Bidirectional control of hand prosthesis for amputees

A new breakthrough with sensory feedback to the brain

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1

Cybathlon 2016 Zurich

2

Restoring sensations: a key issue

Problem

Amputees do not have **their hand & associated sensations**

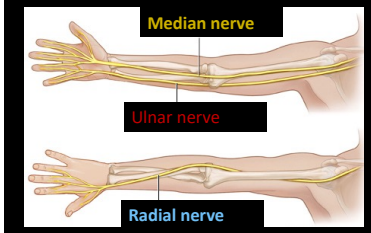
⇒ How to interface action / perception & afferent / efferent?

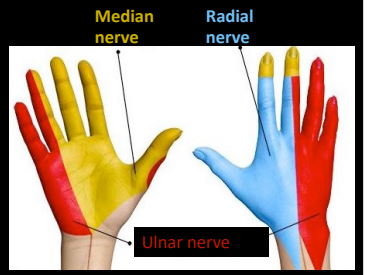
⇒ Patients' needs : highest torque, dexterity, safety, phatom pain relief

5

Towards a neural interface

- Mechanical feedbacks are quite poor:
  - Transmodality
  - Very few discremination levels
- Sensory nerve should be much better:
  - Natural sensation
  - Different types of sensations
  - More discremination levels

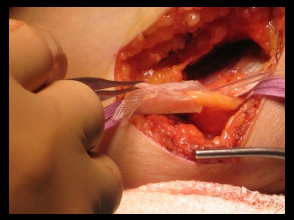


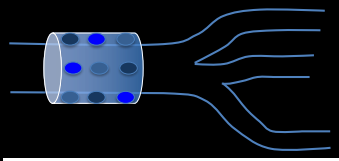


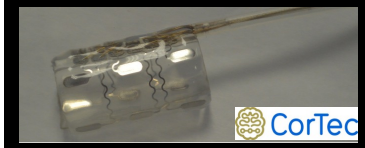
6

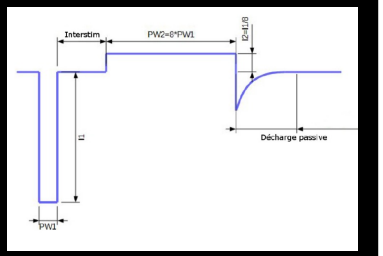
Multiple sensory feedback

- Selectivity









Maciejasz et al., MBEC, 2017

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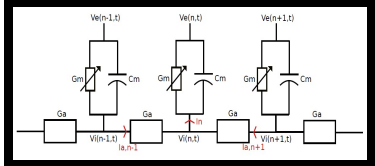
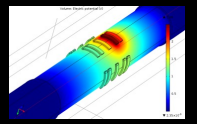
7

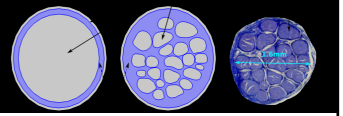
Biophysics

Dali et al. JNE, 2018





$$\nabla \sigma \nabla V = 0$$



$$I_{stim}^{th}(\mathrm{PW}) = \frac{j^{th}(\mathrm{PW})}{\max_n\{\mathbf{R} * \Phi(\mathrm{PW})\mathbf{D}\}} \cdot \frac{\pi dl}{G_a}$$

$$\begin{pmatrix} V_e(1) \\ V_e(2) \\ \vdots \\ V_e(n_{fr}) \end{pmatrix} = \begin{pmatrix} R_1(1) & R_2(1) & \cdots & R_{n_c}(1) \\ R_1(2) & \ddots & & \vdots \\ \vdots & & \ddots & R_{n_c}(n_{fr}-1) \\ R_1(n_{fr}) & \cdots & \cdots & R_{n_c}(n_{fr}) \end{pmatrix} \begin{pmatrix} I_1 \\ I_2 \\ \vdots \\ I_{nc} \end{pmatrix}$$

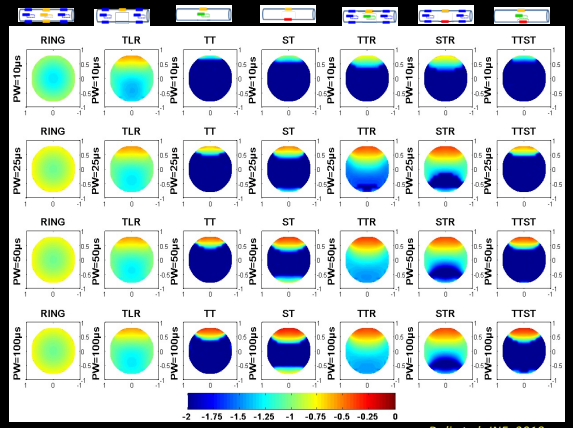
$$V_e = \mathbf{R} \times I = \mathbf{R} \times \mathbf{D} \times I_{stim}$$

10/11/22

- 8

8

Multicriteria evaluation



Dali et al. JNE, 2018

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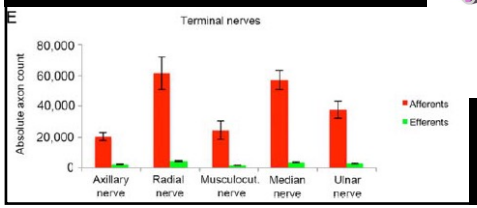
- 9

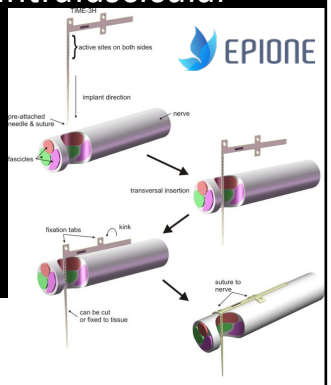
9

Getting into the nerve, intrafascicular

Afferent are about 10 times more numerous than efferent

Gesslbauer et al., Annals of Neurology, 2017





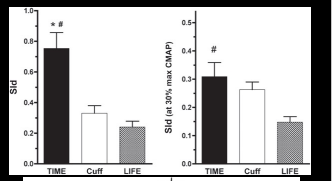
Boretius et al. Biosensors & Bioelectronics, 2010

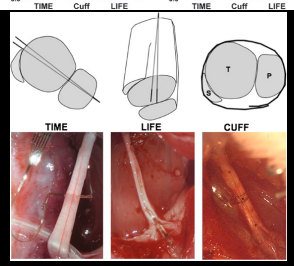
- 10

10

Electrode's comparison

	12 cuff tripolar	TIME 10	LIFE 8
Intra fascicular selectivity	-	+	+
Inter fascicular selectivity	+	+	-
Threshold	-	+	+
Impedance	+	-	-
Placement	+	-	--
Stability	>15y	?	?



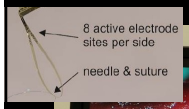


Badia et al. JNE, 2011

11

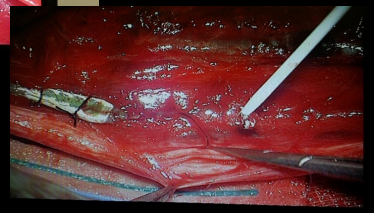
Eliciting selective sensations

EPIONE



Step 1: Find the ulnar and median nerves,
Step 2: Insulate the nerve,
Step 3: Neurolysis of the nerve,

Step 4: Implantation of 4 electrodes TIME-4H,
Step 5: Test the impedances
Step 6: Stitching of the electrode.

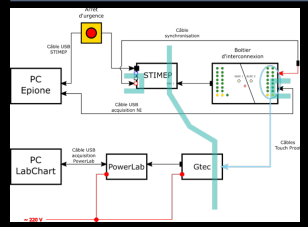


12

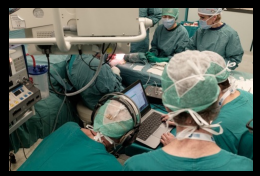
EPIONE

Setup

Swiwwmedic/DK/ IT/Seerbia
2+3 patients

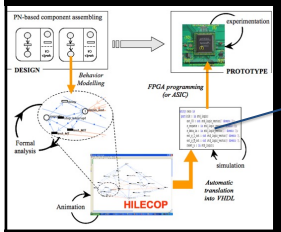


➔ **Stimulation parameters**:
- Biphasic pulse, 40µA and 300µs
- 100µs high impedance between phases.
- **56 contacts!**

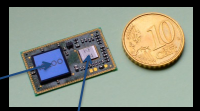


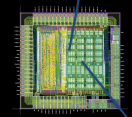
13

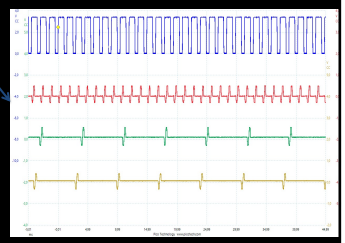
Specific technology



Andreu et al. JNE, 2009







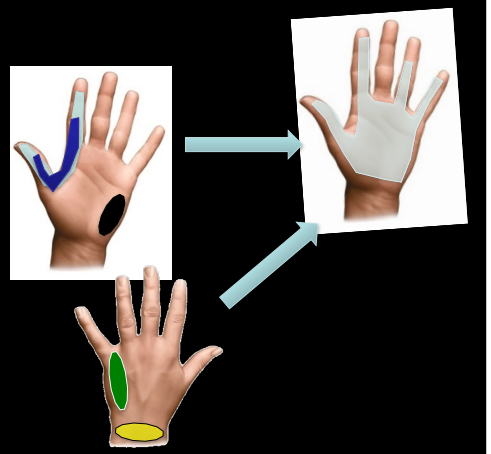
- Complex but safe
- Adapted to theoretical foundings
- Patient specific

14

TIME sensation feedback mapping

- Simultaneous multicontact stimulation was achieved

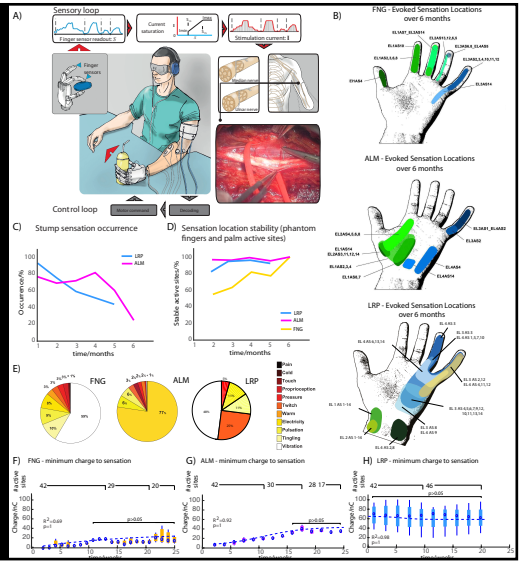
150 us, 460 uA split in:
t2l2=12.5%-8.6 nC
t2l5=31.25%-21 nC
t2r7=18.75%-13 nC
t3r4=18.75-13 nC
t3r5=18.75-13 nC



Raspopovic et al. Sci.Trans.Med., 2014

15

Petrini et al., Annals of Neurology 2018



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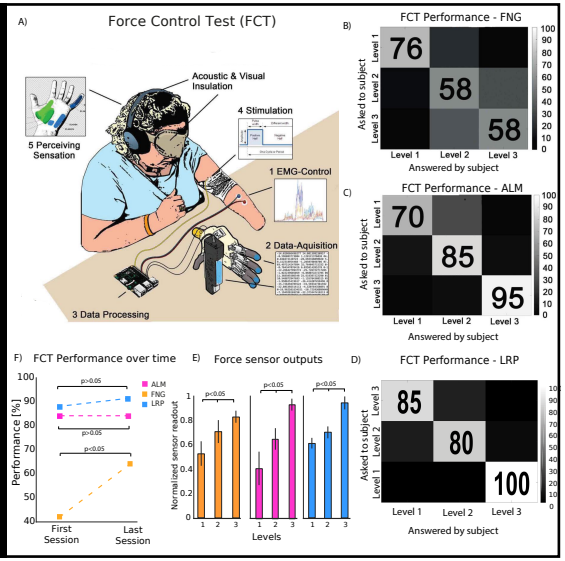
16

Petrini et al., Annals of Neurology 2018



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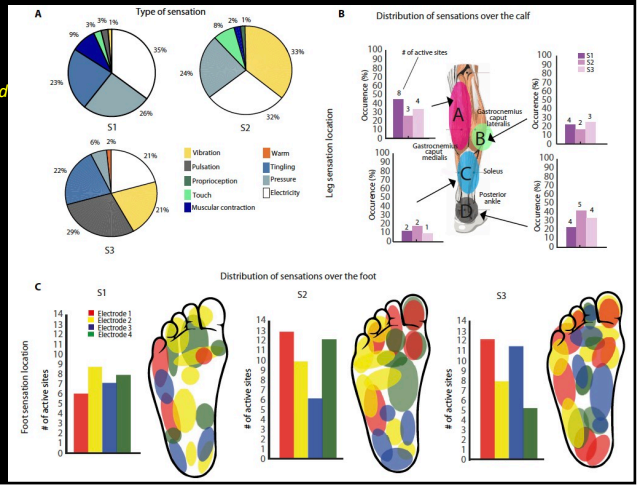
17

TIME EPIONE feedback

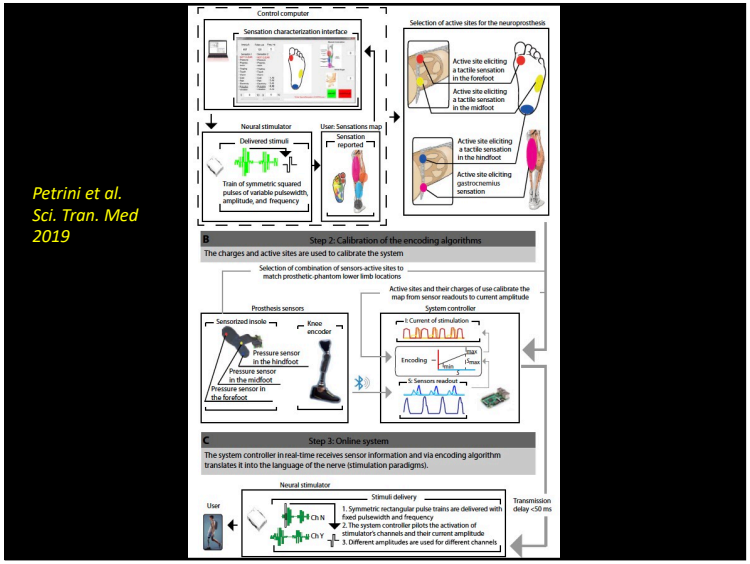
18

Impressive sensation repertoire

Petrini et al. Sci. Tran. Med 2019



19

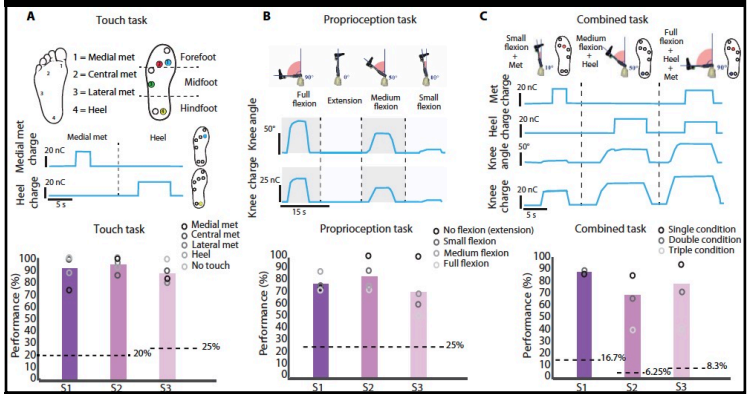


Petrini et al. Sci. Tran. Med 2019

20

A high level of pattern recognition

Petrini et al., Sci. Tran. Med.,2019

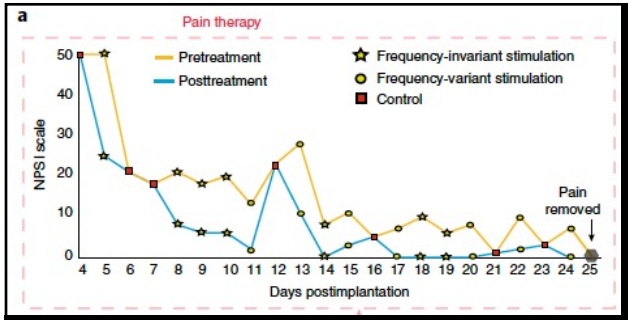


21

Lower limb results

Petrini et al., Nature Med, 2019

22



Petrini et al., Nature Med, 2019

The acute (transient) reduction of pain could be explained by the gate theory (the inhibition exerted by large afferents on the nociceptive spinothalamic pathways)

The gradual reduction of pain until complete disappearance, may be due to sensory feedback, which triggered beneficial neuroplastic changes in the brain

23

Conclusion

- Complex control vs. simple activation is less effective without rich feedback
- Rich feedback can be achieved only with direct neural interface eliciting real sensations of a phantom limb!
- Multidisciplinary research from theory to clinical trial *(real time processing, multichannel neural coding, biophysics, neurophysiology, ASIC, formal SW dev.)*
- Fundamental Neurosciences paradigms can be exploreed (*plasticity, neural coding, neuromodulation*)

24

Thanks

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25