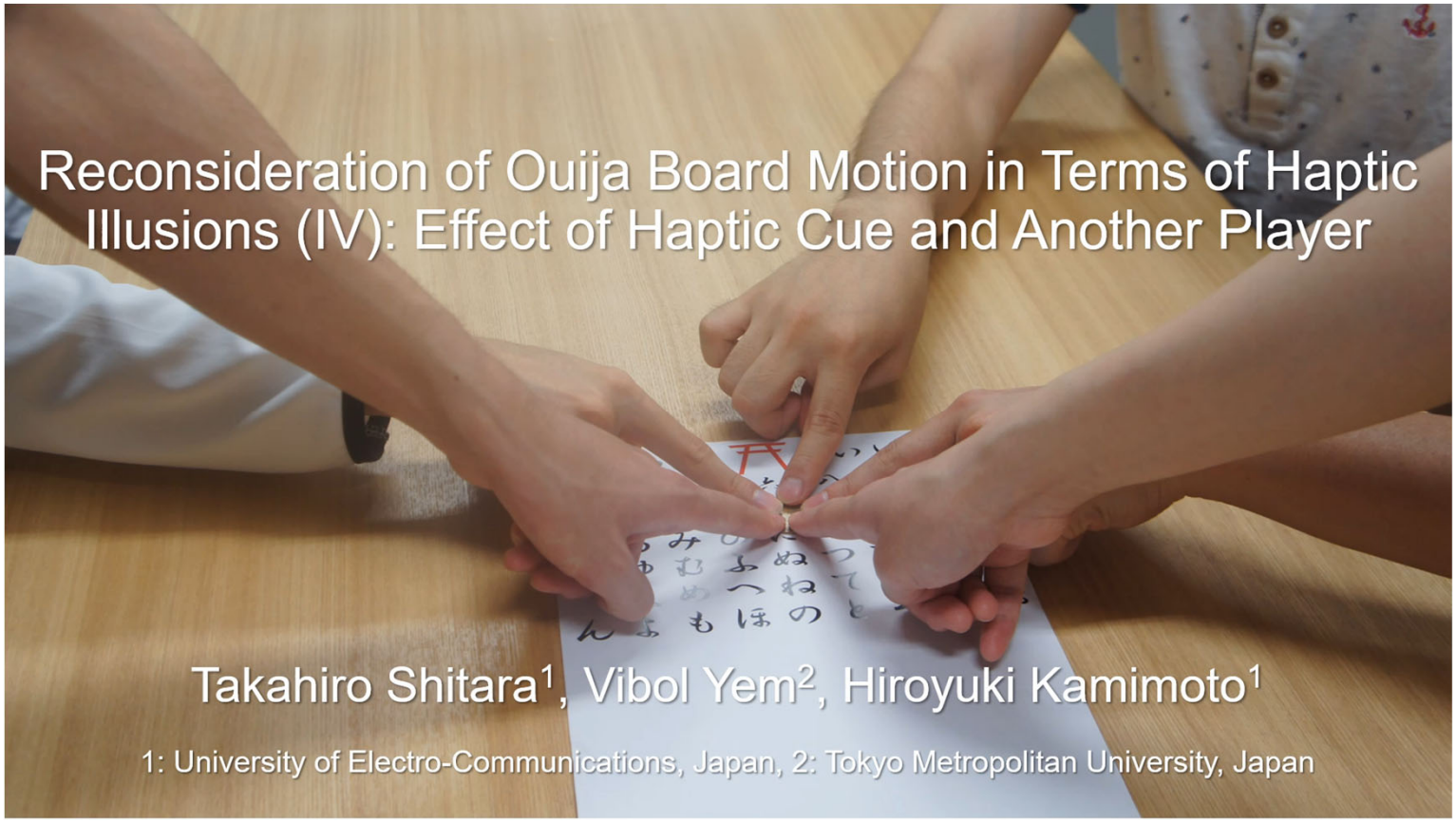
http://reality.ei.tuat.ac.jp/
A pseudo-force-feedback device by fingertip tightening for multi-finger object manipulation
G Inaba, EuroHaptics2016
稲葉、藤田：指先圧迫による擬似反力提示装置の提案と試作,日本VR学会論文誌,2007.



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).

T. Shitara, V. Yem, H. Kajimoto: Reconsideration of Ouija Board Motion in Terms of Haptic Illusions (IV): Effect of Haptic Cue and Another Player, SIGGRAPH2019 Poster, 2019.7

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

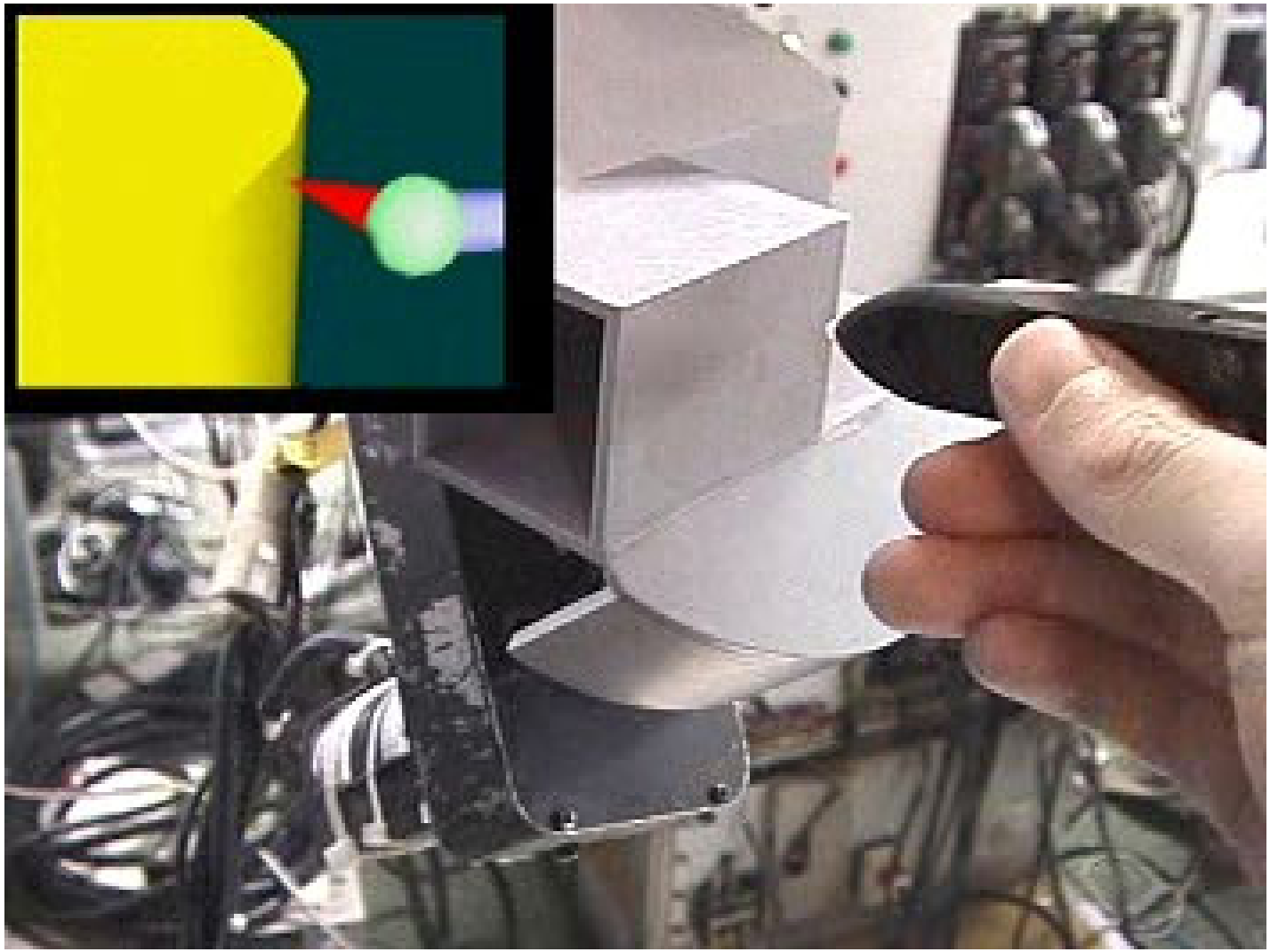
CAVE automatic virtual environment (Wikipedia)
https://en.wikipedia.org/wiki/Cave_automatic_virtual_environment

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)



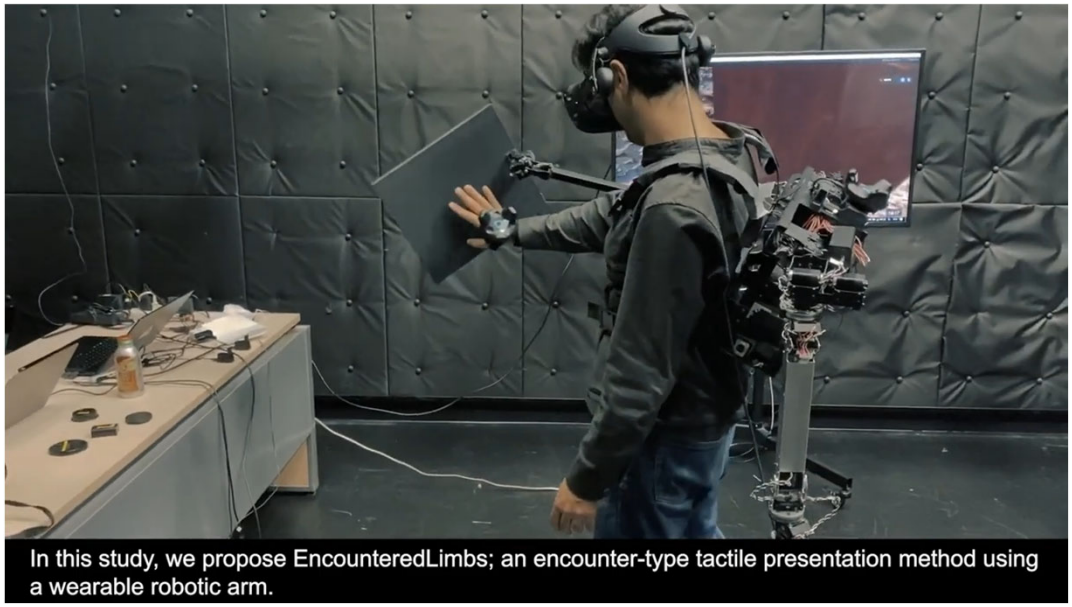
http://tachilab.org/modules/projects/aed.html

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)

ウエアラブルな遭遇型
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

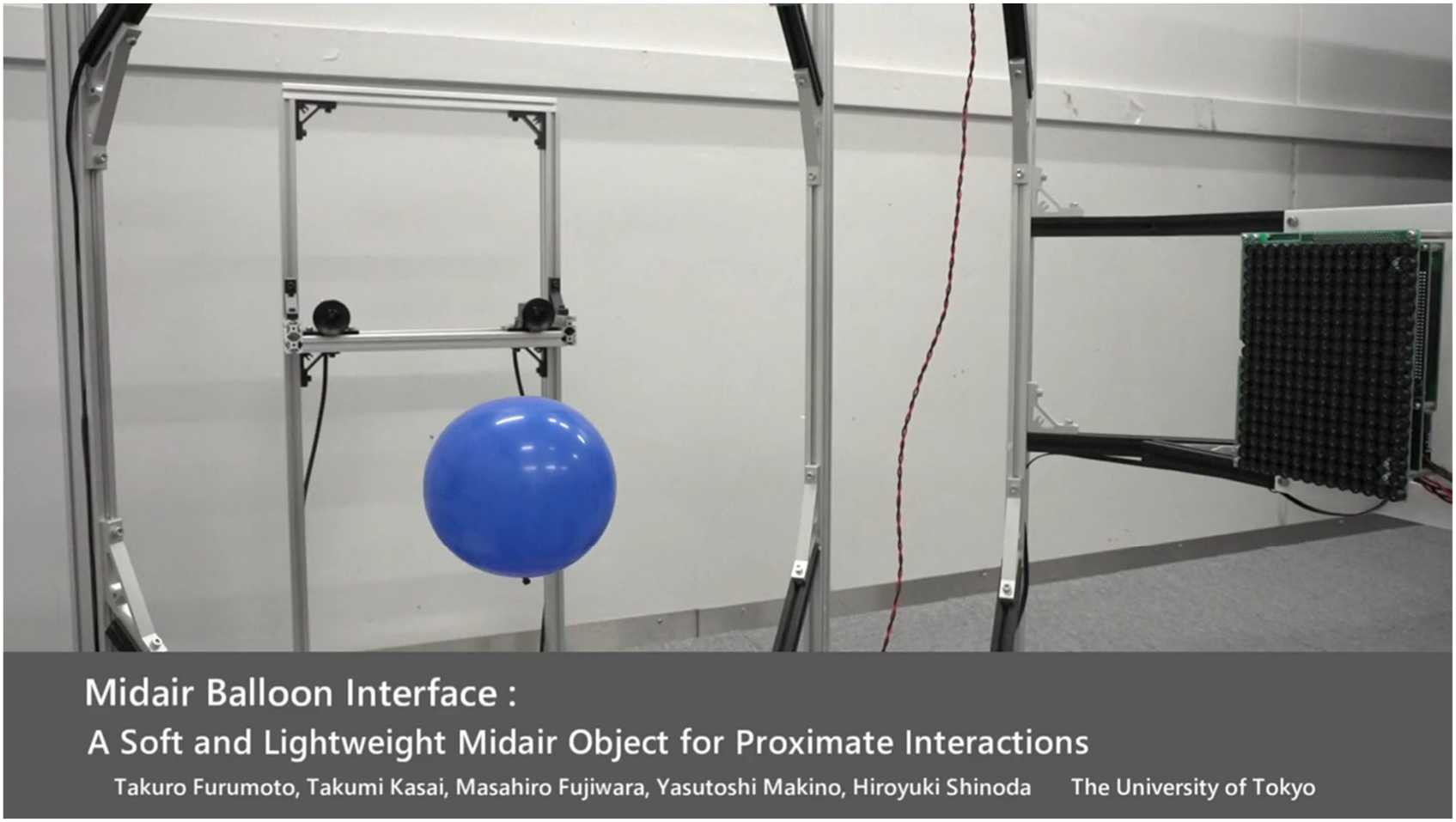
https://www.youtube.com/watch?v=uOhxQ5nKO6U



(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=pLEdvauF4Qg

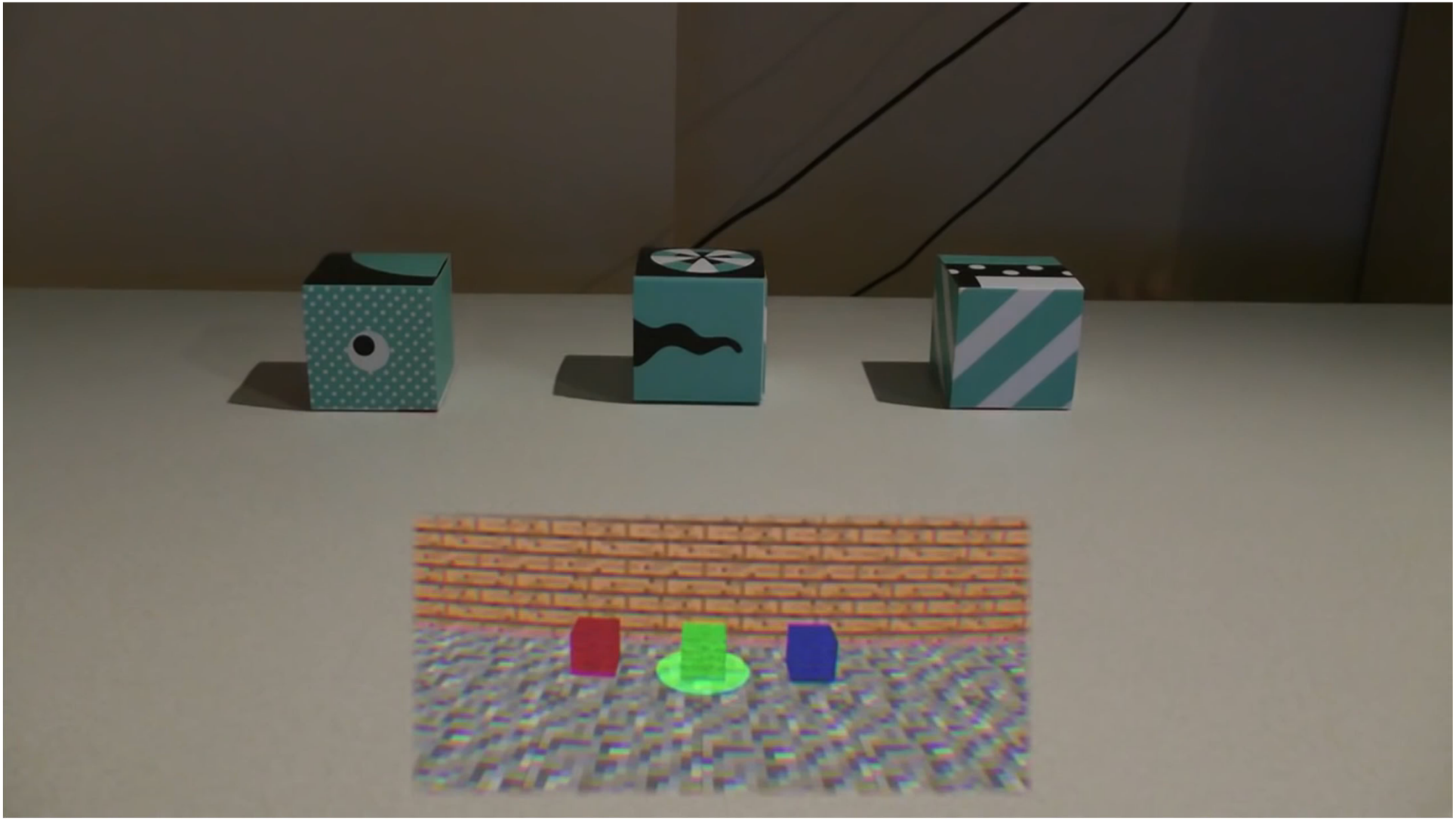
(UIST2021) Midair Balloon Interface: A Soft and Lightweight Midair Object for Proximate Interactions Takuro Furumoto, Takumi Kasai, Masahiro Fujiwara, Yasutoshi Makino, Hiroyuki Shinoda



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

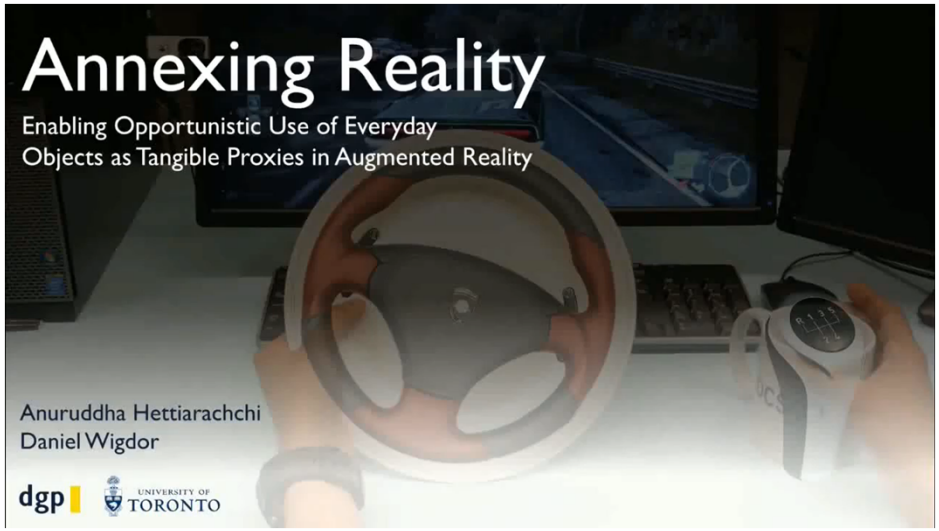
(CHI2016) Haptic Retargeting: Dynamic Repurposing of Passive Haptics for Enhanced Virtual Reality Experiences, Mahdi Azmandian, Mark Hancock, Hrvoje Benko, Eyal Ofek, Andrew D. Wilson



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

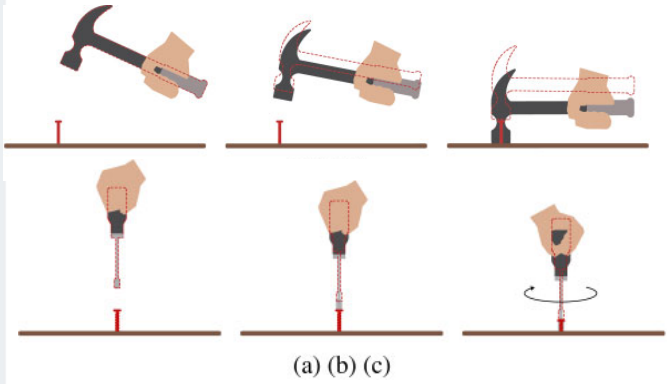
HMDによる視覚誘導によって，現実の物体を異なる場所で触っているように感じさせる.

Haptic Retargeting的な研究



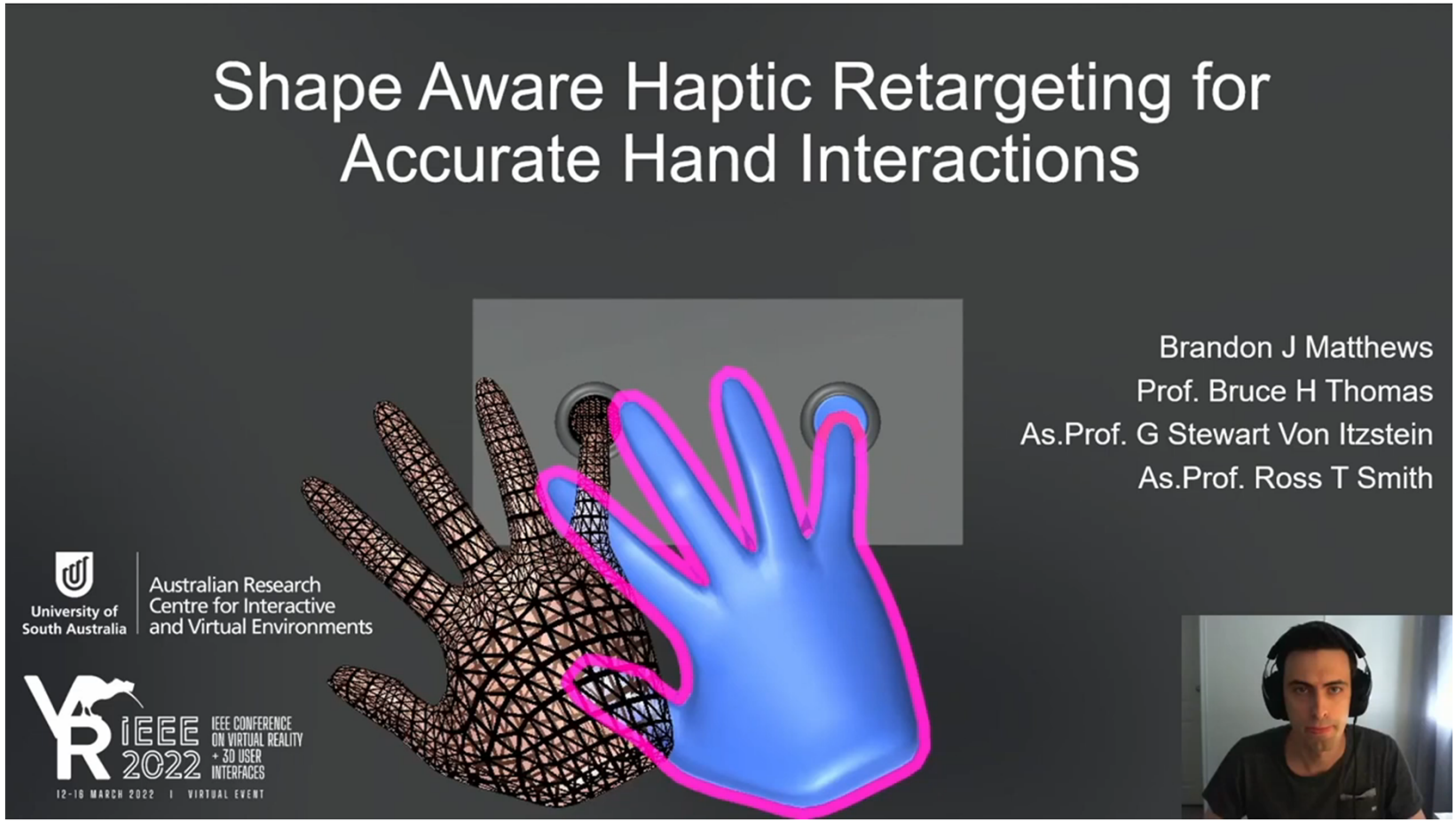
https://www.youtube.com/watch?v=xL3WJQuyZiI
(CHI2016) Annexing Reality: Enabling Opportunistic Use of Everyday Objects as Tangible Proxies in Augmented Reality, Anuruddha Lakmal Hettiarachchi, Daniel Wigdor現実空間の物体をVR空間の物体として触らせることで触覚を提示

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



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.

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

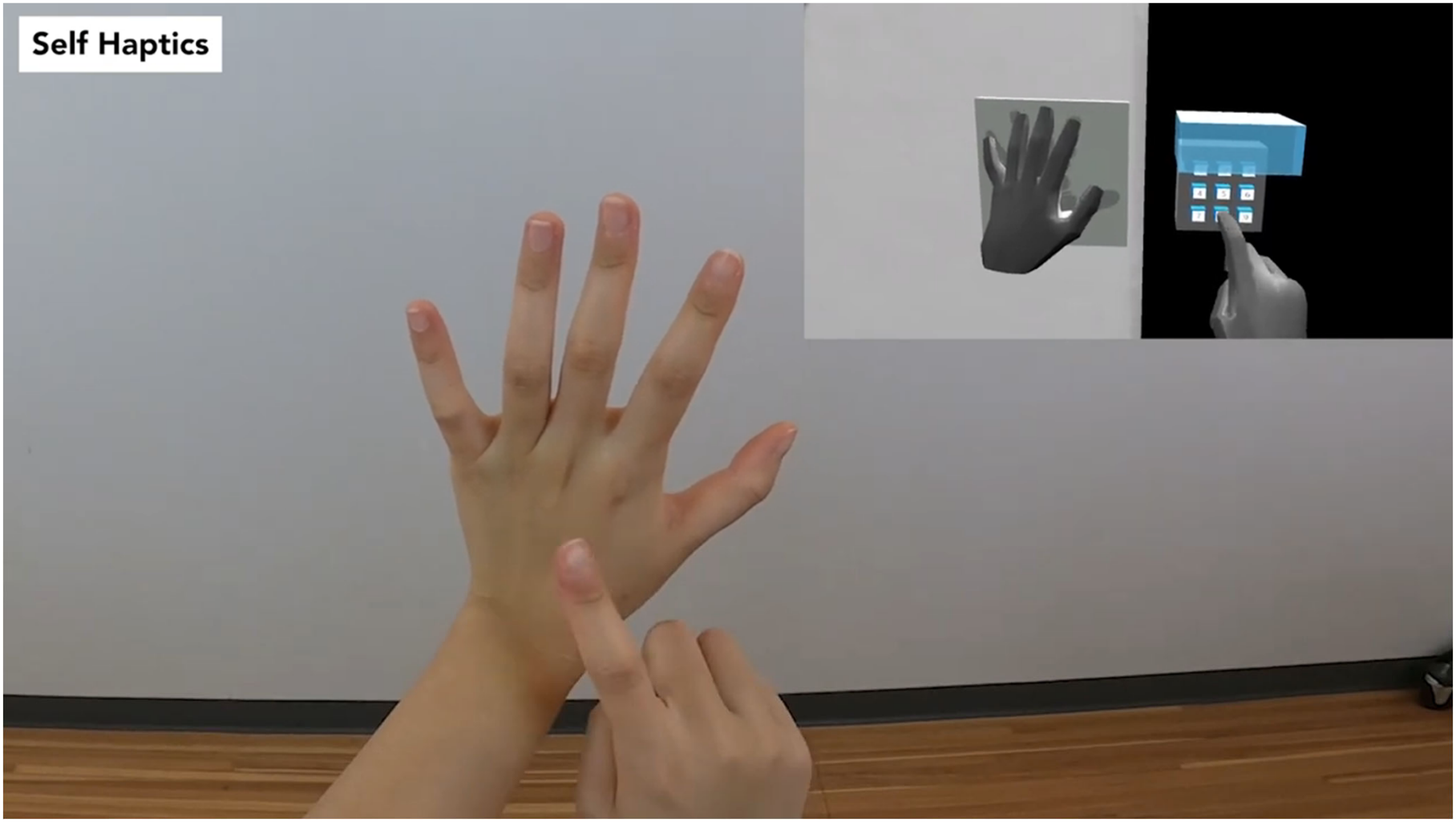


Haptic Retargetingをより精緻化。手指メッシュ形状と対象物メッシュ形状を考えてそのあいだの距離を取ることで、エッジ形状まで表現可能なretargetingが出来る

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=m2mbOdkPeN0

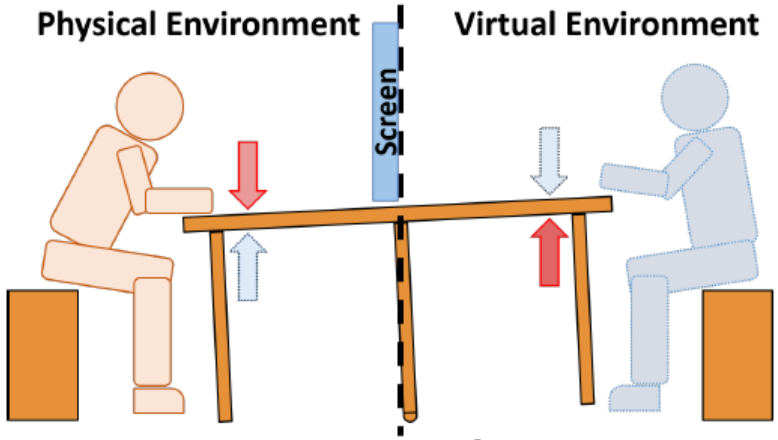
(UIST2021) Retargeted Self-Haptics for Increased Immersion in VR without Hand Instrumentation Cathy Mengying Fang, Chris Harrison

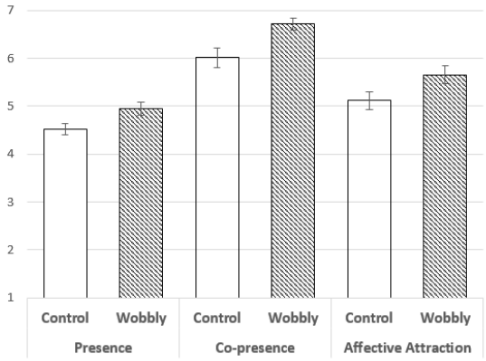


自分の非利き手をHaptic Retargetingの対象にする
Make your non-dominant hand the target of Haptic Retargeting

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 Raij

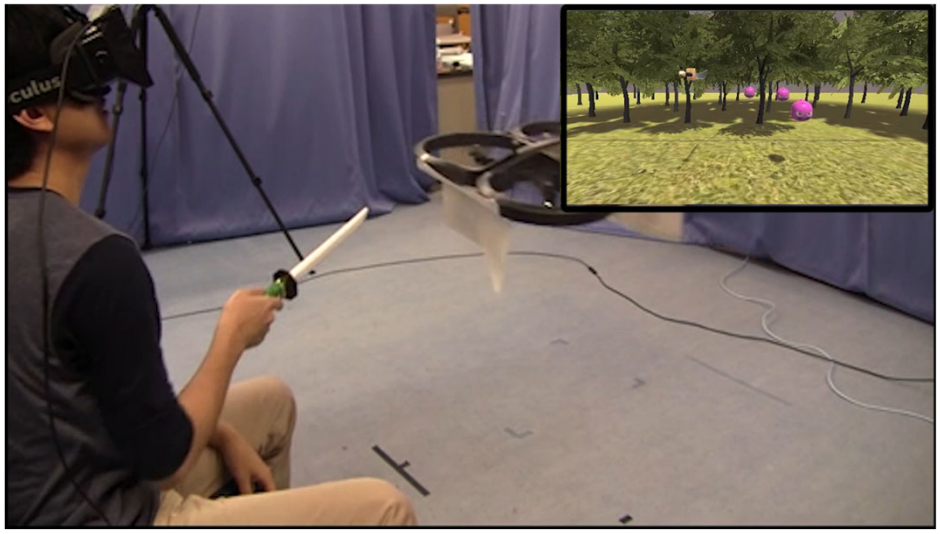




対面VR環境で机に微細なガタつきを設ける．VR側にもこのガタつきが反映される．VR内のVirtual Humanはこのガタつきに微かに応答する（机の下を覗きこむなど）．すると臨場感，空間共有感などが強調される．現実のものを使ったちょっとしたHapticsが現実感を底上げする好例。

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.

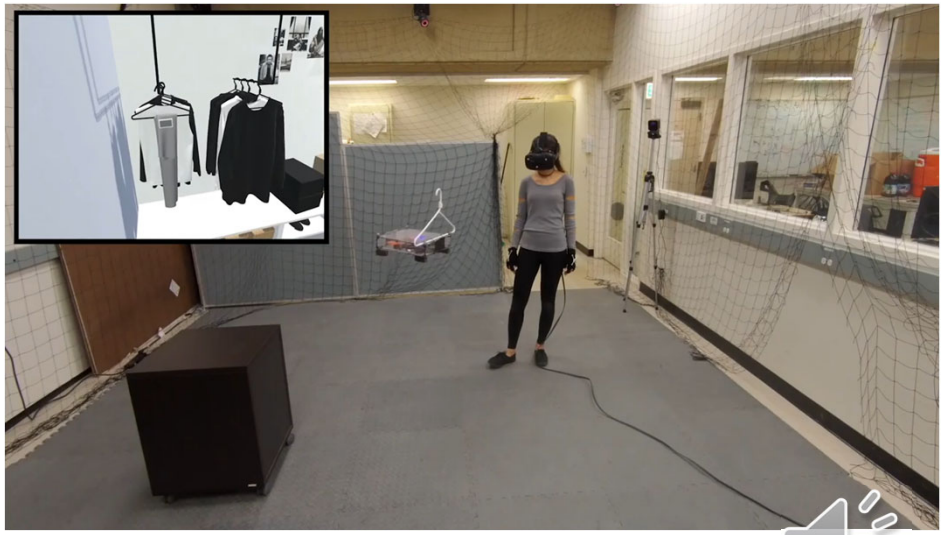
Drone based haptics (encounter-type).



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.



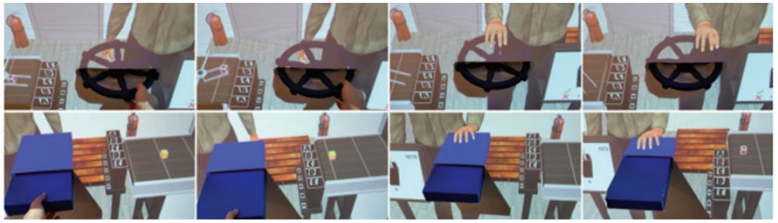
https://www.youtube.com/watch?v=JJV6fbCqm6g
(CHI2019) Beyond The Force: Using Quadcopters to Appropriate Objects and the Environment for Haptics in Virtual Reality, Abtahi et al.

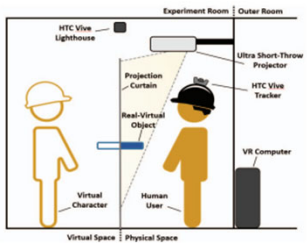
(CHI2020) Haptic-go-round: A Surrounding Platform for Encounter-type Haptics in Virtual Reality Experiences, Hsin-Yu Huang;Chih-Wei Ning;Po-Yao Wang;Jen-Hao Cheng;Lung-Pan Cheng

- https://www.youtube.com/watch?v=AvB4rxwzbmE
- Haptics用のデバイスが周りに多数配置されている。

(IEEEVR2024) Real-Virtual Objects: Exploring Bidirectional Embodied Tangible Interaction with a Virtual Human in World-Fixed Virtual Reality

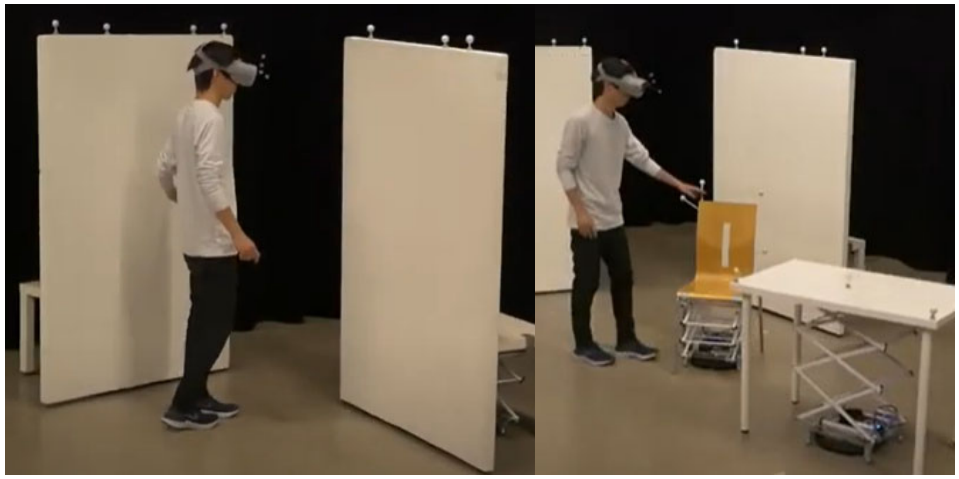
Lal Lila Bozgeyikli (University of Arizona, USA)



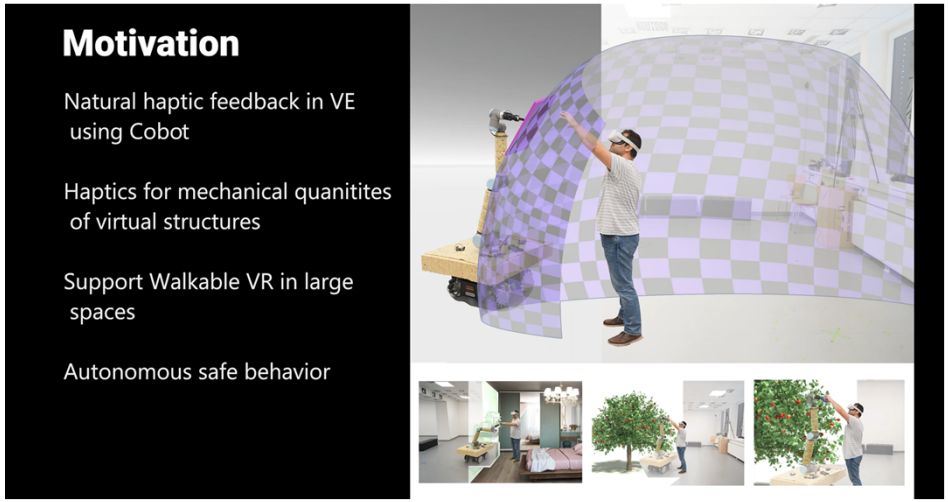


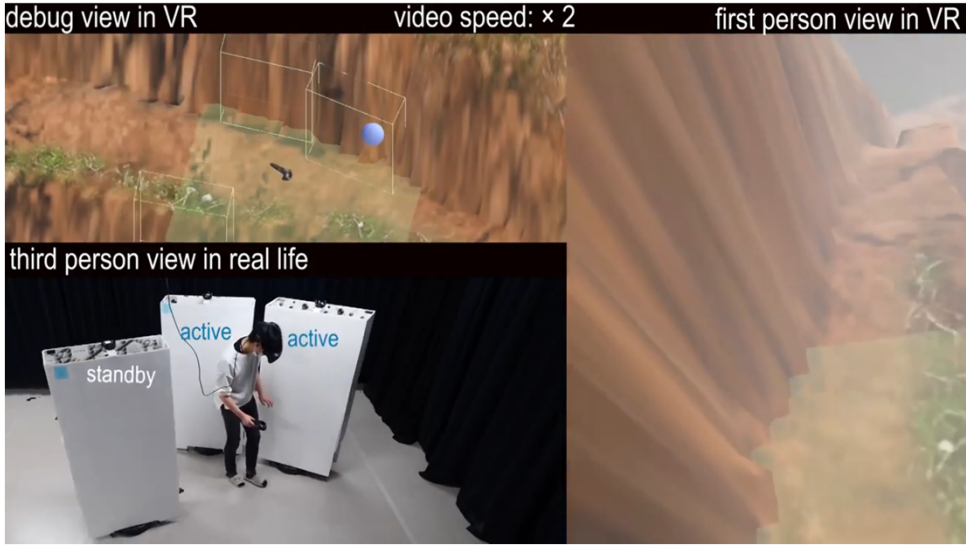
- リアルとバーチャルの組み合わせでバーチャルヒューマンと協調作業
- Cooperative work with virtual humans by combining real and virtual

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

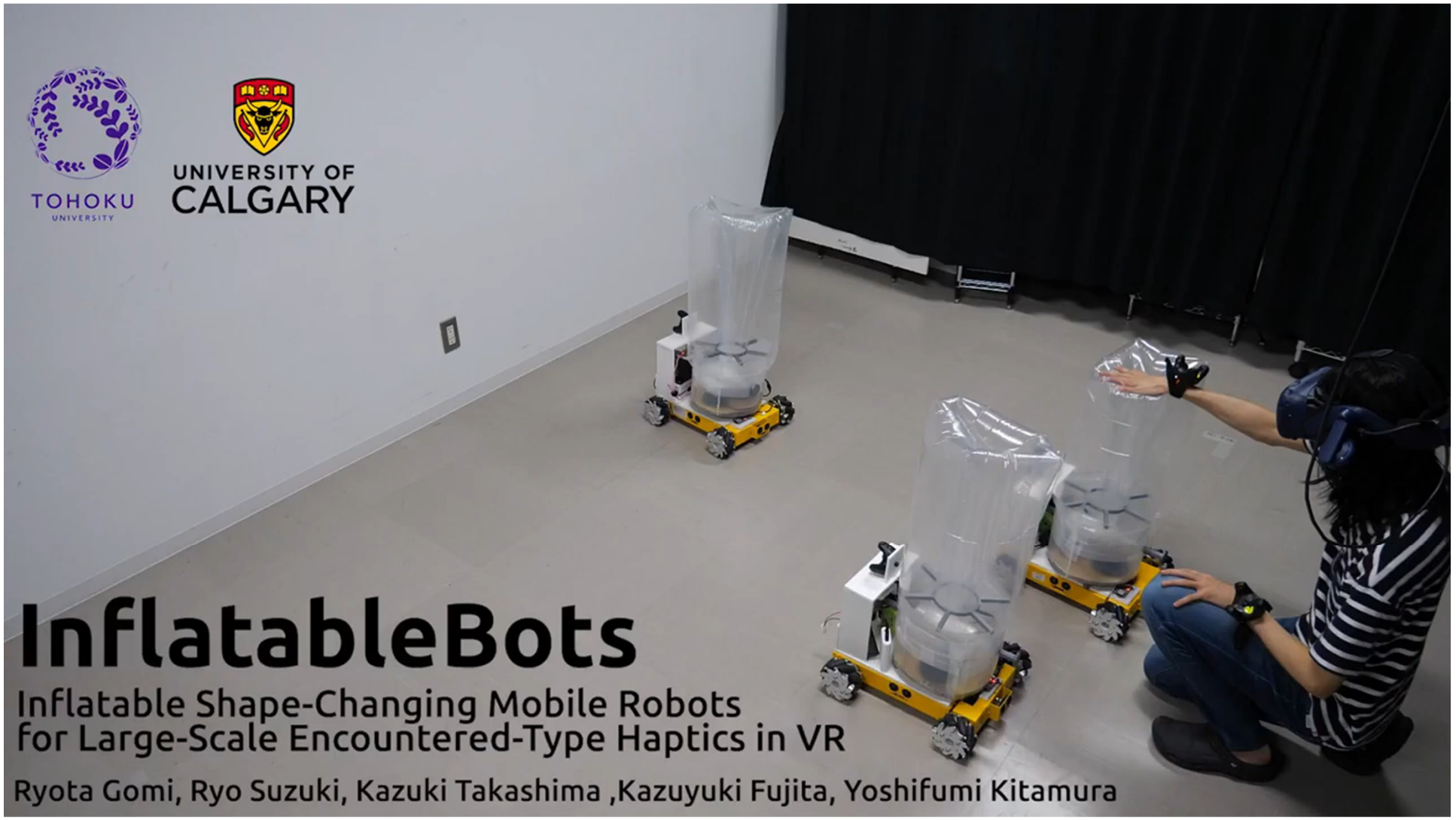




(UIST2020) ZoomWalls: Dynamic Walls that Simulate Haptic Infrastructure for Room-scale VR World
YAN YIXIAN, Kazuki Takashima, Anthony Tang, Takayuki Tanno, Kazuyuki Fujita, Yoshifumi Kitamura
https://www.youtube.com/watch?v=t6J65a1S1y0

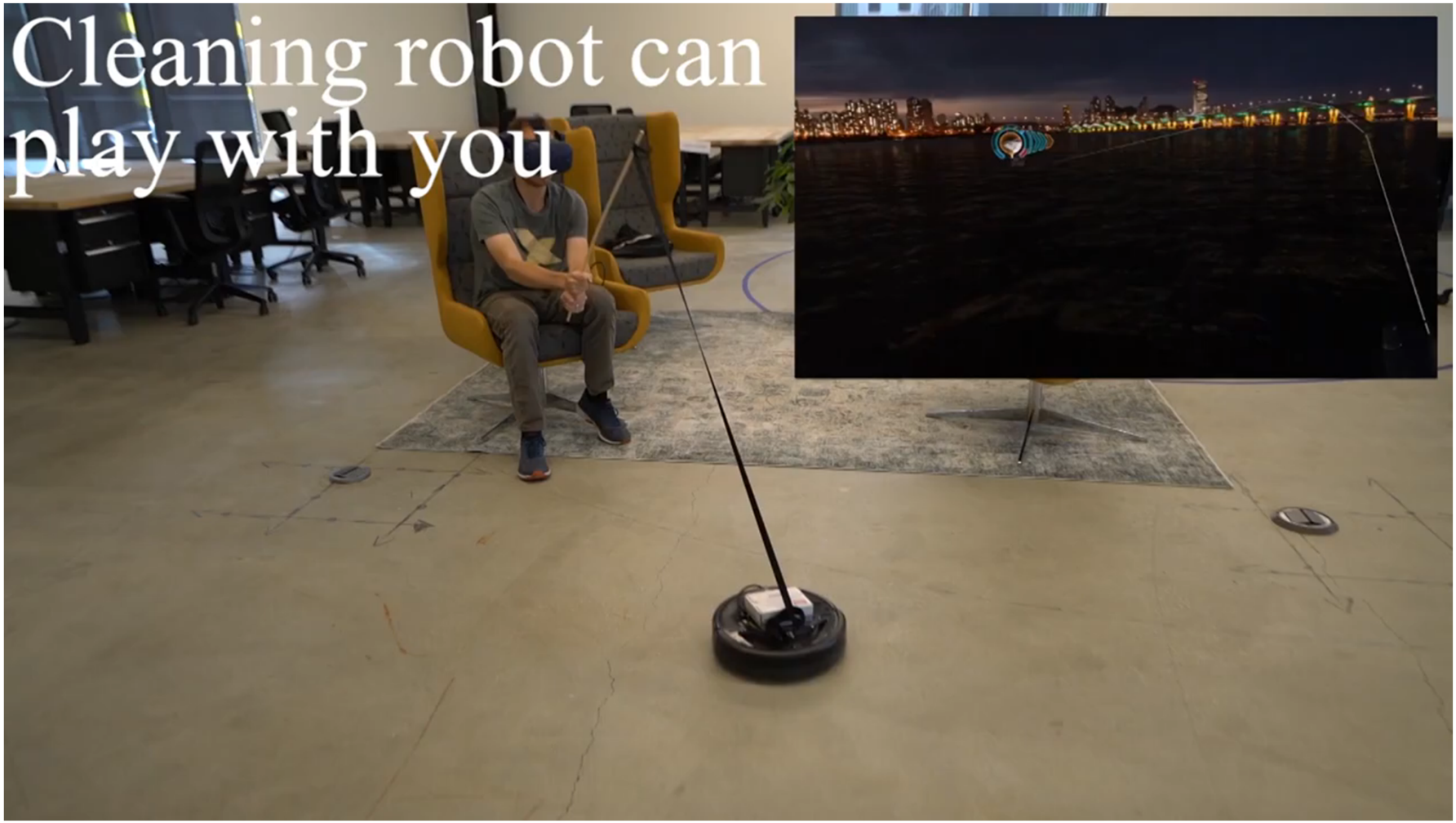
(IEEEVR2023) CoboDeck: A Large-Scale Haptic VR System using a Collaborative Mobile Robot
Soroosh Mortezapoor, Khrystyna Vasylevska, Emanuel Vonach, Hannes Kaufmann
可動運台にのったロボットアームで板を動かし、「壁」を提示する。大型の「遭遇型」ディスプレイ

(CHI2024) InflatableBots: Inflatable Shape-Changing Mobile Robots for Large-Scale Encountered-Type Haptics in VR
Ryota Gomi, Ryo Suzuki, Kazuki Takashima, Kazuyuki Fujita, Yoshifumi Kitamura
https://www.youtube.com/watch?v=WzJVj9jN7_4



- 遭遇型触覚をルンバ的移動ロボット＋風船でやるもの
- Encounter type haptics is achieved by moving robots and inflatables.

(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

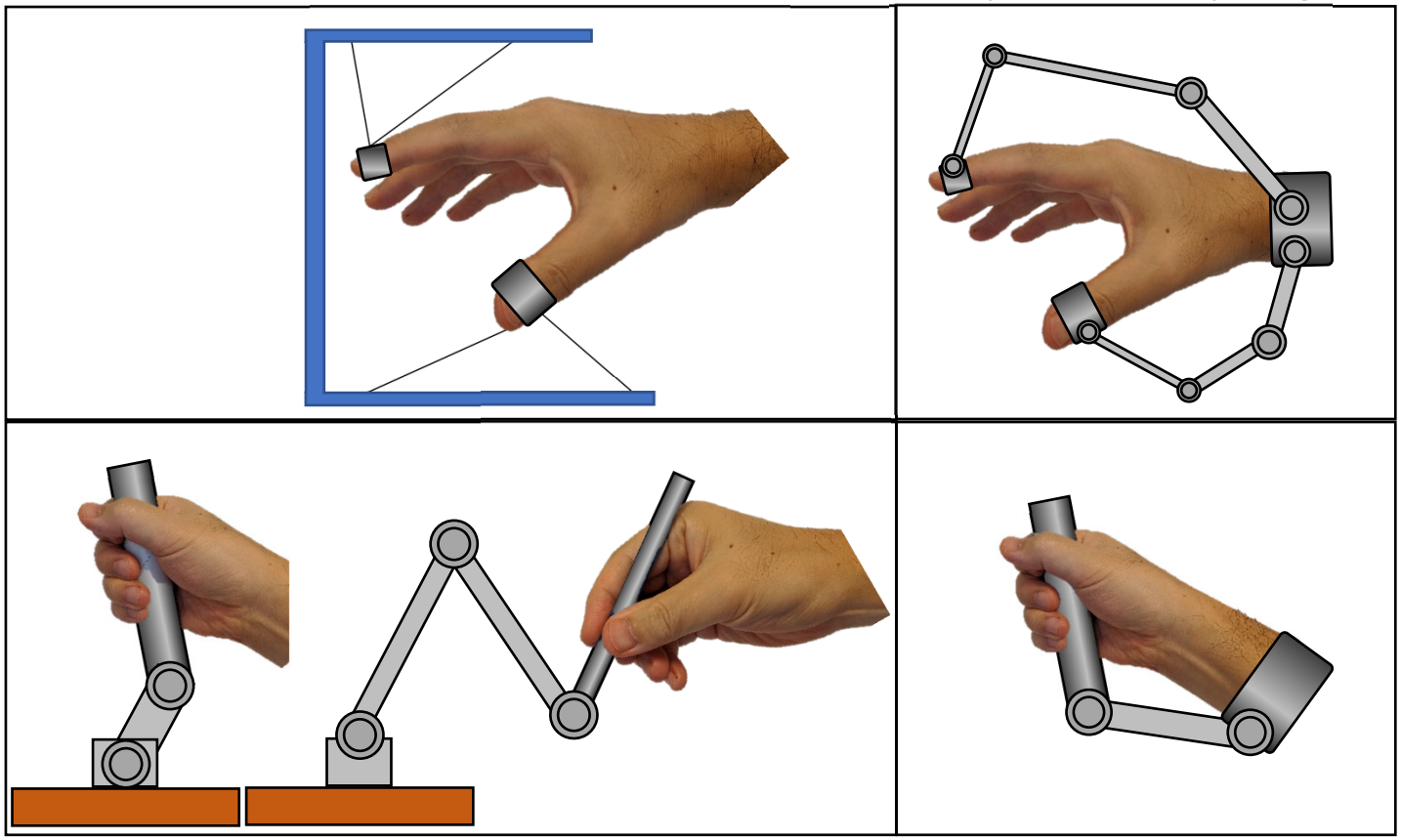
CAVE automatic virtual environment (Wikipedia)
https://en.wikipedia.org/wiki/Cave_automatic_virtual_environment

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。

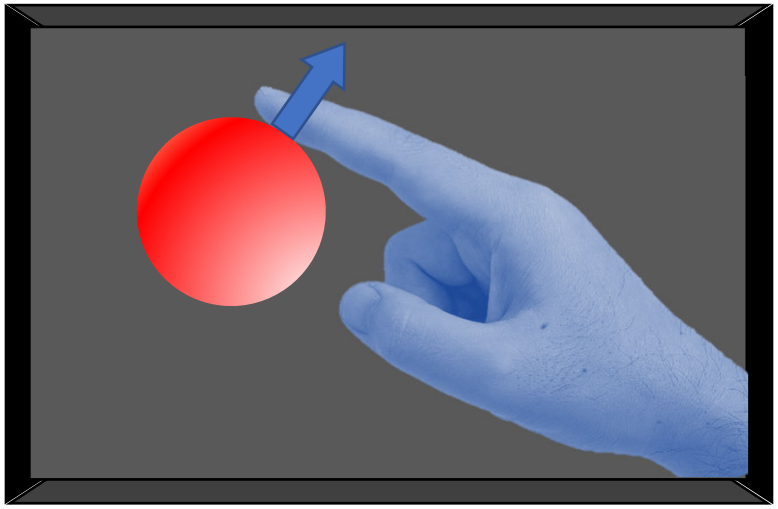
Like visual and auditory displays, there are environmental type and non-environmental type.

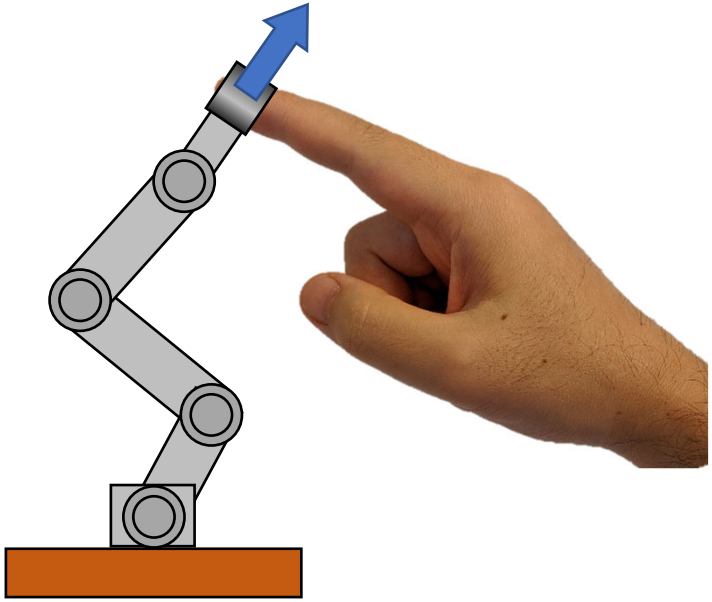
非環境型の力覚ディスプレイの形態
Configurations of non-environmental haptic displays

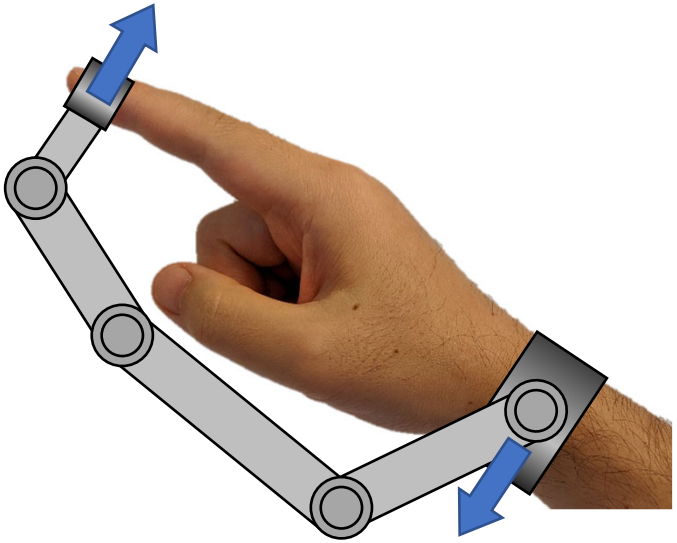


- 装着型か、把持型か／Wear or Hold
  - 装着型：手の振る舞いの再現 Wear type presents “hand, finger” behavior.
  - 把持型：ツールの振る舞いの再現 Hold type presents “tool” behavior.
- 環境接地か、身体接地か／How it is grounded
  - 環境接地：外界に対して力を発揮 Force is applied from environment.
  - 身体接地：別の身体部位との間に力を発揮 Force is exerted in between body parts.

接地はなぜ重要か Why grounding matters?

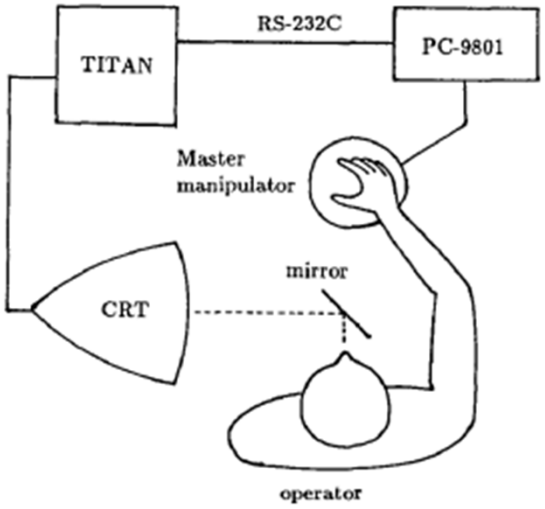


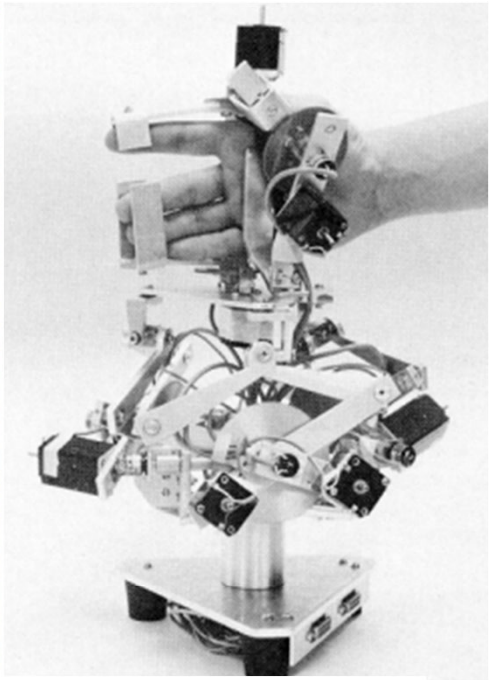


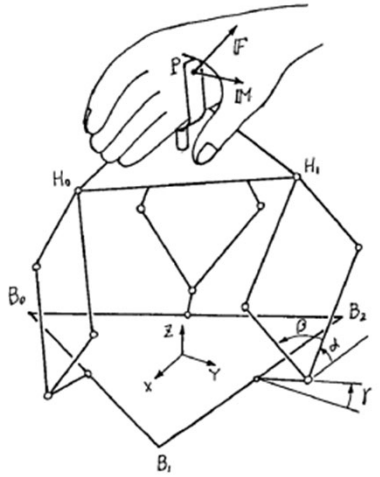


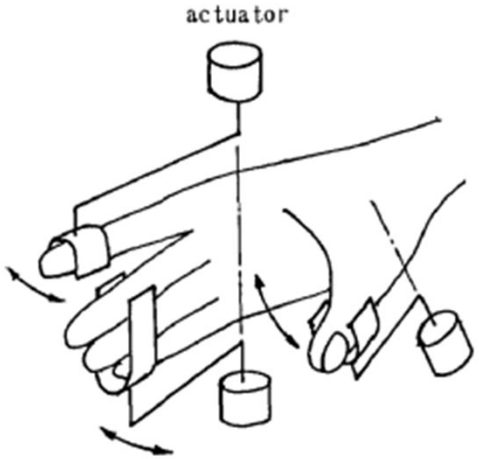
環境に接地すると所望の力のみ提示可能。身体に接地すると作用反作用で他の力が発生する。
When grounded to the environment, the desired force can be presented. When grounded to the body, the action-reaction generates other forces.

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

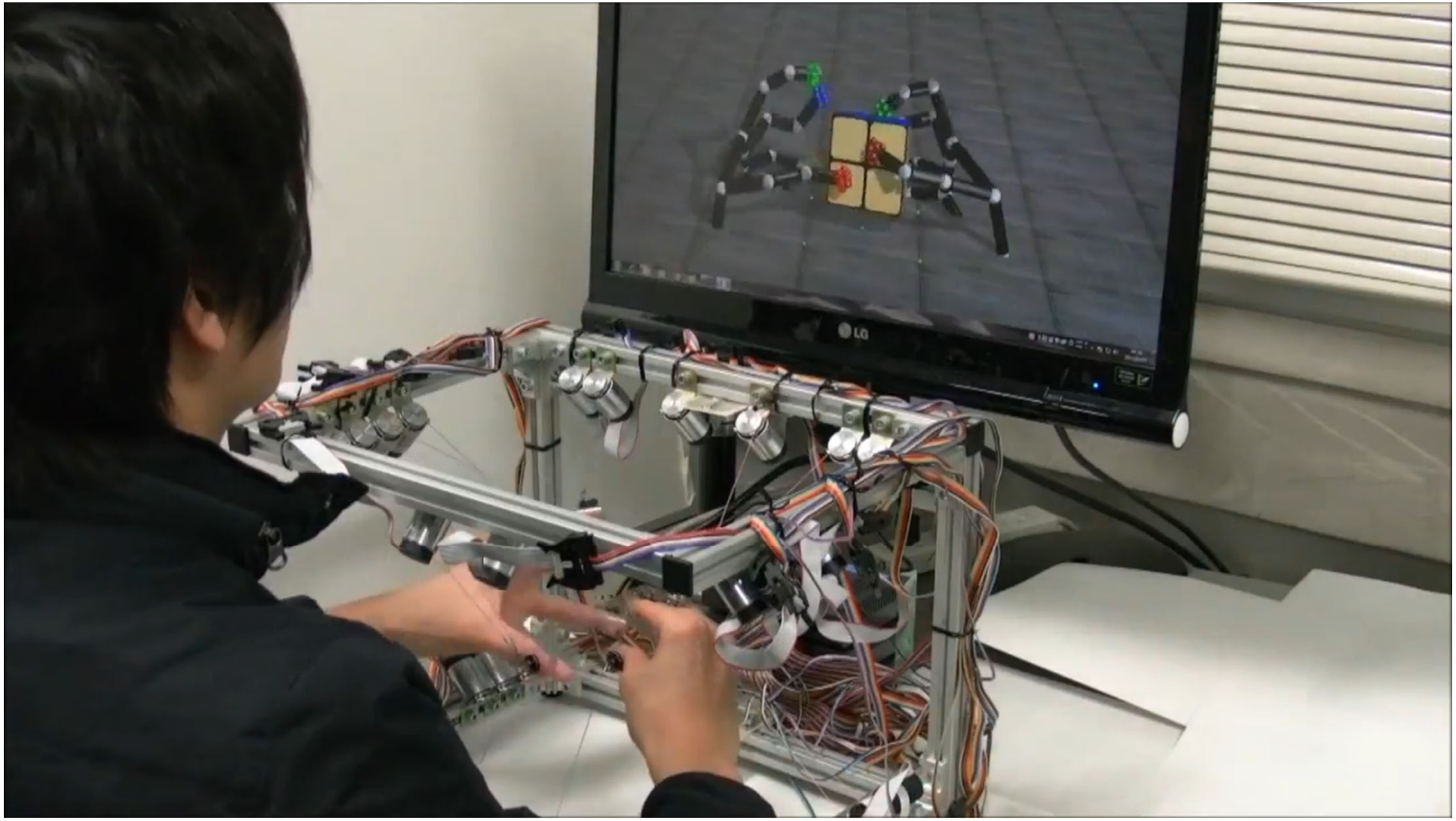
CyberGrasp/CyberForce

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

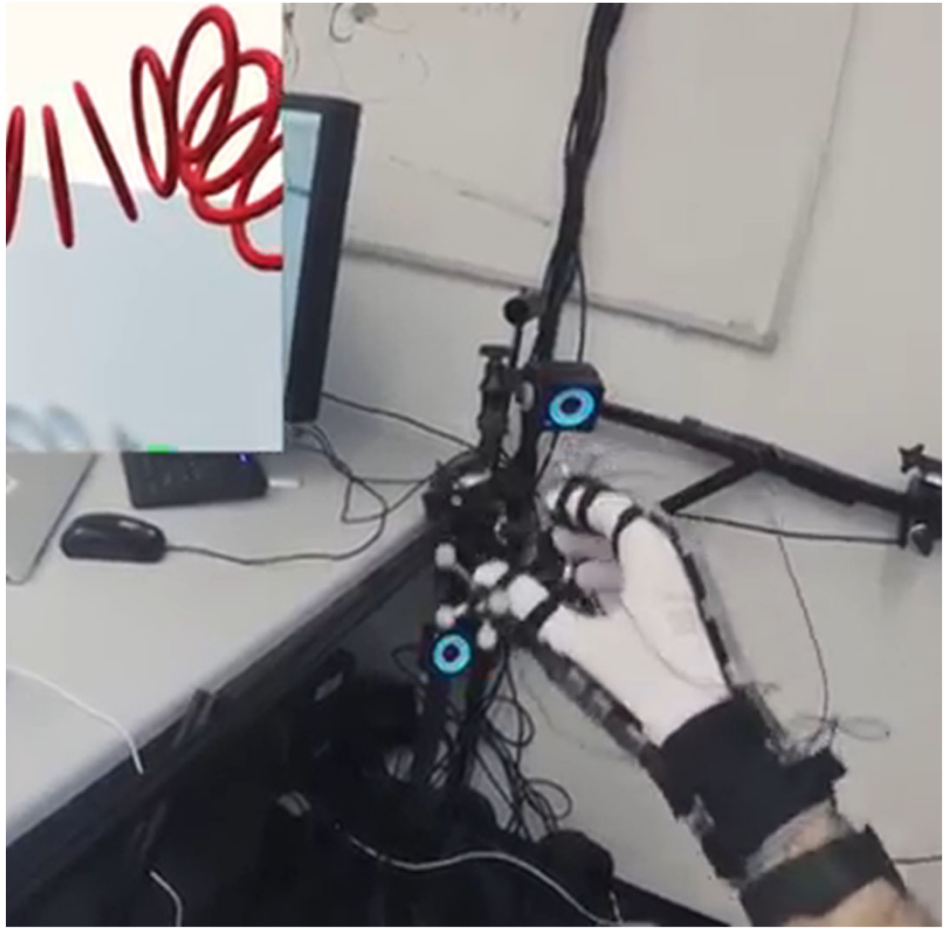


- Wear type. Environment grounded.
- (left) 4 finger, (right) 4 finger
- One finger is pulled by 3 wires

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



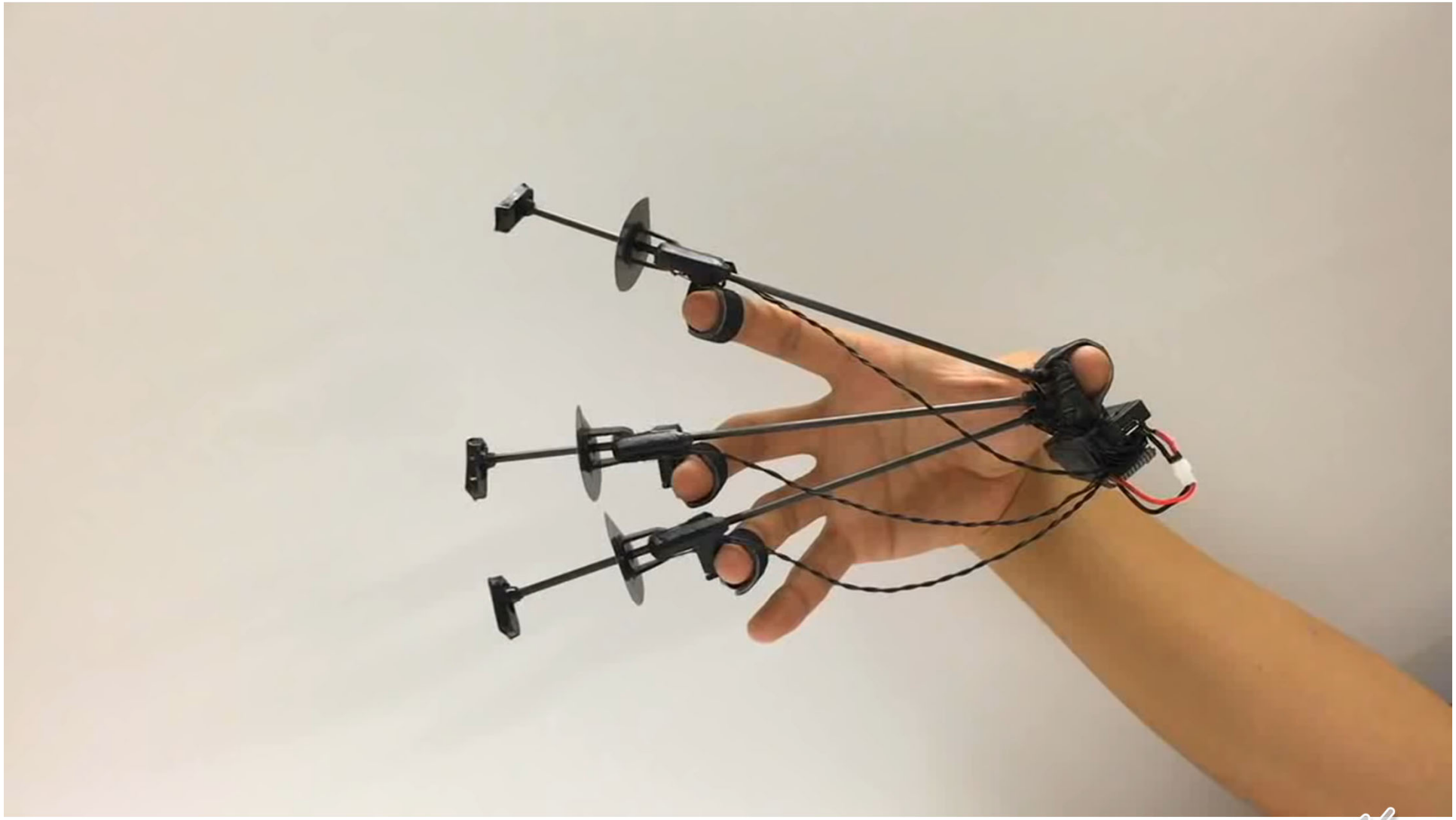
https://www.youtube.com/watch?v=fgRaw9k-Eu8
(CHI2018) DextrES: Wearable Haptic Feedback for Grasping in VR via a Thin Form-Factor Electrostatic Brake, Hinchet et al.

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=yt1QNWO8mqg
(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エアラブル力覚を提供。手掌部にハンドルとして接地。

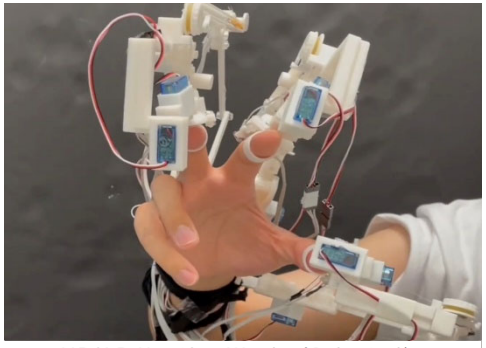
指同士で接地する Mutual grounding to fingers



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



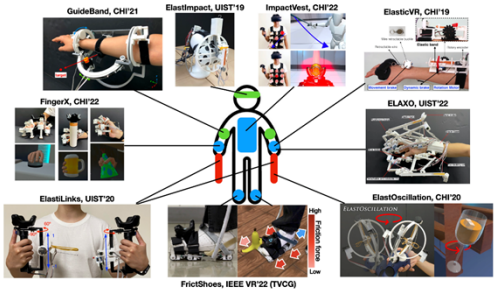
ELAXO :

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

uist 2022

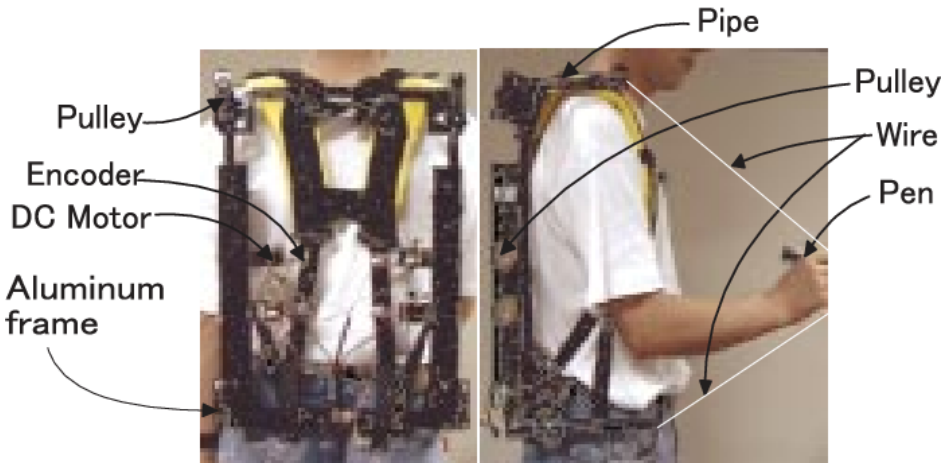
DELTA



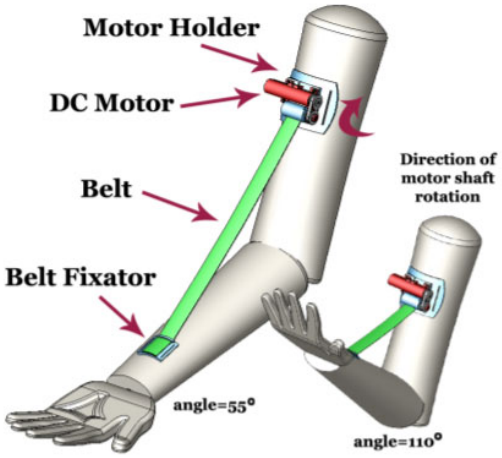
https://www.youtube.com/watch?v=TlyaZPgD390&list=PLqhXYFYmZ-VdaPIMTFVH5K5brMDJClfAn&index=17

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)



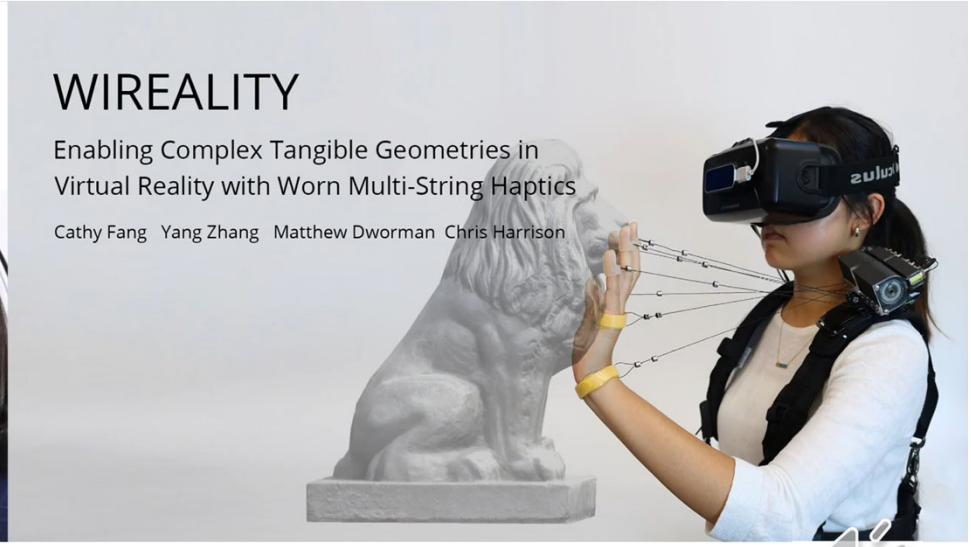
(IEEEVR2001) HapticGEAR: The development of a wearable force display system for immersive projection displays. Hirose et al.



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

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

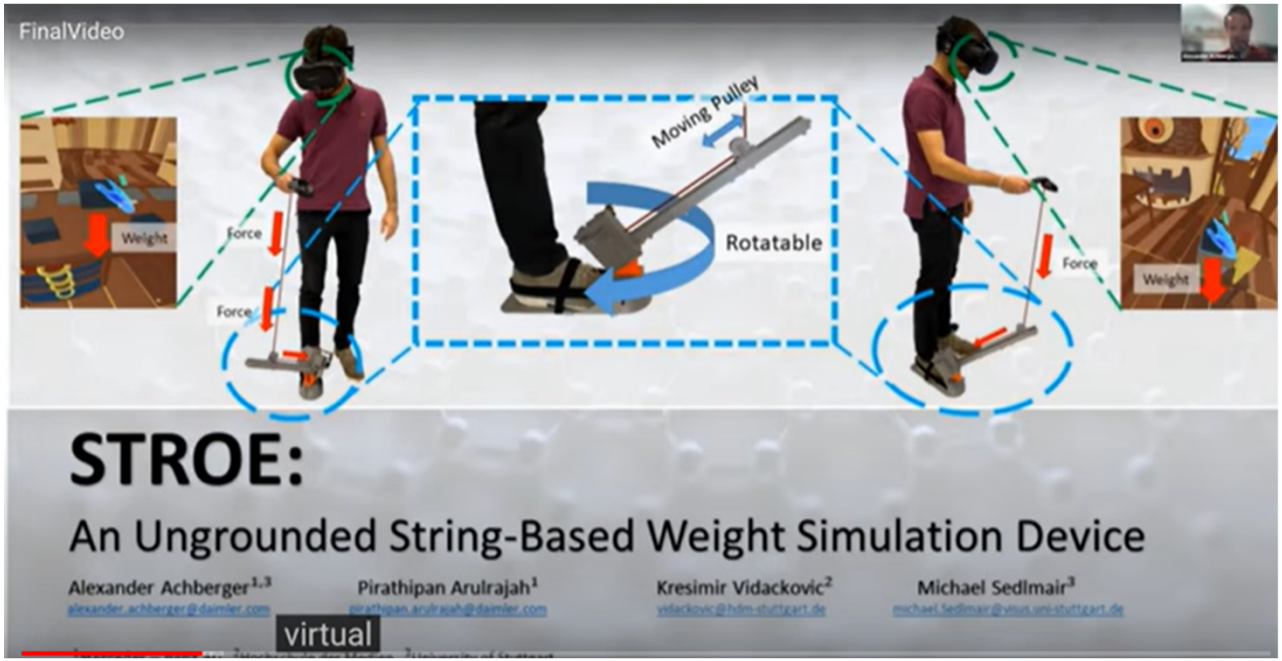
(IEEEVR2019) HapticSphere: Physical Support To Enable Precision Touch Interaction in Mobile Mixed-Reality, Wang et al.

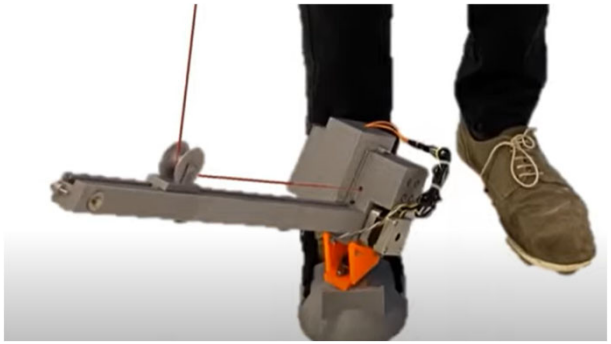


https://www.youtube.com/watch?v=-0mZJaTVQKQ

(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

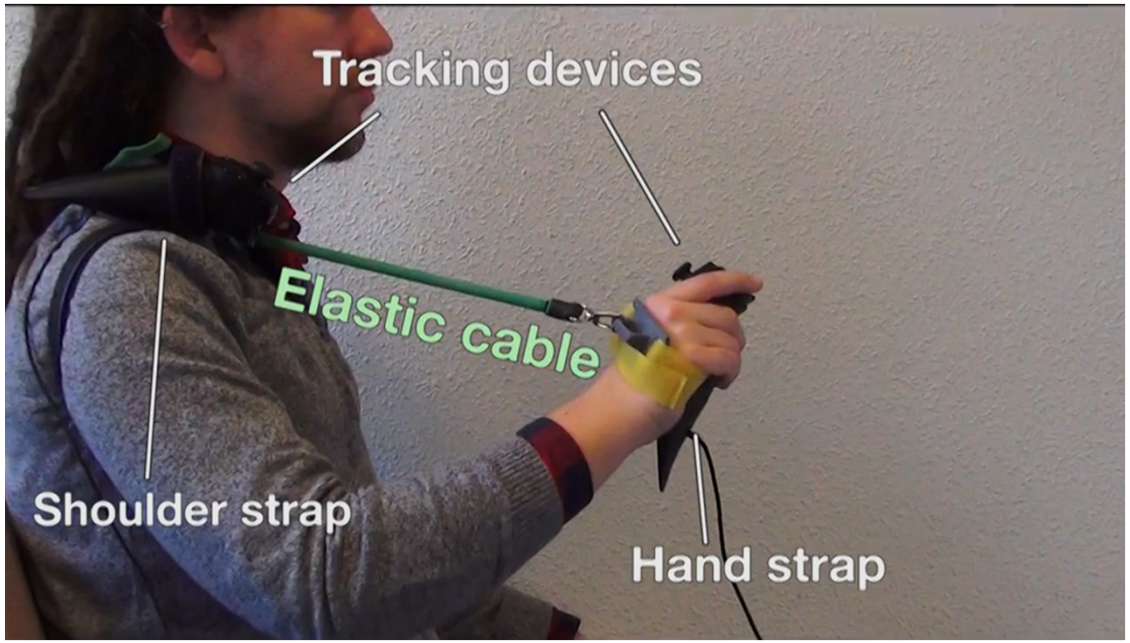




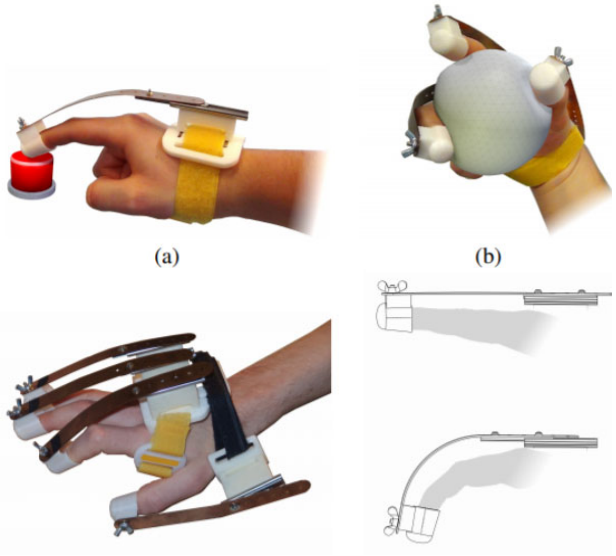
Ungroundedワイヤベースで重さ感を知覚させる。足とハンドヘルドコントローラの間で力を提示する Grounded to the user's foot.

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.

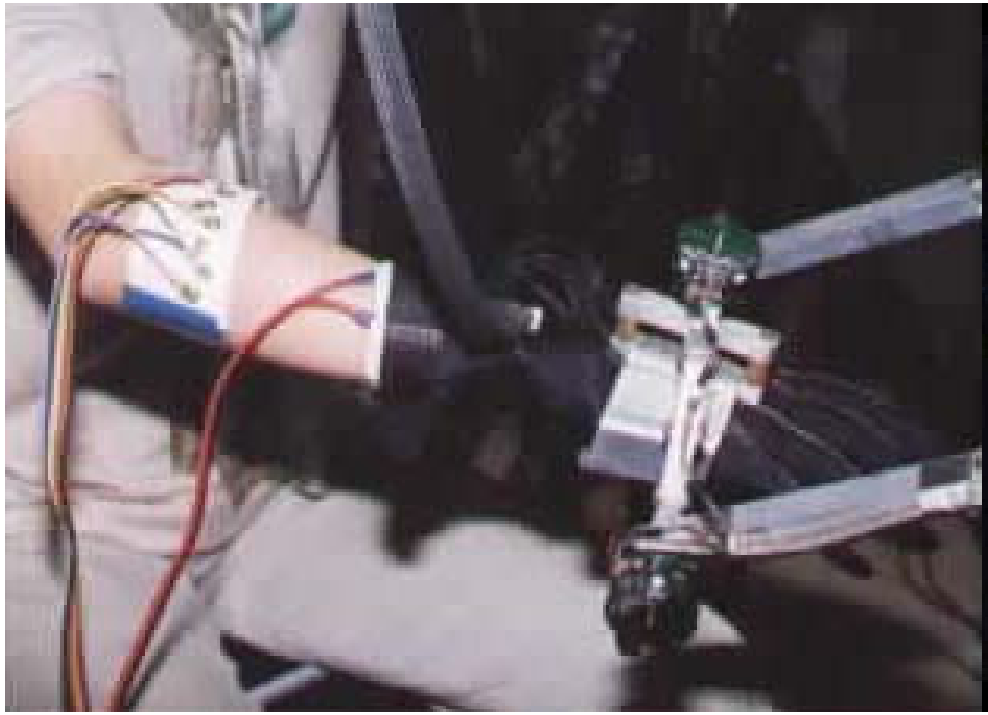
- 手・指に対してパッシブな弾性力を提示することで，VR空間での力覚の納得感を高める．
- A passive elastic plate enhances realism of force perception in VR space.

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

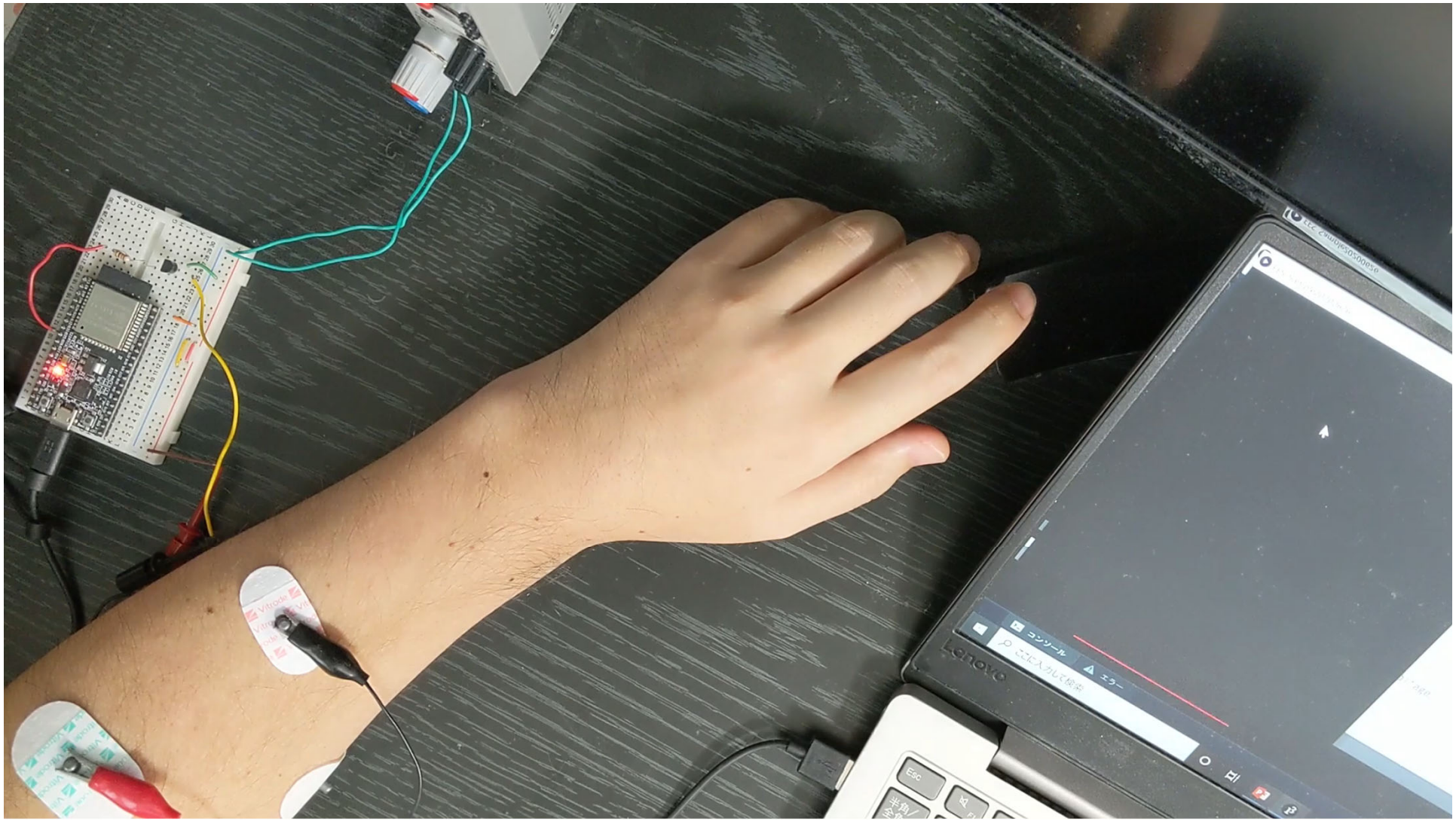
筋電気刺激とVR / EMS and VR

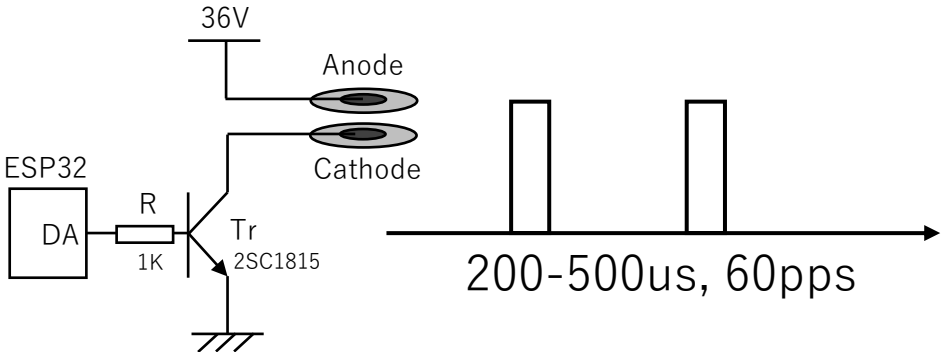


稲見, 川上: 仮想体感装置, 特開平7-20978

IVRC1993
https://www.youtube.com/watch?v=9QVd45N1j00

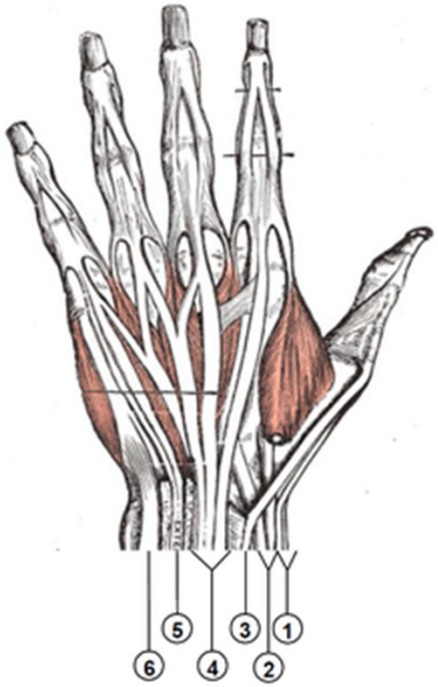
- 拮抗筋の電気刺激で抵抗力を提示。軽量。ただし刺激場所での触覚も生じる。
- 接地部位は身体。機能的電気刺激の分野では古くから利用
- Antagonist Muscle is electricall stimulated. Light weight, but strong tactile sensation also. Grounded to joint. Used in the field of Functional Electrical Stimulation (FES).



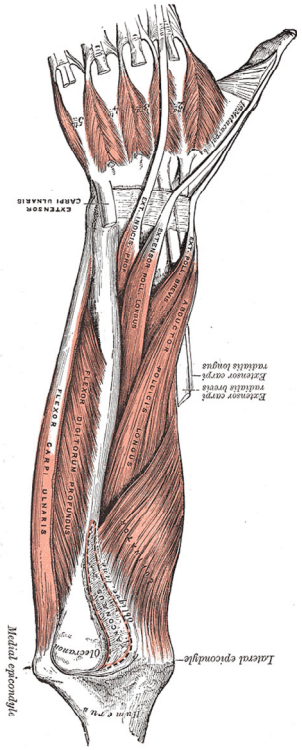


（この回路は安全ではないので非推奨です。
必要なら問い合わせてください。
This circuit is not safe and not recommended. ）

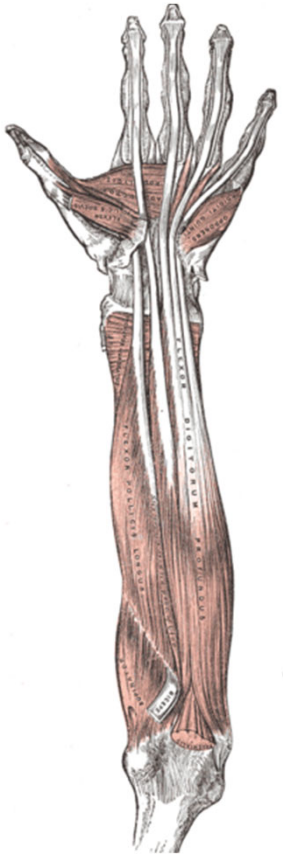
（参考）指を動かす筋肉／Muscles for fingers



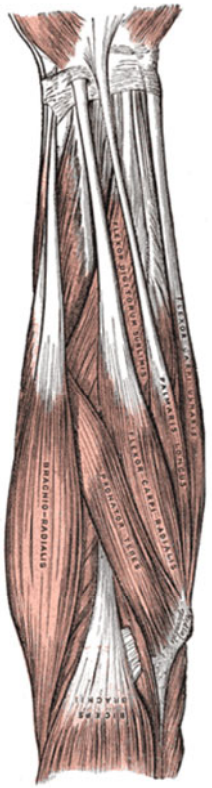
https://en.wikipedia.org/wiki/Muscles_of_the_hand



Deep muscles of the posterior forearm（背側）



Deep muscles of the anterior forearm (腹側）



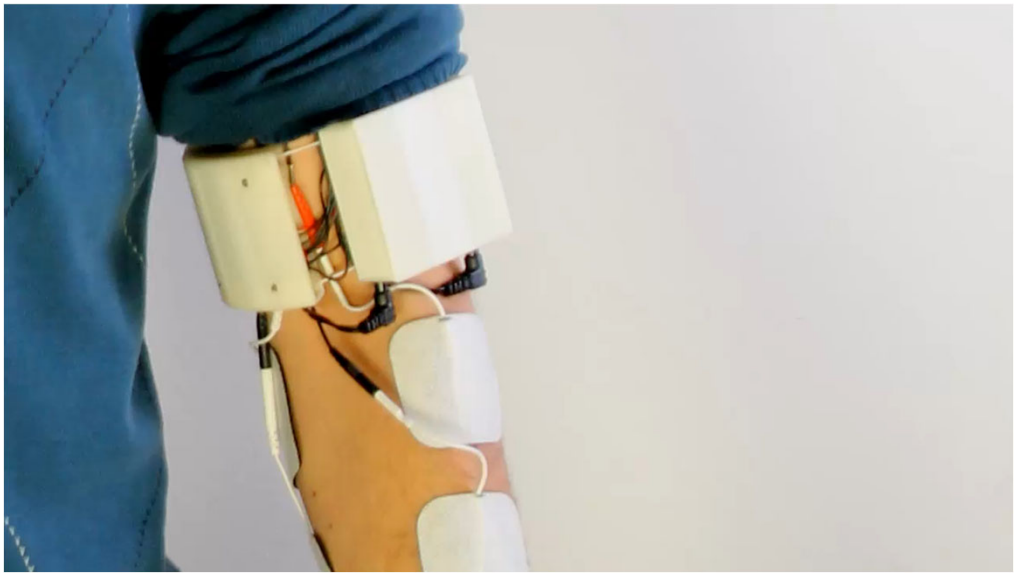
Superficial muscles of the forearm

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 & coase 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

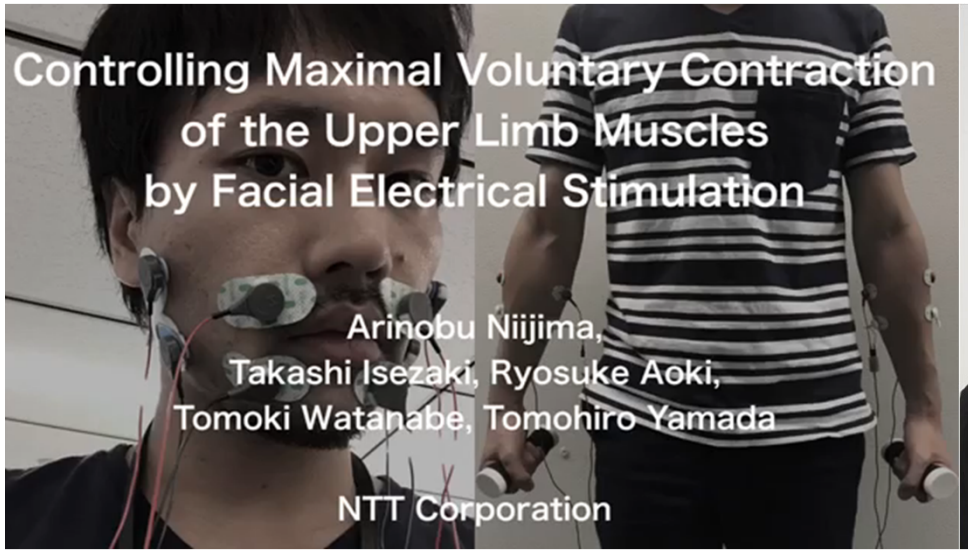
https://www.youtube.com/watch?v=9XBoZyfB8hY
(CHI2011) PossessedHand: Techniques for controlling human hands using electrical muscles stimuli, Tamaki et al.



https://www.youtube.com/watch?v=KMxIfj7zhlw
(CHI2015) Proprioceptive Interaction, Lopes et al.

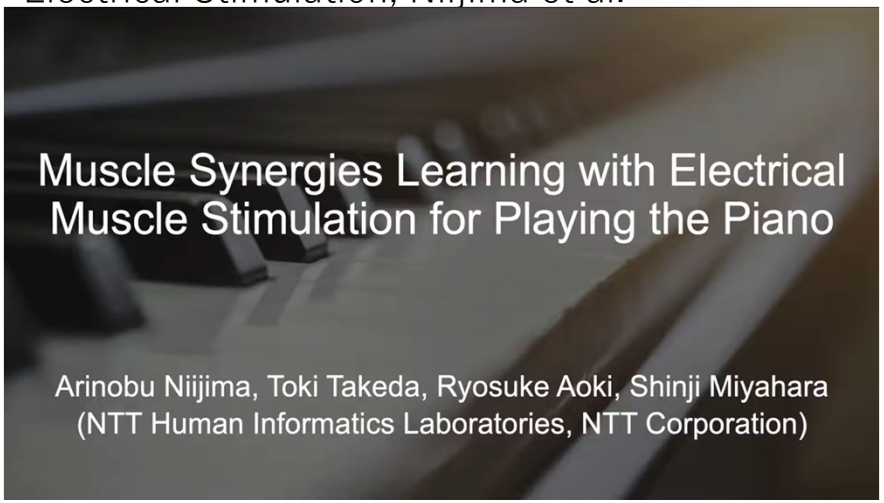
https://www.youtube.com/watch?v=qHRn05Kmzew
(CHI2018)Adding Force Feedback to Mixed Reality Experiences and Games using Electrical Muscle Stimulation, Lopes et al.

EMS for HCI



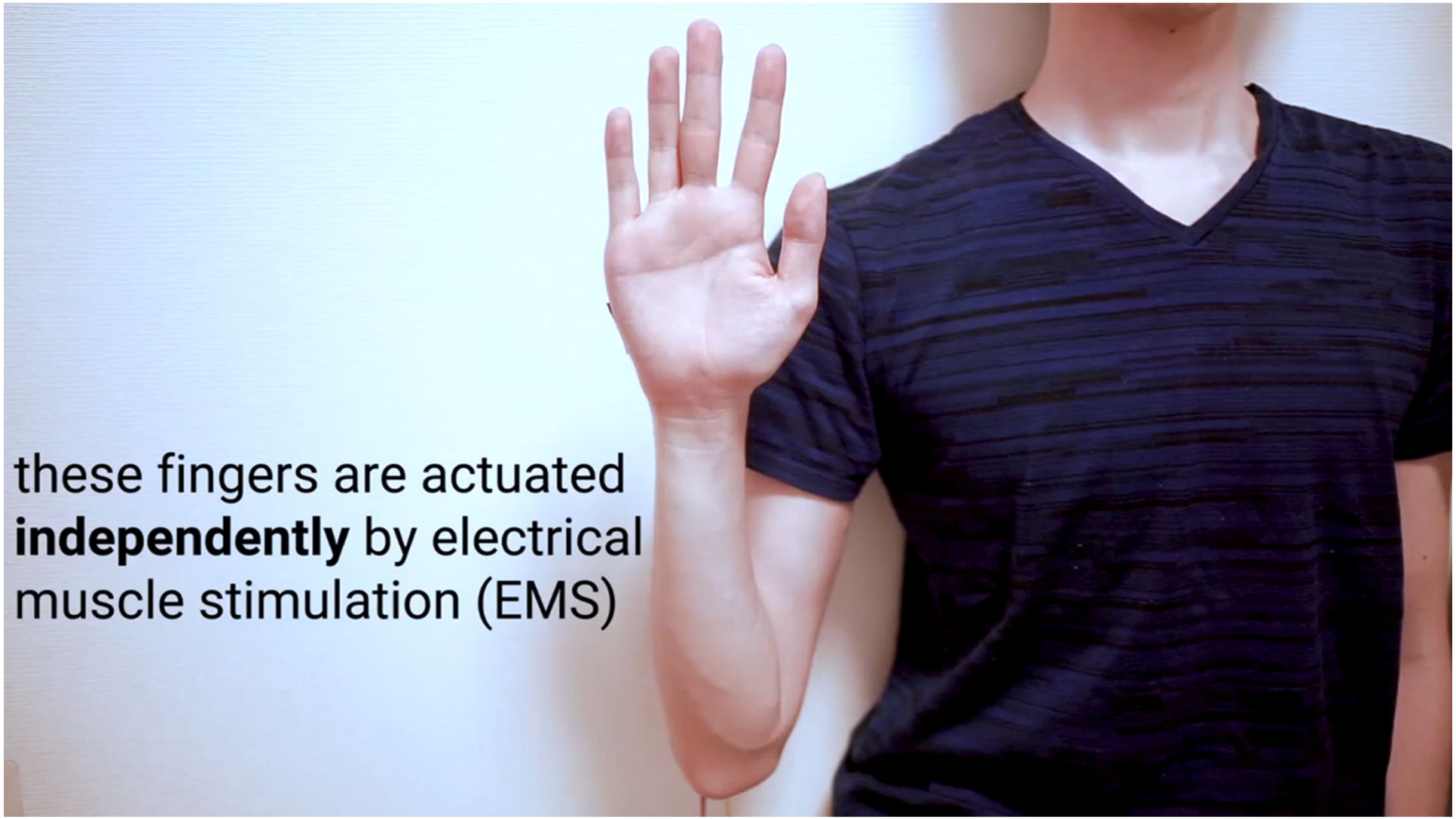
https://www.youtube.com/watch?v=R1DDTgT5X04
(CHI2018) Controlling Maximal Voluntary Contraction of the Upper Limb Muscles by Facial Electrical Stimulation, Niijima et al.

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

(CHI2021) Increasing Electrical Muscle Stimulation's Dexterity by means of Back of the Hand Actuation
Akifumi Takahashi, Jas Brooks, Hiroyuki Kajimoto, Pedro Lopes



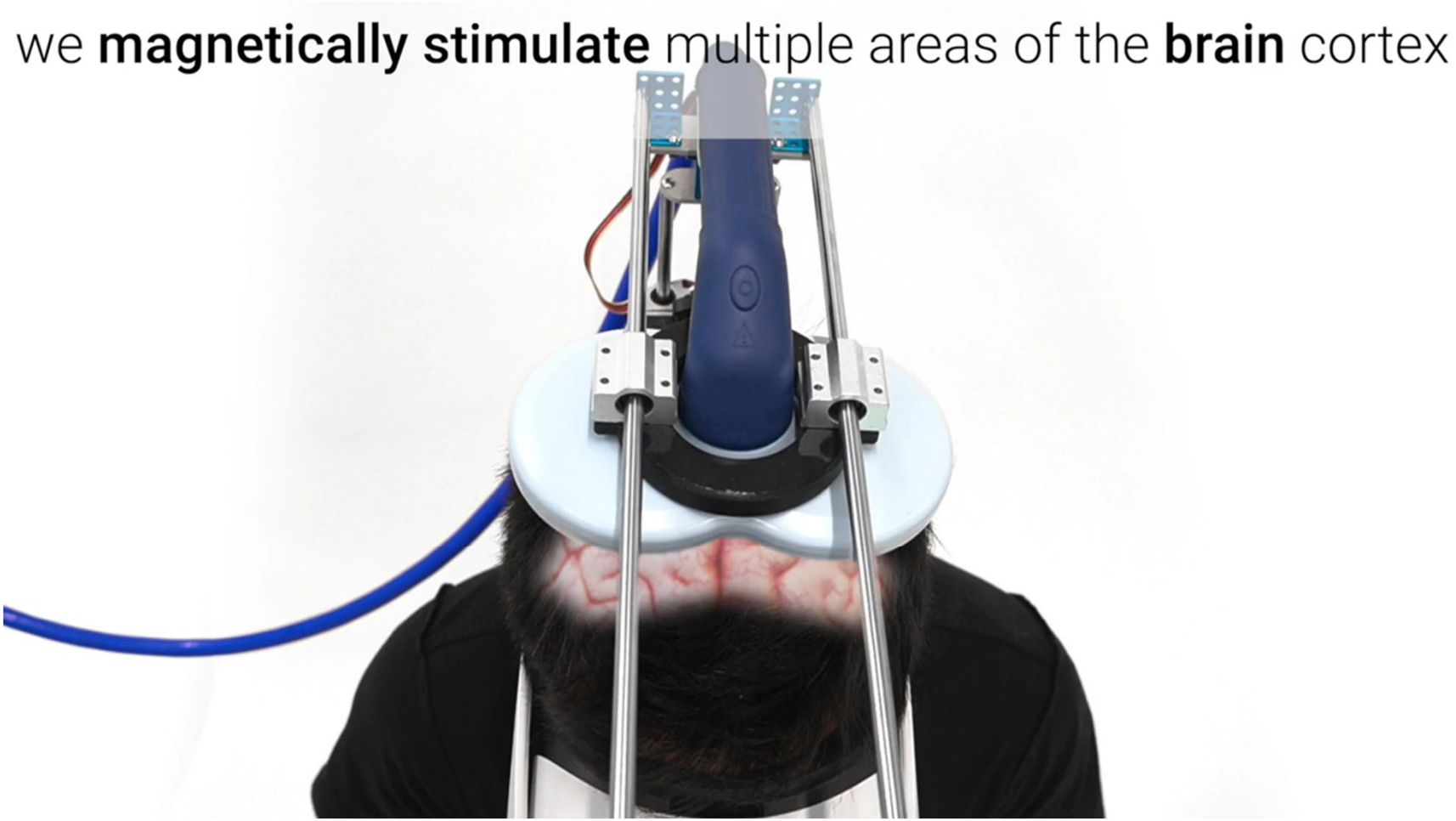
https://www.youtube.com/watch?v=Sp8Eo9t90A8

- 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

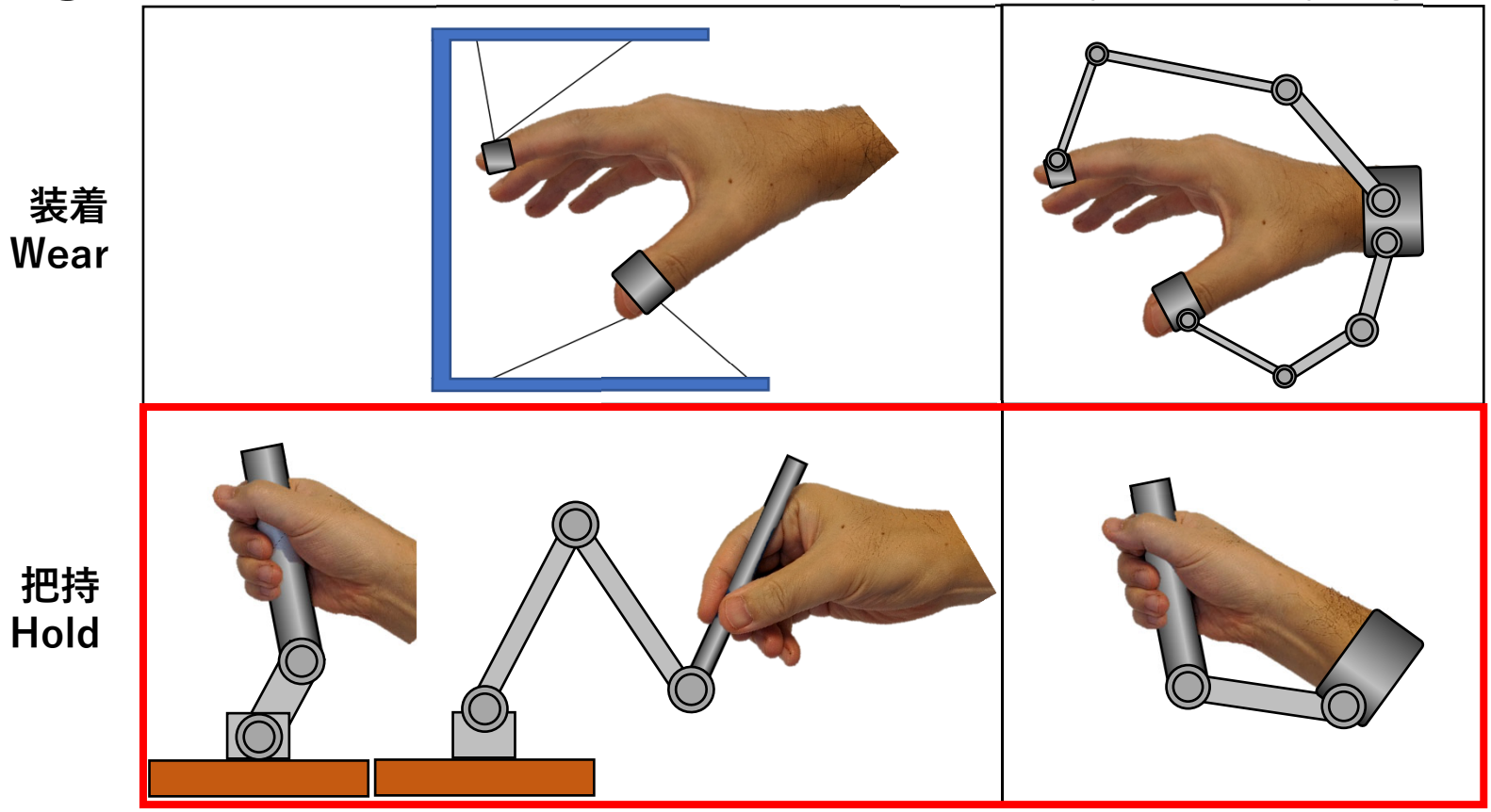
指先の機械的ブレーキと筋電気刺激を組み合わせることでより正確な指姿勢指定が出来る
More precise finger posture specification by combining mechanical braking of the fingertips with myoelectrical stimulation.
https://www.youtube.com/watch?v=arxIyor4Hq4&list=PLqhXYFYmZ-VeKUIuttbQWomTQ-oXF6PLf&index=54

(CHI2024) Haptic Source-effector: Full-body Haptics via Non-invasive Brain Stimulation, Yudai Tanaka, Jacob Serfaty, Pedro Lopes
https://www.youtube.com/watch?v=0NMlkxXFx3c



- 脳への磁気刺激による力覚・触覚提示
- Magnetic pulse stimulation to the brain to present force and tactile sensation.

非環境型の力覚ディスプレイの形態
Configurations of non-environmental haptic displays



- 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.

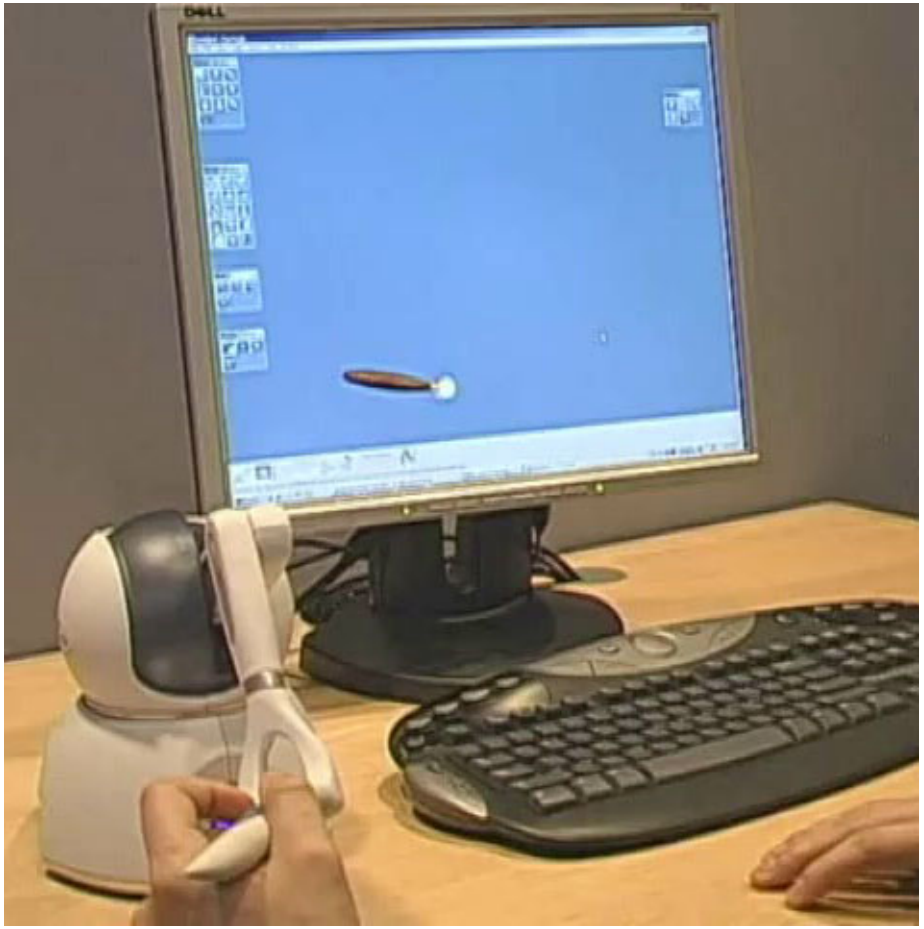
PHANToM (SensAble)→TouchX

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 Environmet and Teleoperator Systems, 1994.

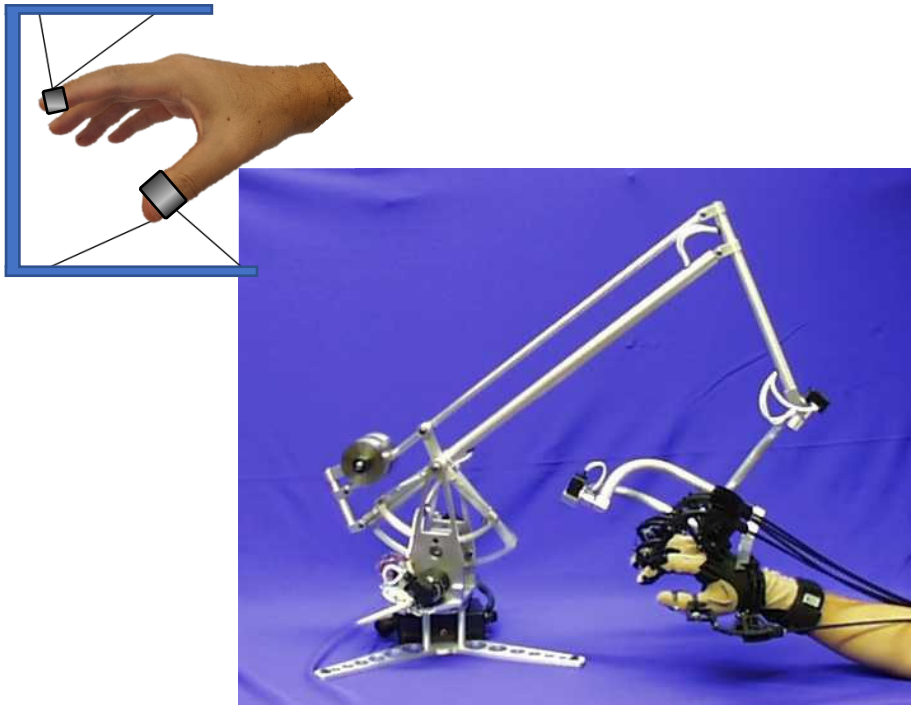
PHANToM, PHANToM Omni (SensAble)

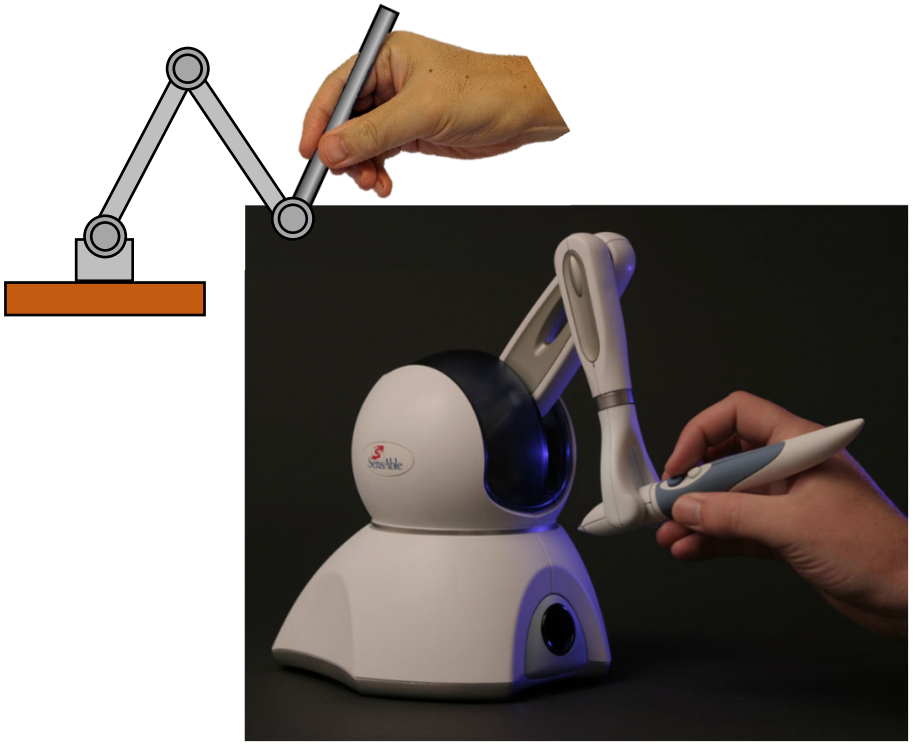


http://www.youtube.com/watch?v=u9jdhUvOmMw&feature=related

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

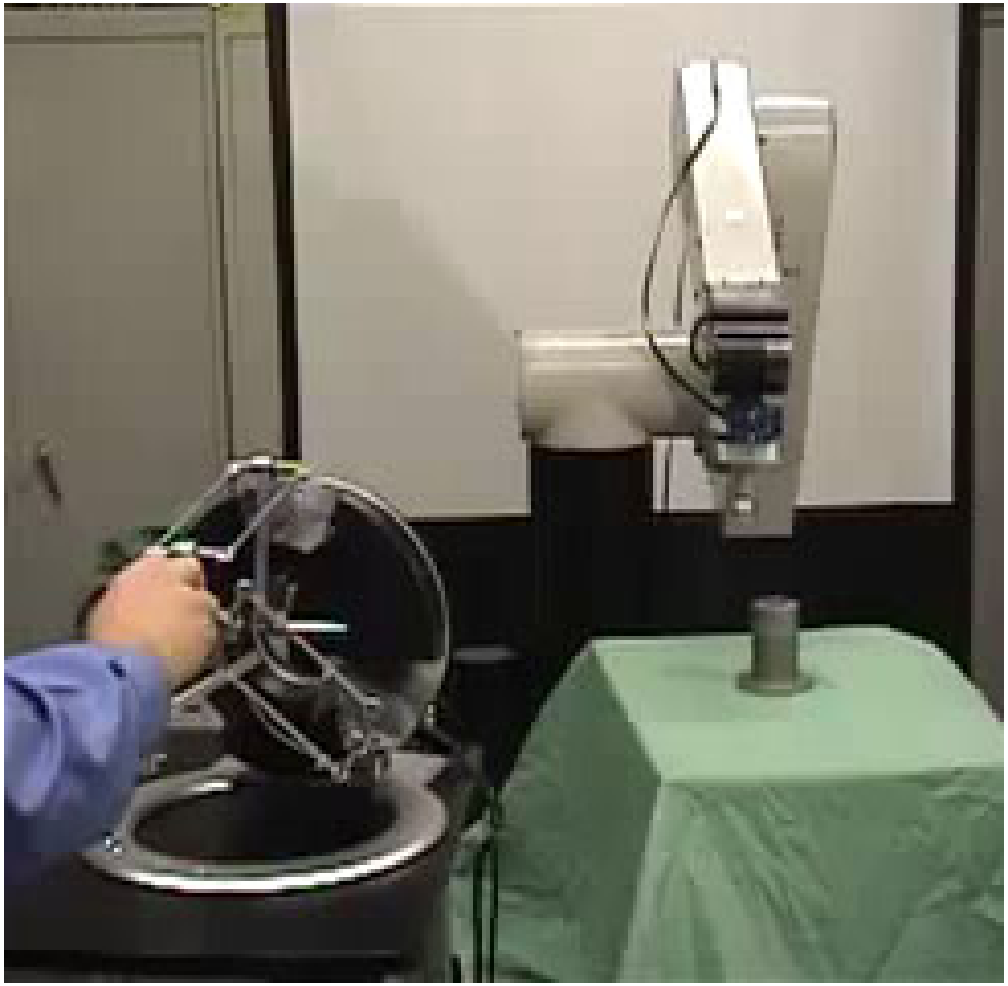
装着型と把持型の小さくて大きな違い
Small but significant difference between wear type and grip type





- 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)

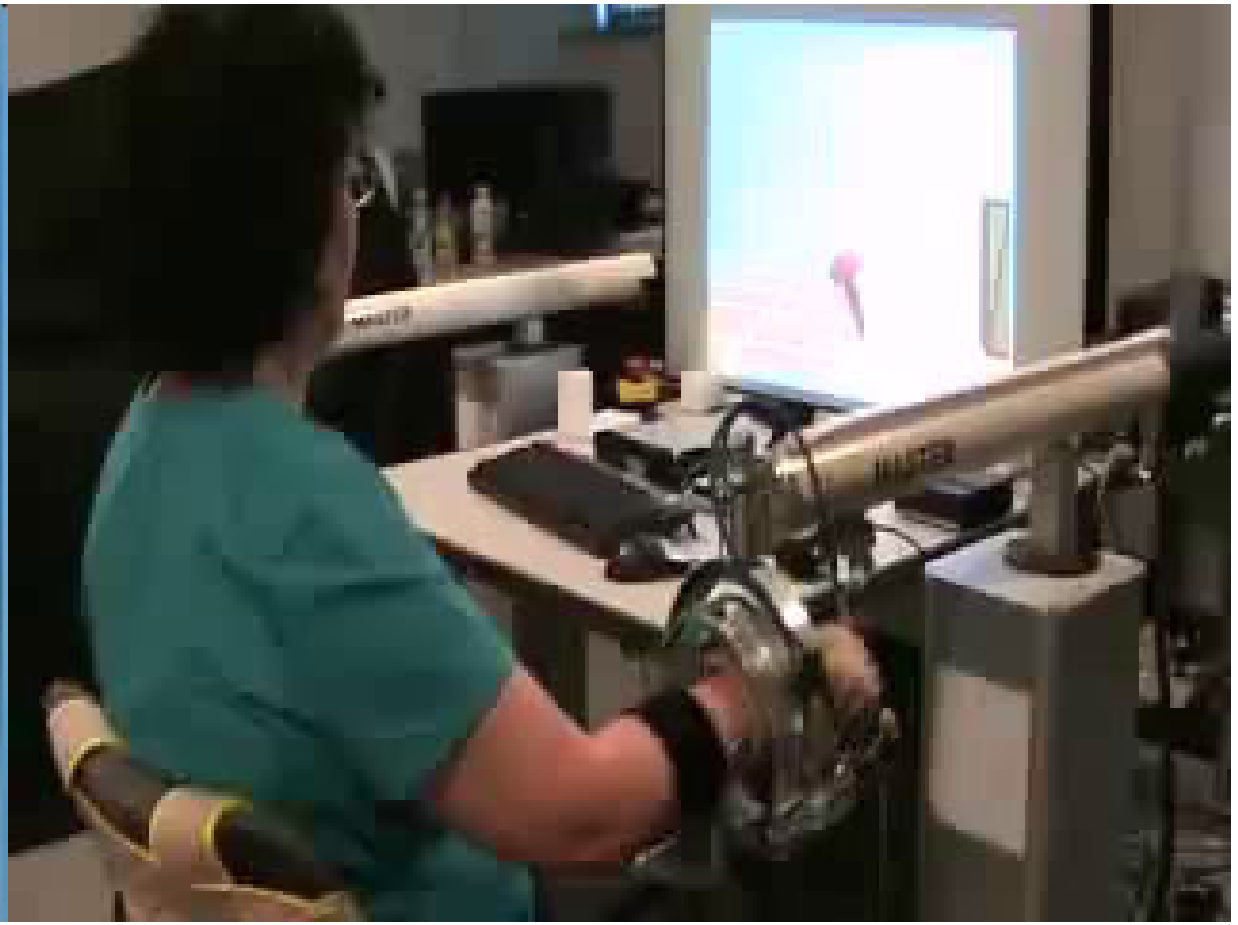
http://www.youtube.com/watch?v=mW70eIK9Yrs

Falcon (Novint)

把持型SPIDAR

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

HapticMaster (MOOG FCS)

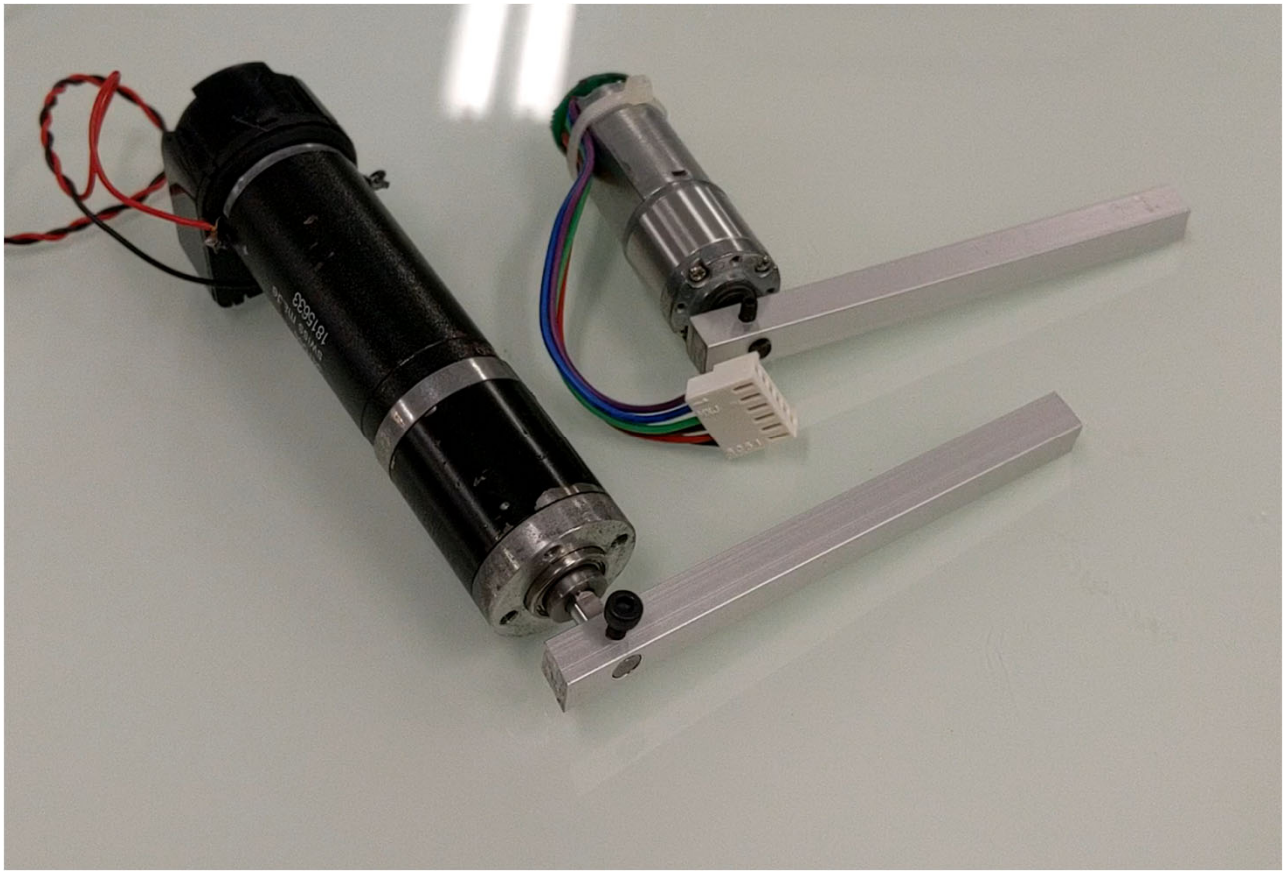


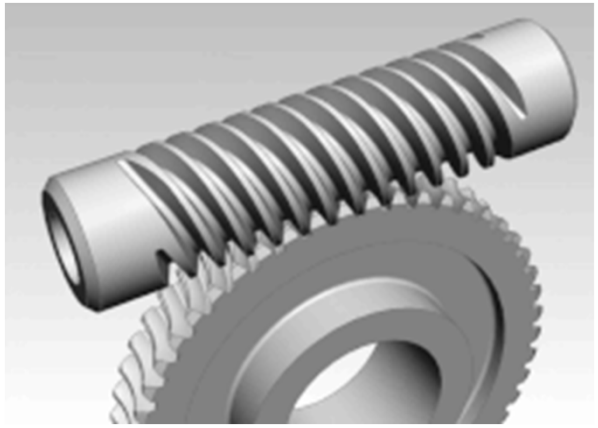
http://www.youtube.com/watch?v=tgGEcE1VS6I

- 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

Van der Linde R.Q., Lammertse P., Frederiksen E., Ruiter B(2002) The HapticMaster, a new high-performance haptic interface

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.
- ウオームギア/ Worm gear：バックドライバビリティ無 Not back-dribable.

出力軸を直接触るため、バックドライバブルかどうかで制御が変わる。

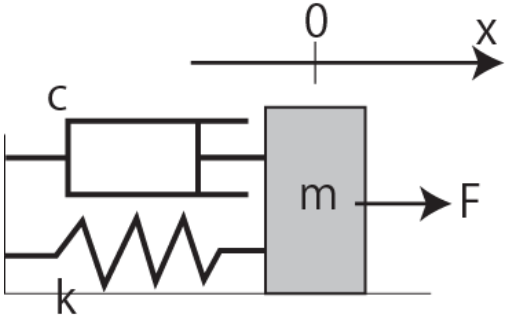
As Human handles output shaft directly, control method is closely related to back-drivability

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?



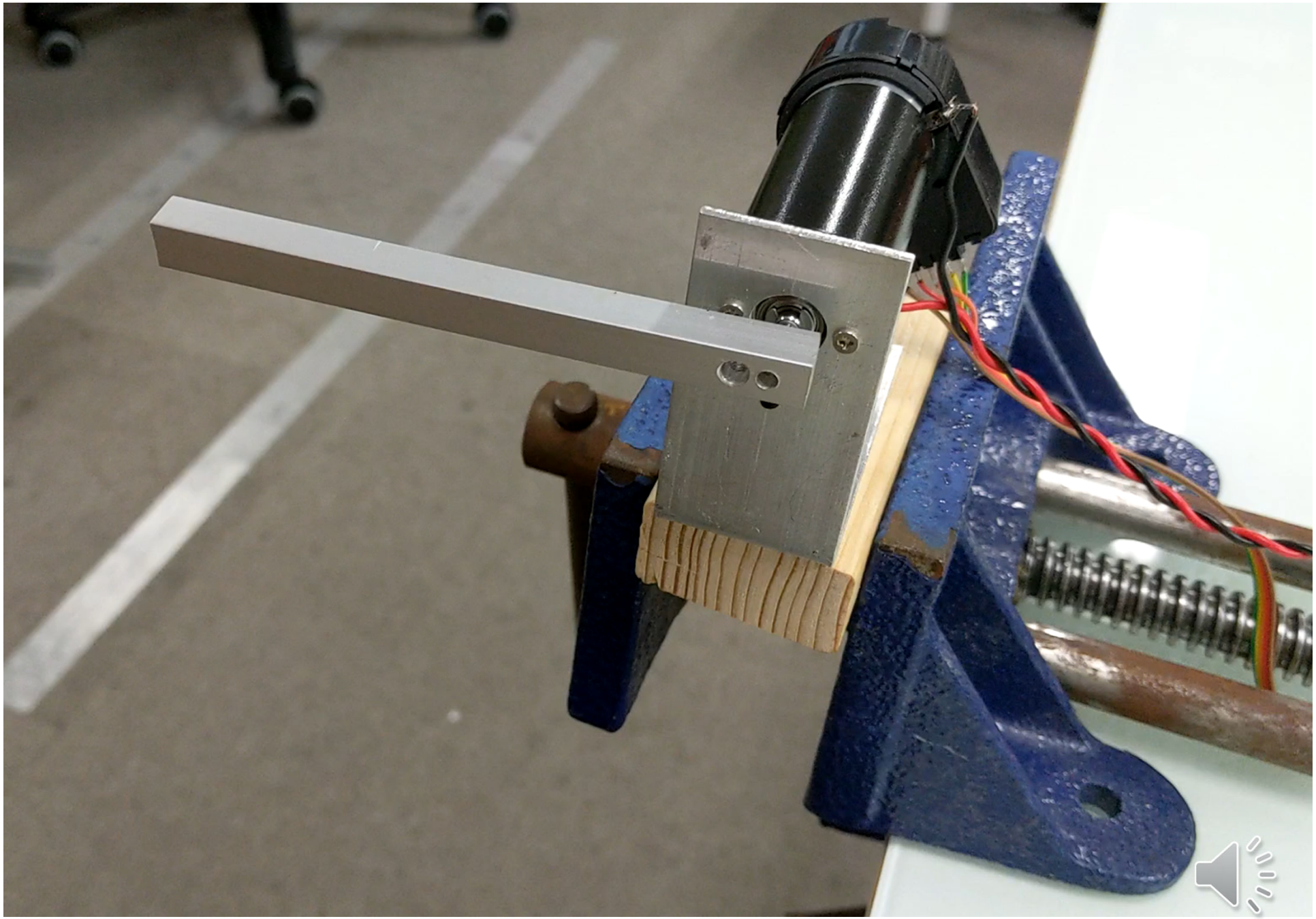
$$m\ddot{x} = f - c\dot{x} - kx$$

インピーダンス型のシミュレート手法

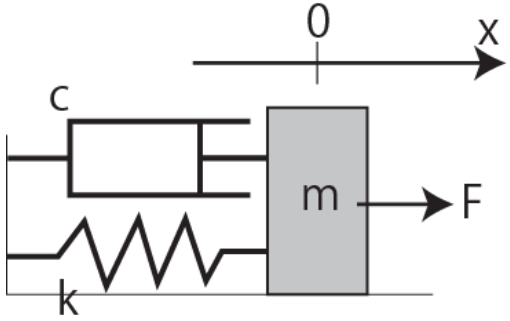
- 手先の位置を計測.
- 位置や速度に応じた力を出力.
- 手先が壁にめり込むところから開始するから，力覚ディスプレイは操作者の力だけで動かせる必要＝バックドライバビリティ有

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?



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

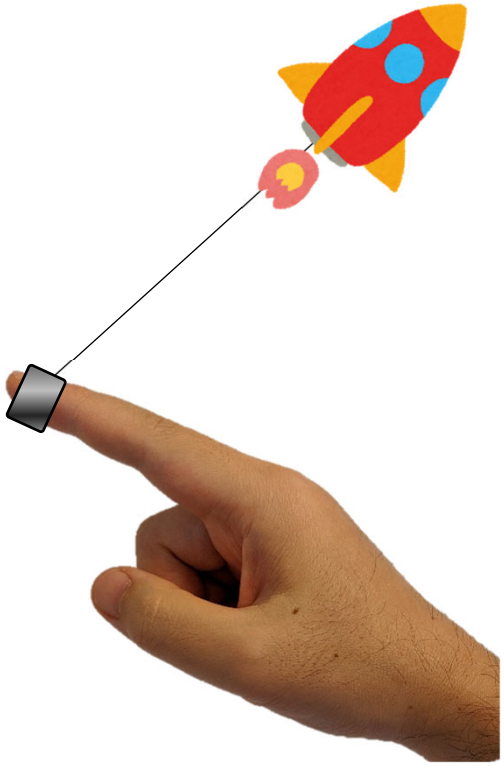
アドミッタンス型のシミュレート手法

- 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

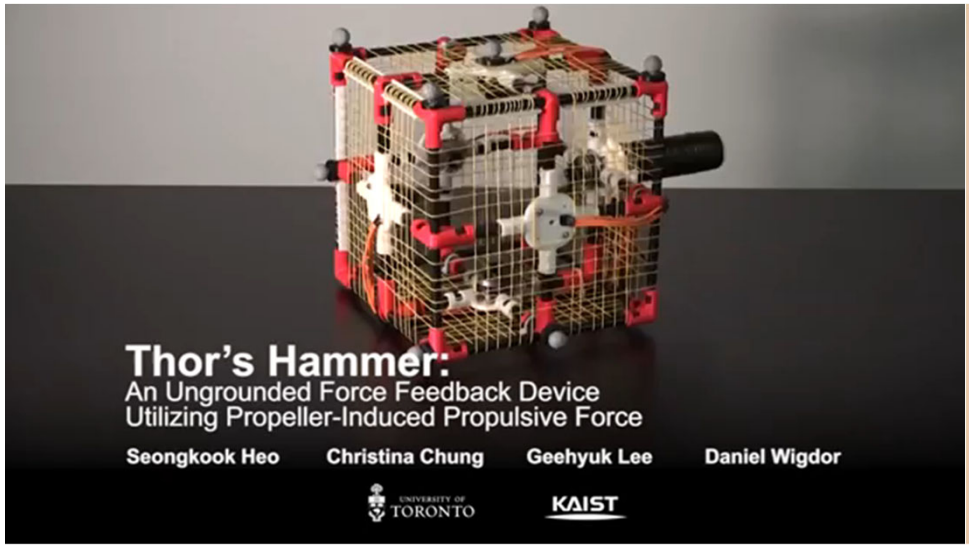
- Measure operator’s force
- Calculate world’s behavior according to the force, and change position of the grip.
- Force sensor is necessary, but back-drivability is not. Rigid robot can be used such as industrial robot.

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

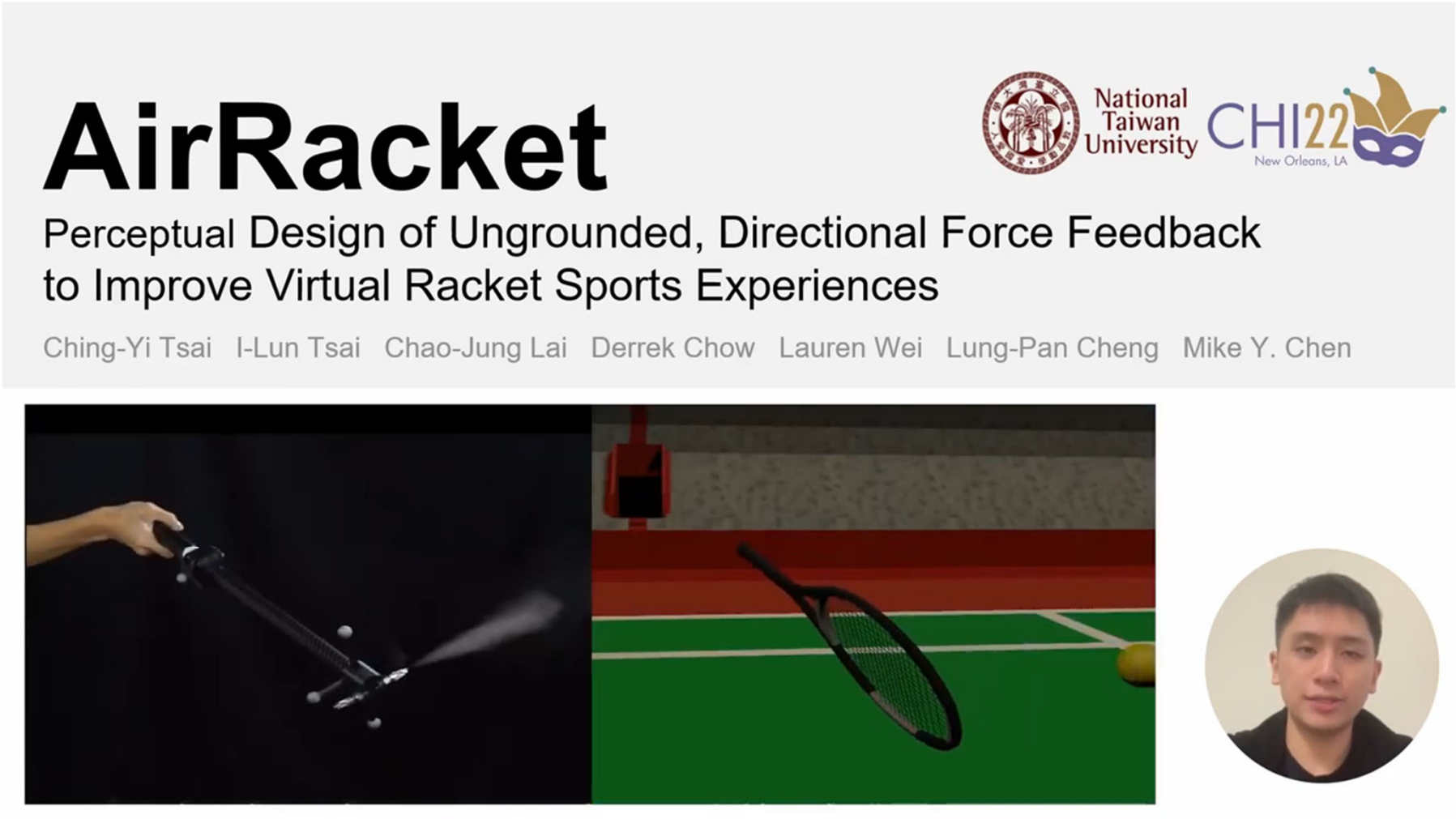
プロペラによる力覚提示

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

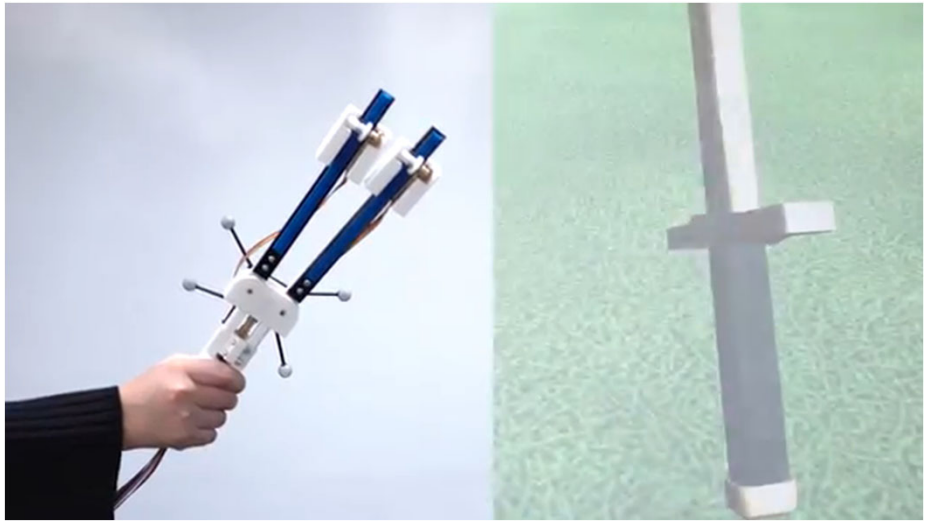
(CHI2022) AirRacket: Perceptual Design of Ungrounded, Directional Force Feedback to Improve Virtual Racket Sports Experiences Ching-Yi Tsai, I-Lun Tsai, Chao-Jung Lai, Derrek Chow, Lauren Wei, Lung-Pan Cheng, Mike Y. Chen



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



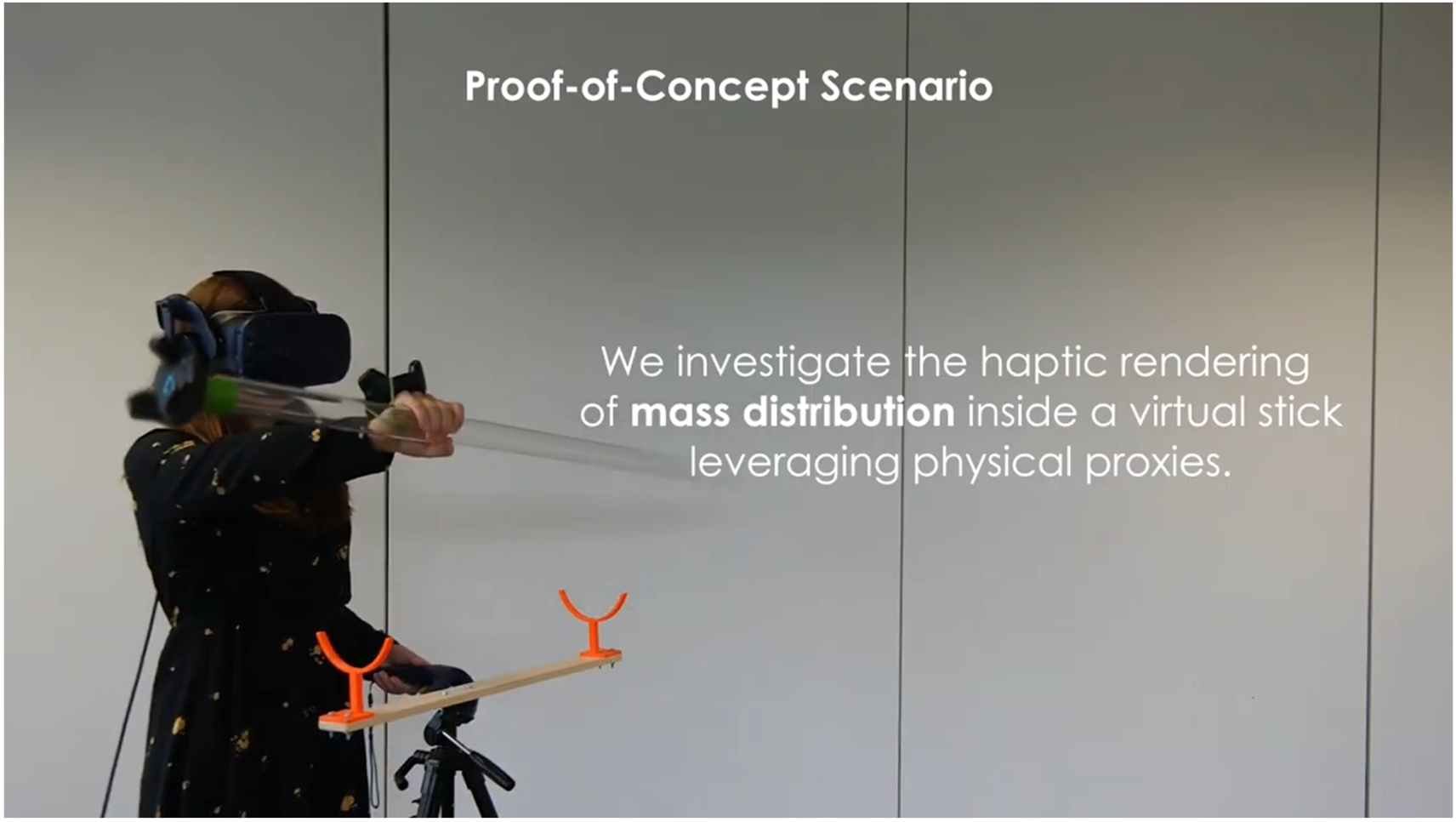
https://www.youtube.com/watch?v=TJA7psWM8sY
(SIGGRAPH2018) Transcalibur: Weight Moving VR Controller for Dynamic Rendering of 2D Shape Using Haptic Shape Illusion, Jotaro Shigeyama　Takeru Hashimoto　Shigeo Yoshida　Taiju Aoki　Takuji Narumi　Tomohiro Tanikawa　Michitaka Hirose
重心位置を変化させる＋ビジュアルの組み合わせで様々な武器を再現。

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

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．

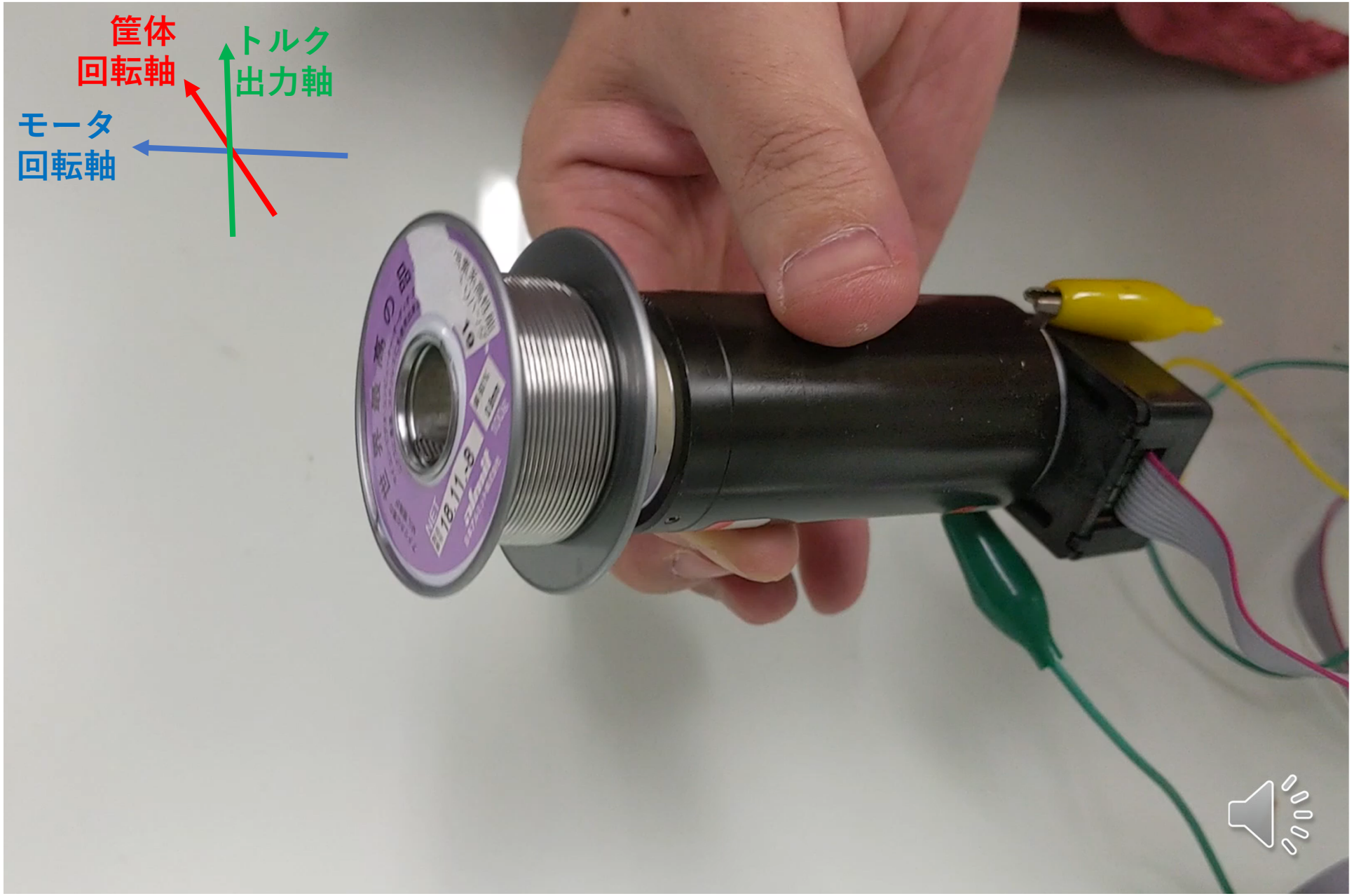
(IEEEVR2021) André Zenner, Kristin Ullmann, Antonio Krüger
Combining Dynamic Passive Haptics and Haptic Retargeting for Enhanced Haptic Feedback in Virtual Reality



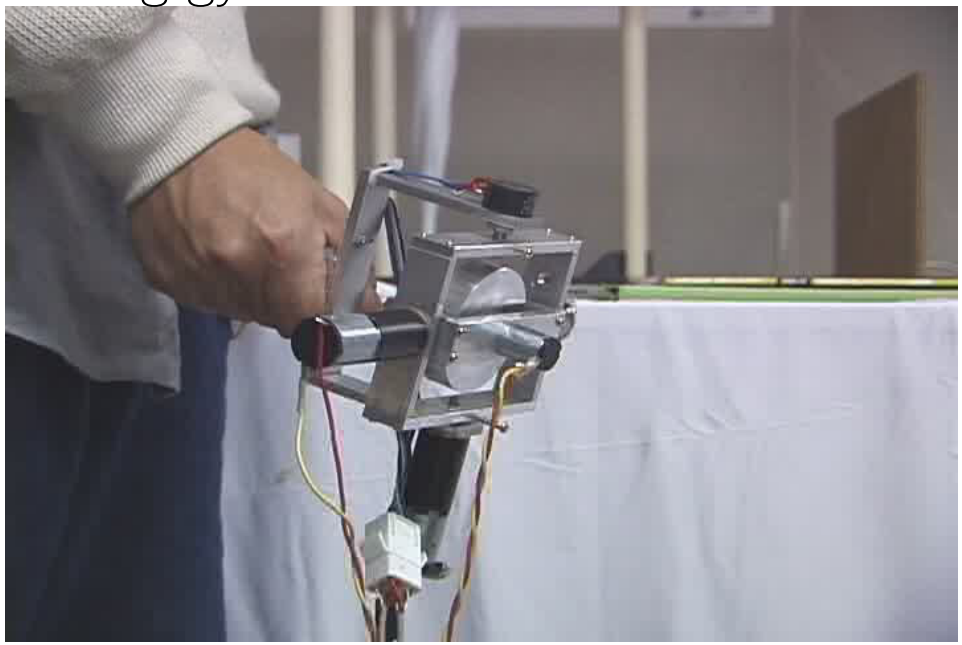
https://www.youtube.com/watch?v=C2zprVoPEzs

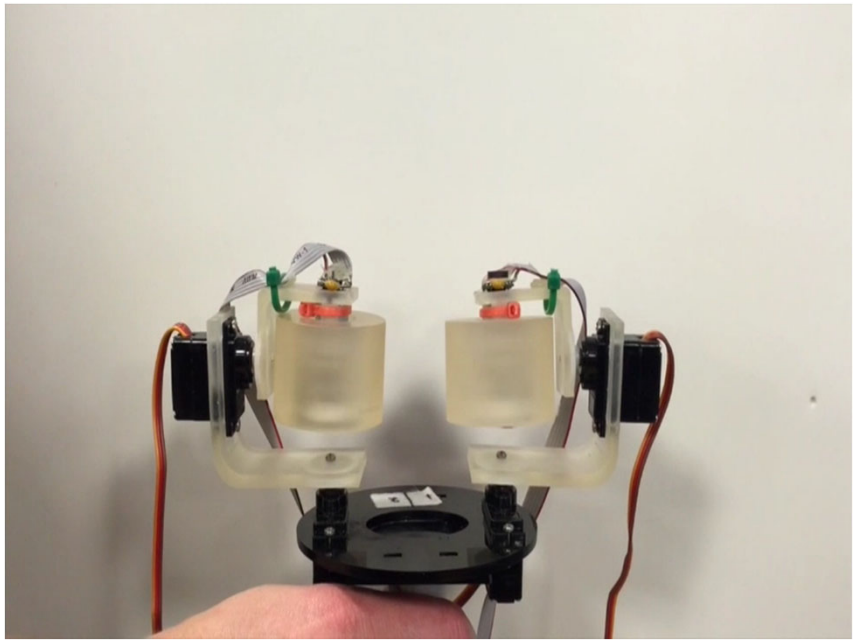
- 棒の中の重りの重心移動と、視覚映像の手の位置ずらし（Retargeting)を組み合わせて、所望の重心位置の棒を表現する。
- Combining the center-of-gravity shift of the weight in the stick and the hand displacement (retargeting) of the visual image, the stick with the desired center-of-gravity position is represented.

ジャイロ効果の利用/ Using gyro effect



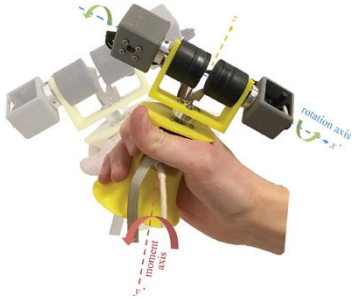
ジャイロ効果の利用：定速回転→回転軸変動
Using gyro effect: Rotation axis is turned

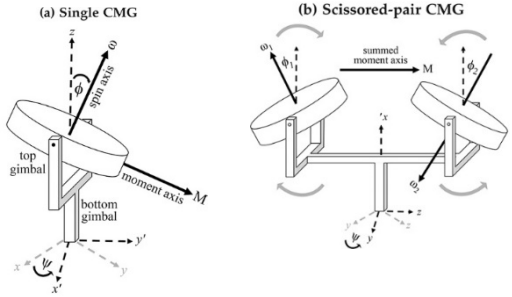




吉江　将之、矢野博明、岩田　洋夫　：ジャイロモーメントを用いた力覚呈示装置、日本VR学会論文誌Vol.7 No.3（2002）
http://intron.kz.tsukuba.ac.jp/gyro/gyro_j.html

•https://www.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」のさきがけ的研究。The hard disk is rotated and the gyroscopic effect generates torque, which is made to feel like resistance.





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.

(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=jqxv95YCnhs&list=PLqhXYFYmZ-VdaPIMTFVH5K5brMDJClfAn&index=47

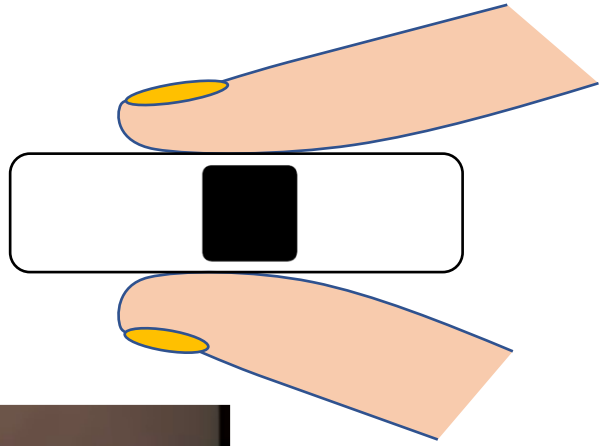
持ち物の性質（慣性や粘性）を推定することを目的に、3自由度モーメントフィードバックを生成
能動的に力を出すのではなく、回転に対するインピーダンスを変えることで、把持物の重さ等を表現
Generate 3-DOF moment feedback for the purpose of estimating the properties (inertia and viscosity) of the handheld objects.

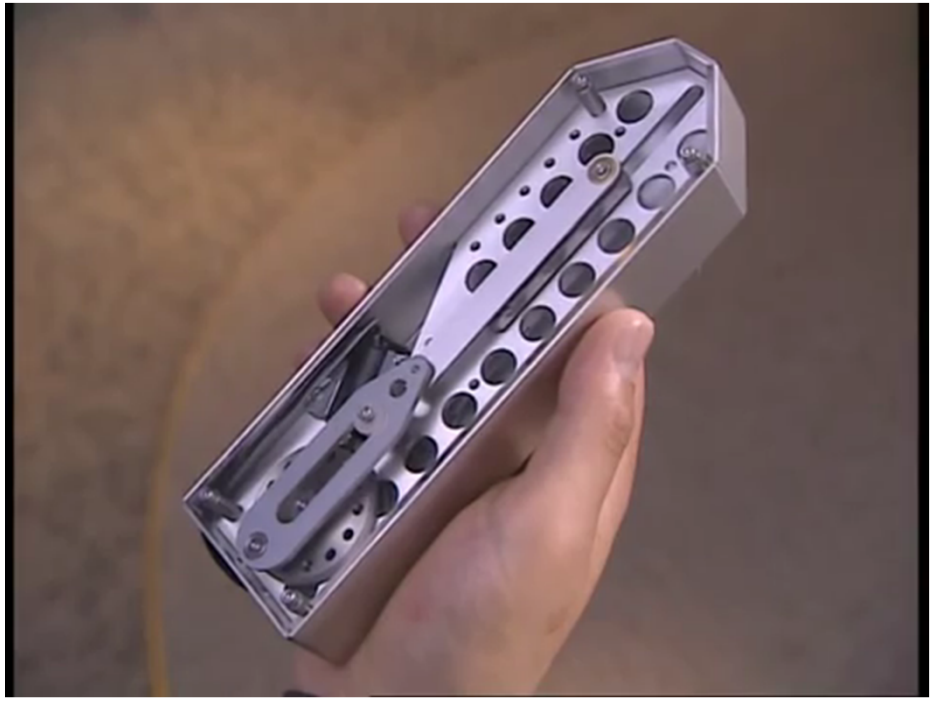
回転速度変化/ Change of rotation speed

https://youtu.be/J8YvKIxFmTs?t=492
Daijiro Koga et al., Virtual Chanbara, Siggraph2002
http://www.siggraph.org/s2002/conference/etech/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

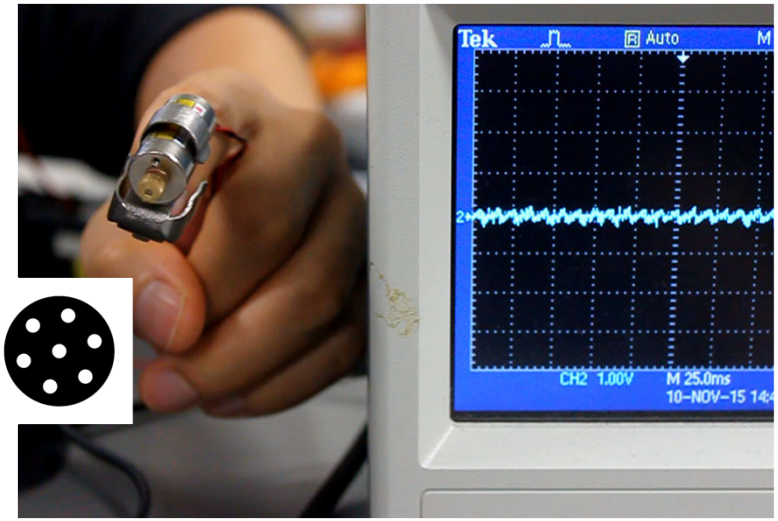
http://www.kecl.ntt.co.jp/human/burunavi/

Traxion (Rekimoto et al. 2013～)

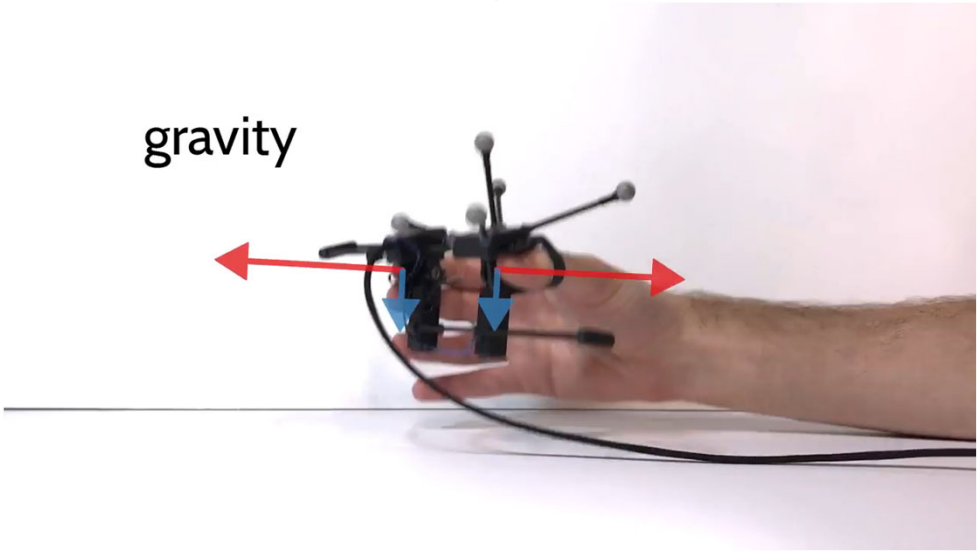
https://vimeo.com/84665437

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

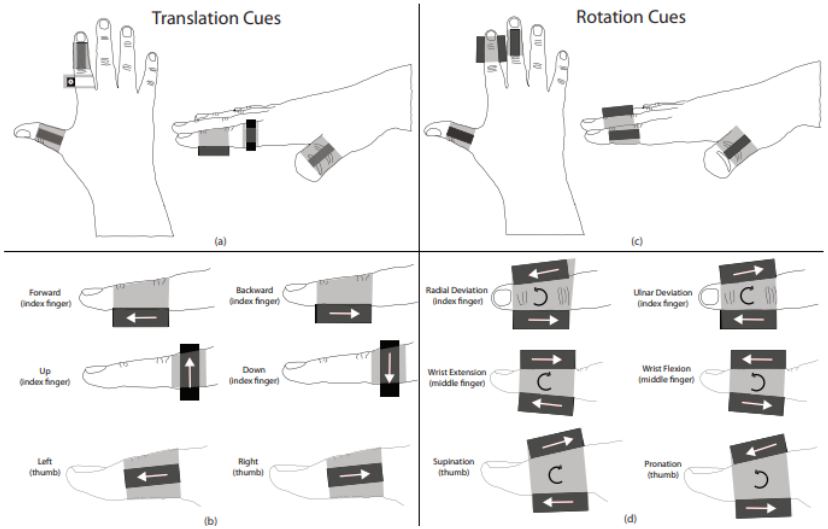
回転も含めた多自由度提示：Multi-DoF presentation



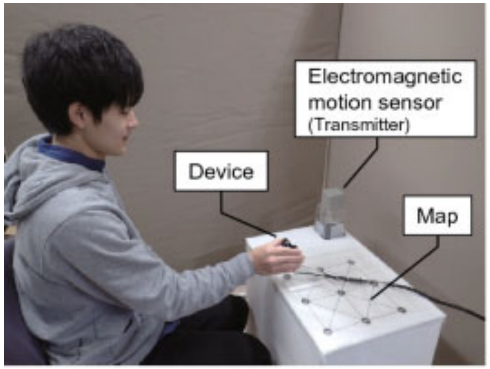
V. Yem, R. Okazaki and H. Kajimoto, "Vibrotactile and Pseudo Force Presentation using Motor Rotational Acceleration." Proc. of IEEE HapticsSymposium 2016.

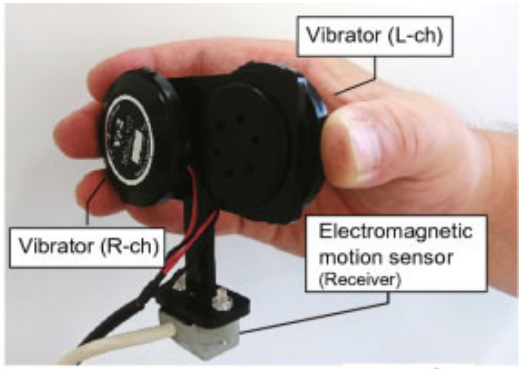


Choi (UIST2017) Grabity: A Wearable Haptic Interface for Simulating Weight and Grasping in Virtual Reality https://www.youtube.com/watch?v=Vj79OLcxnDk
把持力は親指と人差指の間で出し、２つの上下振動子で上下重量感とトルク感を提示。



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



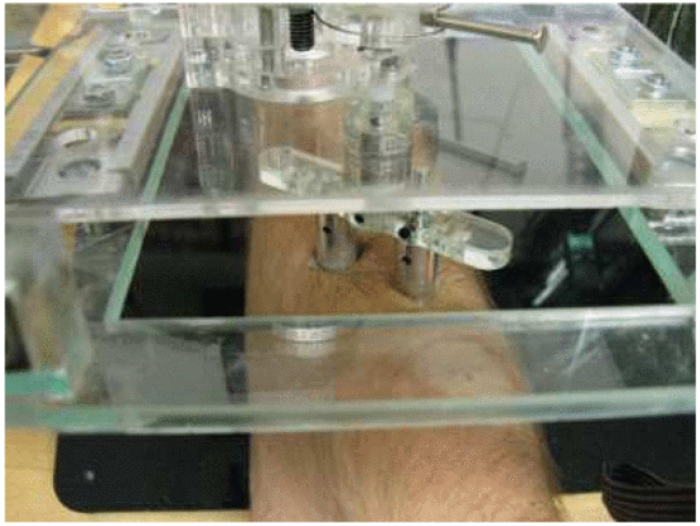


Tanabe (EuroHaptics2020) Motion Guidance Using Translational Force and Torque Feedback by Induced Pulling Illusion
https://link.springer.com/chapter/10.1007/978-3-030-58147-3_52

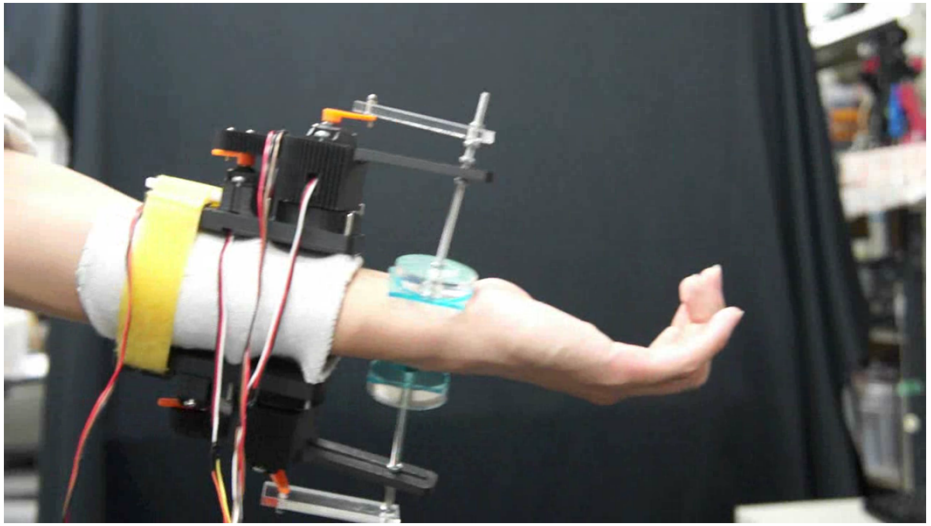
ハンガー反射の身体の他の部位への適用（前腕，腰）

Nakamura et al., Application of Hanger Reflex to wrist and waist. IEEE VR 2014

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.



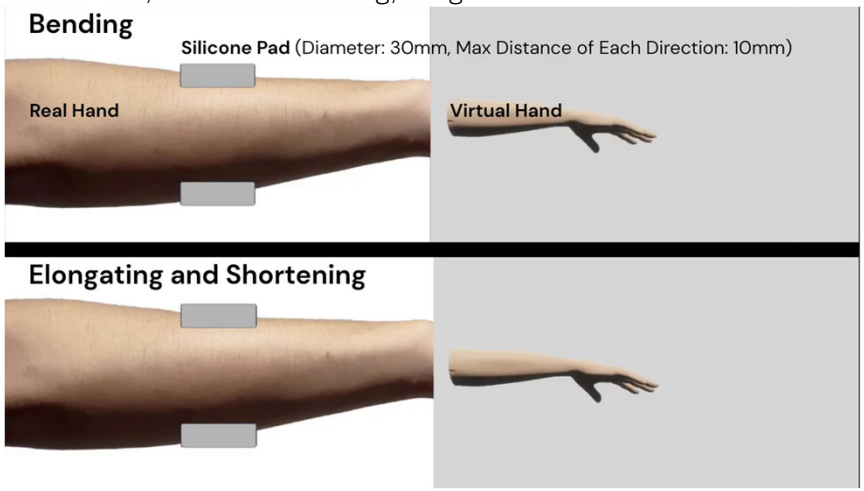
https://dl.acm.org/doi/10.1145/2160125.2160141
(AH2010) Transmission of forearm motion by tangential deformation of the skin. Kuniyasu et al.

https://www.youtube.com/watch?v=HsC4gczjDJ0
(CHI2019) Springlets: Expressive, Flexible and Silent On-Skin Tactile Interfaces, Hamdan et al.

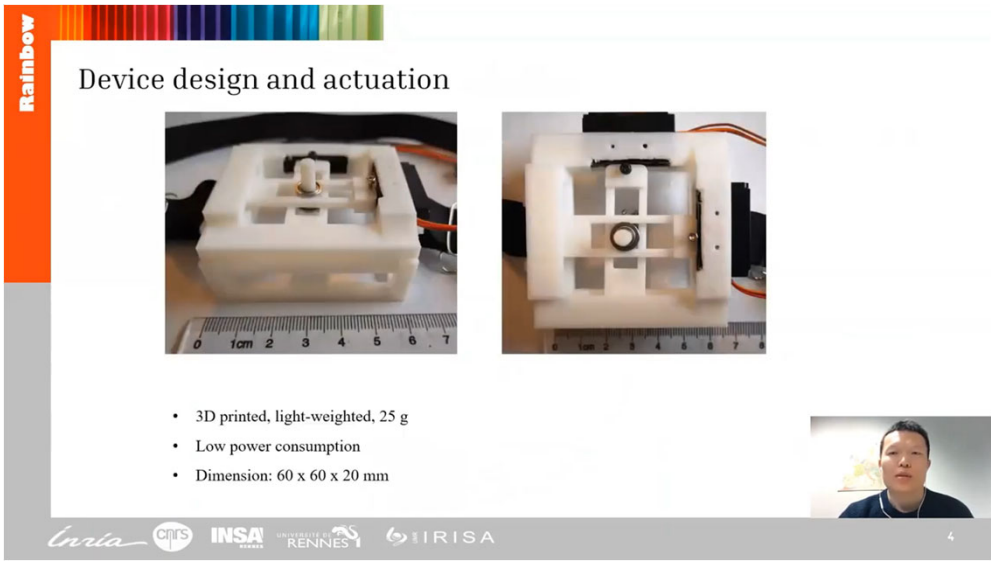
https://www.youtube.com/watch?v=H-megrNfqDo
(CHI2015) Skin Drag Displays: Dragging a Physical Tactor across the User's Skin Produces a Stronger Tactile Stimulus than Vibrotactile, Ion et al.

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

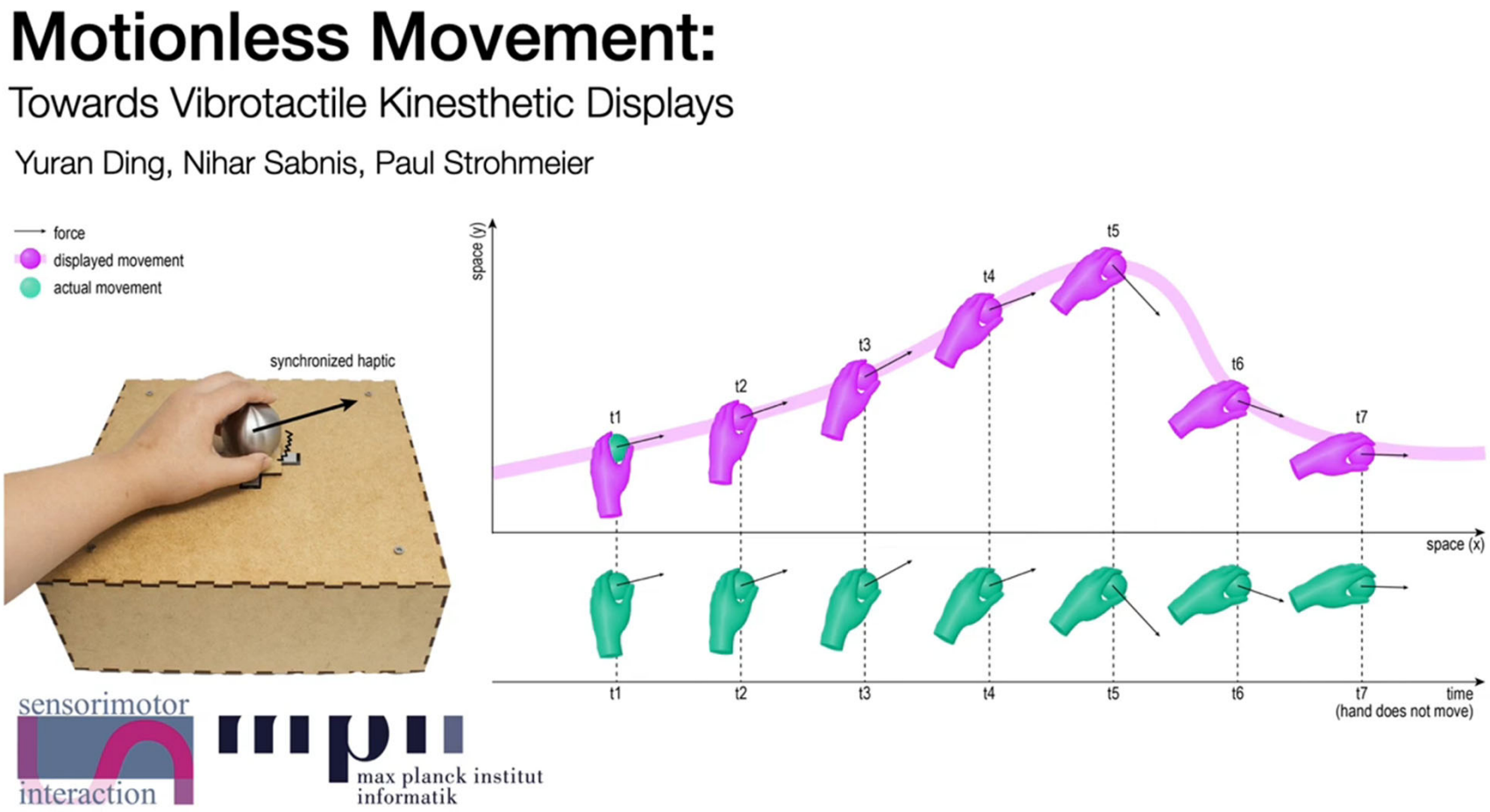


(CHI2024) ArmDeformation: Inducing the Sensation of Arm Deformation in Virtual Reality Using Skin-Stretching
Yilong Lin, Peng Zhang, Eyal Ofek, Seungwoo Je
https://www.youtube.com/watch?v=eRu2S1ECdw8



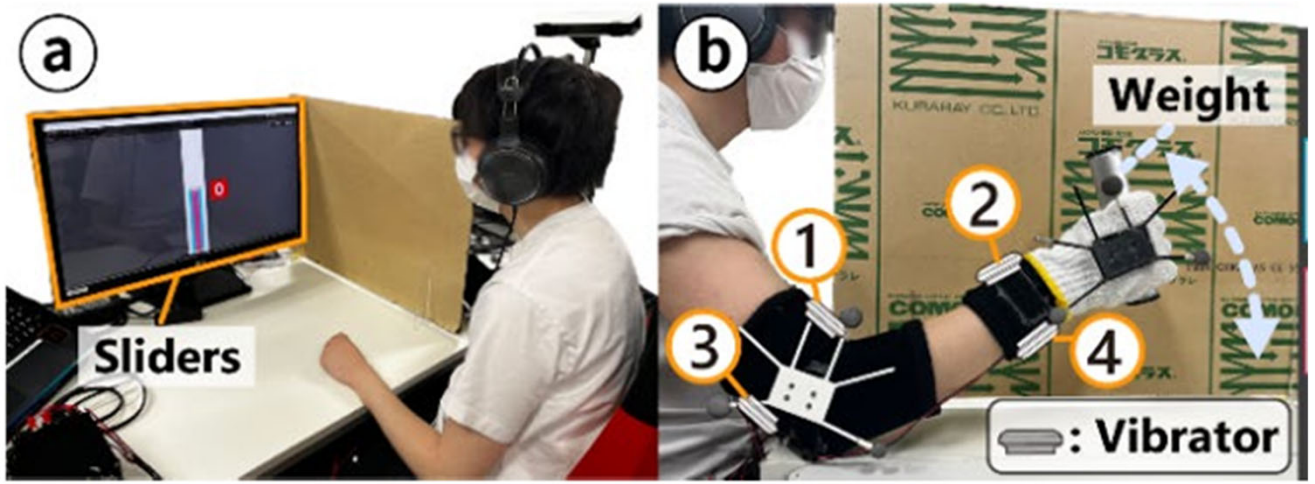
https://www.youtube.com/watch?v=A_L8dVo9nkQ&list=PLXRBbyxY9IBW4kMSsuq1KzEhzIkBKmUWj&index=6
(HS2022) L. Kuang, M. Aggravi, P. Robuffo Giordano, C. Pacchierotti, Wearable Cutaneous Device for Applying Position/Location Haptic Feedback in Navigation Applications

(CHI2024) Motionless Movement: Towards Vibrotactile Kinesthetic Displays
Yuran Ding, Nihar Sabnis, Paul Strohmeier
https://www.youtube.com/watch?v=hebA0b4z5wQ



- Grain vibrationと呼ばれる、「柔らかさ」提示のための振動レンダリング手法を利用して力入力に対する運動を表現。
- Using technique named grain vibration, which was originally for compliance presentation, movement is expressed without motion.

運動錯覚の利用 Application of Kinesthesia



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

Ogawa, Matsumoto, Aoyama, Narumi. Expansion of detection thresholds for hand redirection using noisy tendon electrical stimulation. *ISMAR*2023

Hirao, Amemiya, Narumi, Argelaguet, Lecuyer. Leveraging tendon vibration to extend pseudo-haptic sensations in vr, IEEE TVCG2023

- 腱への振動入力による運動錯覚現象により、持っているものの「重さ」を変化して知覚させる。
- 腱への振動入力や電気刺激によって運動感覚に「ノイズ」を与え、視覚的なHaptic Retargetingの許容範囲を大きくする。
- Change in the 'weight' of grasping object is modulated by Kinesthesia.
- Vibratory input to tendons and electrical stimulation creates 'noise' in the motor sense and increases the tolerance of visual Haptic Retargeting.

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

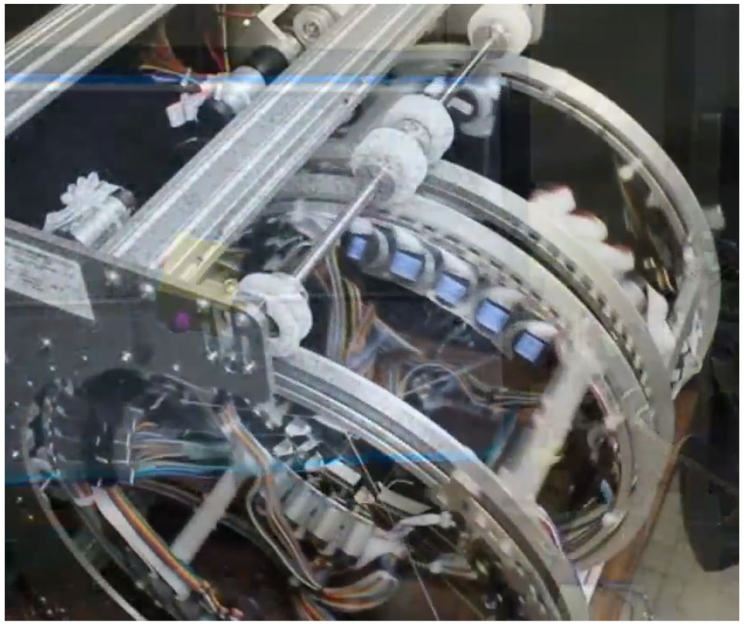
（再）触覚ディスプレイの応用分野の方向性
Elements of application for tactile display

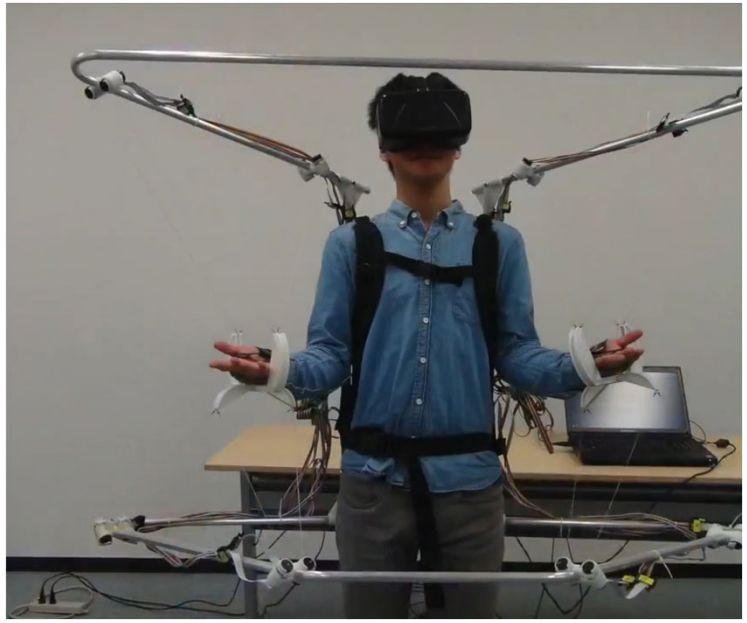
- **Touch Panel & Mobile**
  - 市場が巨大。差別化要素としての触覚
- **Emotion, Affection**
  - 触覚は驚きから愛情まで、幅広い情動へ働きかけることが出来る
- **Navigation, Instruction**
  - 触覚は身体座標に直接提示できる。また無意識の運動も誘導できる
- **Reality, Multimodal**
  - 触覚が視聴覚に加わることで存在感、現実感を上げることが出来る
- **The Whole Body**
  - 身体全体への触覚提示により、触覚にも臨場感を生じる
- **Tactile AR**
  - 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.

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

inTouch: A Medium for Haptic Interpersonal Communication CHI 1997
https://tangible.media.mit.edu/project/intouch/

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

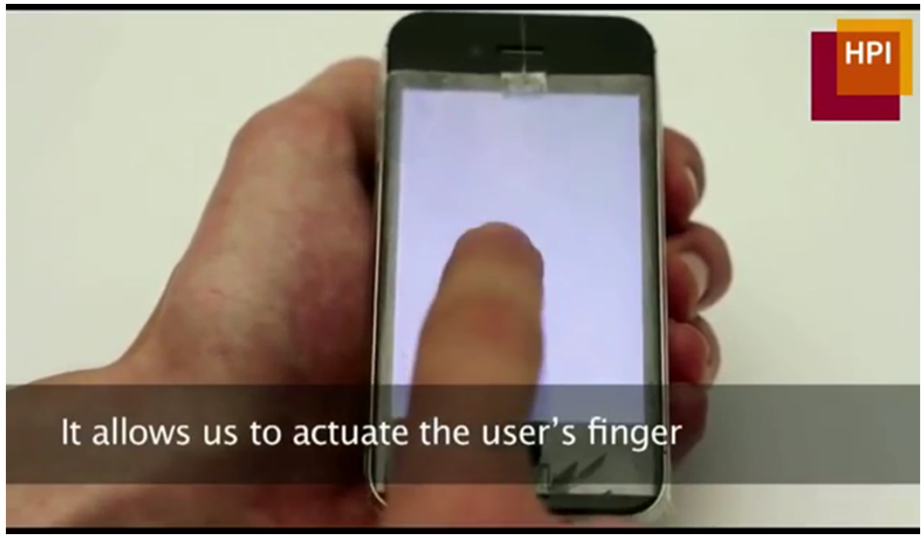
ロボット遠隔手術／Robotic Tele-Surgery: da Vinci

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

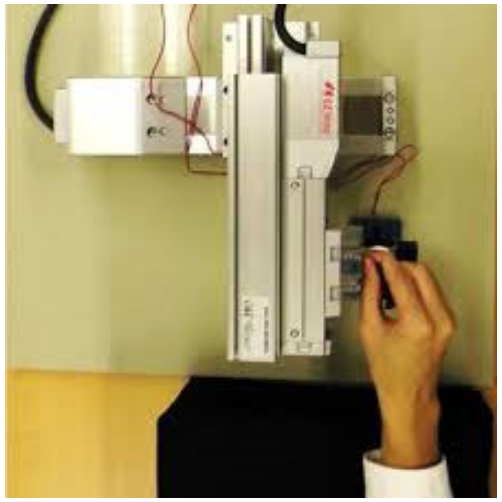
da Vinchi: **製品としては力の提示なし。人の入力から振動を除く等のサポートはあり。**
研究としては力覚提示各種あり。
daVinchi: No force presentation. Low pass filtering of human input to eliminate vibration.

指を駆動して情報提示 Display by actuation

Navigation
Instruction
Mobile

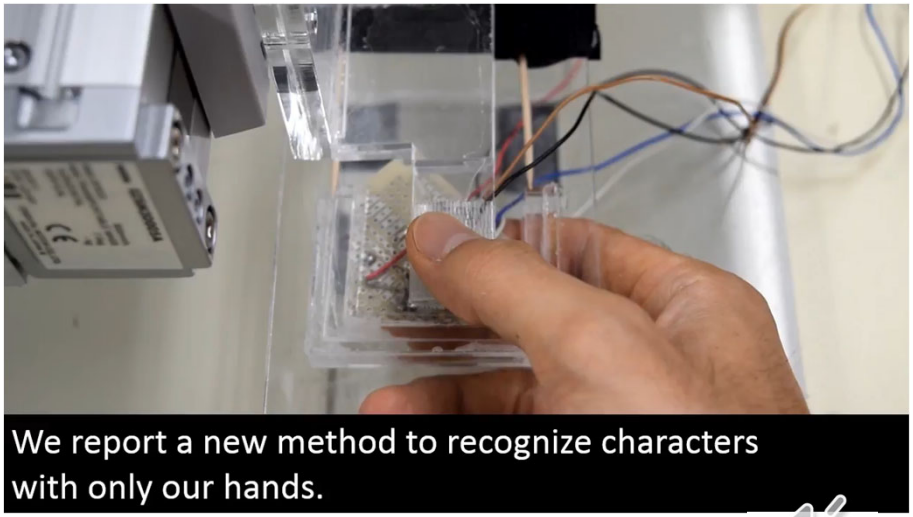


https://www.youtube.com/watch?v=xxAO8dxP-zI



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.

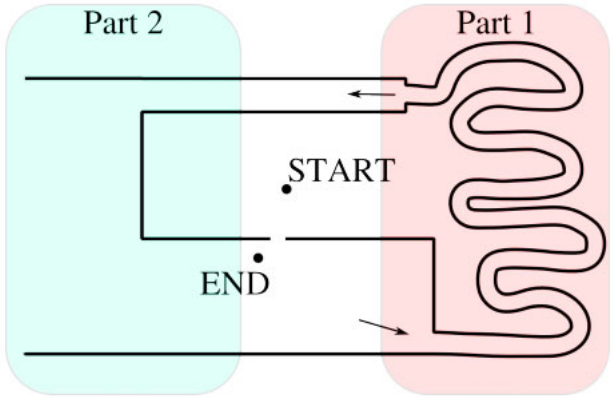
ロボットトレーニング：ゴルフ
Robot Golf Training

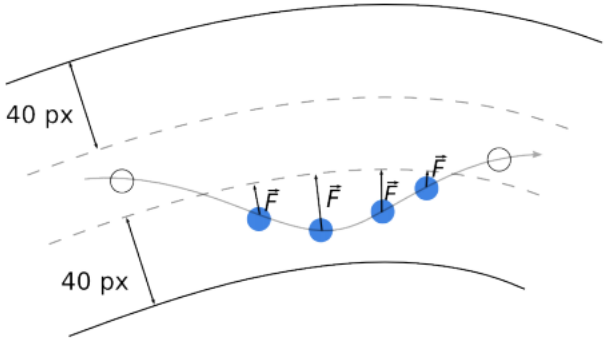
Navigation, Instruction

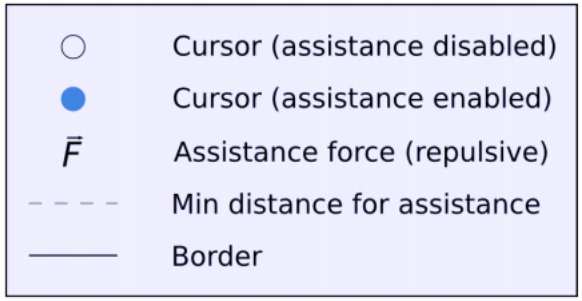
http://robogolfpro.com/

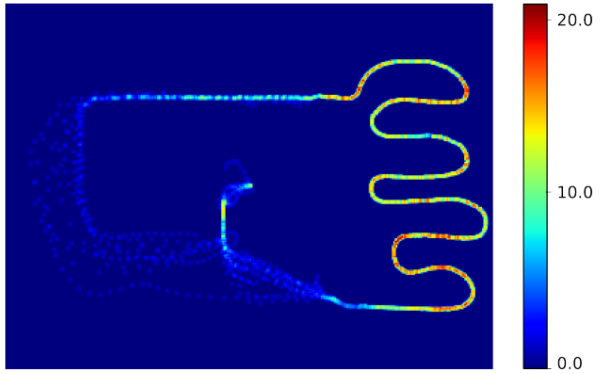
難易度の自動調整　Adjustment of difficulty

Navigation, Instruction









- 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。

Laurent George, Maud Marchal, Loeiz GLONDU & Anatole Lécuyer
Combining Brain-Computer and Haptic Interfaces: Detecting Mental Workload to Adapt Force-Feedback, EuroHaptics2012

(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

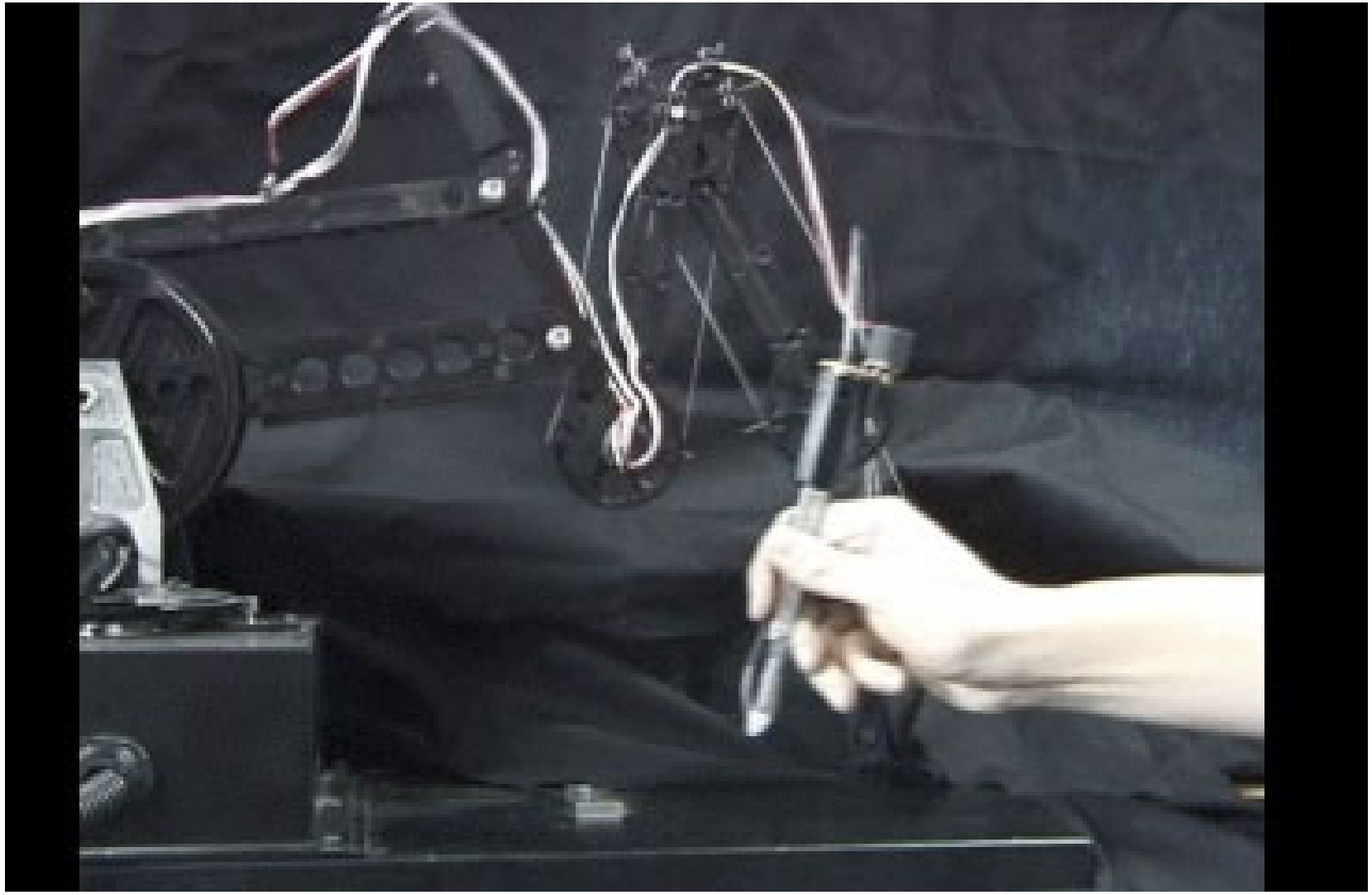
Navigation, Instruction

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

Haptic AR



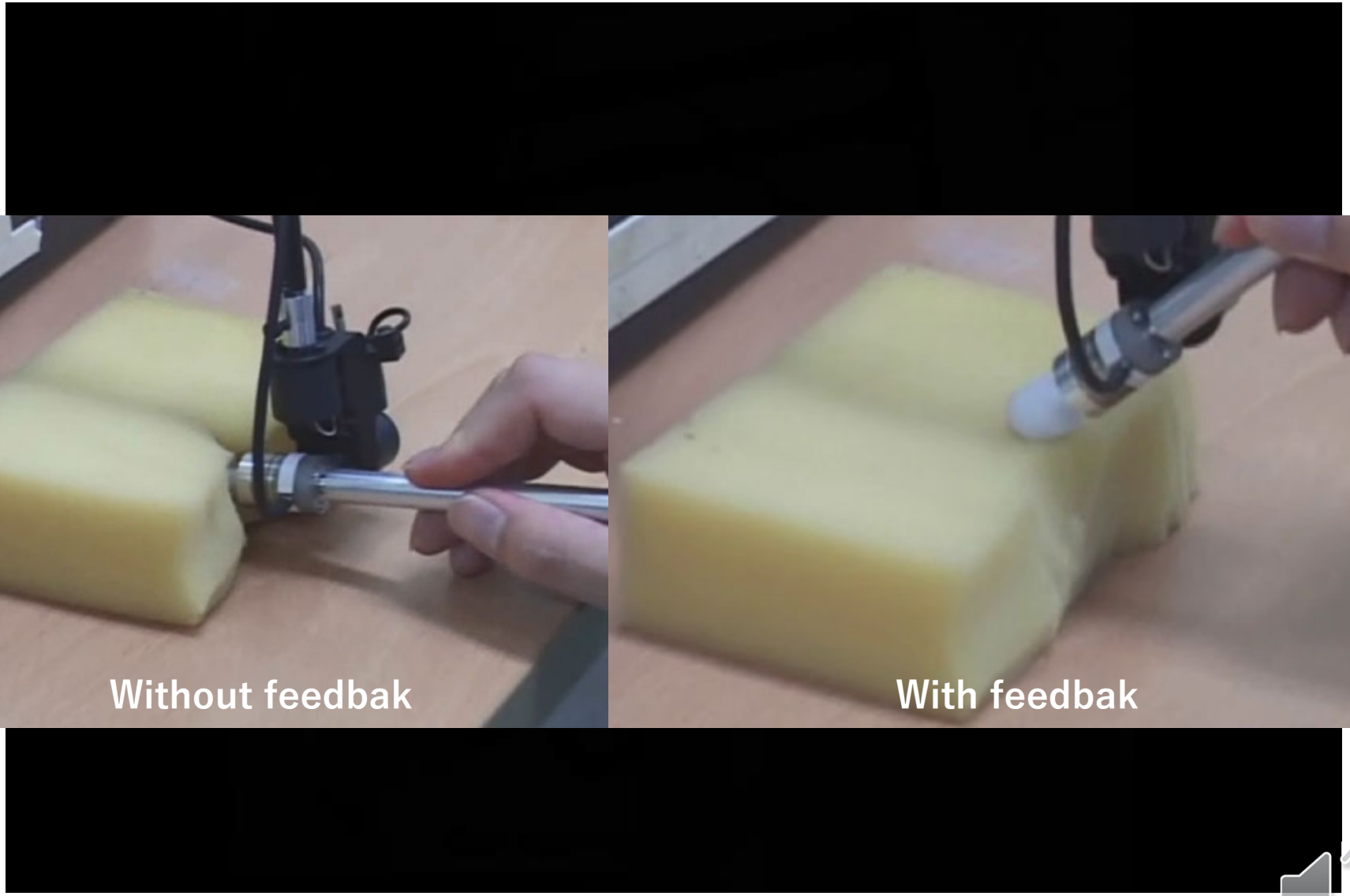
https://youtu.be/GaOtiDuvngE

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): 力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

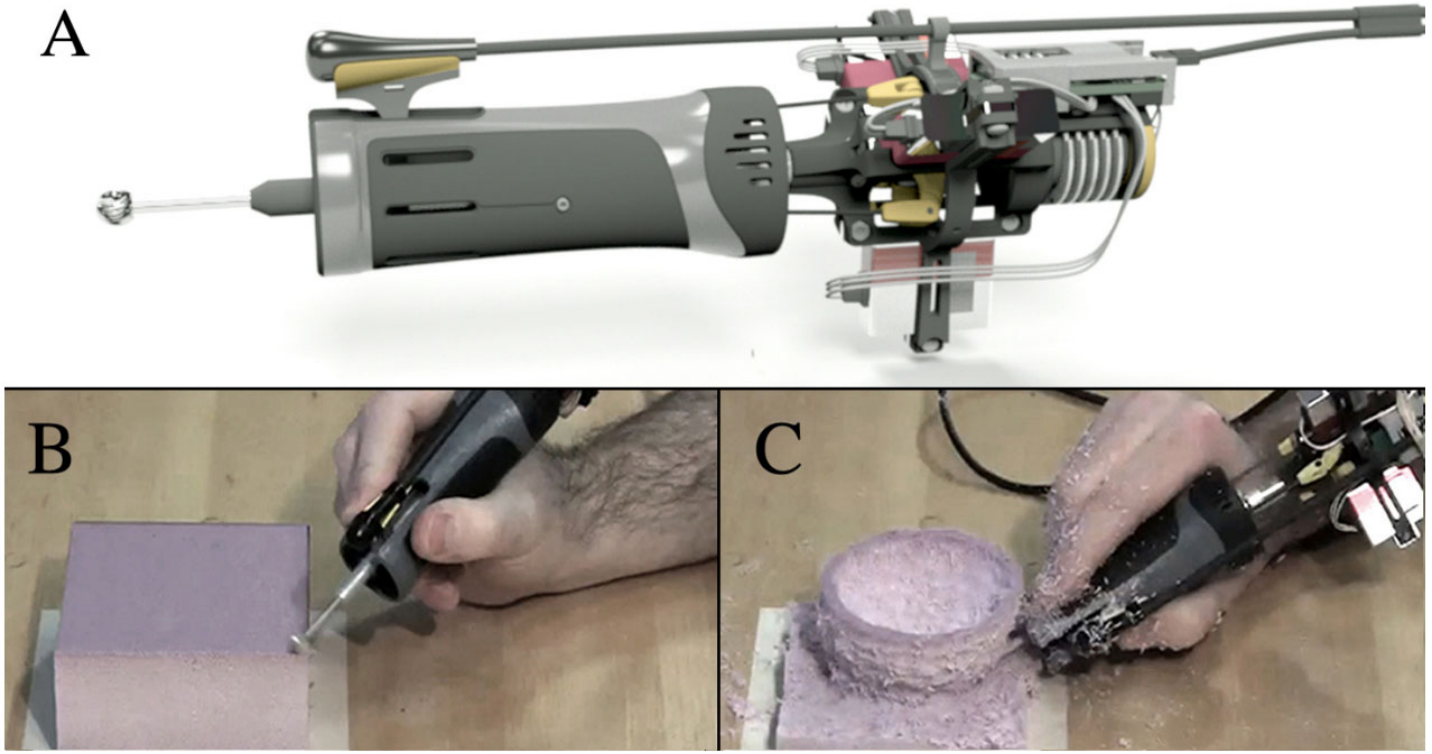
Haptic AR



Stiffness Modulation for Haptic Augmented Stiffness Shifting: Improving the Perceived Hardness of a Virtual Surface, Gabjong Han, Seokhee Jeon, Seungmoon Choi, Haptics Symposium 2010

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

Haptic AR



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、鑿の歯を竪に返すや否や斜に、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、小鼻のおっ開ぴ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。そう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」と自分はあん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うはずはない」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い出した。はたしてそうなら誰にでもできる事だと思い出した。それで急に自分も仁王が彫ってみた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

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.

Emotion, Affection, Communication

Haptic AR

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持った。

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 antagnistic 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 Goldi tendon organ.

4.サイズー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

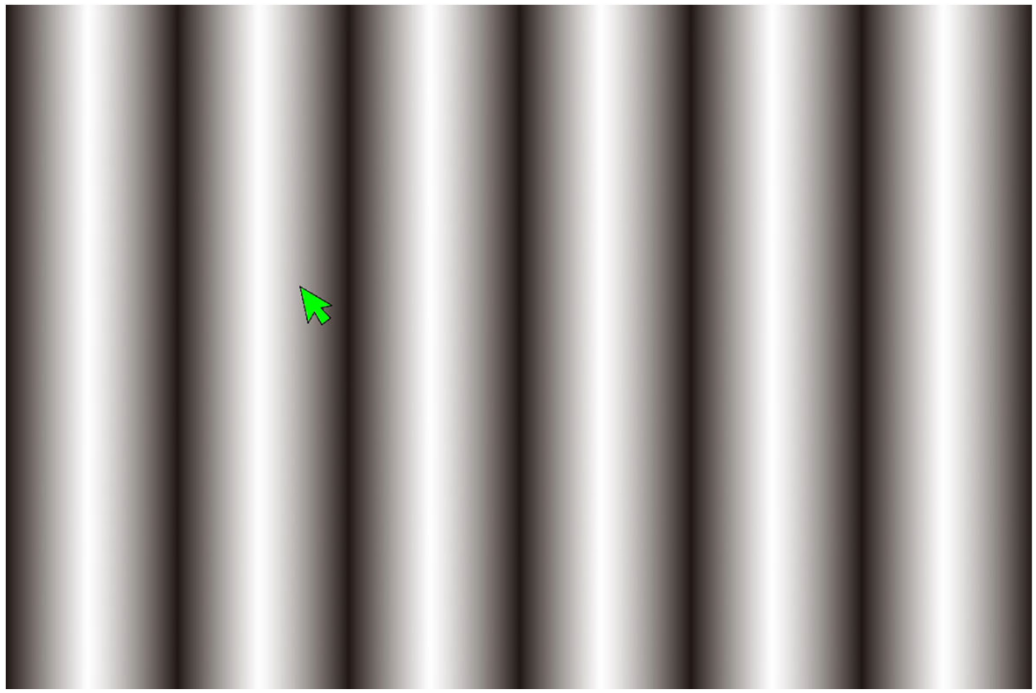
9.遭遇型ハプティックデバイスについて説明せよ Explain encounter type haptic device.

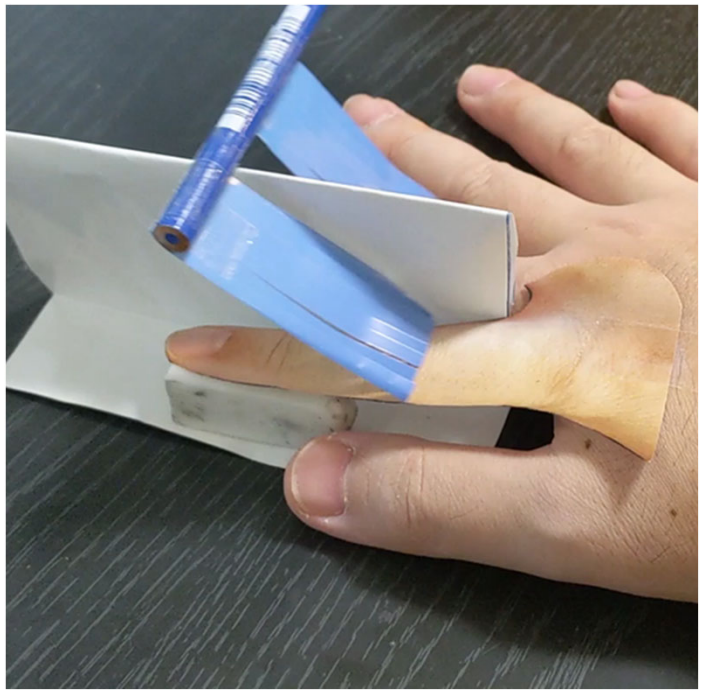
10.装着型ハプティックデバイスについて説明せよ Explain wear type haptic device.

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：錯触覚の体験
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トだとどうか。
  - 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