Brain plasticity for alternative hand control:

From phantoms to robotic fingers

Tamar Makin

plasticity-lab.com

Concluions

Neuroimaging can be a double-edged sword for clinical development

Brain plasticity is limited and is not driven by input loss

Representational similarity analysis can help us find novel representations

Some brain plasticity can be induced by meaningful input

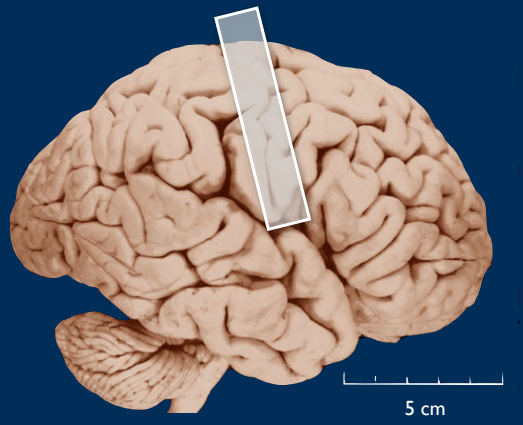
Phantom limb pain

Phantom limb pain is difficult to treat

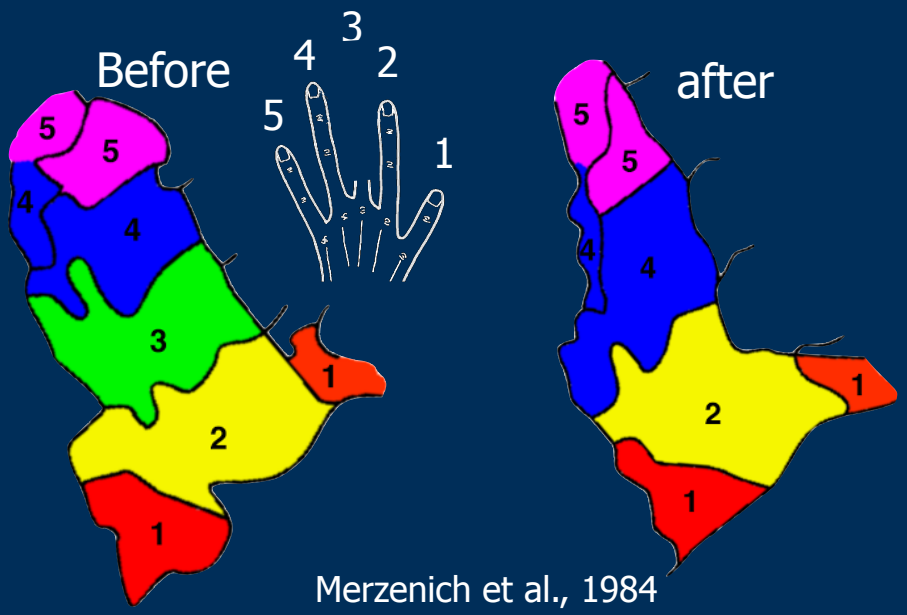
“This magic box of neurological trickeries”

Brain reorganisation in primary somatosensory cortex

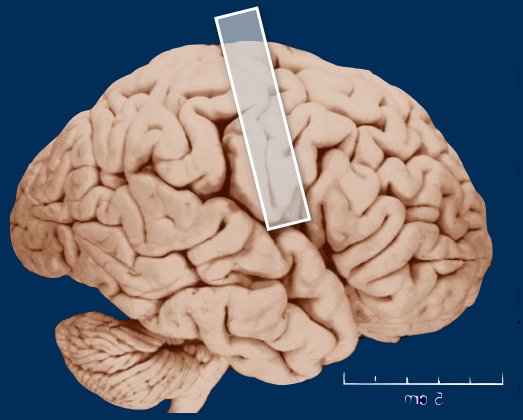
Penfield and Rasmussen, 1950



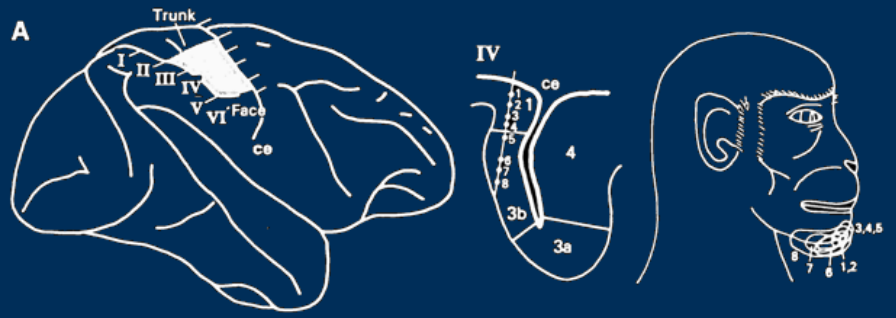
Brain reorganisation in primary somatosensory cortex



Merzenich et al., 1984



Merzenich et al., 1984

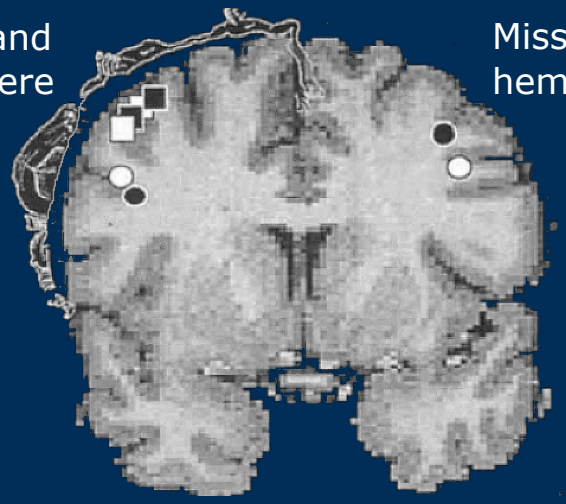


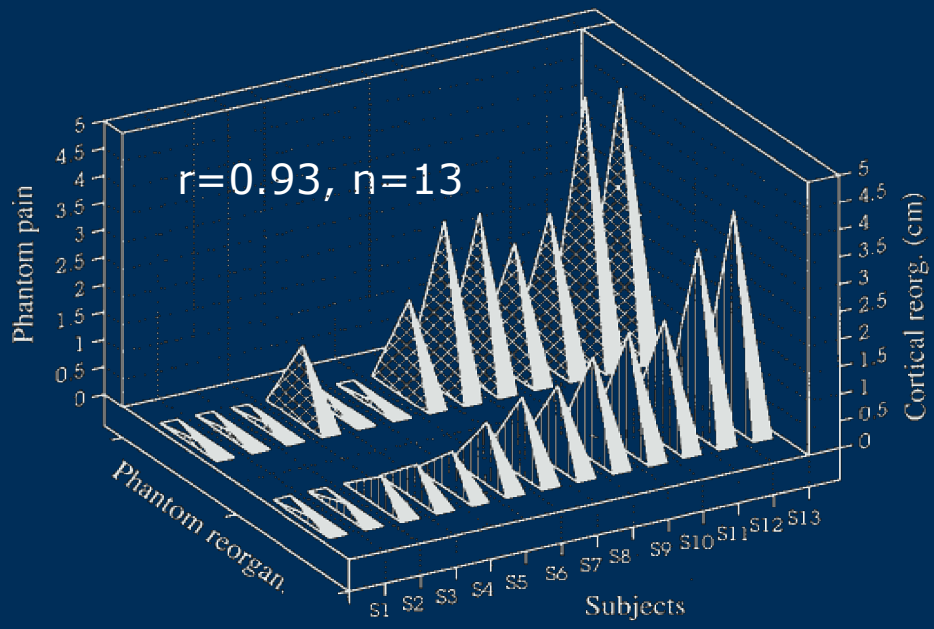
Pons et al., 1991, Science

Brain reorganisation in primary somatosensory cortex

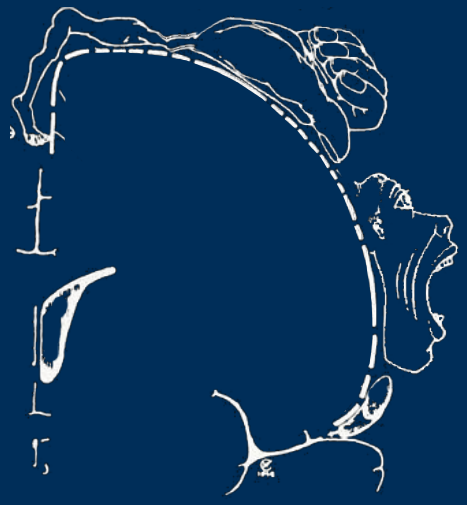
Intact hand hemisphere

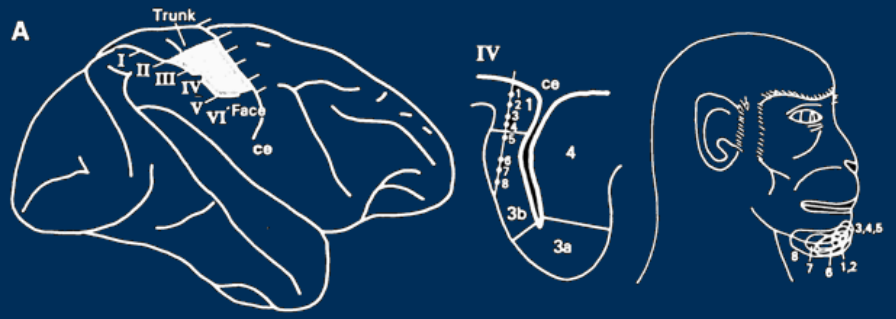
Missing hand hemisphere





Flor et al., 1995, Nature





Pons et al., 1991, Science

The paradox of brain reorganisation

Sensory deprivation → cortical reorganisation → phantom pain

Treatment effectiveness challenged

-Brodie et al., (2007). European Journal of Pain

-Rothgangel et al., (2011). Int J Rehabil Res

-Thieme et al., (2016). J Pain

-Barbin et al., (2016). Annals of Phys and Rehab Med

-Imaizumi et al., (2017) Front. Hum. Neurosci.

-Rothgangel et al., (2018) Clin Rehabil

-Richardson and Kulkarni (2018) J Pain Res

-Colmenero et al., (2018) Prosthet Orthot Int.

- Ol et al., (2018), Scand. J. Pain

-Aternali and Katz (2019) F1000

-Gundez et al., (2021) Neurorehabil. Neural Repair

- Wang et al., (2021) Clin. Rehabil.

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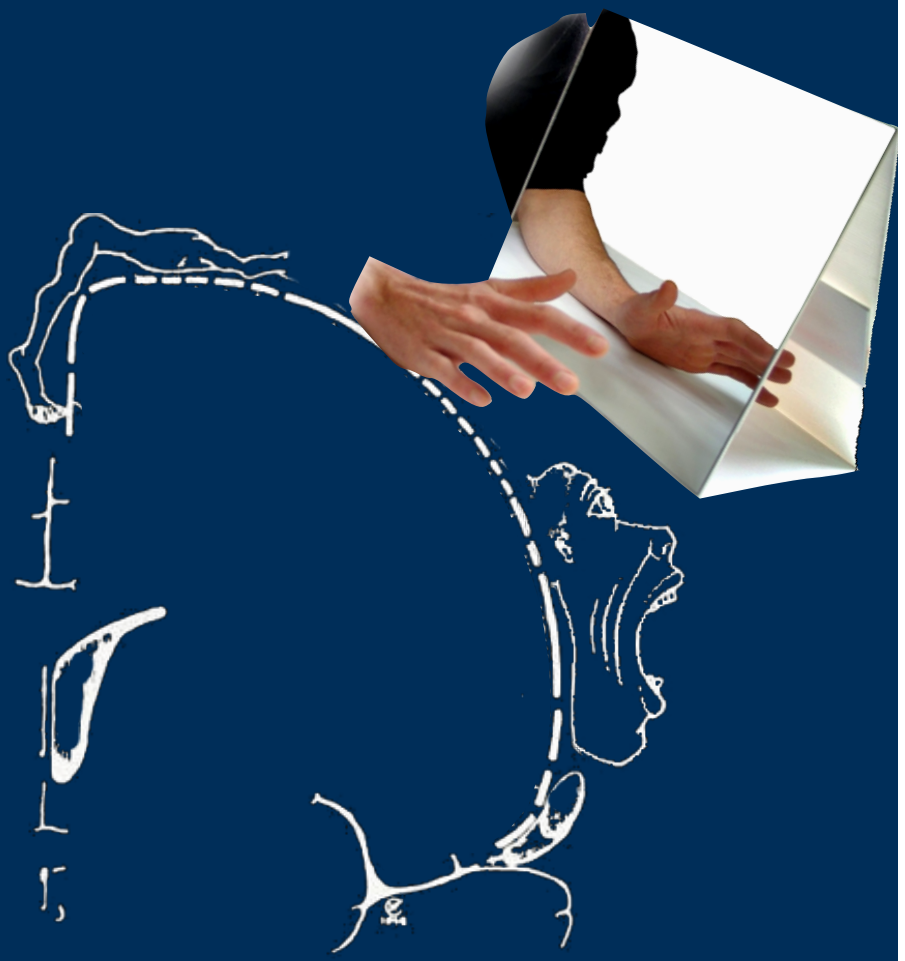

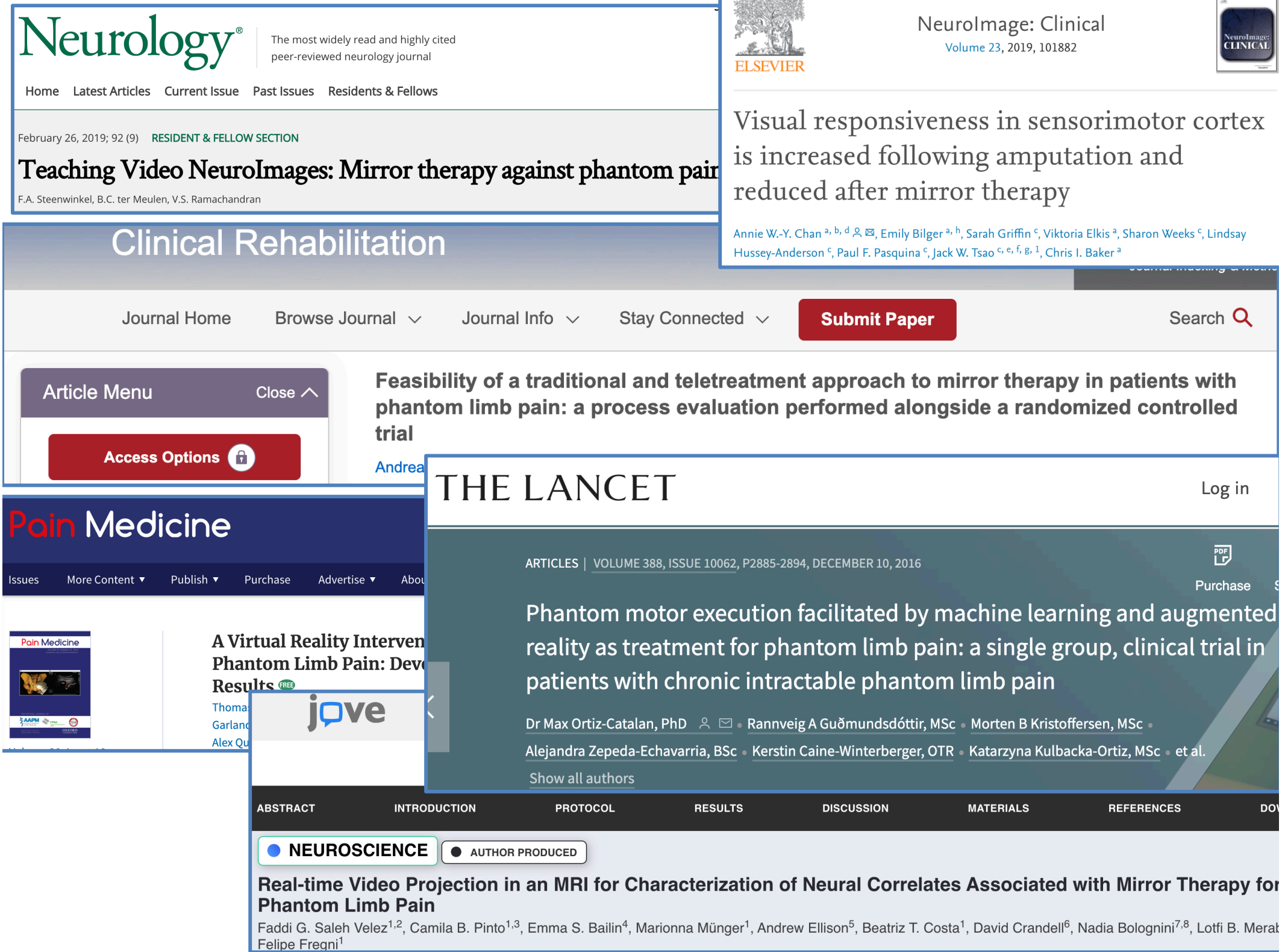

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Teaching Video NeuroImages: Mirror therapy against phantom pain
F.A. Steenwinkel, B.C. ter Meulen, V.S. Ramachandran

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NeuroImage: Clinical
Volume 23, 2019, 101882
Visual responsiveness in sensorimotor cortex is increased following amputation and reduced after mirror therapy
Annie W.-Y. Chan [a, b, d], Emily Bilger [a, h], Sarah Griffin [c], Viktoria Elkis [a], Sharon Weeks [c], Lindsay Hussey-Anderson [c], Paul F. Pasquina [c], Jack W. Tsao [c, e, f, g, 1], Chris I. Baker [a]

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Phantom motor execution facilitated by machine learning and augmented reality as treatment for phantom limb pain: a single group, clinical trial in patients with chronic intractable phantom limb pain
Dr Max Ortiz-Catalan, PhD • Rannveig A Guðmundsdóttir, MSc • Morten B Kristoffersen, MSc • Alejandra Zepeda-Echavarria, BSc • Kerstin Caine-Winterberger, OTR • Katarzyna Kulbacka-Ortiz, MSc • et al.
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jove
ABSTRACT INTRODUCTION PROTOCOL RESULTS DISCUSSION MATERIALS REFERENCES DO
NEUROSCIENCE AUTHOR PRODUCED
Real-time Video Projection in an MRI for Characterization of Neural Correlates Associated with Mirror Therapy for Phantom Limb Pain
Faddi G. Saleh Velez[1,2], Camila B. Pinto[1,3], Emma S. Bailin[4], Marionna Münger[1], Andrew Ellison[5], Beatriz T. Costa[1], David Crandell[6], Nadia Bolognini[7,8], Lotfi B. Merab
Felipe Fregni[1]

From phantoms to supernumerary robotic fingers

Phantom hands

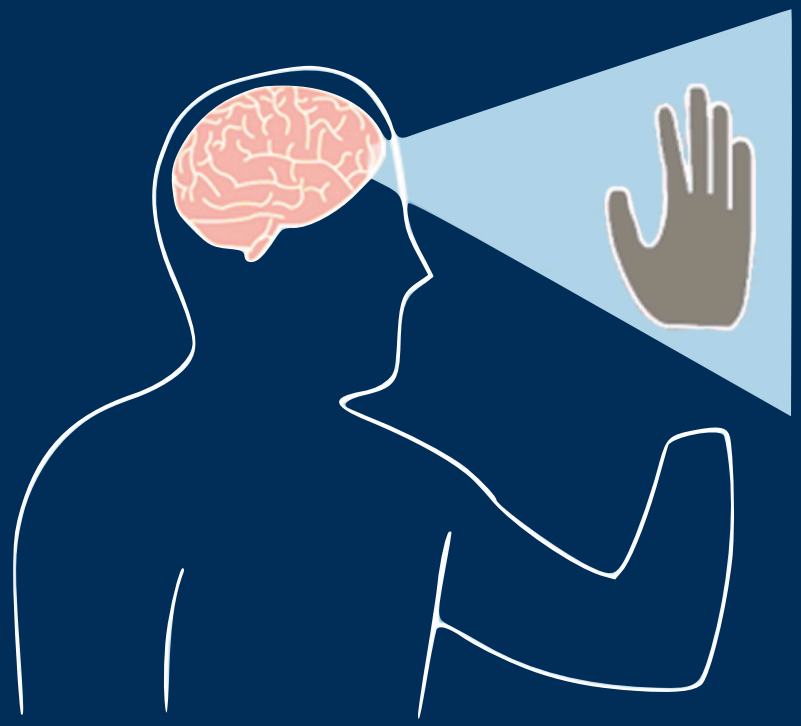
Feet

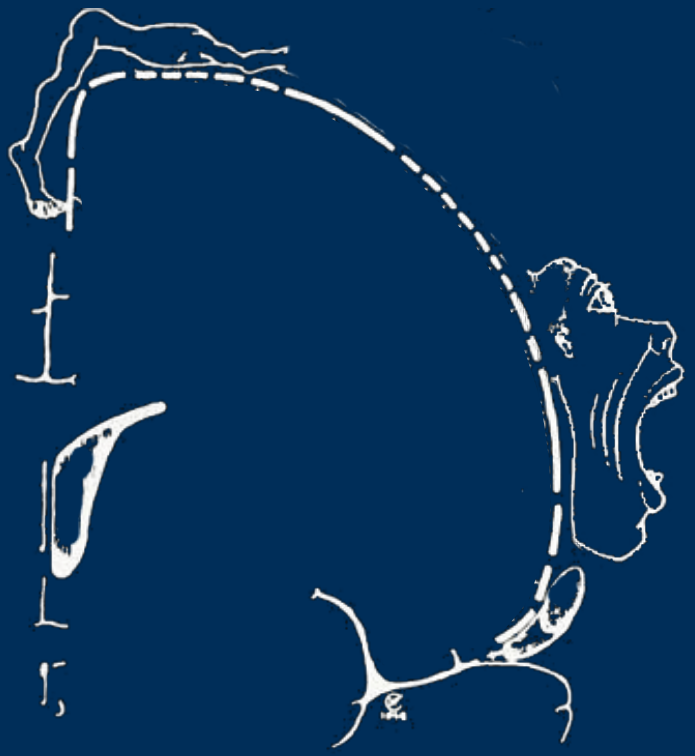
Extra thumbs

Artificial limbs

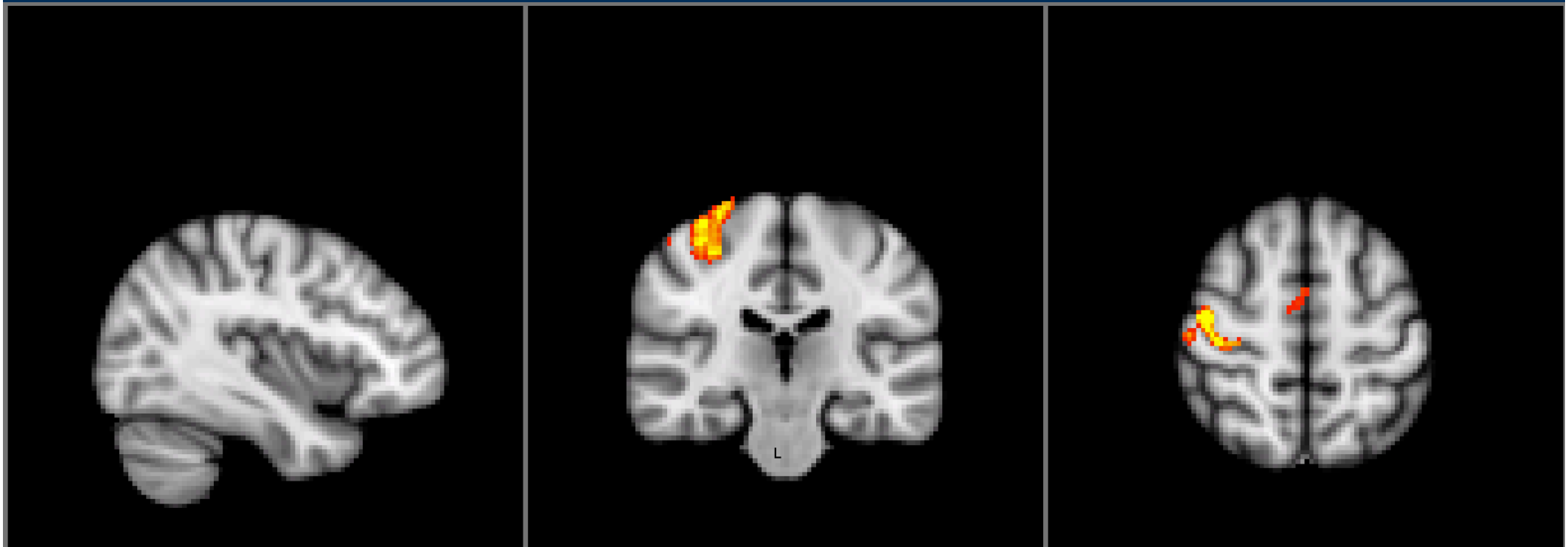
The paradox of brain reorganisation

Sensory deprivation → cortical reorganisation → phantom pain

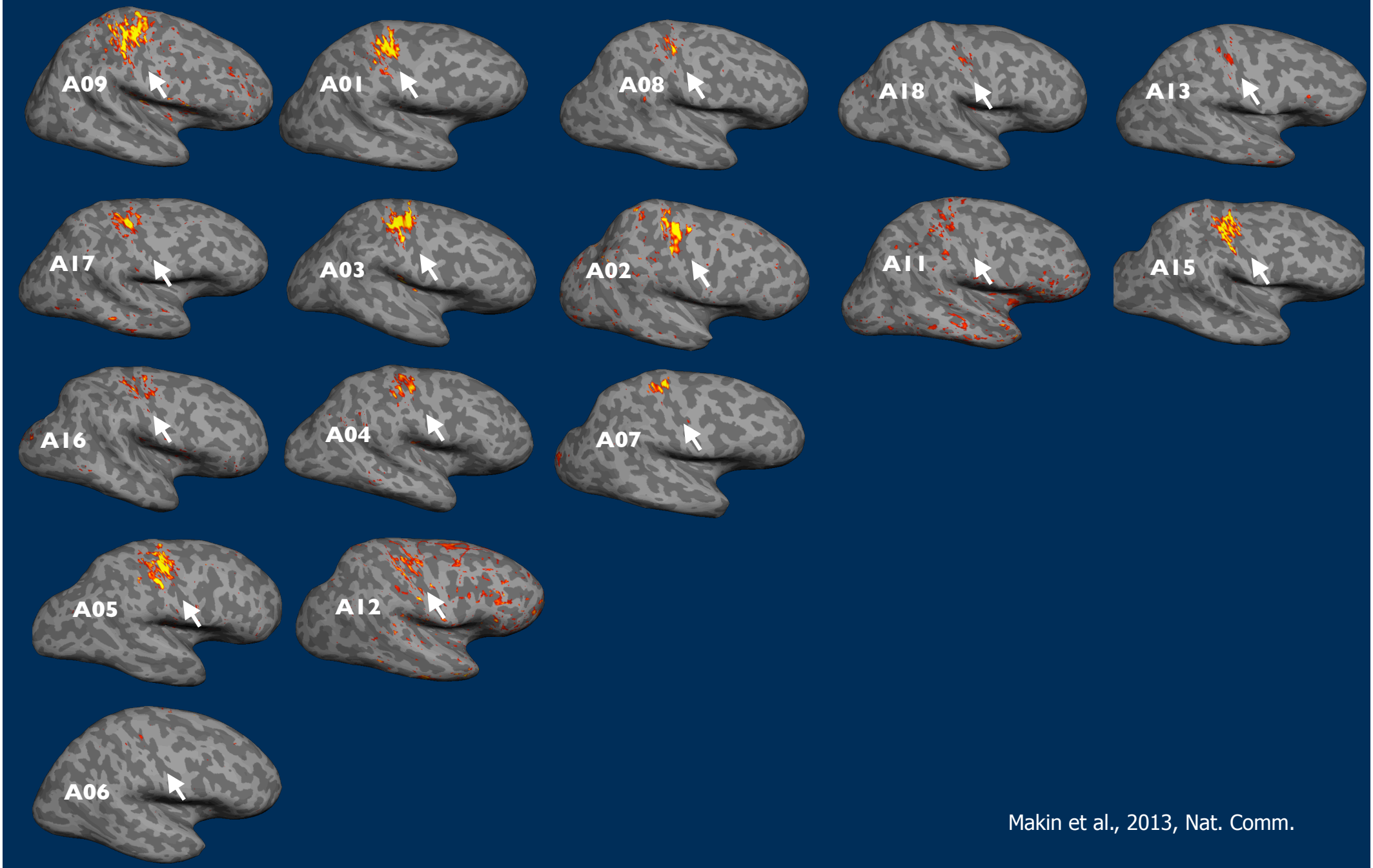




Phantoms in the Brain



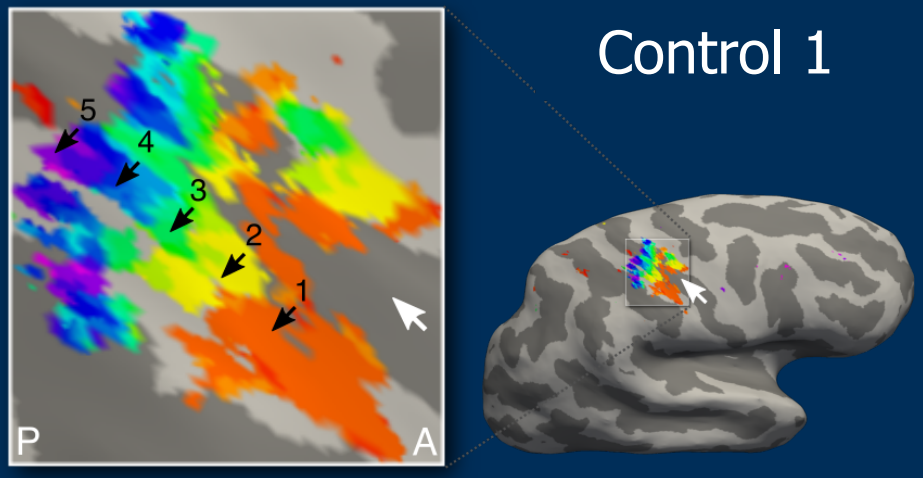
Preserved Representation of the Phantom Hand in Amputees

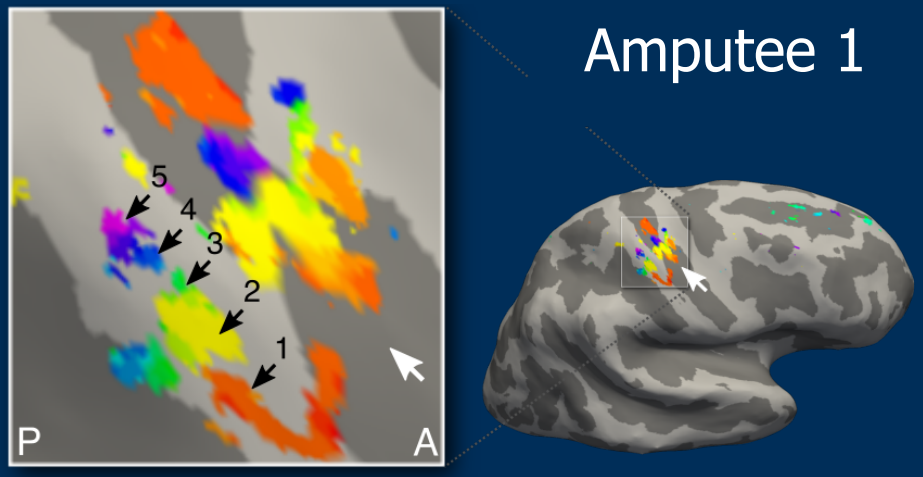


Makin et al., 2013, Nat. Comm.

Phantom Finger Maps in Amputees

Sanne Kikkert





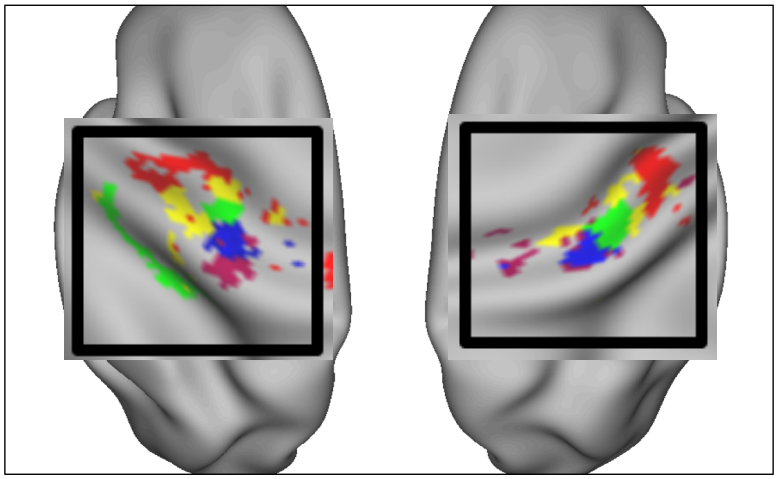
Above elbow,
31 years since amputation

Kikkert et al., eLife, 2016

Does losing a hand impact its brain representation?

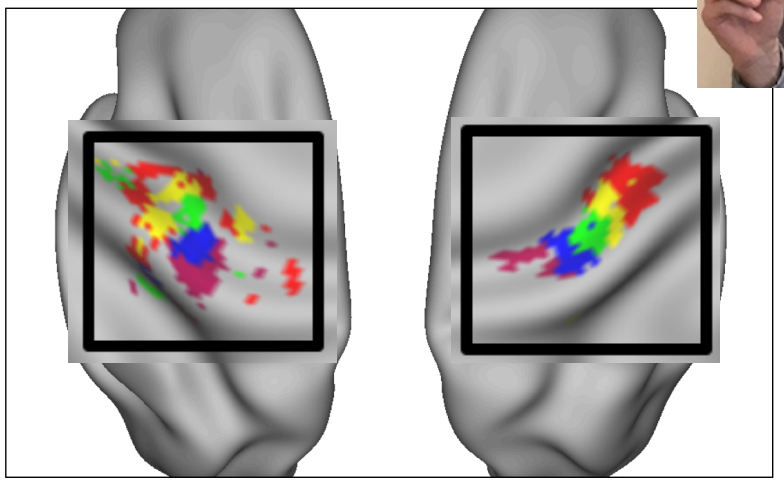
Hunter Schone

3 days Pre-Amputation



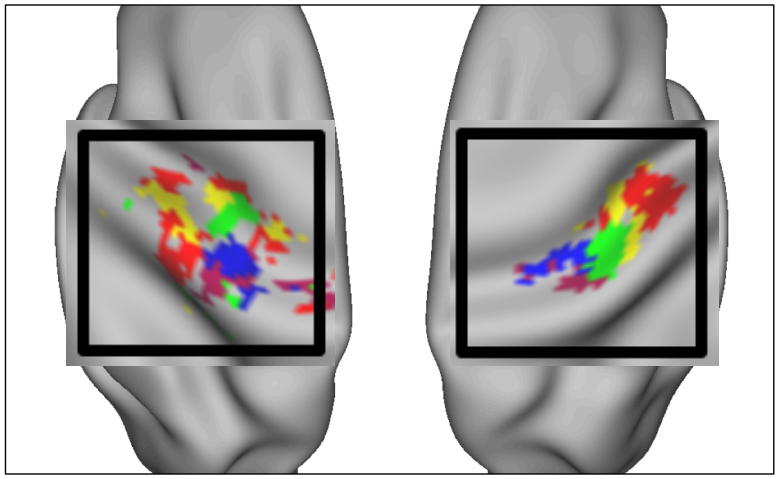
Unhealthy Healthy

2 days Pre-Amputation



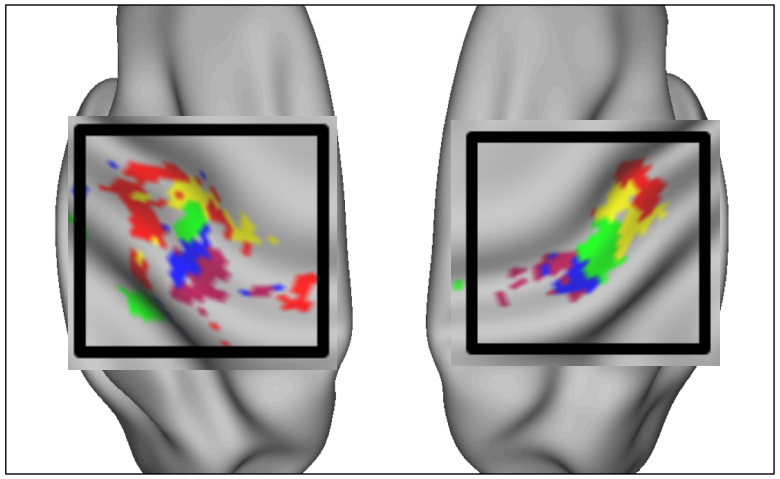
Unhealthy Healthy

3 months Post-Amputation



Phantom Intact

6 months Post-Amputation

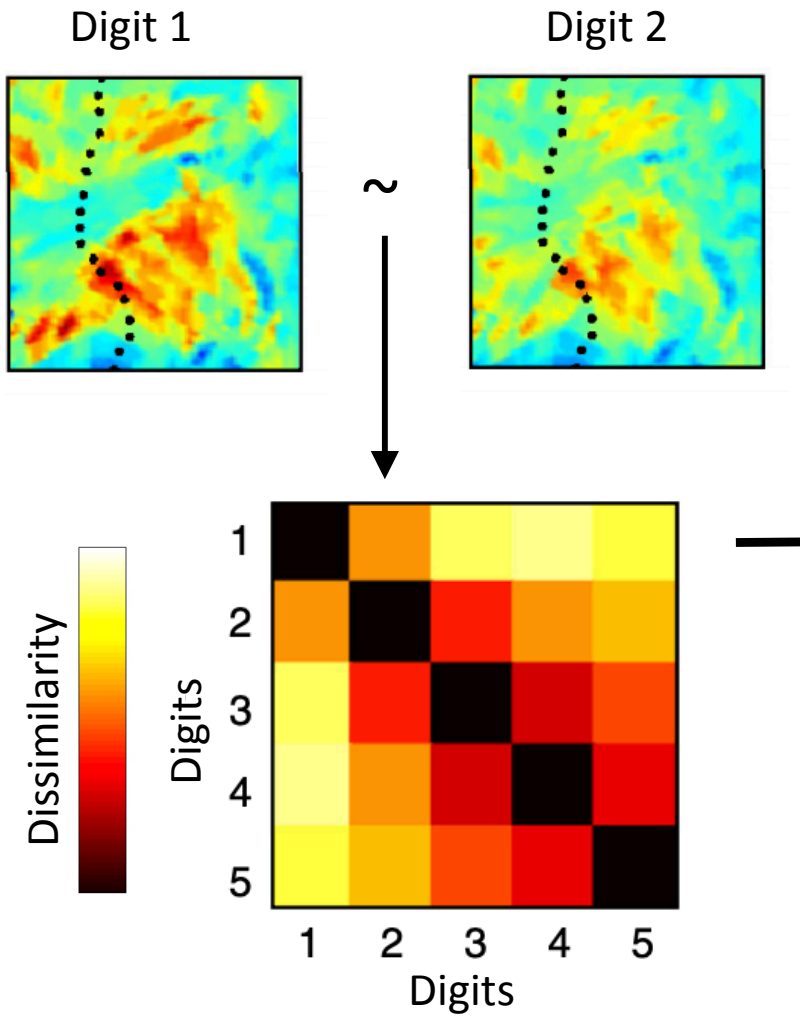


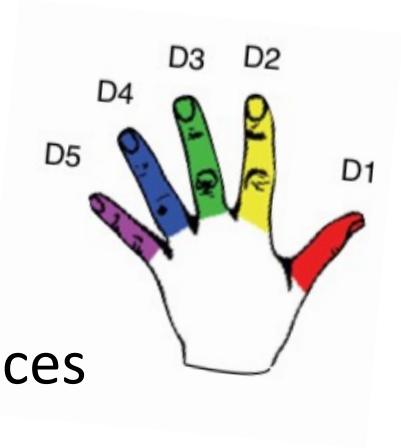
Phantom Intact

Schone et al., in progress

Representational similarity analysis of finger representation

Task: Single-digit movement or touch



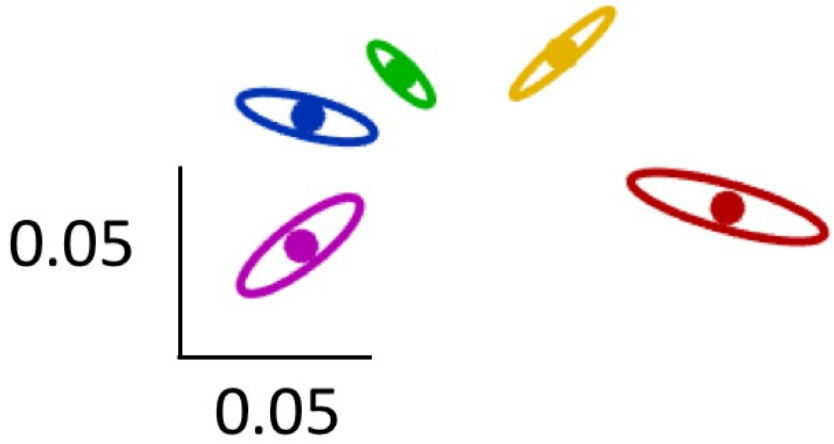


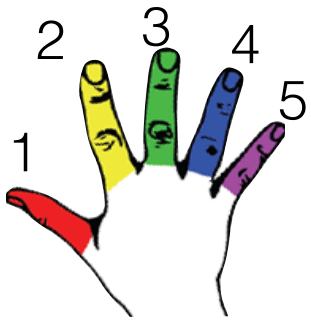
dissimilarity as distances

Representational similarity analysis of phantom hands

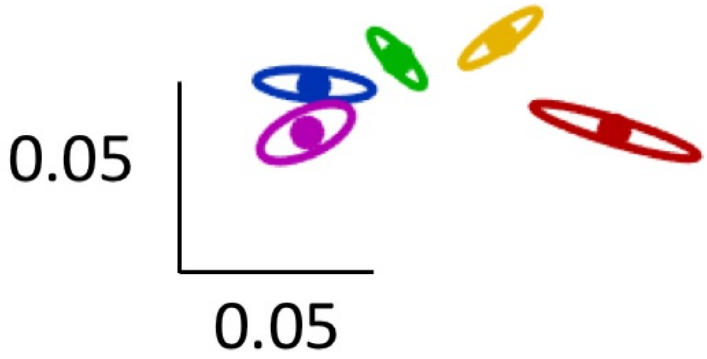
Daan Wesselink

Intact controls (n=11)

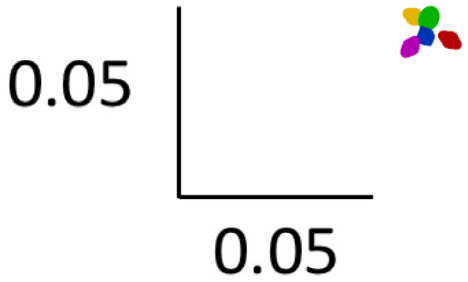




Acquired amputees (n=17)



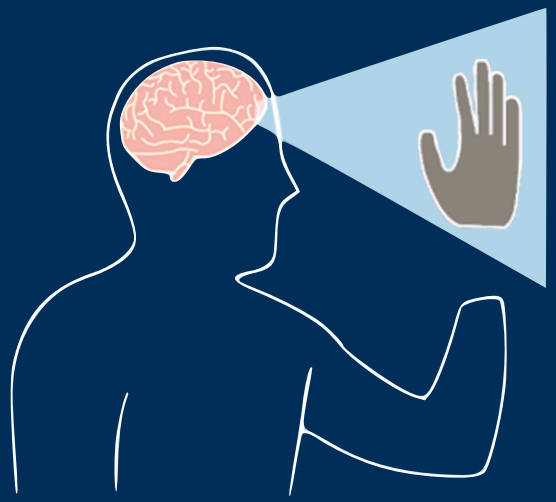
Congenital one-handers (n=13)

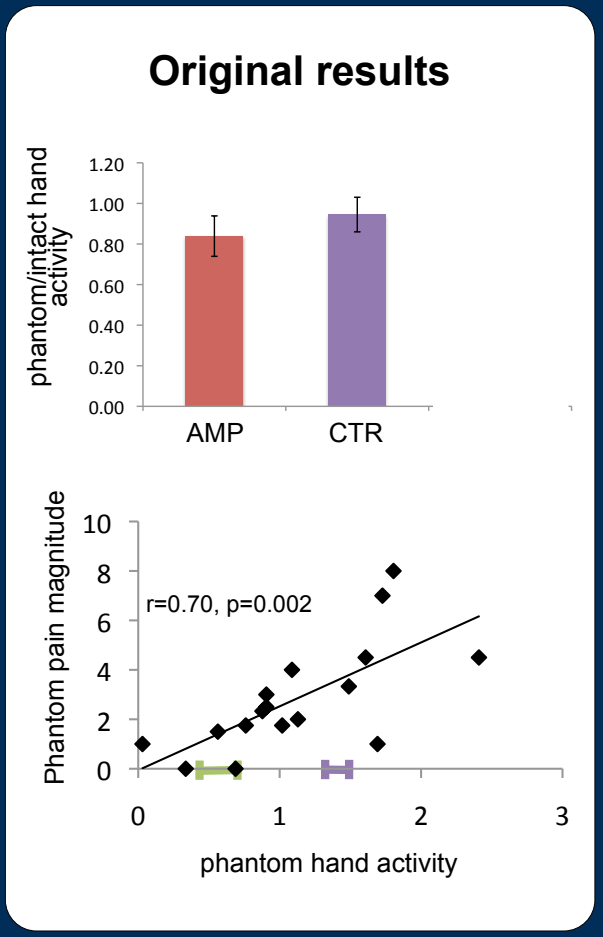


Wesselink et al., eLife, 2019

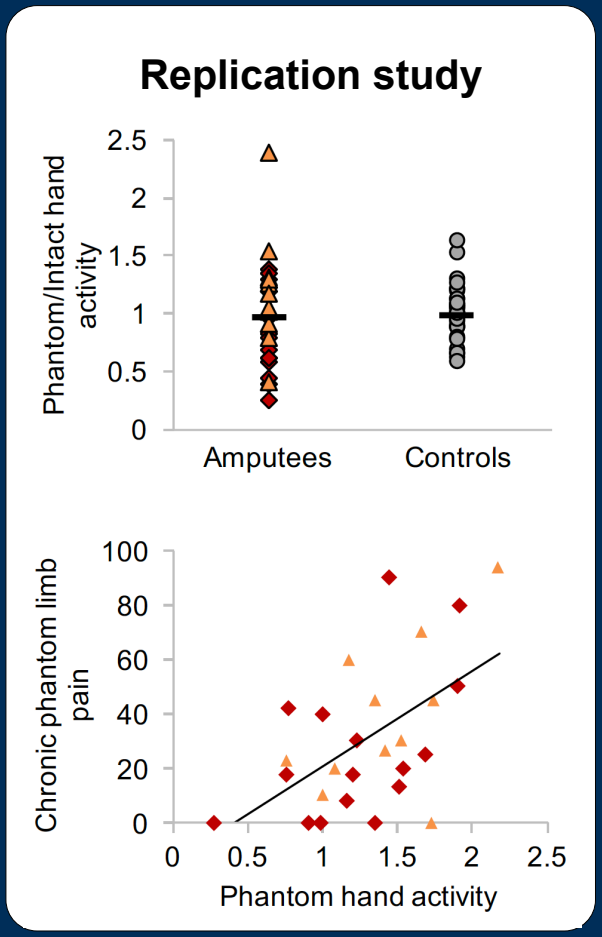
The paradox of brain reorganisation

Sensory deprivation → cortical reorganisation → phantom pain





Makin et al., 2013,
Nature Communications

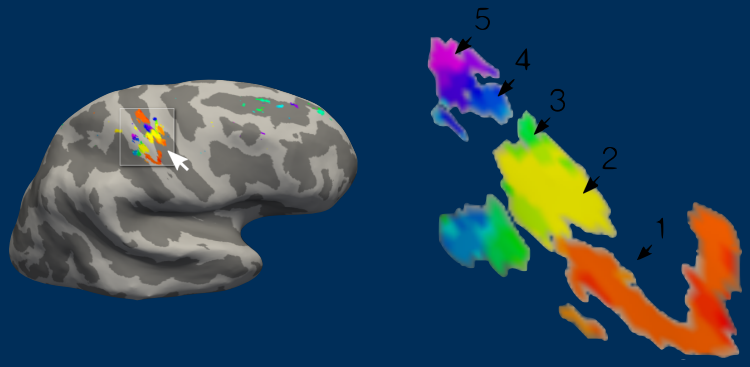


Kikkert et al., 2018,
Cortex

Interim conclusions: neural correlates of phantom pain

Textbook: maladaptive reorganisation

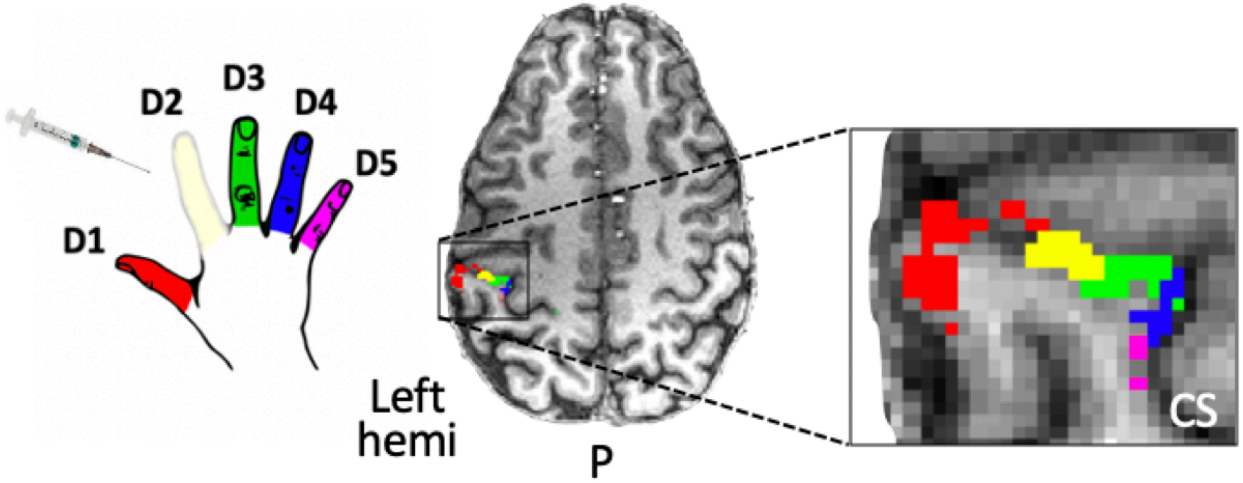
Our findings: preserved local organisation



What about reorganisation?

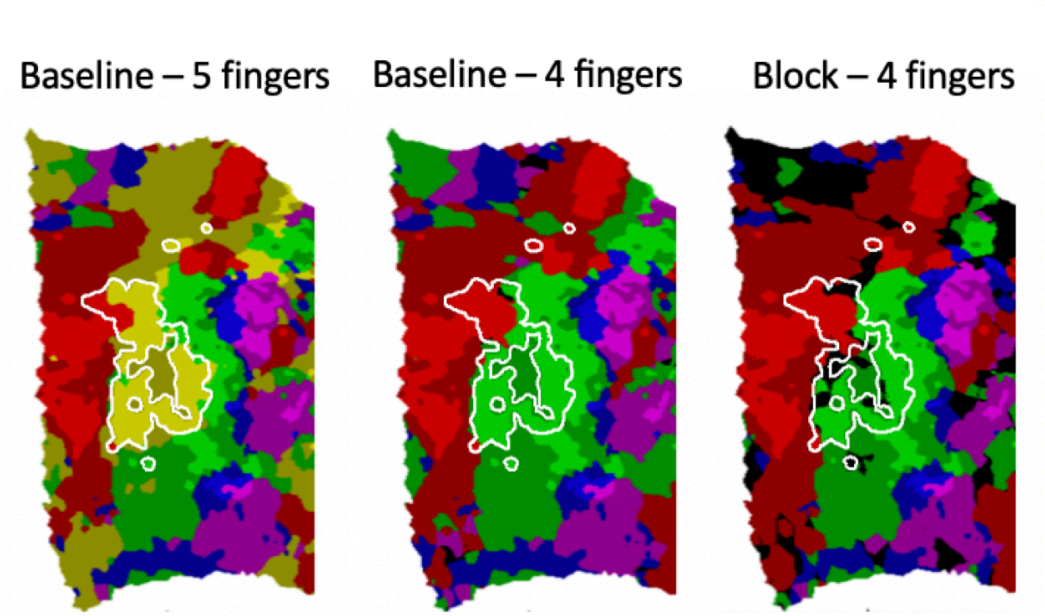
Replicating the remapping effect using local anaesthesia

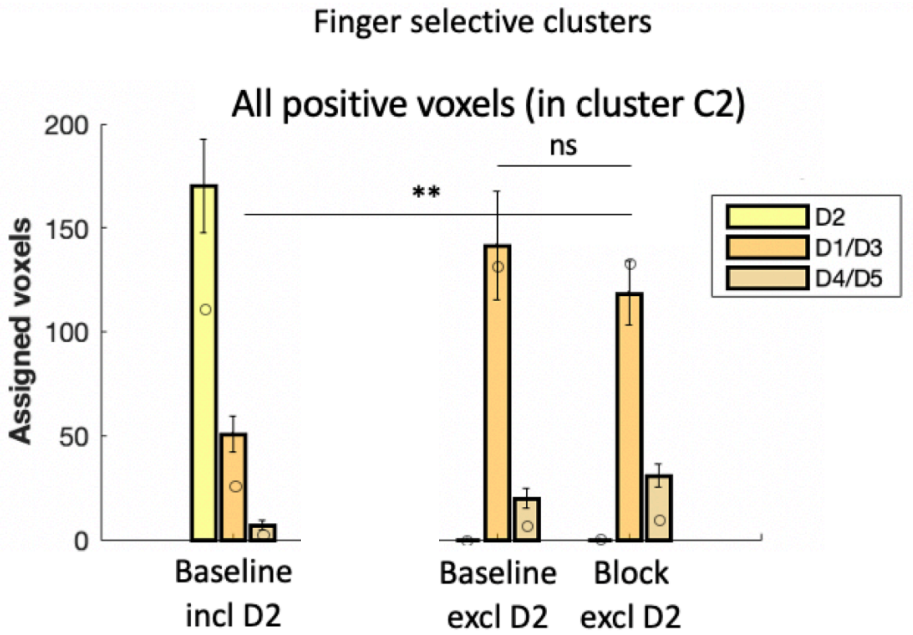
Daan Wesselink

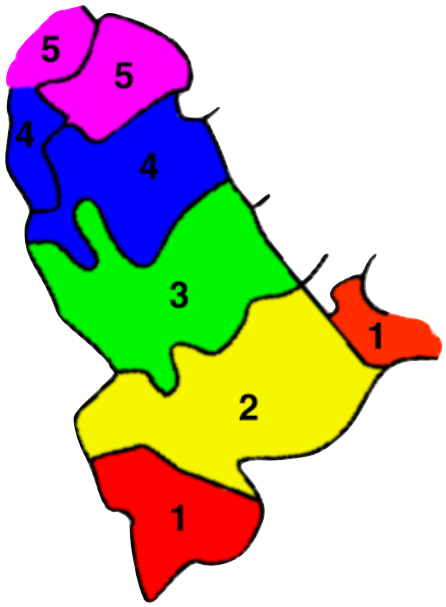


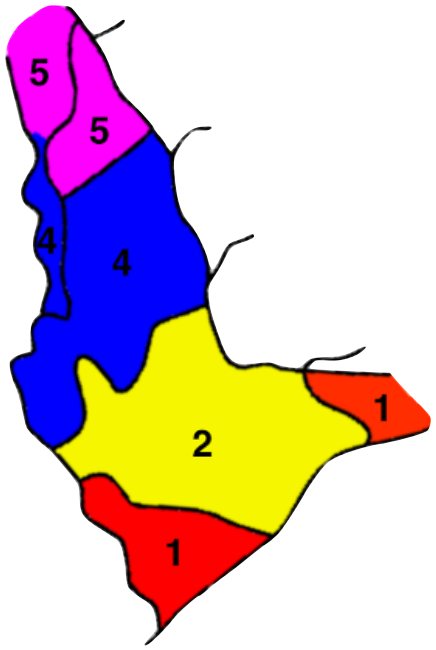
Wesselink et al., Science Advances, 2022

Replicating the remapping effect using local anaesthesia







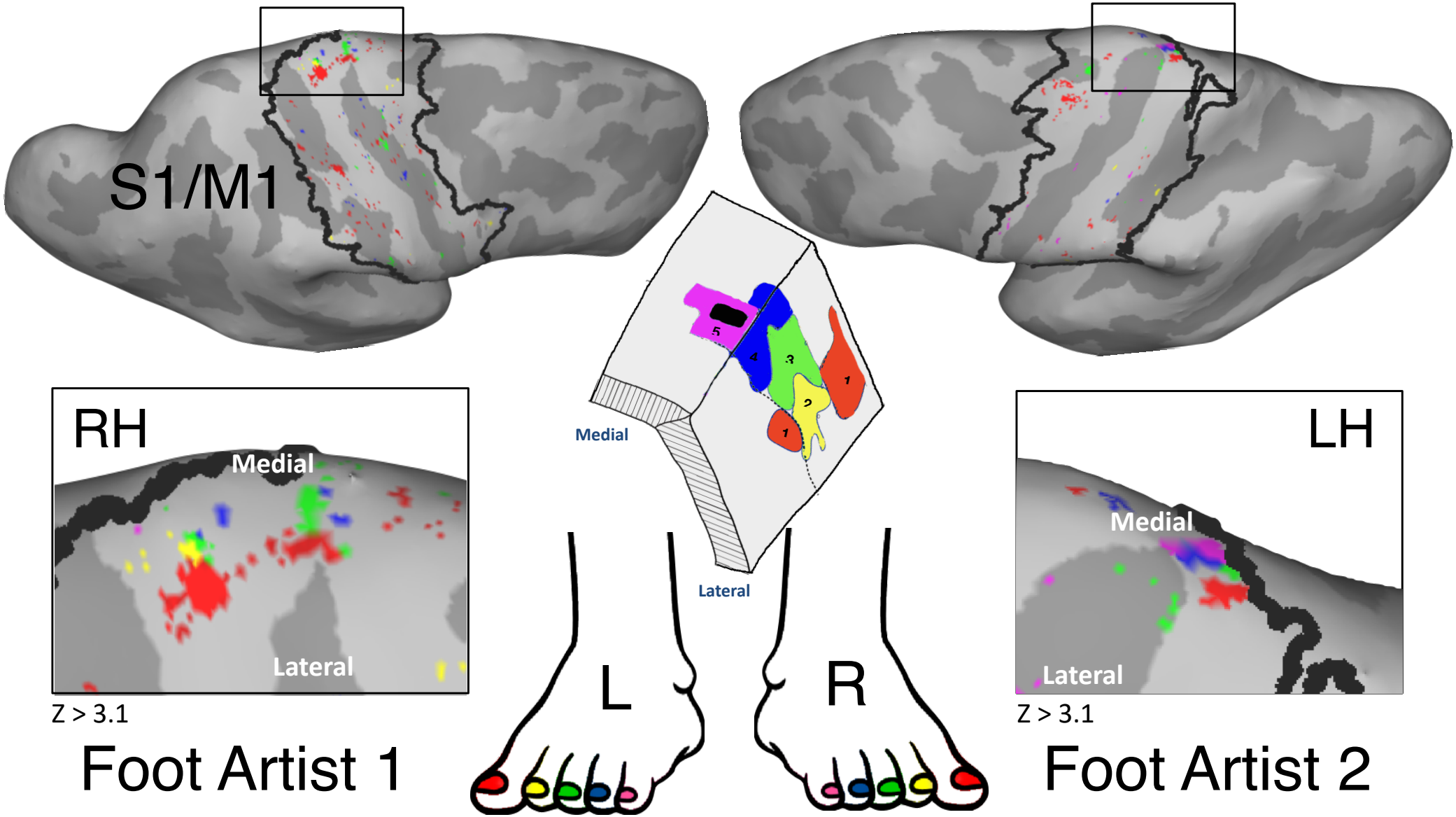


Wesselink et al., Science Advances, 2022

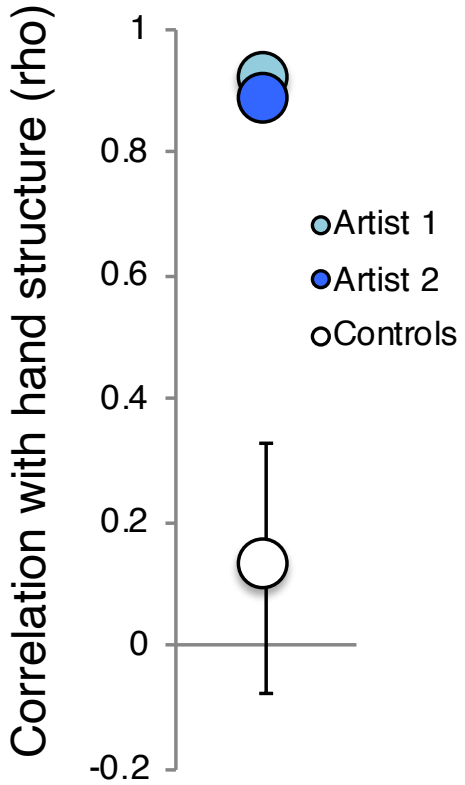
Should we give up on reorganisation?

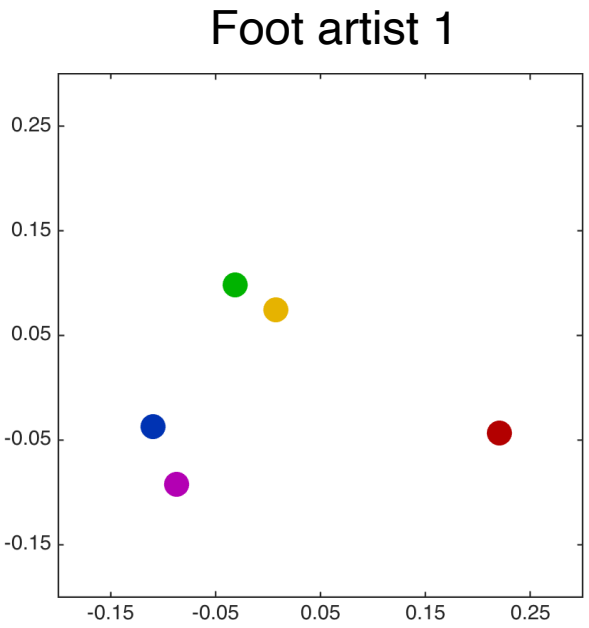
Bob Ross Day -
Plasticity Lab
August 2019, ICN

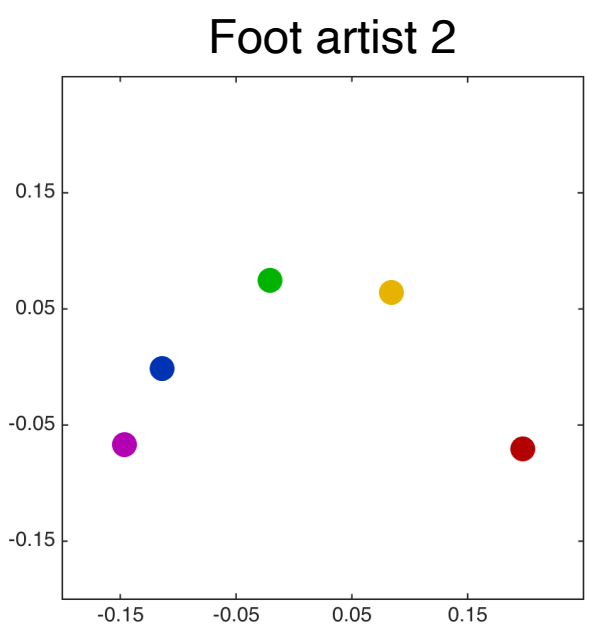
Toe maps in artist's **foot area**

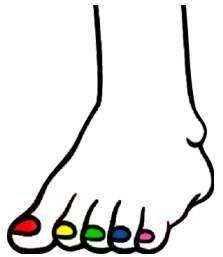


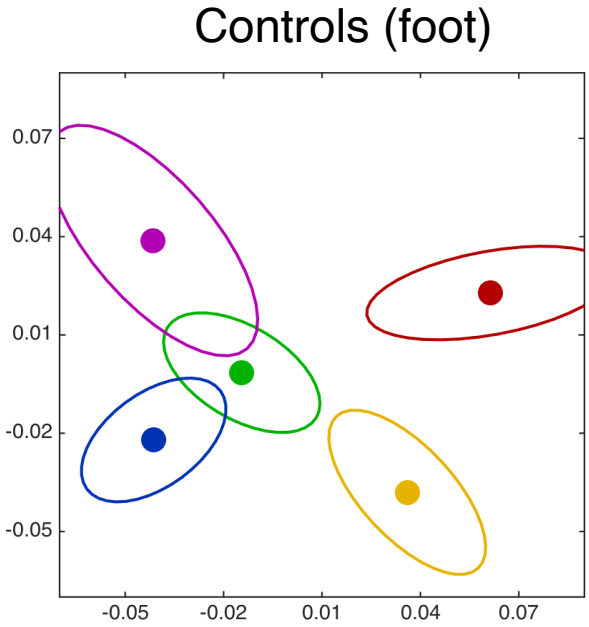
Toe maps in artist's foot area

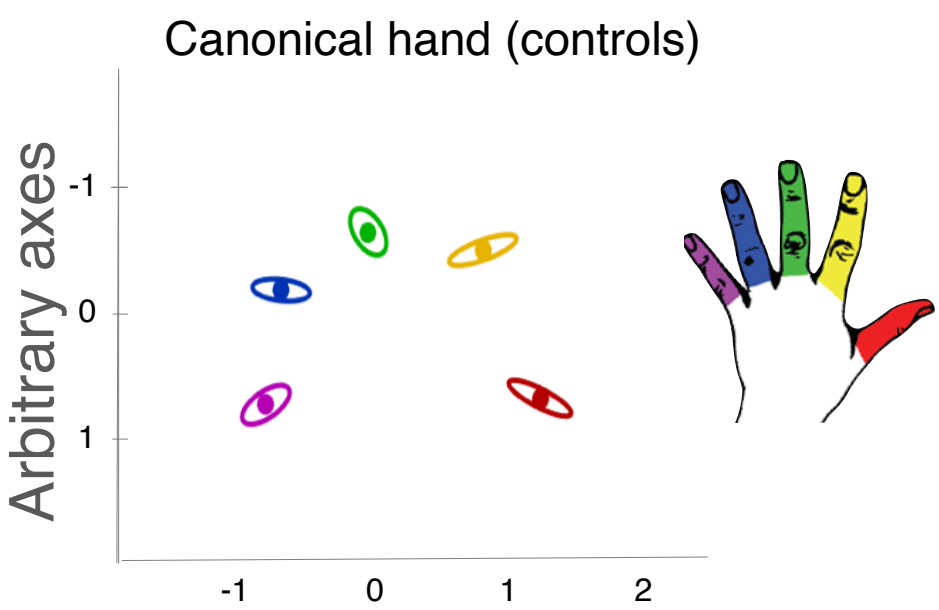












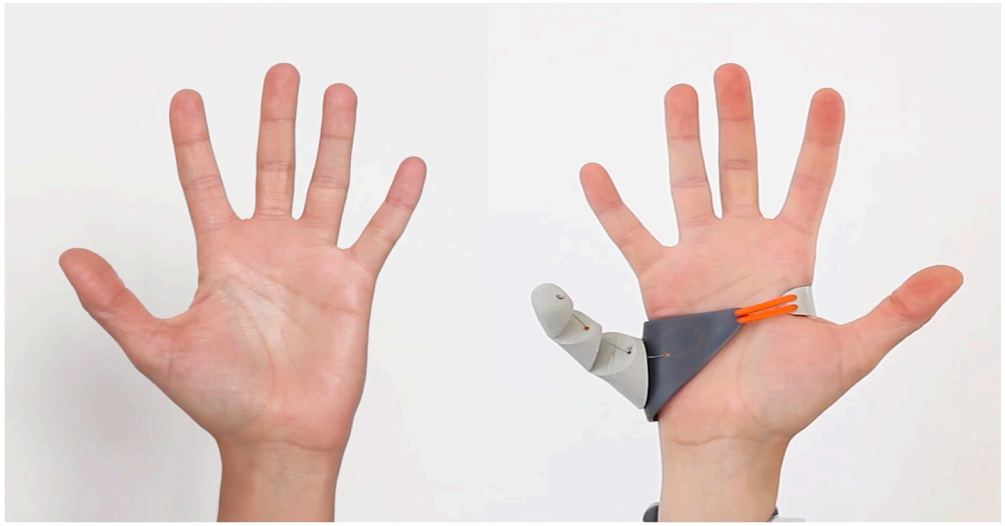
Dempsey-Jones & Wesselink et al.,
Cell Reports, 2019

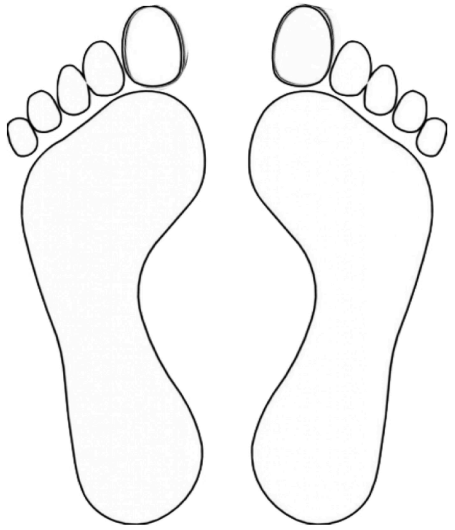
Should we give up on the adults brain?

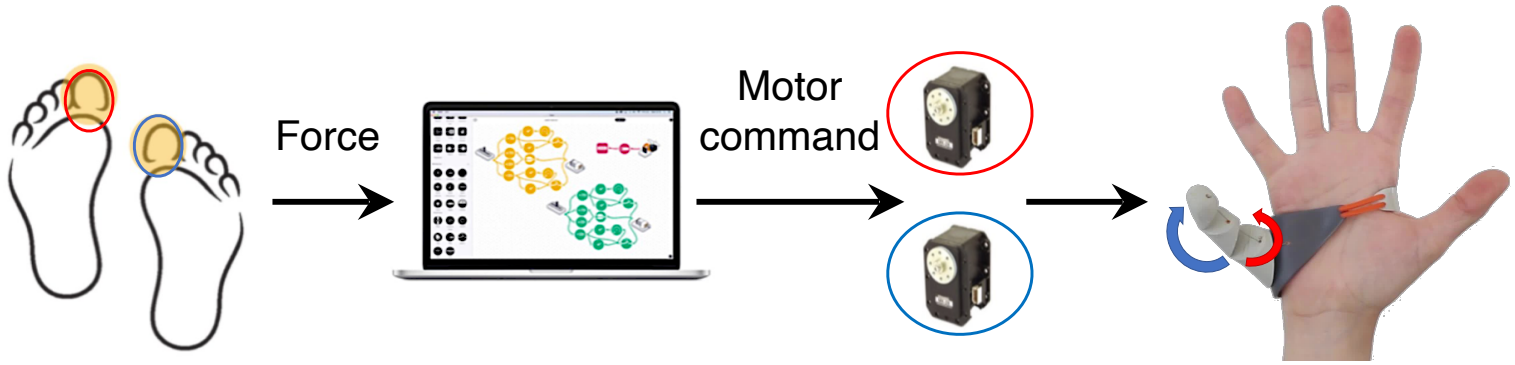
Dani Clode

i: @dani_clode
w: daniclode.com

Operating the Third Thumb with the toes





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3
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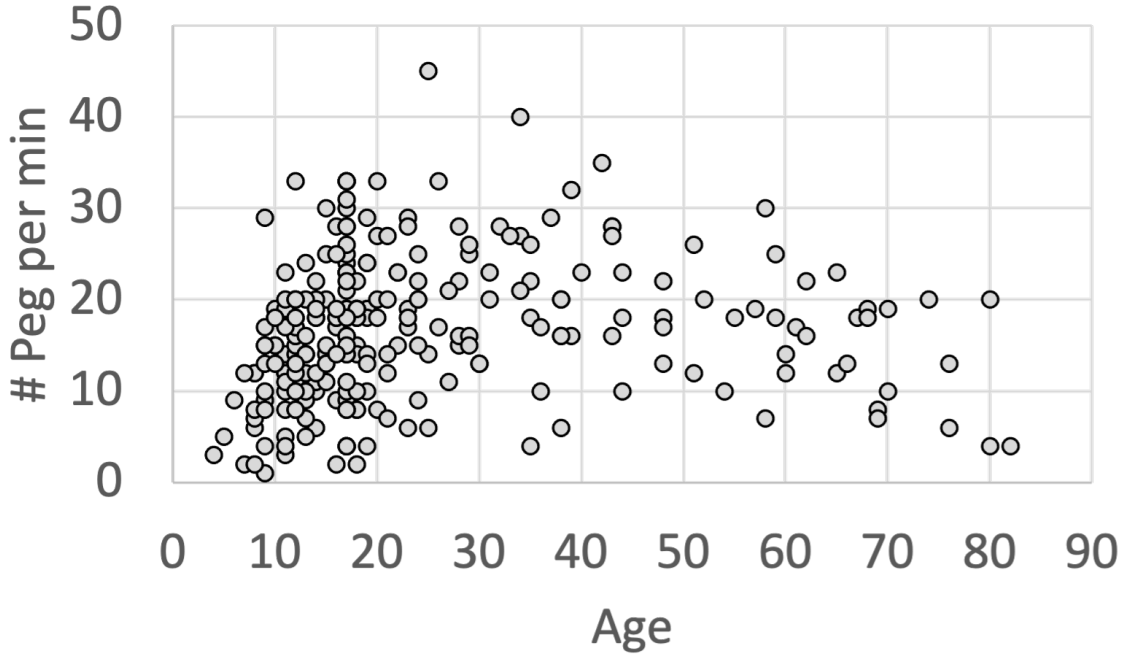
Left Hand Area
Right Hand Area
ins adapt to control an extra body part?
UCL
What is 3D Printing?
How do our brains adapt to
TRY ON A THIRD THUMB!
PRESS YOUR FEET HERE

First time experience using the Third Thumb (578 participants)

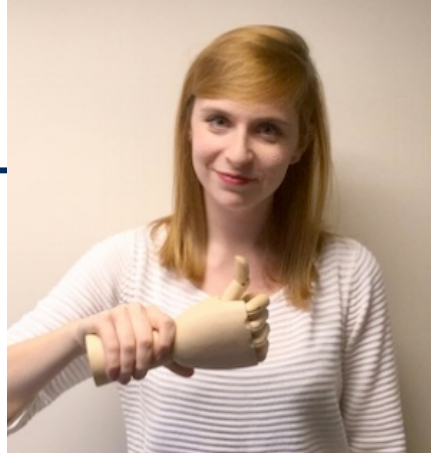
Thumb-hand collaboration

(Almost) everyone (99%) can learn to use the Third Thumb within a minute

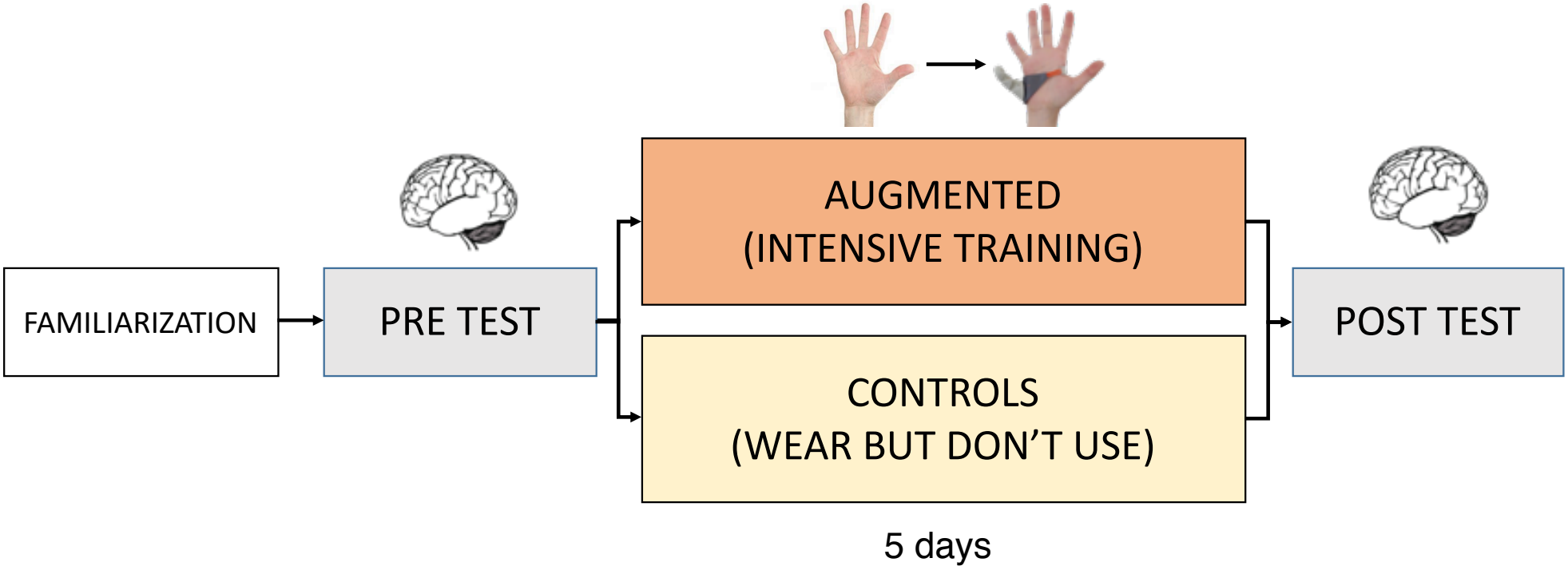
Thumb individuation task



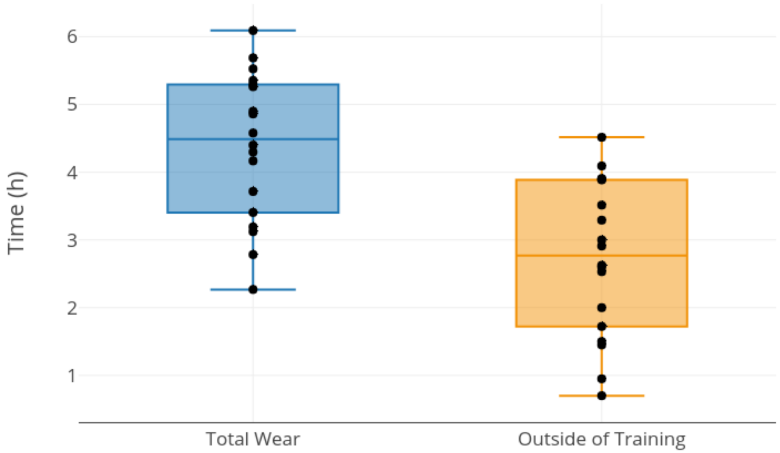
Study design

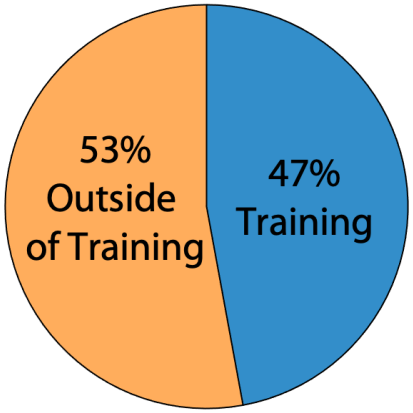


Paulina Kieliba

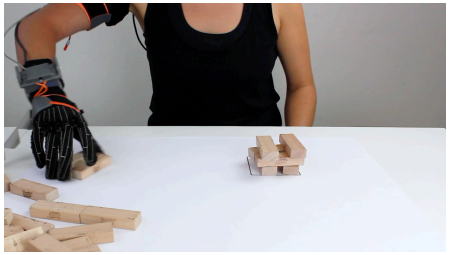


Average Daily Wear Time





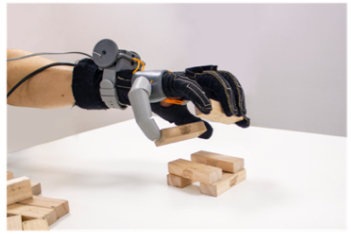
Training works..



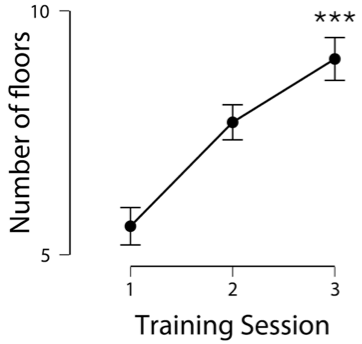
Collaboration

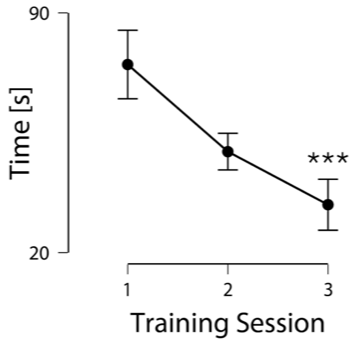
Shared Supervision

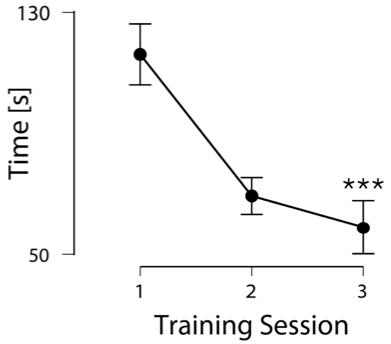
Individuation

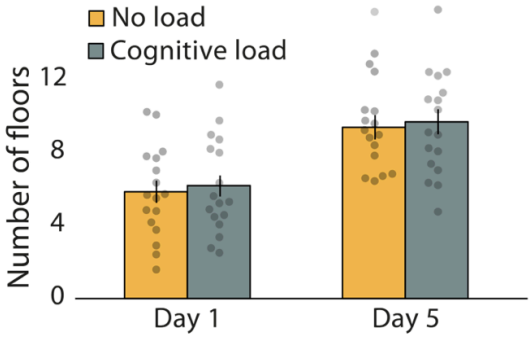


Collaboration

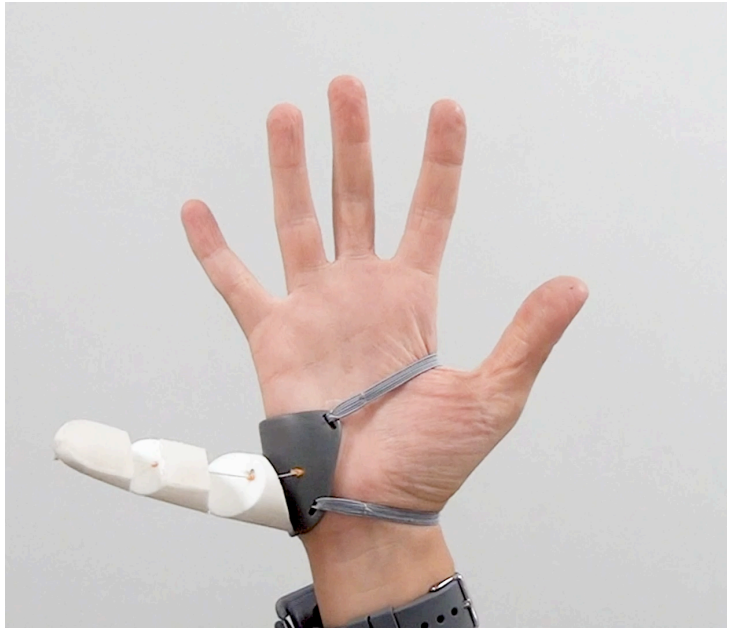


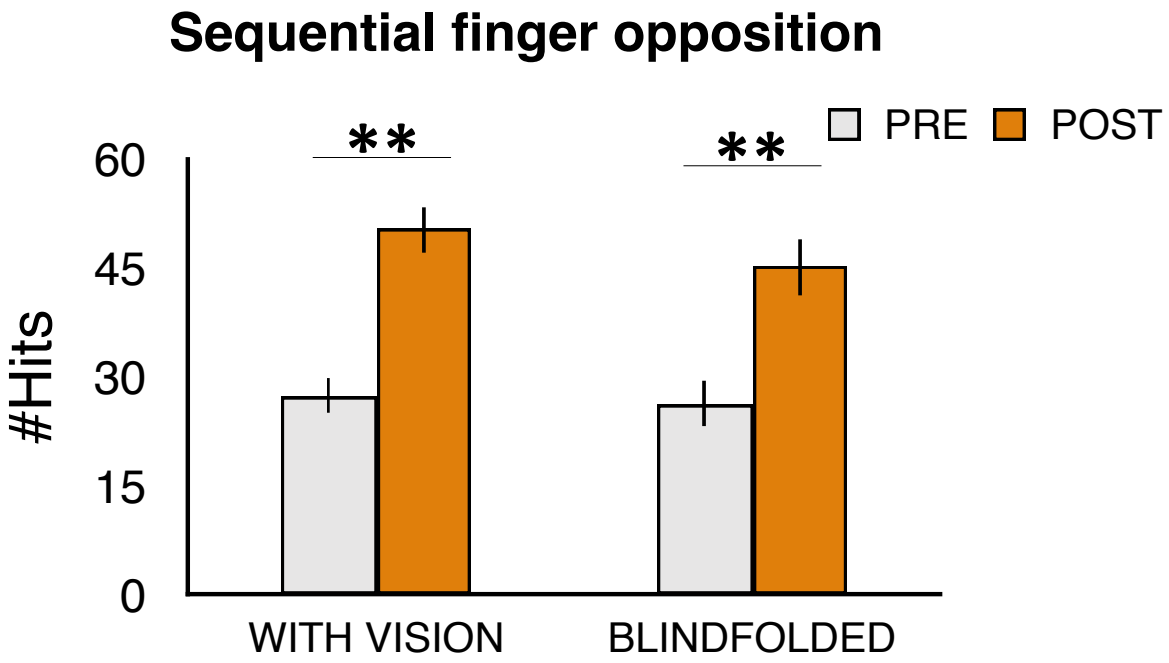




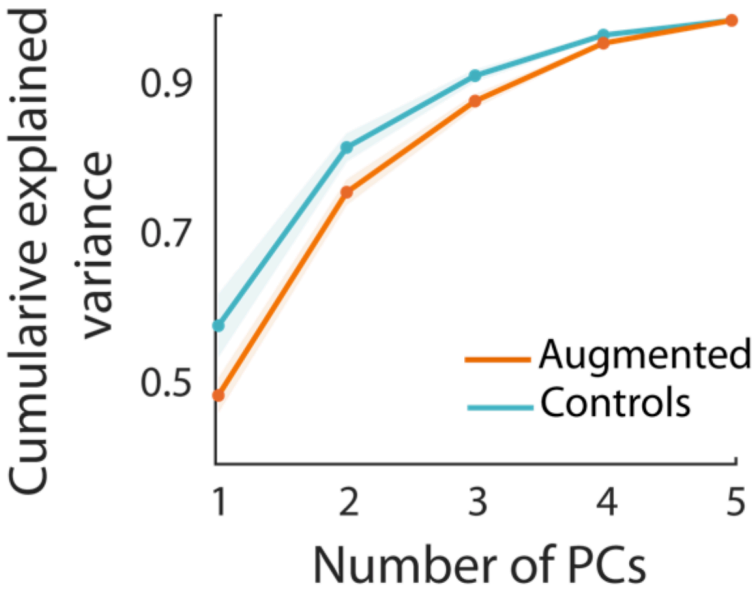


Hand-robot Coordination Improves with Training



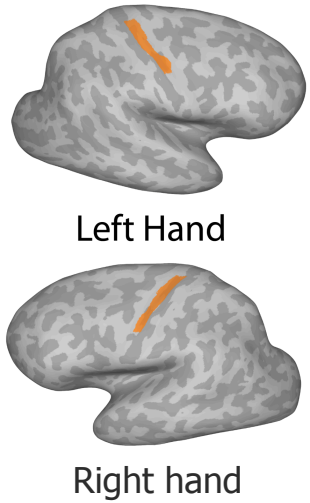


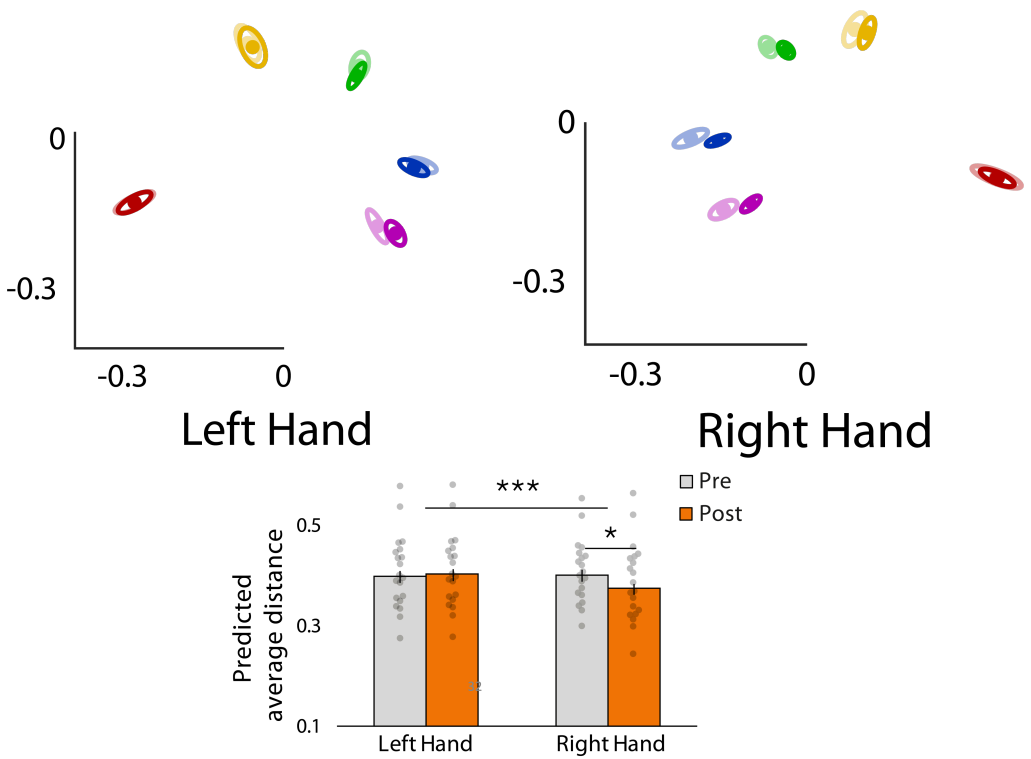
Changed Finger Synergies with Third Thumb



Kieliba, et al., *Science Robotics, 2021*

M1 Results: Post training

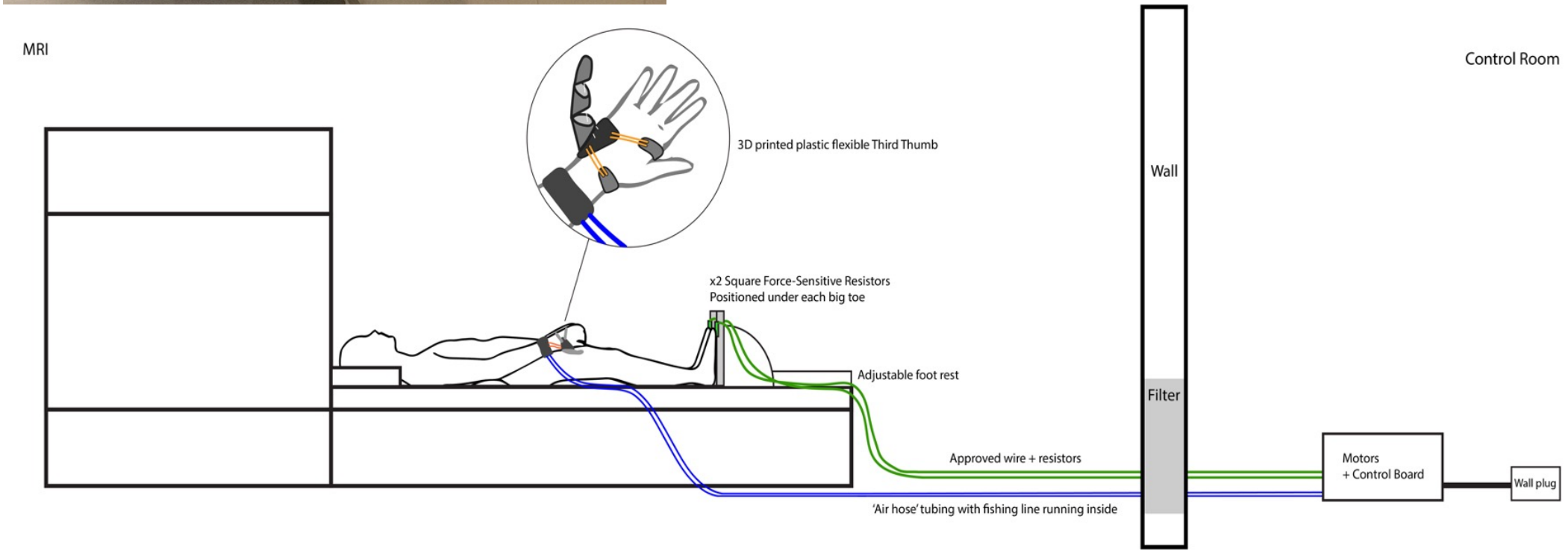


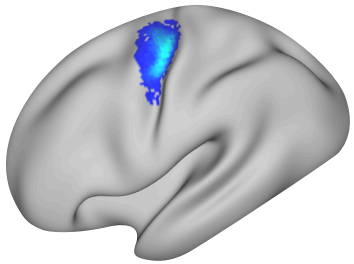


Kieliba, et al., *Science Robotics, 2021*

Elena Amoruso

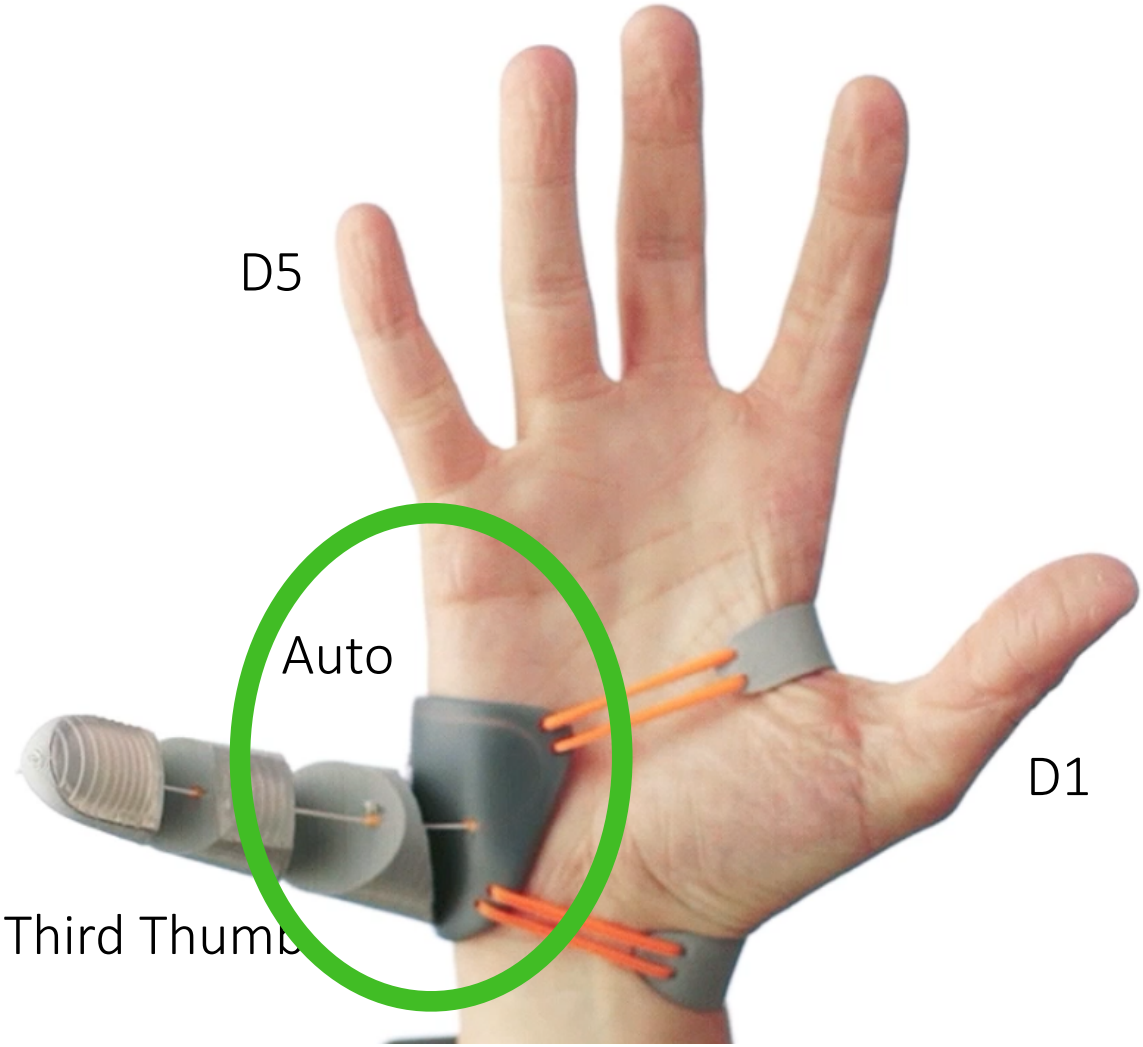
MRI compatible set-up

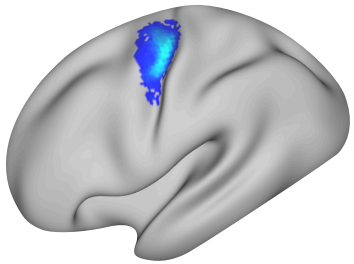




What's in a thumb?

Third Thumb = Toe + Auto





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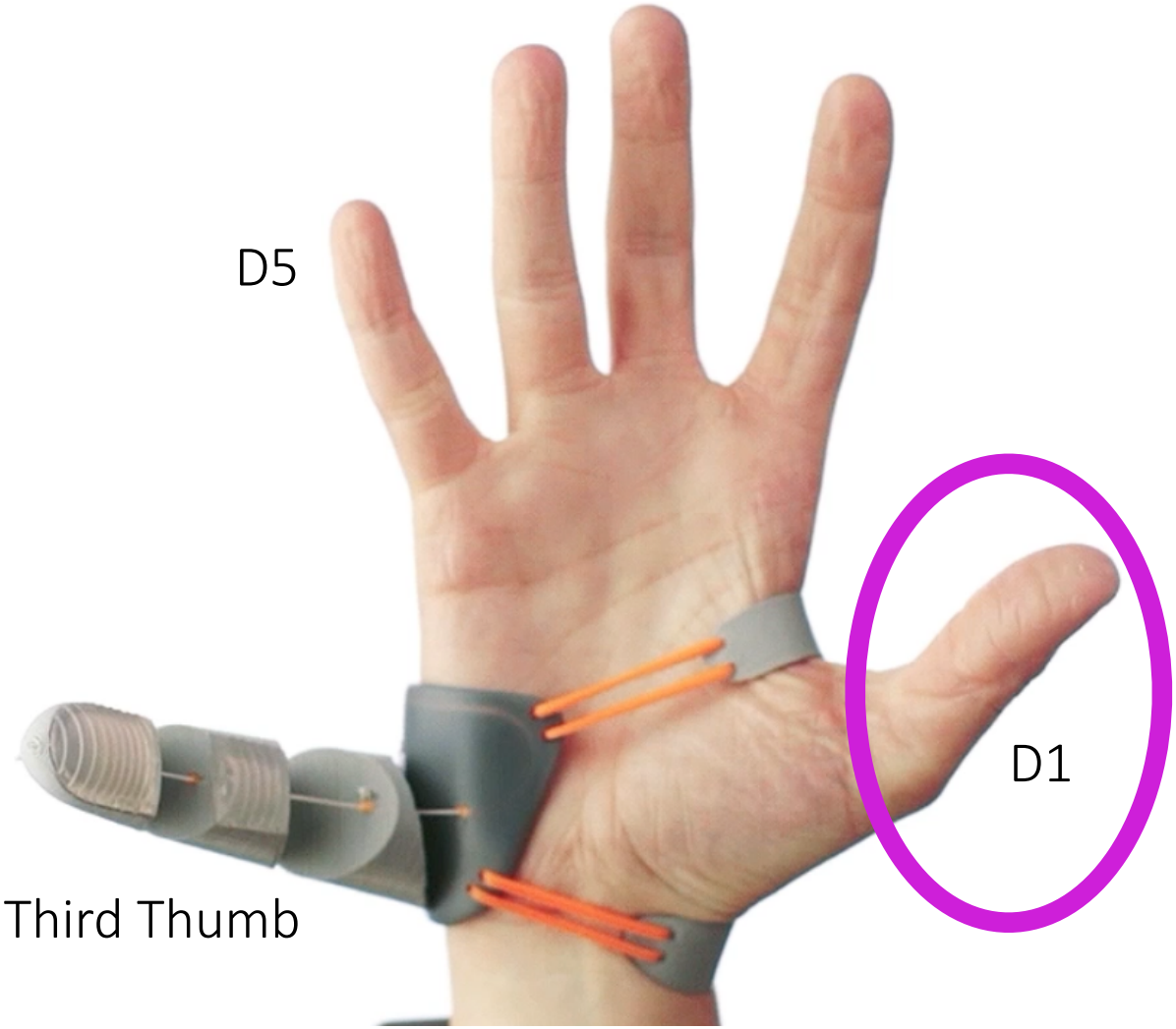
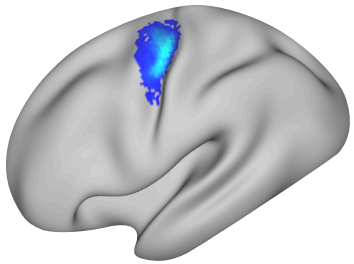
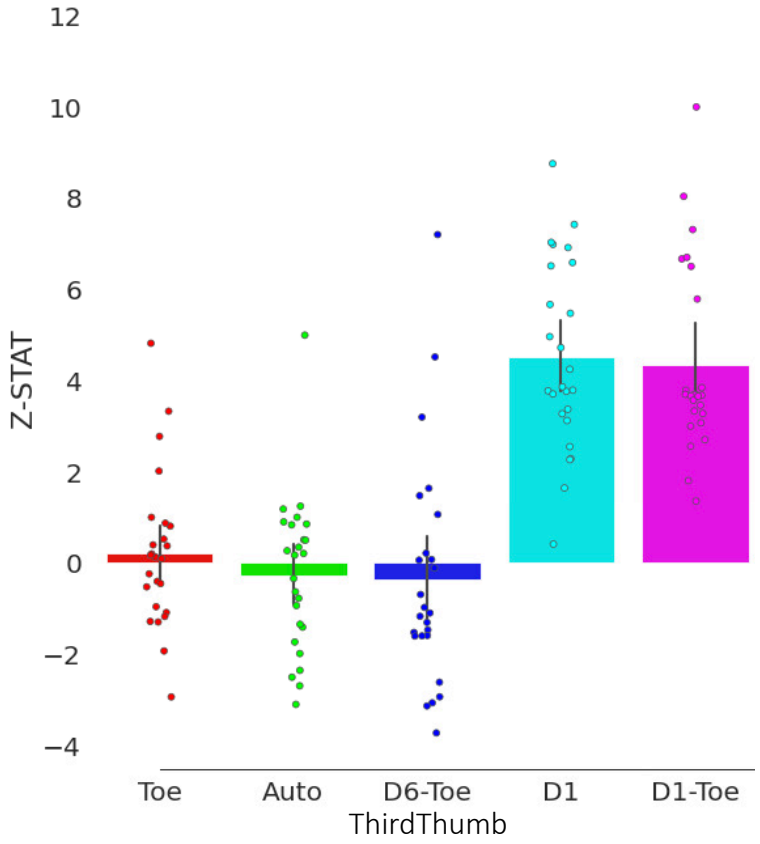


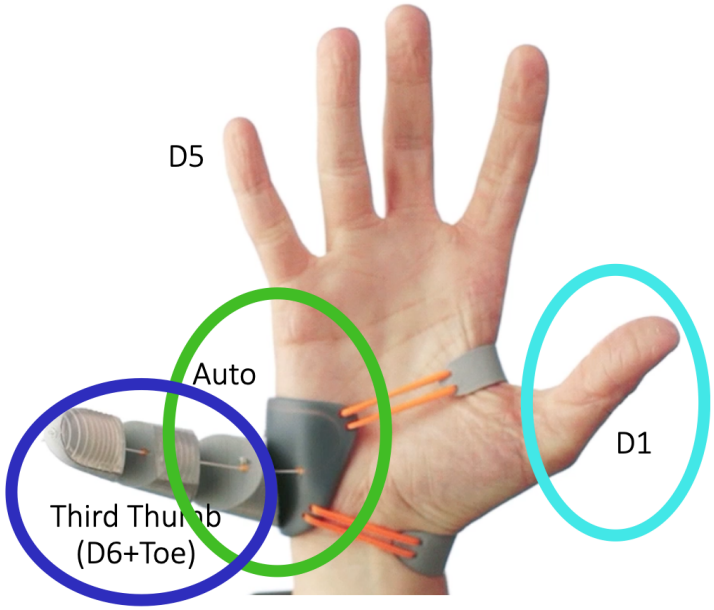
D1+Toe = Toe + D1



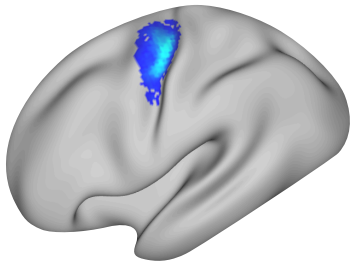
What's in a thumb? M1 Hand area

Univariate



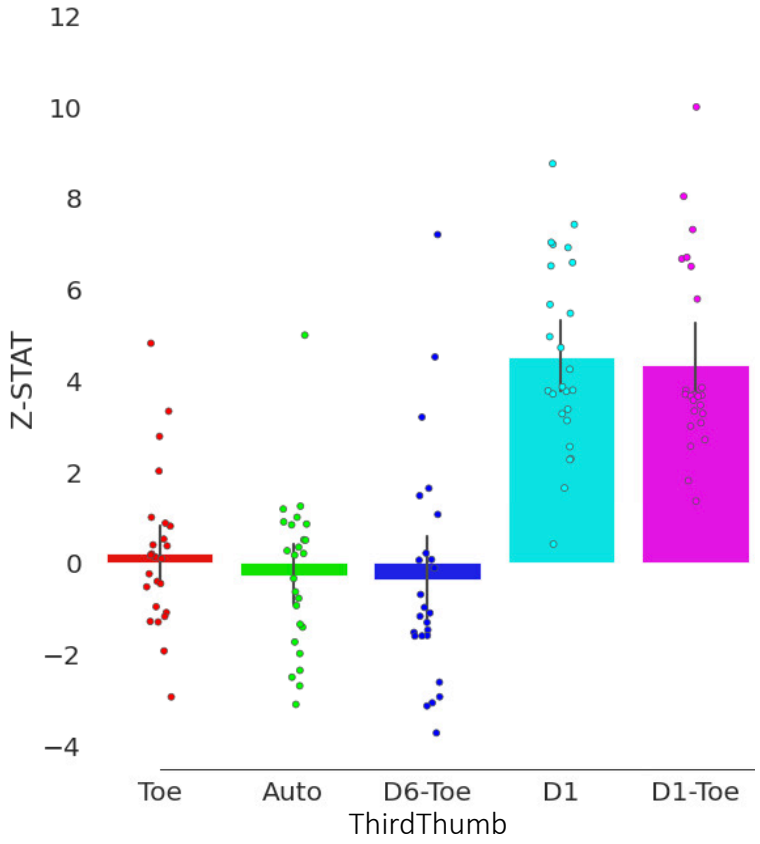


Amoruso et al., in preparation

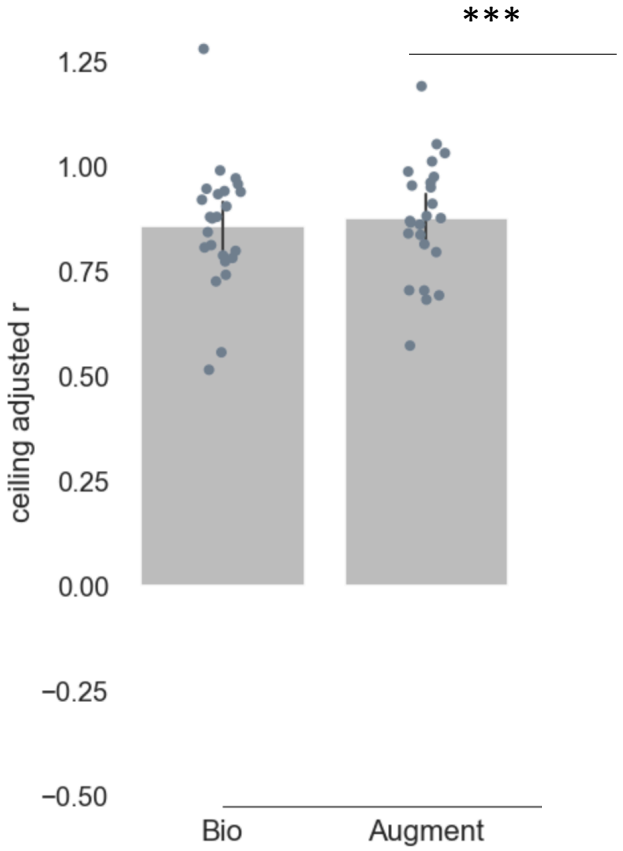


What's in a thumb? M1 Hand area

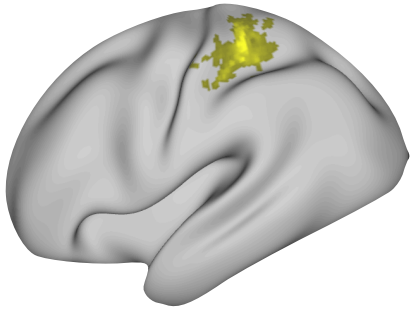
Univariate



Multivariate

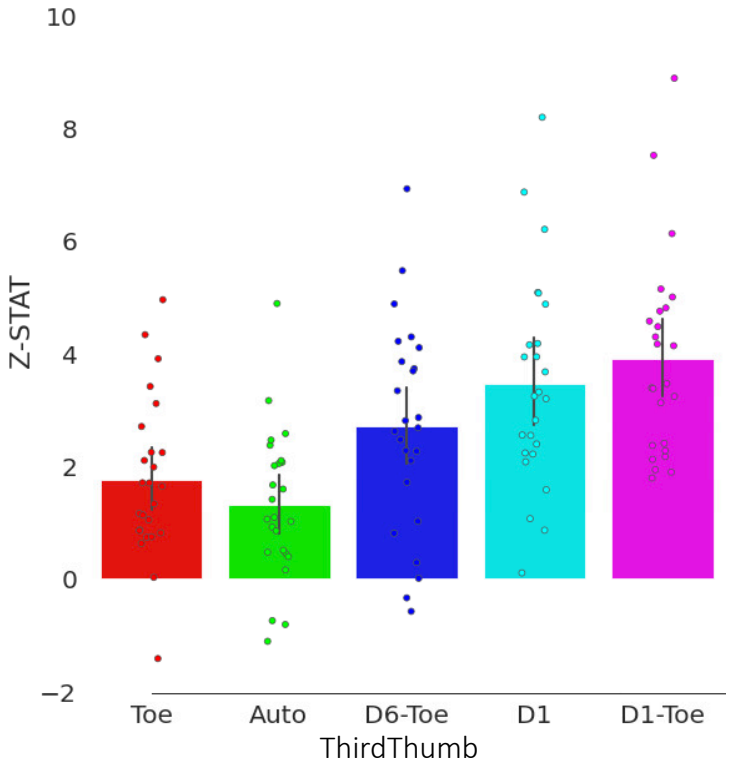


Amoruso et al., in preparation

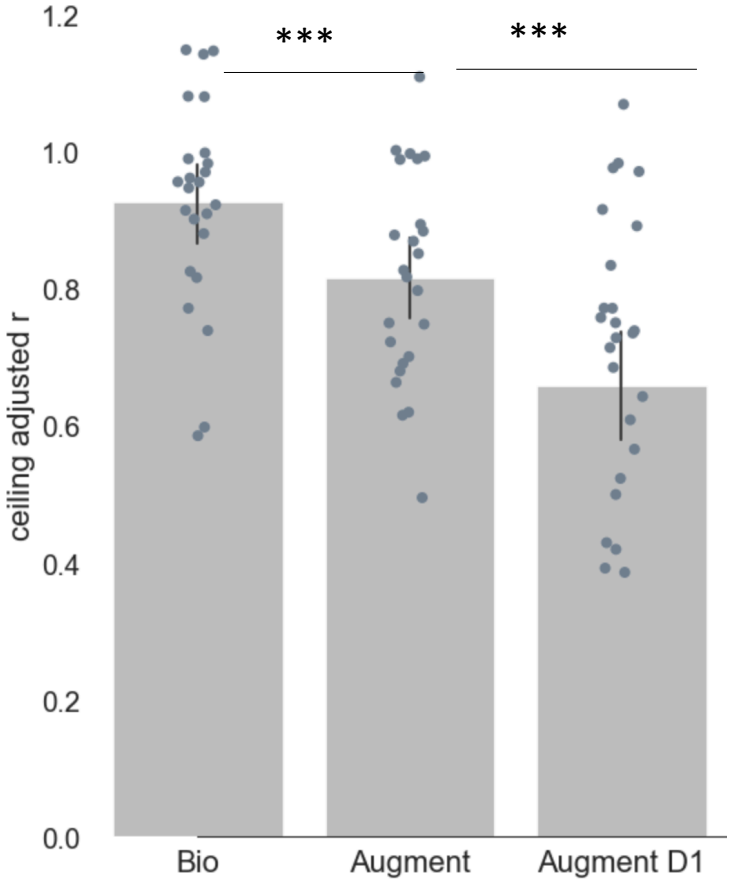


What's in a thumb? Superior parietal cortex

Univariate



Multivariate



Amoruso et al., in preparation

What about amputees?

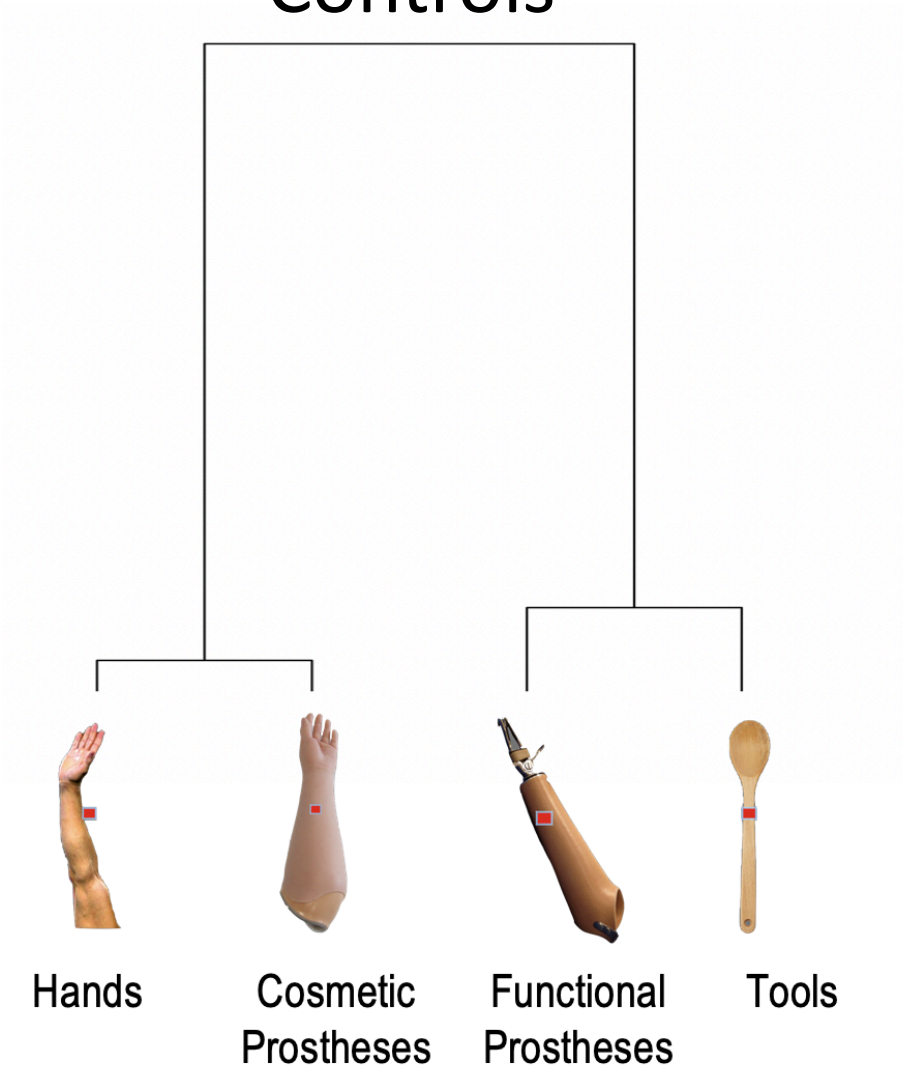
Artificial limbs activate hand-selective (visual) brain areas

van den Heiligenberg et al., Brain, 2018

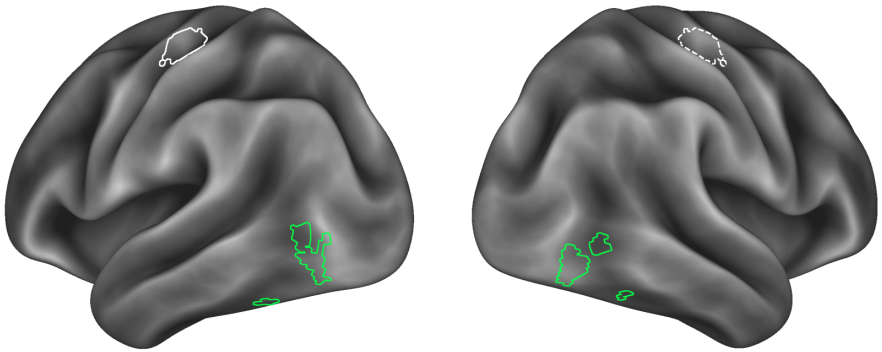
Brain decoding of artificial limbs

Roni
Maimon-Mor

Controls

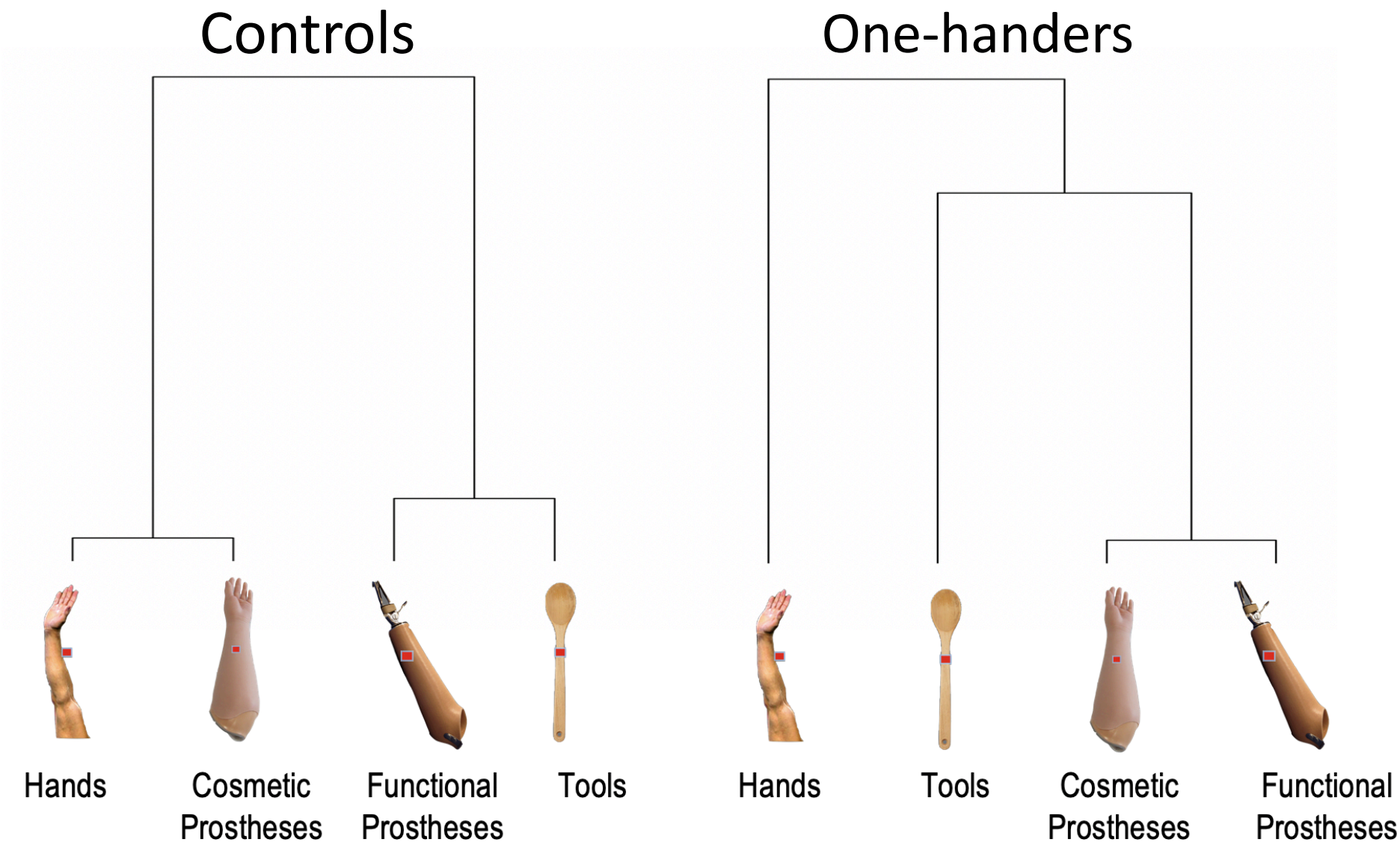


visual ‘hand’ areas



Maimon-Mor et al., PLOS Biology, 2020

Brain decoding of artificial limbs



Maimon-Mor et al., PLOS Biology, 2020

Concluions

Neuroimaging can be a double-edged sword for clinical development

Brain plasticity is limited and is not driven by input loss

Representational similarity analysis can help us find novel representations

Some brain plasticity can be induced by meaningful input

plasticity-lab.com

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w: daniclode.com