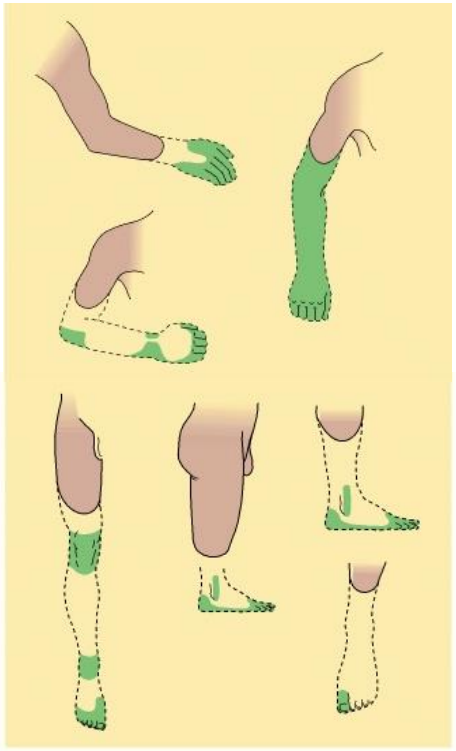
Embodiment of prosthesis into the body

Noritaka KAWASHIMA, Ph.D
National Rehabilitation Center for Persons with Disability

Phantom limb

A phantom limb is the perception that an amputated limb is still attached to the body and is moving with other body parts (Melzack 1992; Ramachandran & Hirstein 1998)

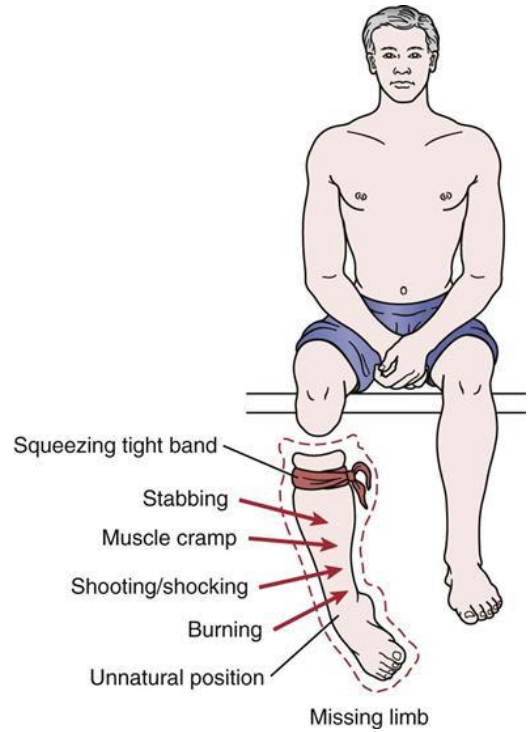
General description of phantom limb



- Almost all (95%-) amputees experience phantom limb phenomenon immediately after the amputation
  (Ramachandran and Hirstein 1998, Halligan et al. 1999)
- 50-80% of them complain phantom limb pain
  (Jansen et al. 1983, Kooijman et al. 2000, Fraser et al. 2001)

Experience of pre-amputation pain largely affect to the condition of phantom limb and an incidence of phantom limb pain (Nilolajsan et al. 1997)

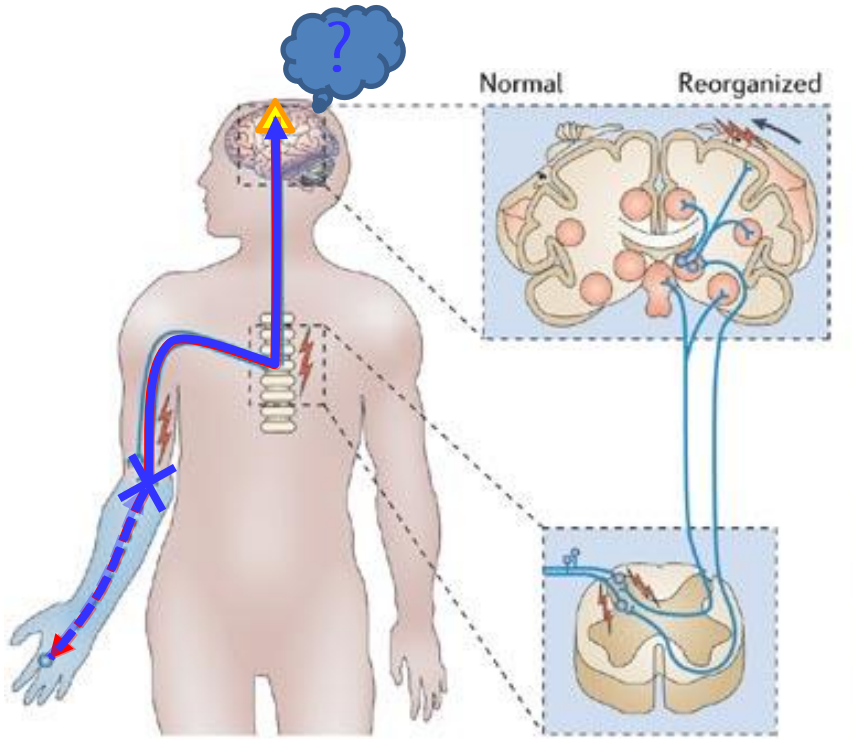
The type and extent of phantom limb (pain) are highly variable



The factors/elements for determining the condition of phantom limb is not fully understood.

What's happen after limb amputation

— neural mechanisms underlying cortical reorganization —



Flor (Nat Review Neurosci 2006)

- Sensorimotor cortex still exist even after amputation

  →Motor cortex is capable to send descending motor command

- Sensory feedback does not come back to the brain

  →Motor error: accumulating

  (Potential reason for phantom pain)

- After amputation…

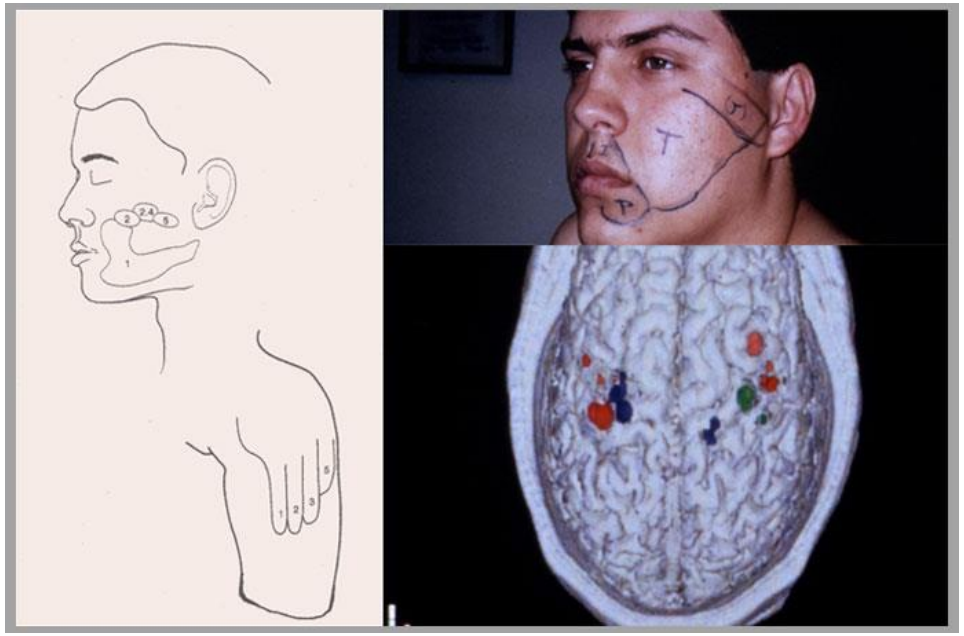
  ①Missing part: inactivated

  ②Residual part: more activated

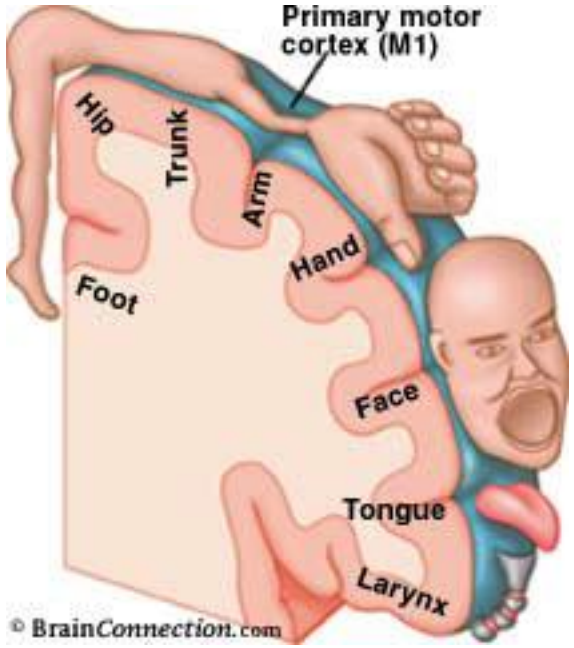
Adjacent area invade to the area which used to innervate missing area: cortical reorganization

Referred sensation / Dual perception

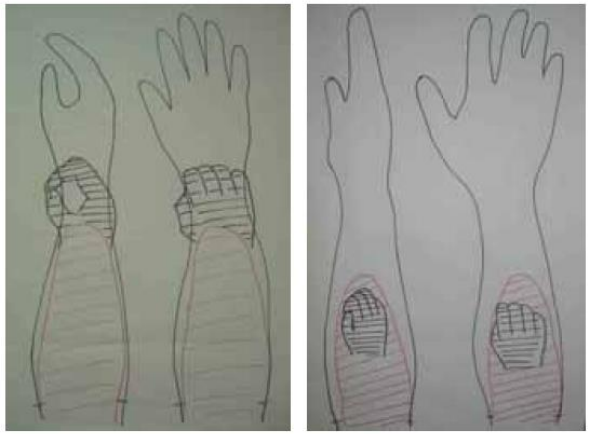
A perception at the missing part (≒phantom limb) evoked by sensory stimulation to a residual body part



Ramachandran and Hirstein (Brain 1998)



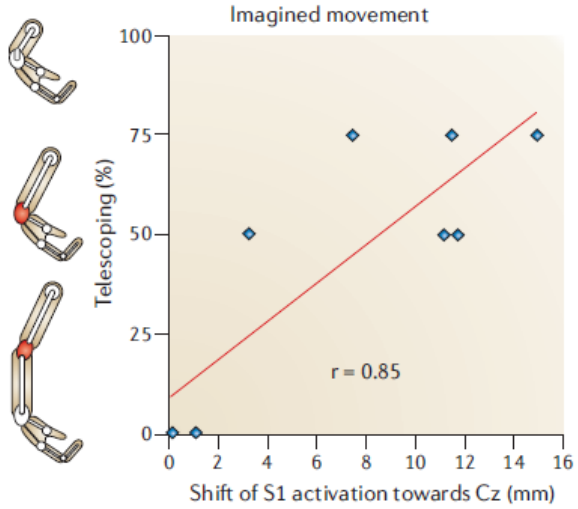
Factors affecting to Phantom limb pain
— Relevance to cortical reorganization—

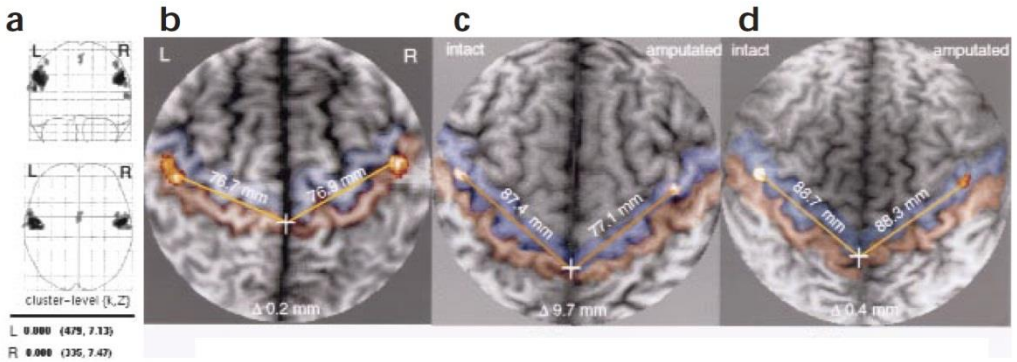


Telescoping：
The phenomenon phantom limb shrink into the stamp. Telescoping is depend on time post injury and the use of prosthesis.

Telescoping has strong relevance to the extent of cortical reorganization

(Flor et al. 2006)





SPM maps of 10 controls

ISOVIEW projection of SPM96 normalized brains of 10 controls

Pain, no myoelectric prosthesis, patient #5

No pain, frequent use of myoelectric prosthesis, patient #6

Potential impact of the use of prosthesis on phantom limb pain

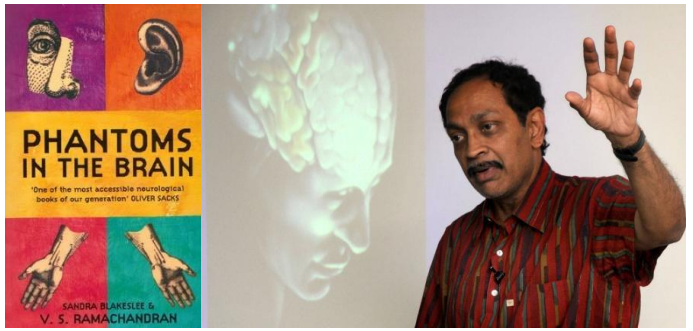
Frequent use of a prosthesis would minimize the extent of cortical reorganization and resultantly contribute to reduce pain

Lotze et al. (Nat Neurosci 1999)

“Mirror box”

The mirror therapy is based on the concept that the mirror induced visual feedback (MVF) of missing limb enhances awareness of one’s own body and has a potential do reduce phantom limb pain.

(Hunter et al. 2003, Kawashima et al. 2009)



NEUROCASE
2009, 15 (6), 478–484

Psychology Press
Taylor & Francis Group

Metal bar prevents phantom limb motion: Case study of an amputation patient who showed a profound change in the awareness of his phantom limb

Noritaka Kawashima[1,2] and Tomoki Mita[1]

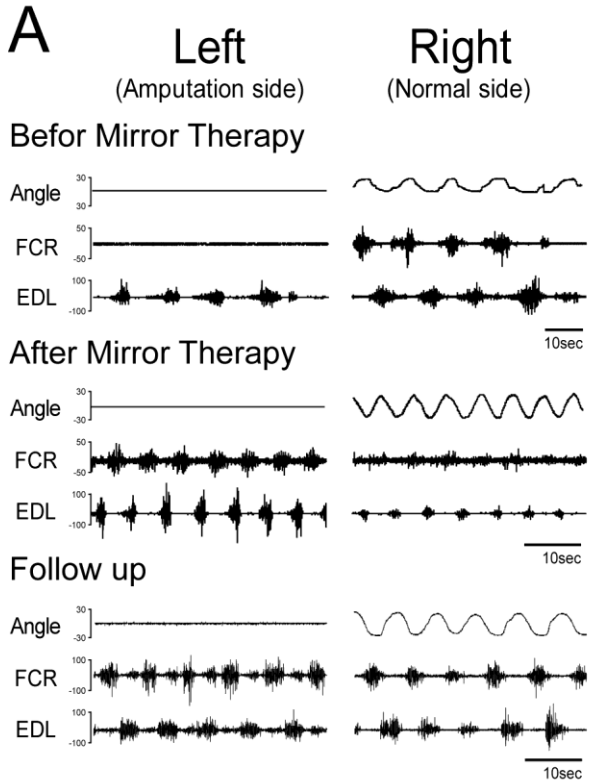
[1]Department of Rehabilitation for the Movement Functions, Research Institute, National Rehabilitation Center for the Persons with Disability, Tokotozawa, Saitama, Japan
[2]Japanese Society for Promotion of Science, Tokyo, Japan

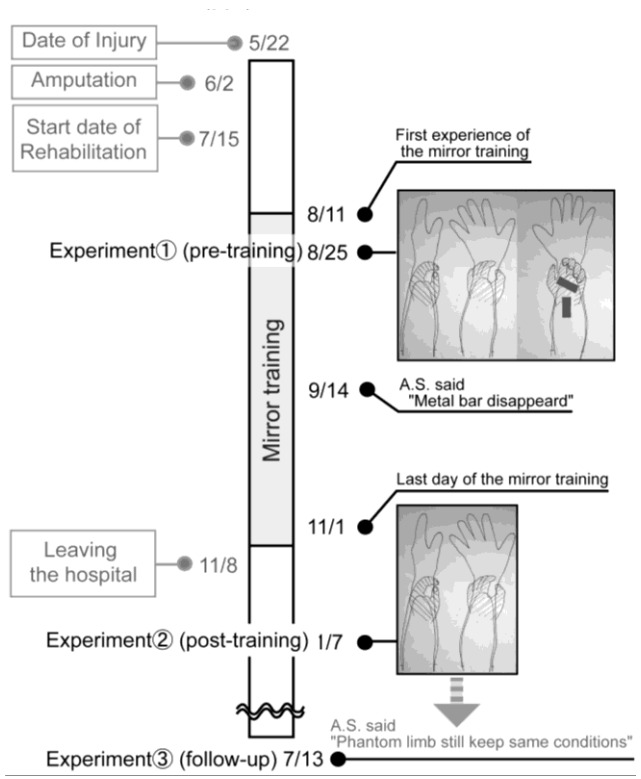
Subject A.S. (69-year-old forearm amputee)

A.S. suffered an accident during working with press machine. He experienced pre-amputation paralysis and the pain for two weeks, and then, the paralyzed forearm was amputated.

"Metal bar" in the phantom hand

He vividly felt existence of hand and wrist, but the wrist motion was prevented by the metal bar held in hand of phantom limb.





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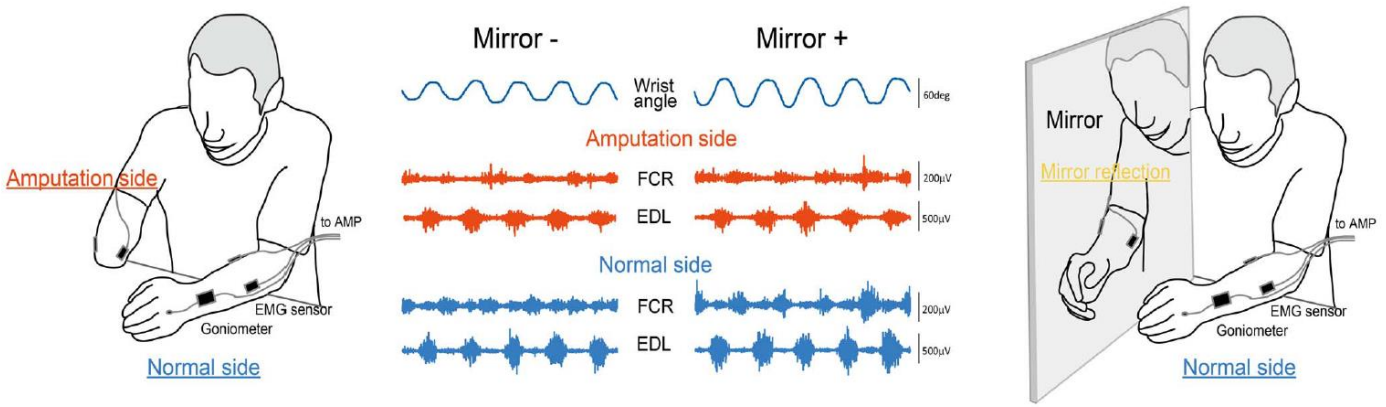
PLOS | ONE

Inter-Individual Difference in the Effect of Mirror Reflection-Induced Visual Feedback on Phantom Limb Awareness in Forearm Amputees

Noritaka Kawashima[1]*, Tomoki Mita[2], Masahiro Yoshikawa[3]



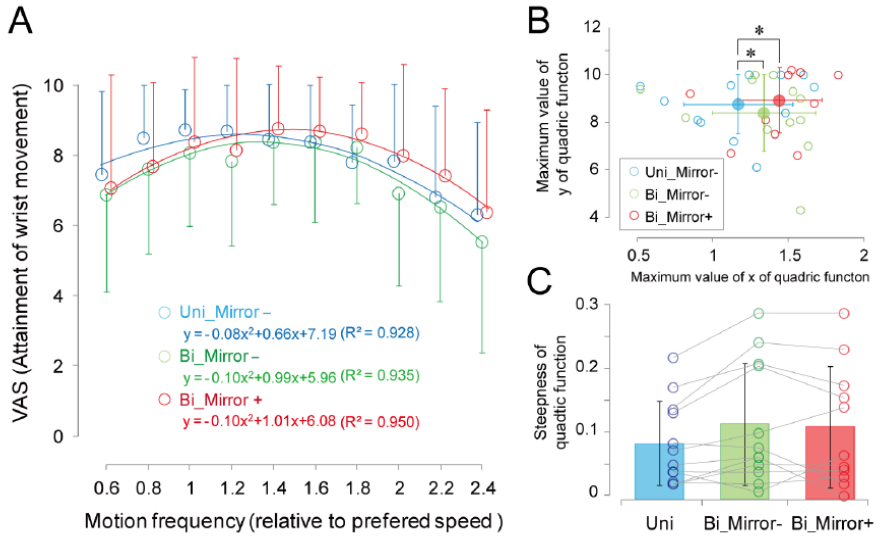


Fig 3. Averaged data of the VAS for each motion frequency and each experimental condition (A). The VAS profile in accordance with motion frequency was well characterized by the quadric function. Comparison of the peak value (B) and the slope (sharpness) of the quadric function (C) of the quadric function among three experimental conditions. The error bars indicate the standard deviation of the mean value. * Significant difference ($p<0.05$).

doi:10.1371/journal.pone.0156349.g003

PLOS | ONE

RESEARCH ARTICLE

Psychophysical Evaluation of the Capability for Phantom Limb Movement in Forearm Amputees

Noritaka Kawashima*, Tomoki Mita

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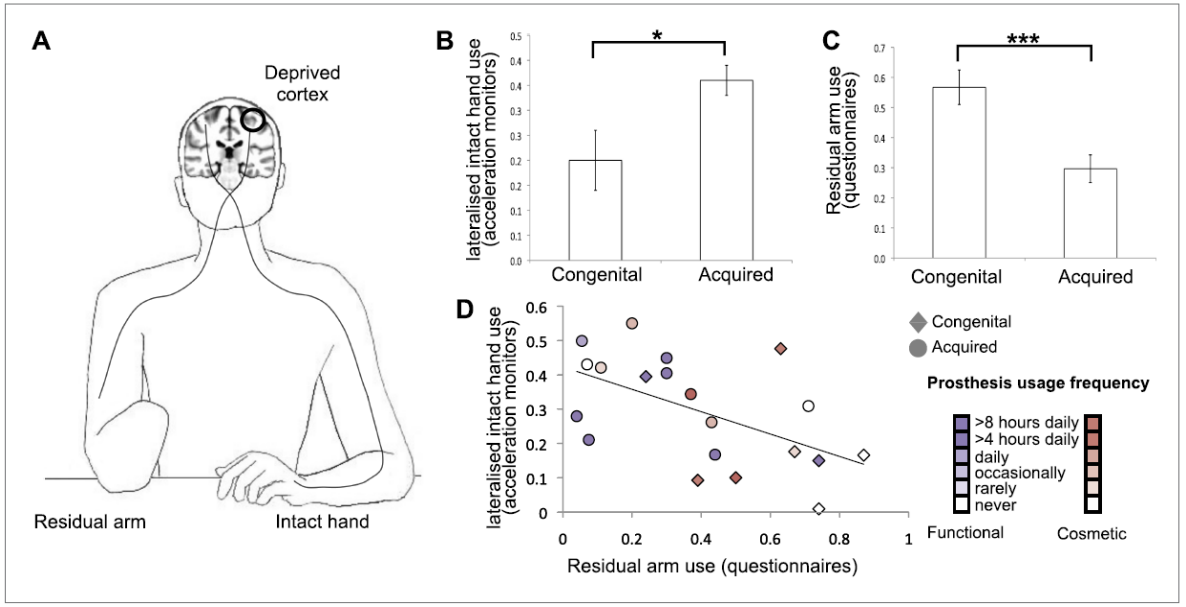
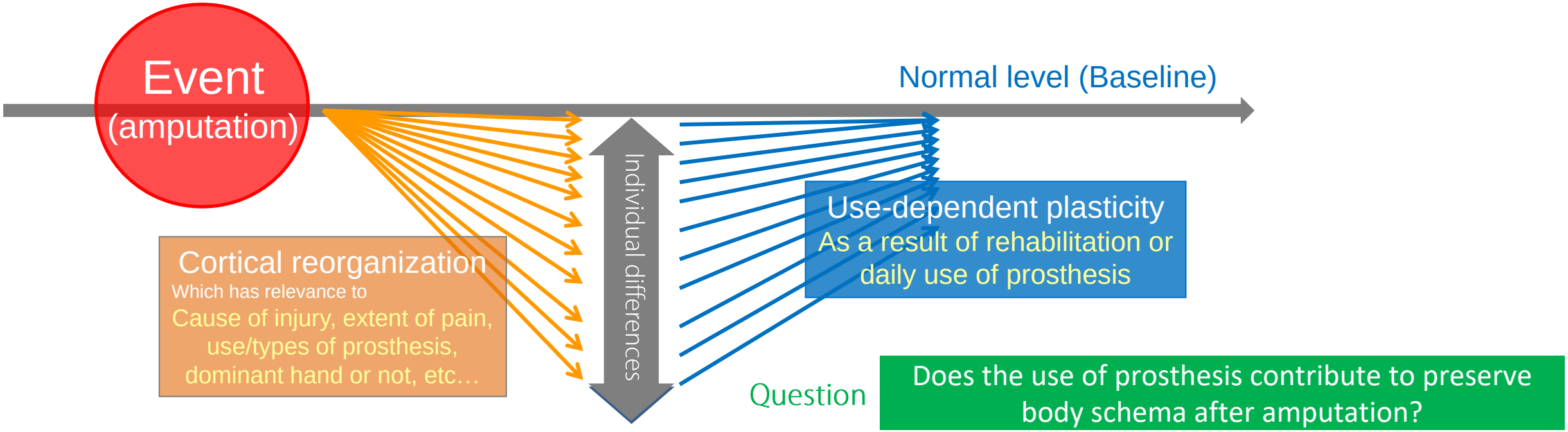
RESEARCH ARTICLE

Deprivation-related and use-dependent plasticity go hand in hand

Tamar R Makin[1]*, Alona O Cramer[1], Jan Scholz[1,2], Avital Hahamy[3], David Henderson Slater[4], Irene Tracey[1,5], Heidi Johansen-Berg[1]

[1]FMRIB Centre, Nuffield Department of Clinical Neuroscience, University of Oxford, Oxford, United Kingdom; [2]Mouse Imaging Centre, The Hospital for Sick Children, Toronto, Canada; [3]Department of Neurobiology, Weizmann Institute of Science, Rehovot, Israel; [4]Oxford Centre for Enablement, Nuffield Orthopaedic Centre, Oxford, United Kingdom; [5]Nuffield Division of Anaesthetics, University of Oxford, Oxford, United Kingdom

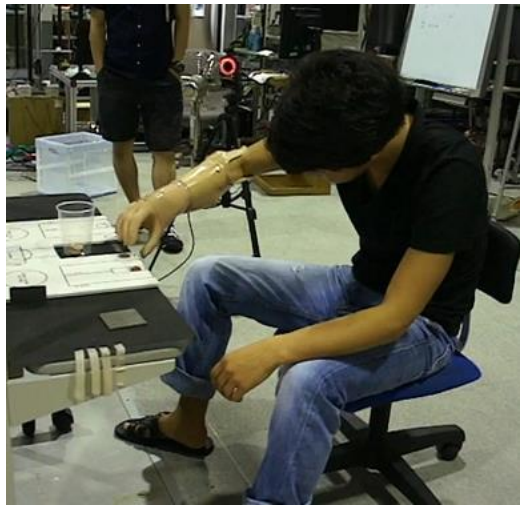


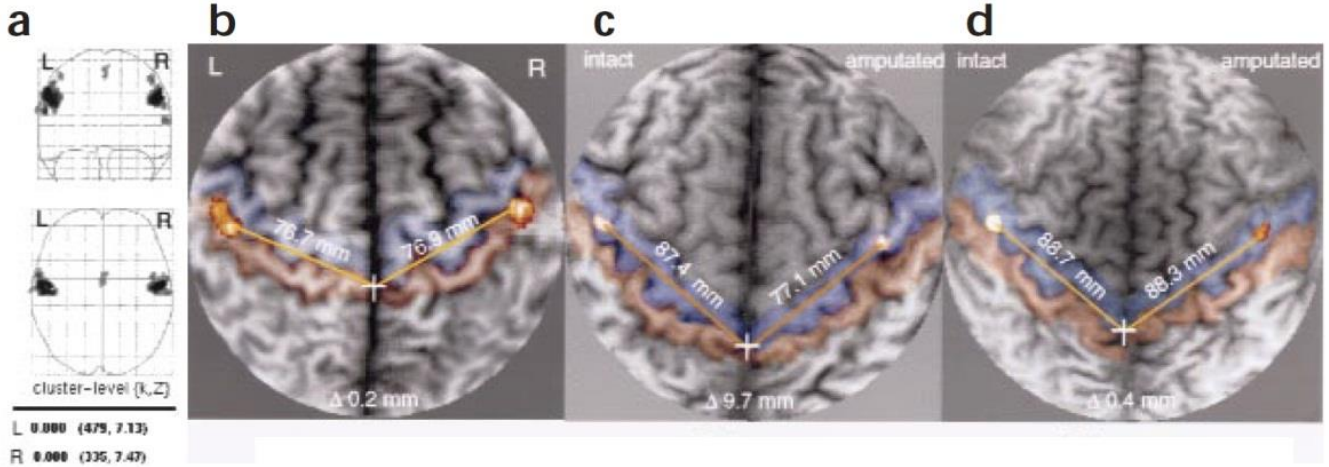


Potential impact of long-term prosthetic use on phantom limb pain

Frequent use of a prosthesis would minimize the extent of cortical reorganization and resultantly contribute to reduce pain

Lotze et al. (Nat Neurosci 1999)





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DISABILITY AND REHABILITATION, 2004; VOL. 26, NO. 16, 963–973

Taylor&Francis
healthsciences

An interpretative phenomenological analysis of the embodiment of artificial limbs

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Department of Psychology, Liverpool Hope University College, Liverpool

Accepted for publication: March 2004

Abstract

Purpose: To gain an understanding of the embodied perceptual experiences of successful prosthesis

higher levels of depression and lower levels of social integration[2,3] than their prosthesis-using counterparts. However, the prevalence of prosthesis use in amputee samples has been found to be as

Sense of Ownership

"the feeling that this body is my own"

Recognition of prosthesis

Prosthesis as a part of body

Prosthesis as a tool

Disability and Rehabilitation, 2008; 30(11): 871–883

informa
healthcare

RESEARCH PAPER

The experience of men using an upper limb prosthesis following amputation: Positive coping and minimizing feeling different

Sense of Agency

"the feeling that I am the agent of an action"

ADAM SARADJIAN[1], ANDREW R. THOMPSON[2] & DIPAK DATTA[1]

[1]*Northern General Hospital, Sheffield, and* [2]*University of Sheffield, UK*

Recognition of prosthesis

High reality, natural behavior as hand

Sense of Ownership
"the feeling that this body is my own"

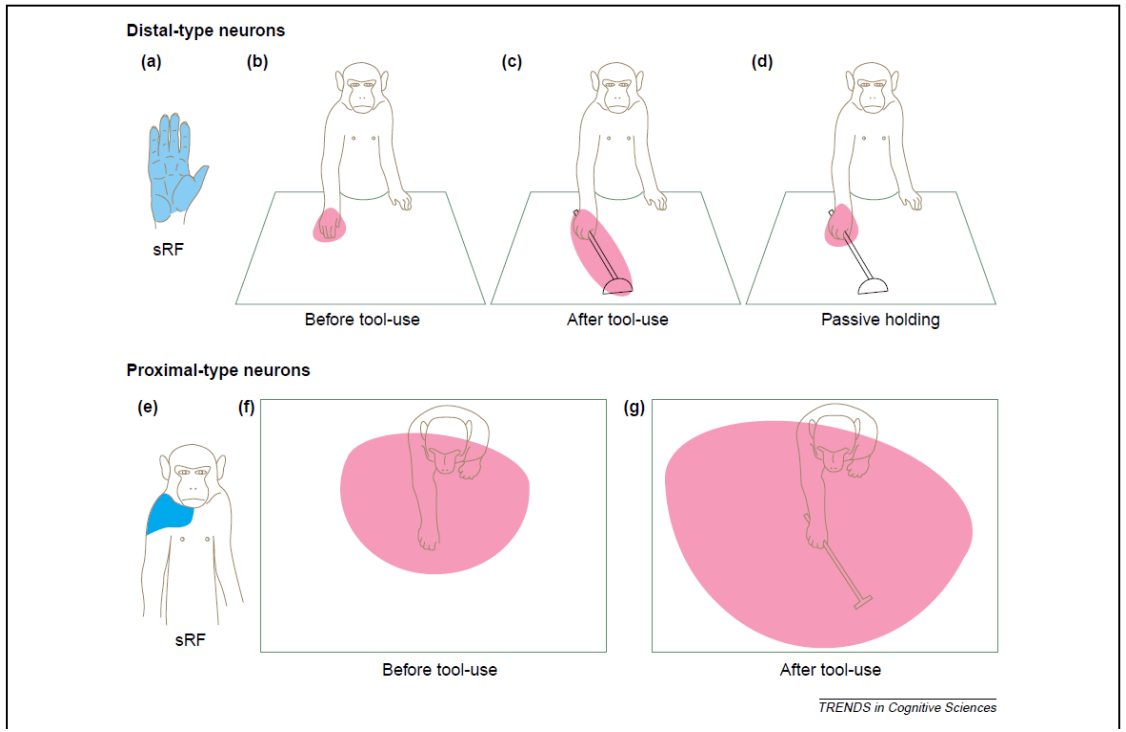
Prosthesis as a part of body

Prosthesis as a tool

Sense of Agency
"the feeling that I am the agent of an action"

High function, easy action as hand

Mechanisms underlying tool embodiment
— Alteration of spatial recognition and responsible brain area —



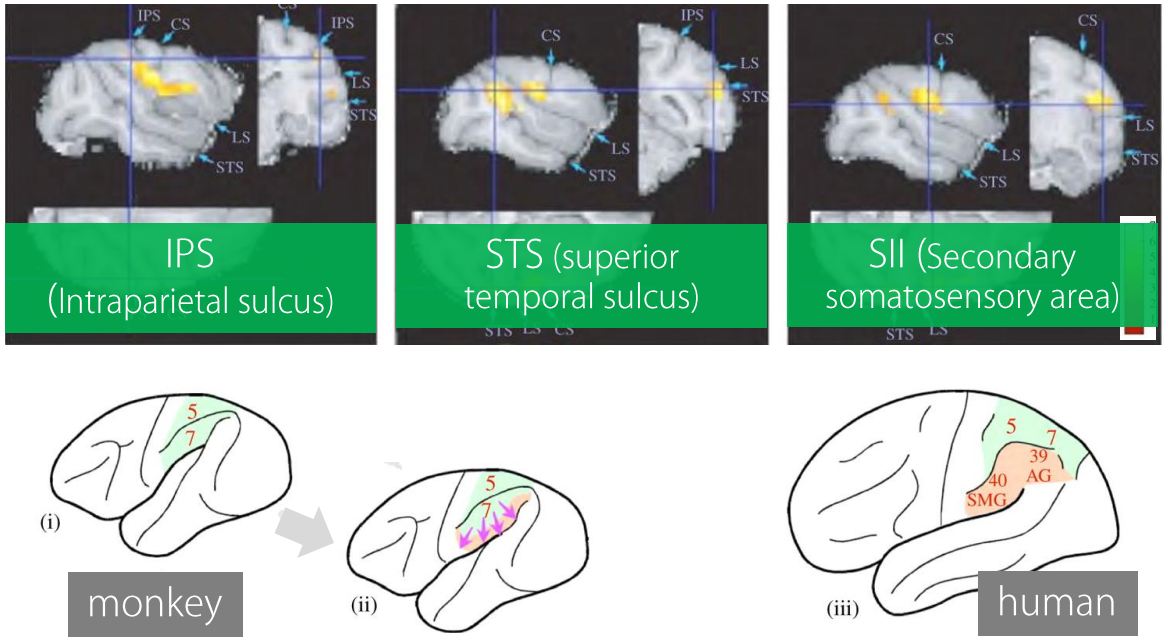
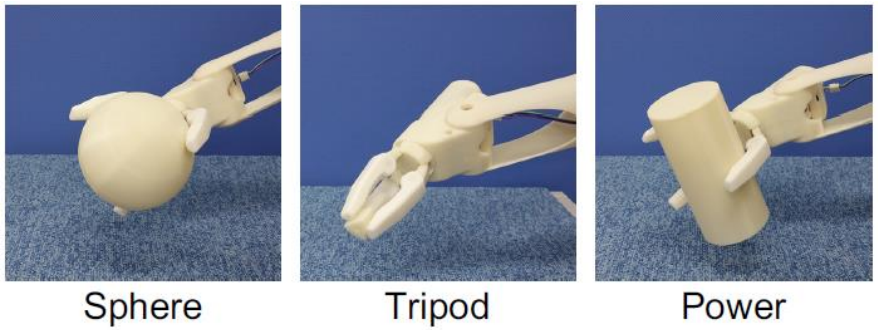


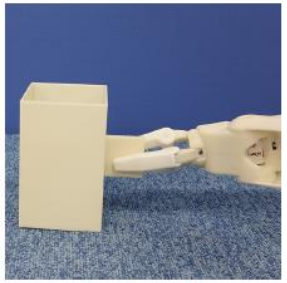
Figure 2. Grey matter increase with improvement in rake task performance. (*a*) Areas where grey matter increased with increasing performance score on the rake task. Sagittal, coronal and horizontal planes with increases in grey matter, including the right intraparietal sulcus (IPS, (i)), the superior temporal sulcus (STS, (ii)) and the secondary somatosensory area (SII, (iii)), are shown. (*b*) Schematic illustrating how tool-use-induced expansion of the parietal cortex of monkeys (i,ii) may contribute to the establishment of a precursor for the formation of human inferior parietal areas (iii), thus creating a novel neural niche that subserves further higher cognitive functions. CS, central sulcus; LS, lateral sulcus. The colour scale indicates the *t* score. (*a*) Reproduced with permission from Quallo *et al.* [21].

3-fingered functional prosthesis “Finch”


Sphere

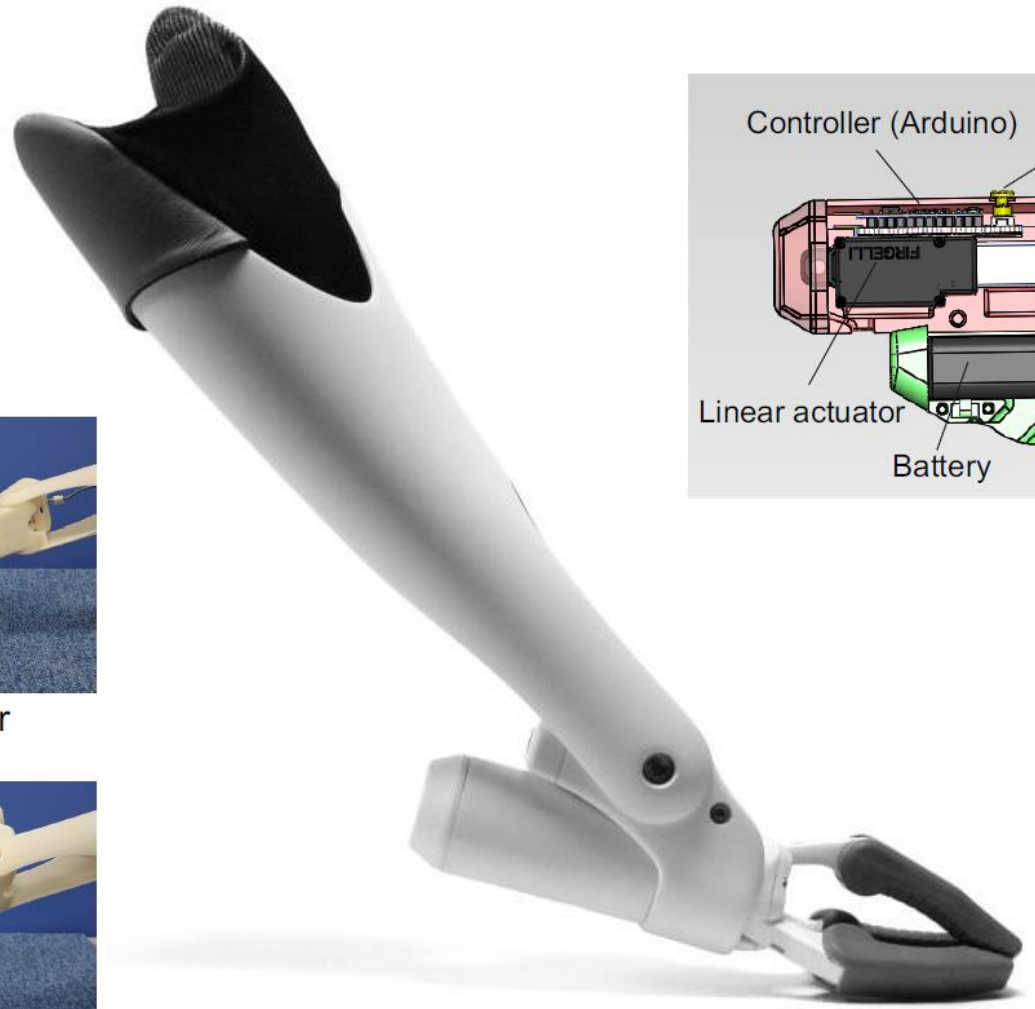
Tripod

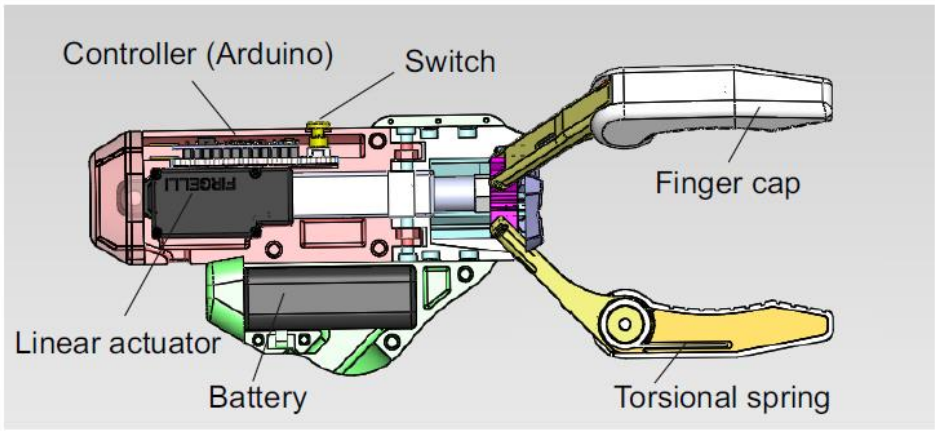
Power


Lateral

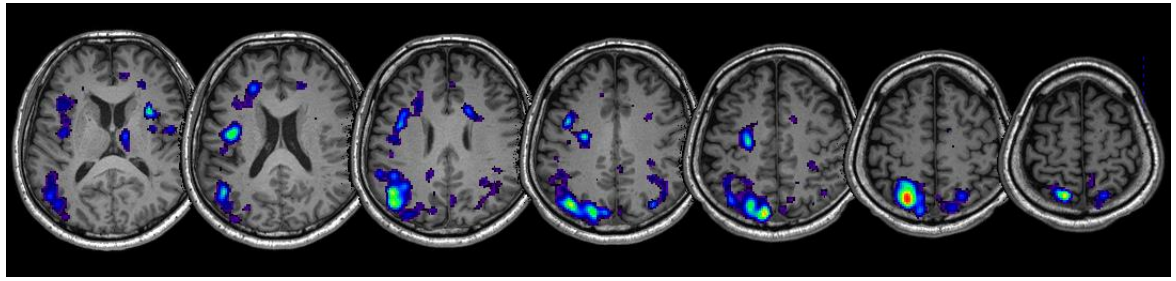

Tip

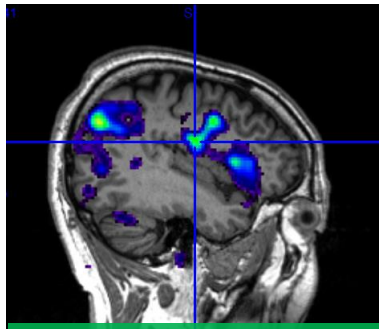

Extension



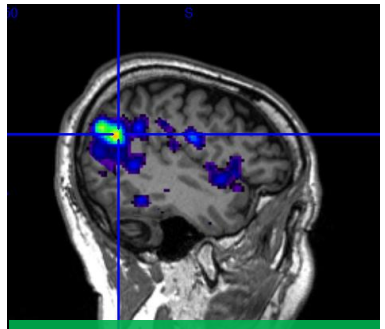


Mechanisms underlying tool embodiment
— Changes of the brain structure (VBM)—

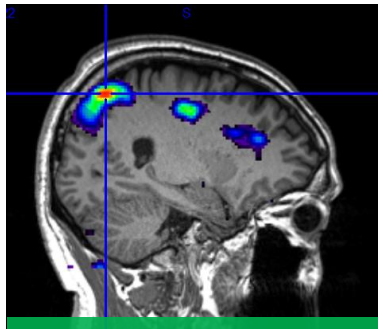




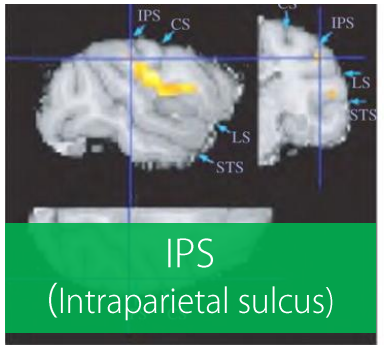
SII (Secondary somatosensory area)



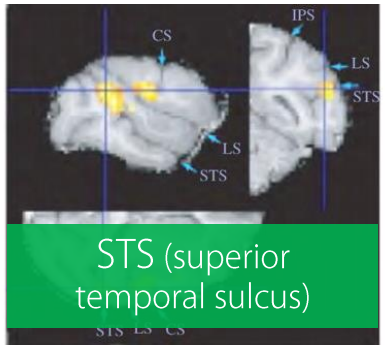
Area 39 (TPJ, Angular guyrus)



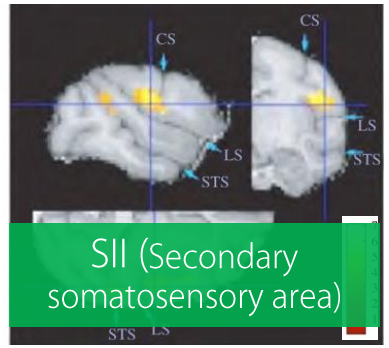
Area 7 (Sperior parietal lobe)



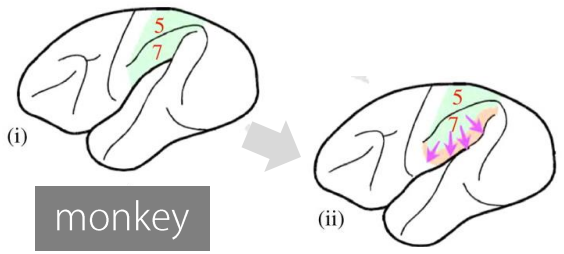
IPS (Intraparietal sulcus)



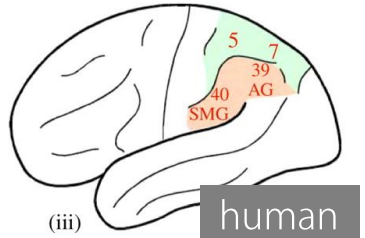
STS (superior temporal sulcus)



SII (Secondary somatosensory area)



monkey



human

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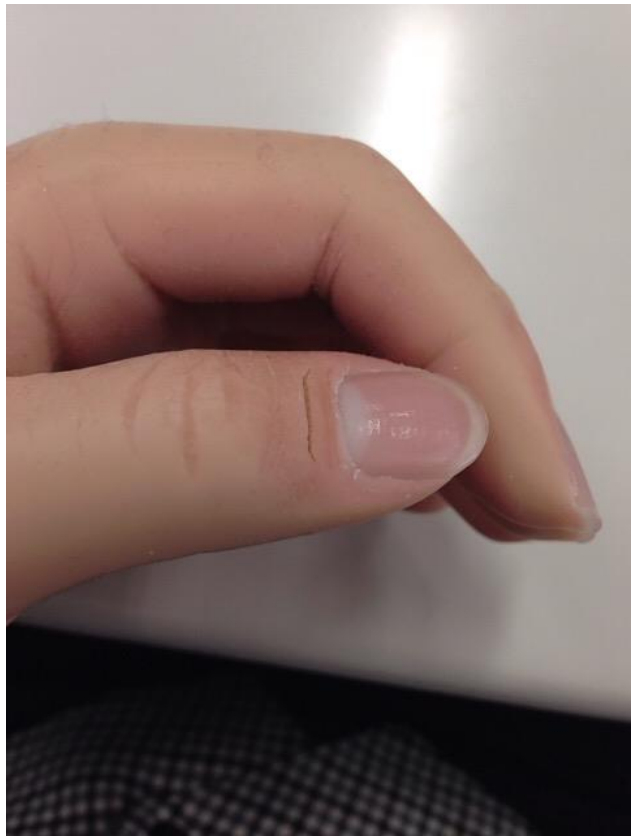
Importance of “reality”
for the preservation of body schema

Is the element of “reality” necessary?

① Use of realistic hand would have potential for the pain relief

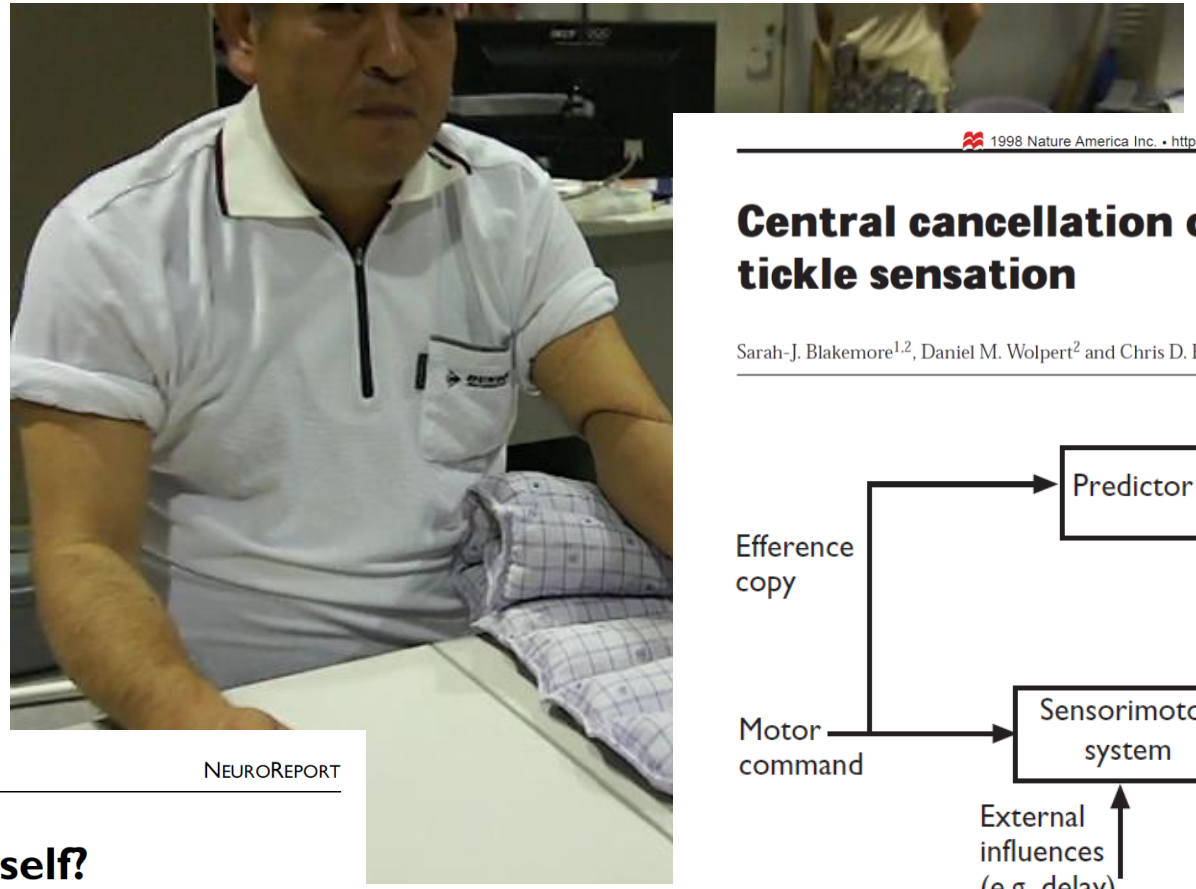
Embodied prosthesis gives a patient… Pain!



Phenomenological evidence for an embodiment of prosthesis into the body

Induction of tickle sensation!

An phenomenological evidence of embodiment of prosthesis



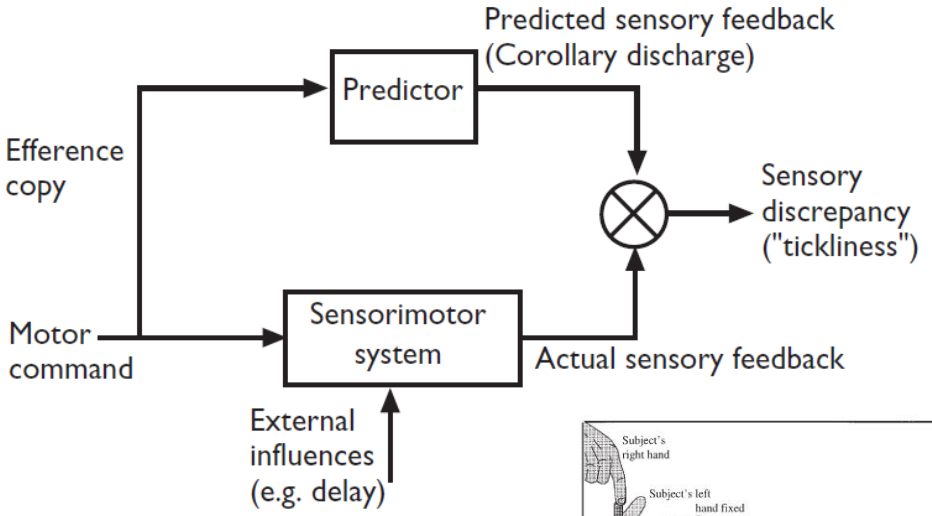
NEUROREPORT

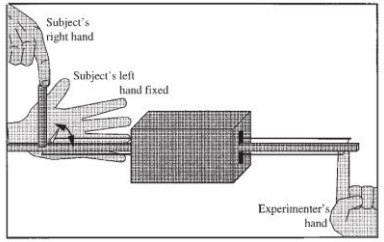
Why can't you tickle yourself?

Sarah-Jayne Blakemore,[CA] Daniel Wolpert and Chris Frith

Central cancellation of self-produced tickle sensation

Sarah-J. Blakemore[1,2], Daniel M. Wolpert[2] and Chris D. Frith[1]





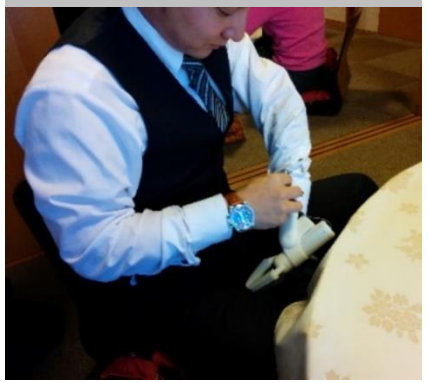
Bodily awareness ↑ ↑ ↑

Embodiment of a prosthesis

Phantom limb pain ↓ ↓ ↓

Ownership-driven embodiment

Daily prosthetic use



Agency-driven embodiment

Start to use
(start to change)

Sense of Ownership

the feeling that this body is my own

Sense of Agency

the feeling that I am the agent of an action