Embodiment of prosthesis into the body

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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 —

- 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...
  ① Missing part: inactivated
  ② Residual part: more activated

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

*Flor (Nat Review Neurosci 2006)*
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)

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

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

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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 quadratic function. Comparison of the peak value (B) and the slope (sharpness) of the quadratic function (C) of the quadratic function among three experimental conditions. The error bars indicate the standard deviation of the mean value. * Significant difference (p<0.05).

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

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

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Event (amputation)

Cortical reorganization
Which has relevance to Cause of injury, extent of pain, use/types of prosthesis, dominant hand or not, etc...

Individual differences

Use-dependent plasticity
As a result of rehabilitation or daily use of prosthesis

Normal level (Baseline)

Does the use of prosthesis contribute to preserve body schema after amputation?

Does the use of prosthesis contribute to preserve body schema after amputation?
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)
An interpretative phenomenological analysis of the embodiment of artificial limbs

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Abstract
Purpose: To gain an understanding of the embodied percep-
tion of artificial limbs in amputees.

Prosthesis as a part of body

Prosthesis as a tool

Recognition of prosthesis

Disability and Rehabilitation, 2004; 26(16): 963-973

RESEARCH PAPER

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

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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

**Recognition of prosthesis**
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 (ii, iii) 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 Qu hold et al. [21].
3-fingered functional prosthesis “Finch”
Mechanisms underlying tool embodiment — Changes of the brain structure (VBM) —

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].
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

Why can’t you tickle yourself?

Sarah-Jayne Blakemore, Daniel Wolpert and Chris Frith
Ownership-driven embodiment

Sense of Ownership
the feeling that this body is my own

Bodily awareness ↑↑↑
Embodiment of a prosthesis
Phantom limb pain ↓ ↓ ↓

Agency-driven embodiment

Start to use (start to change)

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

Daily prosthetic use