FRIEDRICH-ALEXANDER
UNIVERSITÄT
ERLANGEN-NÜRNBERG
FACULTY OF ENGINEERING

Intent detection and somatosensory feedback

#10: *Somatosensory Feedback*

Claudio CASTELLINI, Sabine THÜRAUF

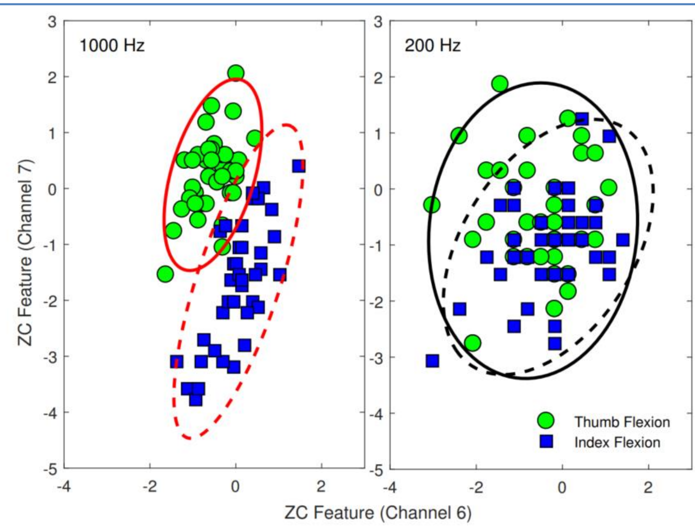


Figure 2. Differences in EMG patterns between using: (**left**) a 1000 Hz sampling rate; and (**right**) a 200 Hz sampling rate. ZC features are extracted from two different EMG channels (6 and 7) during thumb flexion (green circle markers and solid lines) and index flexion (blue square markers and dashed lines). Samples are from Subject 1 of Database 3.

EMG patterns related to two actions. Reproduced from Angkoon Phinyomark, Rami N. Khushaba and Erik Scheme, *Feature Extraction and Selection for Myoelectric Control Based on Wearable EMG Sensors*, MDPI Sensors 2018, 18, 1615

The *rubber hand illusion.* See Botvinick M, Cohen J., *Rubber hands 'feel' touch that eyes see.* Nature. 1998 Feb 19;391(6669):756. doi: 10.1038/35784. PMID: 9486643.

Lecture #10:

Somatosensory Feedback

- somatosensory feedback: what, why, how?
- vibrotactile feedback
- electro-cutaneous feedback (ECS)

Somatosensory feedback

- Recall lecture #1:

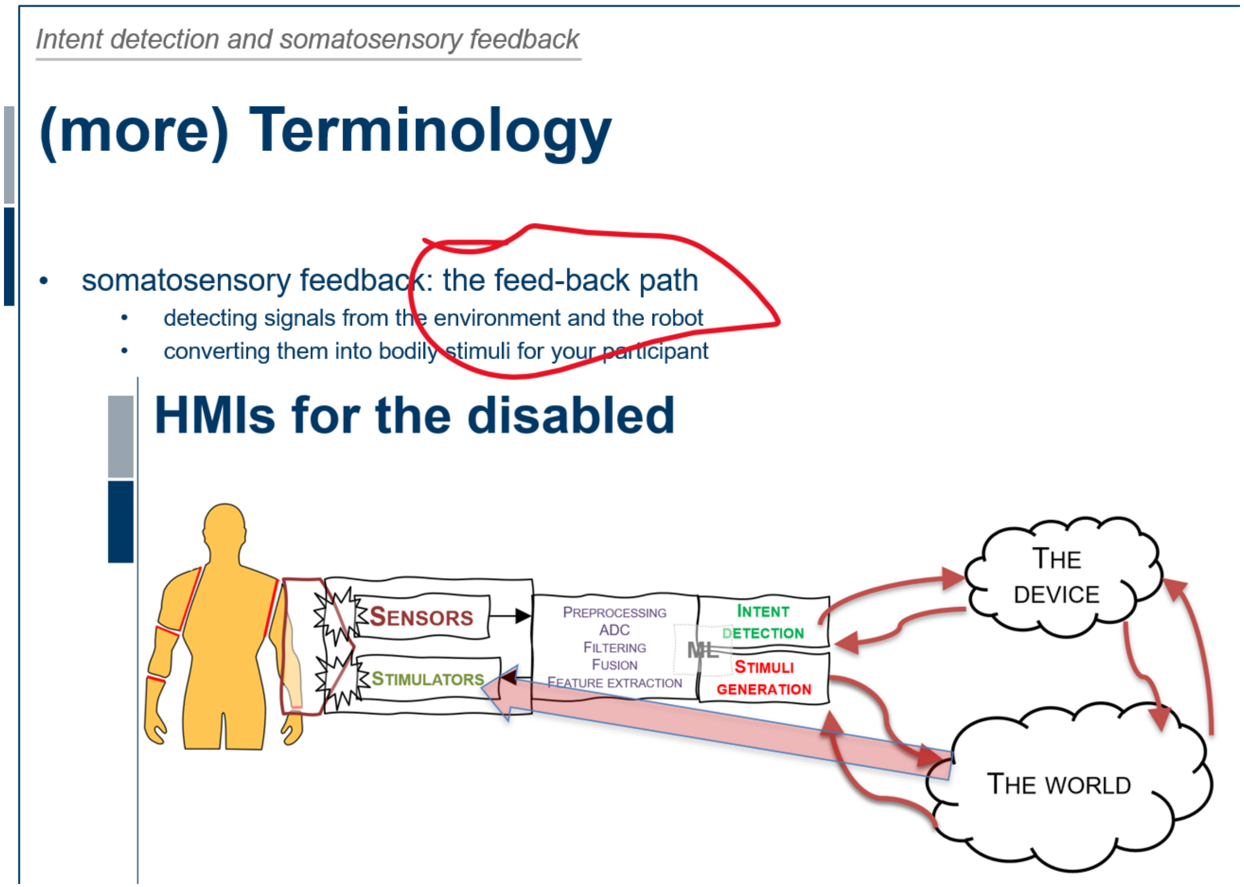
Intent detection and somatosensory feedback

(more) Terminology

- intent detection: the feed-forward path
  - detecting signals out of the participant‘s body
  - converting them into control commands for your robot
- somatosensory feedback
  - detecting signals from the environment and the robot
  - converting them into bodily stimuli for your participant
- bidirectional HMI: an HMI putting together these two paths.
  - it must be unobtrusive
  - it must work in real-time
  - it must be reliable and dexterous
  - and it must be low-power

Somatosensory feedback

- Recall lecture #1:



Somatosensory feedback

- visual and audio feedback are already present:
    - users can *see* what their devices do (although not always! and sometimes they don't *want* to…)
    - users can hear what their devices do (noise associated to motors)
- what about providing *direct stimuli* on the body
    - in order to simulate proprioception and touch?
- really, there already is something the like:
    - the user naturally perceives the weight / resistance of any prosthesis or reha device; plus,
    - in some cases we get direct force-feedback "for free" – body-powered prostheses!

Body-powered prostheses

- pros:
  - cheap / robust / simple (you can service them yourself!)
  - easy to don & doff
  - configurable for voluntary opening / closing
  - extremely reliable
  - provide force somatosensory feedback!

- cons:
  - one DoF only

- essentially useful for trans-radials only
  - custom solutions for trans-humerals have 2 DoFs coupled

Somatosensory feedback

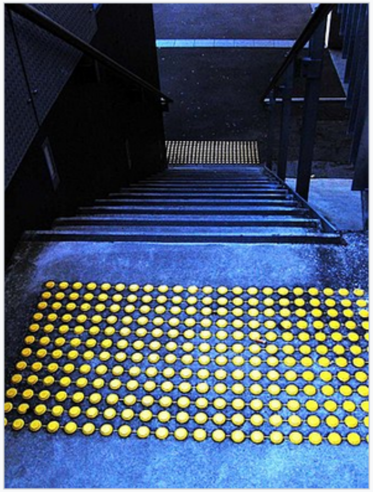
Somatosensory feedback

Somatosensory system

From Wikipedia, the free encyclopedia

The **somatosensory system** is the network of neural structures in the brain and body that produce the perception of touch, as well as temperature, body position (proprioception), and pain.[1] It is a subset of the sensory nervous system, which also represents visual, auditory, olfactory, and gustatory stimuli. Somatosensation begins when mechano- and thermosensitive structures in the skin or internal organs sense physical stimuli such as pressure on the skin (see mechanotransduction, nociception). Activation of these structures, or receptors, leads to activation of peripheral sensory neurons that convey signals to the spinal cord as patterns of action potentials. Sensory information is then processed locally in the spinal cord to drive reflexes, and is also conveyed to the brain for conscious perception of touch and proprioception. Note, somatosensory information from the face and head enters the brain through peripheral sensory neurons in the cranial nerves, such as the trigeminal nerve.

The neural pathways that go to the brain are structured such that information about the location of the physical stimulus is preserved. In this way, neighboring neurons in the somatosensory cerebral cortex in the brain represent nearby locations on the skin or in the body, creating a map, also called a homunculus.


Touch is a crucial means of receiving information. This photo shows tactile markings identifying stairs for visually impaired people.

Contents [hide]

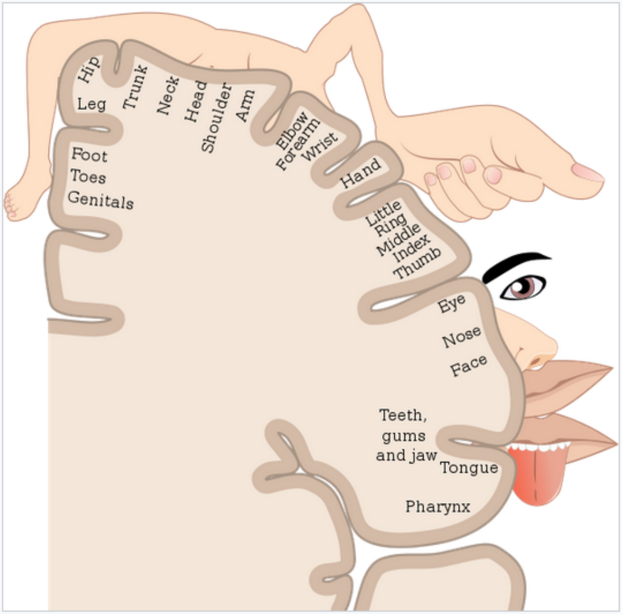
Somatosensory feedback

Cortical homunculus

From Wikipedia, the free encyclopedia

A **cortical homunculus** is a distorted representation of the human body, based on a neurological "map" of the areas and proportions of the human brain dedicated to processing motor functions, or sensory functions, for different parts of the body. The word *homunculus* is Latin for "little man"[1] or "miniature human",[2] and was a term used in alchemy and folklore long before scientific literature began using it. A cortical homunculus, or "cortex man," illustrates the concept of a representation of the body lying within the brain. Nerve fibres—conducting somatosensory information from all over the body—terminate in various areas of the parietal lobe in the cerebral cortex, forming a representational map of the body.

Contents [hide]

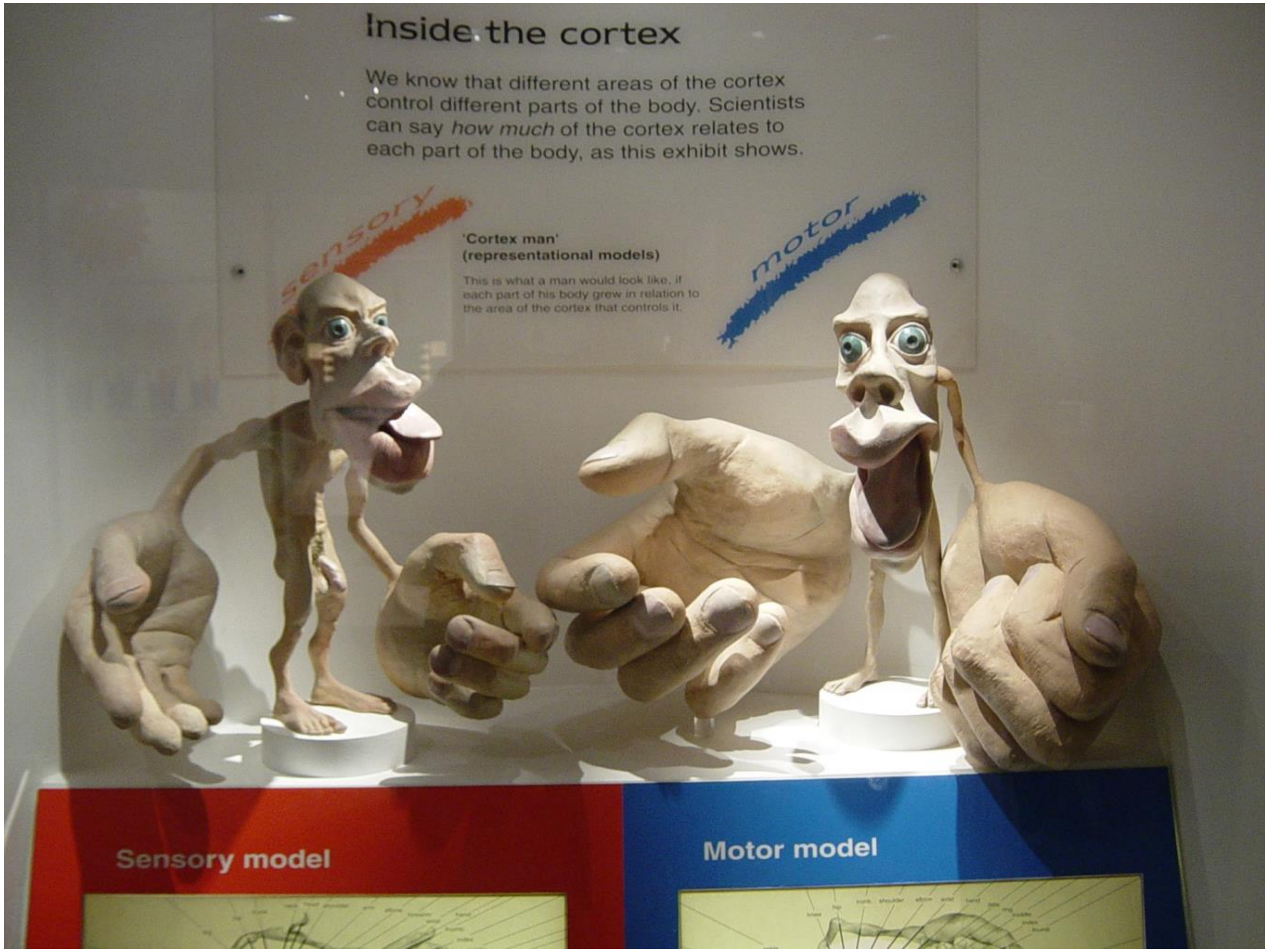


A 2-D cortical *sensory* homunculus created by OpenStax College - Anatomy & Physiology, Connexions Website https://openstax.org/books/anatomy-and-physiology/pages/1-introduction

Types [edit]

A **motor homunculus** represents a map of brain areas dedicated to *motor* processing for different anatomical divisions of the body. The primary motor cortex is located in the precentral gyrus, and

Somatosensory feedback

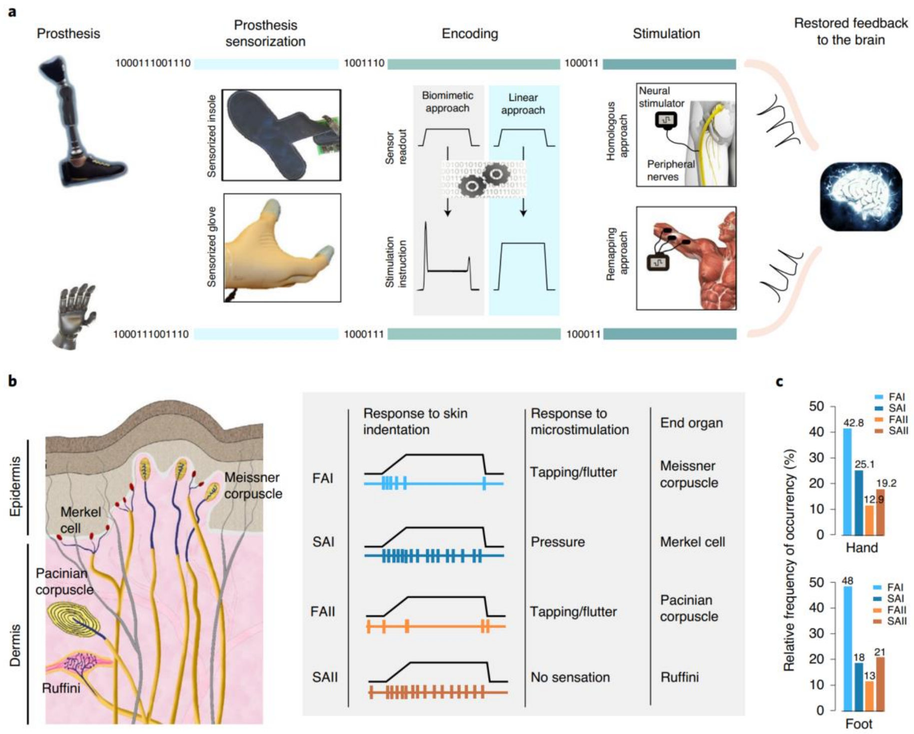


3-D sensory and motor homunculus models at the [Natural History Museum, London]

Raspopovic, S., Valle, G. & Petrini, F.M. Sensory feedback for limb prostheses in amputees. *Nat. Mater.* **20,** 925–939 (2021)

Somatosensory feedback

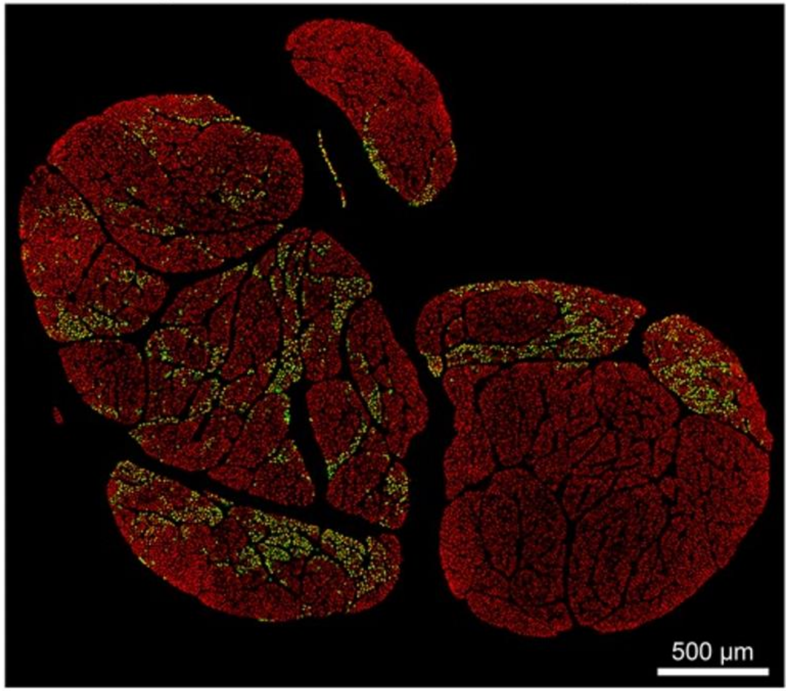
- there are *many different* receptors in the limbs…

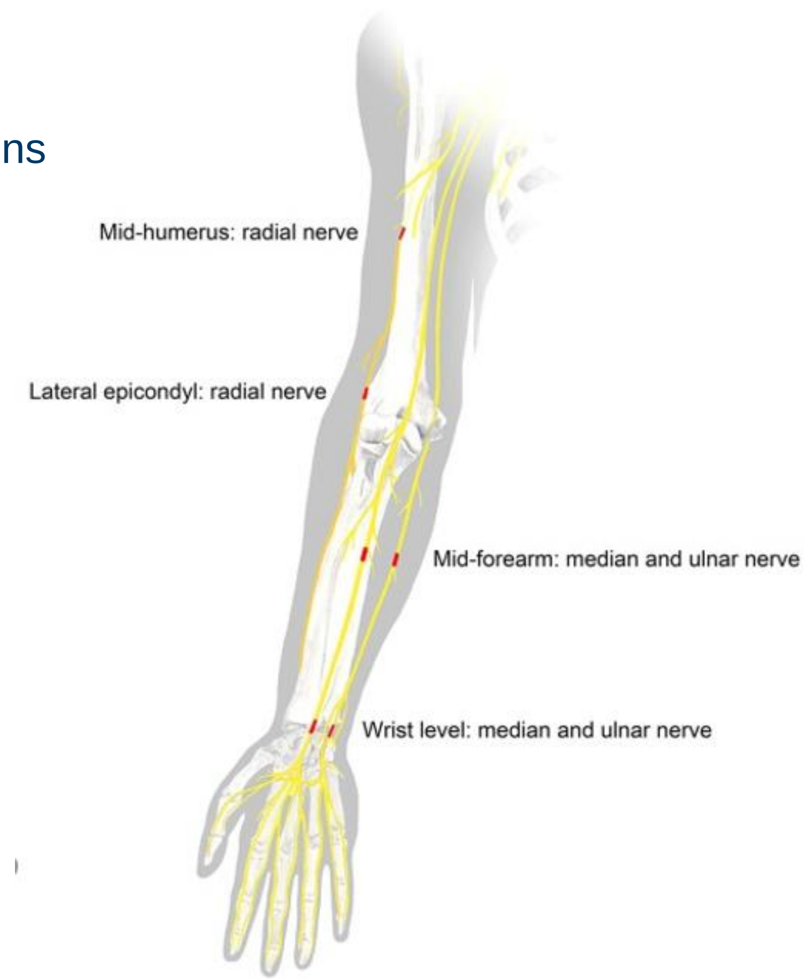


Bernhard Gesslbauer, Laura A. Hruby, Aidan D. Roche, Dario Farina, Roland Blumer and Oskar C. Aszmann., “Axonal components of nerves innervating the human arm,” Ann. Neurol., vol. 82, no. 3, pp. 396–408, Sep. 2017.

Somatosensory feedback

- *…and actually, many* more afferent (sensory) axons then efferent (motor) ones in the forearm!





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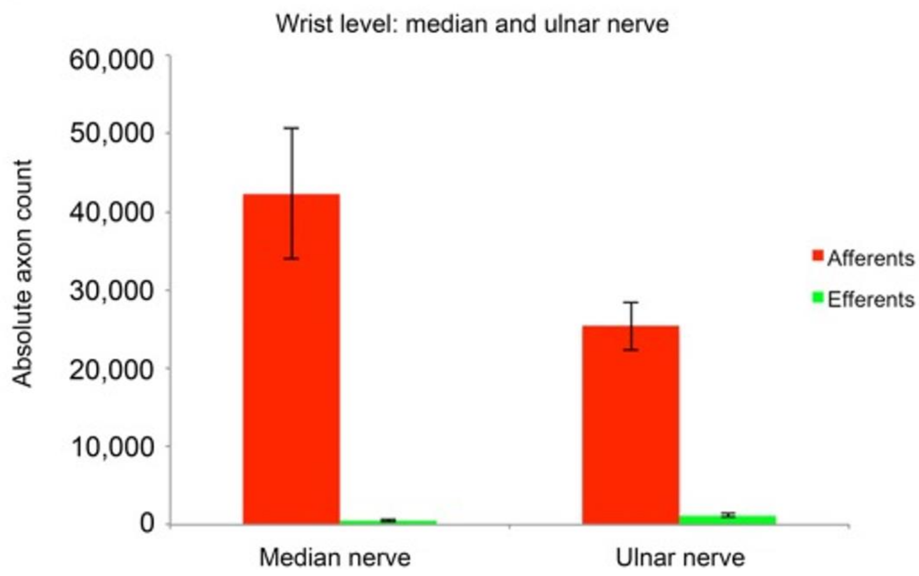

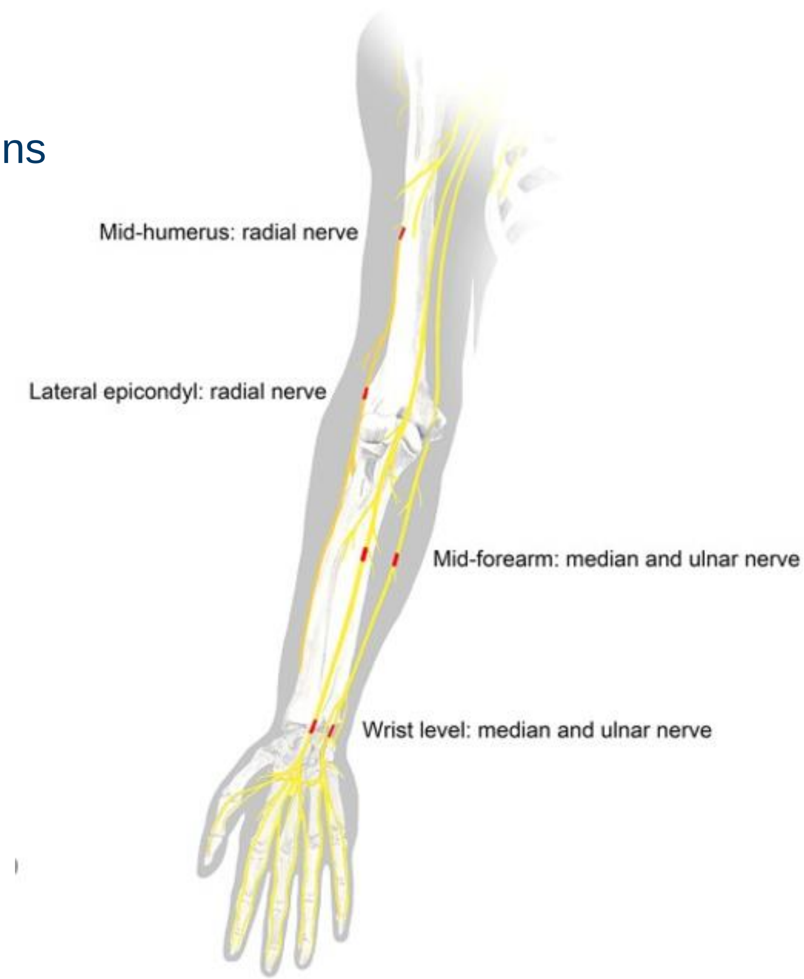

Somatosensory feedback

- lack of somatosensory feedback makes motion essentially impossible

(movie courtesy of Tecnalia)

Botvinick M, Cohen J., *Rubber hands 'feel' touch that eyes see.* Nature. 1998 Feb 19;391(6669):756.

Somatosensory feedback

- fake somatosensory feedback will trick you into anything

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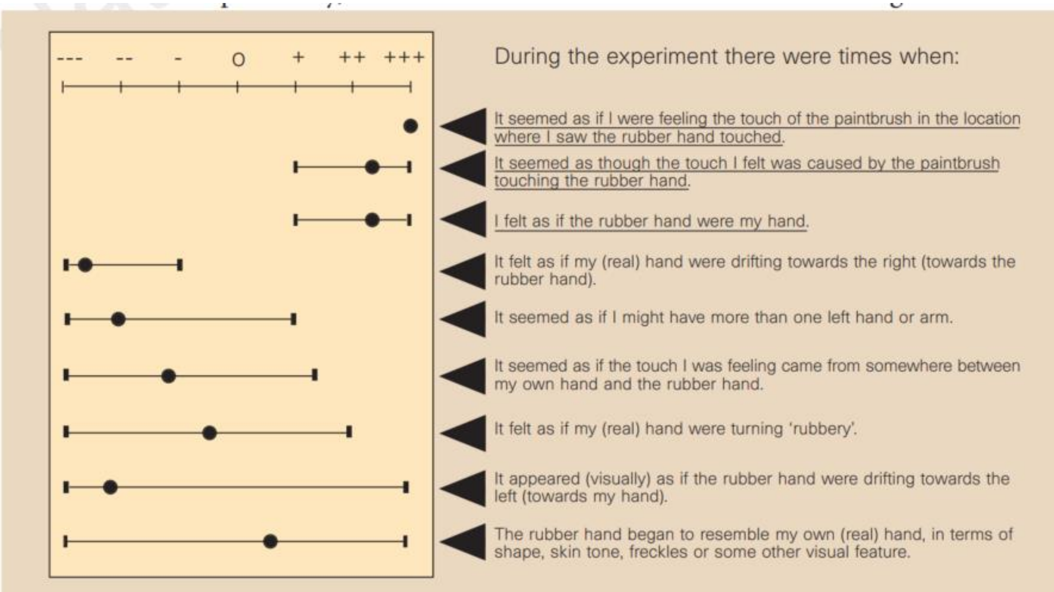


Figure 1 Questionnaire results. The questionnaire included the nine statements shown, presented in a random order. Statements describing the predicted phenomena are underlined. Subjects indicated their response on a seven-step visual-analogue scale ranging from 'agree strongly' (+++) to 'disagree strongly' (---). Points indicate mean responses. Bars indicate response range. The questions underlined showed a statistically significant tendency to evoke affirmative responses ($P<0.002$ for underlined questions, $P<0.018$ after correcting for multiple comparisons).

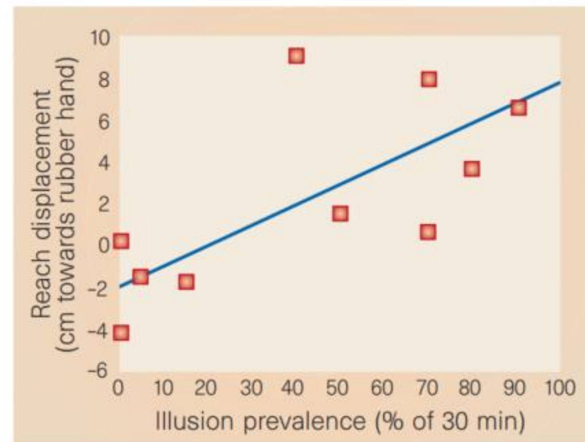


Figure 2 Results of reaching experiment. The *x*-axis indicates the percentage of the 30-min viewing period during which the ownership illusion was experienced. The *y*-axis indicates displacement of the three reaches made after the viewing period from the three made before, calculated as the difference between the means in the two groups. The data is fitted with a least-squares regression line ($y=0.09x-1.4$, r^2 0.47, $p<0.03$).

Sensory substitution

- what is it useful for?

Sensory substitution

From Wikipedia, the free encyclopedia

Sensory substitution is a change of the characteristics of one sensory modality into stimuli of another sensory modality.

A sensory substitution system consists of three parts: a sensor, a coupling system, and a stimulator. The sensor records stimuli and gives them to a coupling system which interprets these signals and transmits them to a stimulator. In case the sensor obtains signals of a kind not originally available to the bearer it is a case of sensory augmentation. Sensory substitution concerns human perception and the plasticity of the human brain; and therefore, allows us to study these aspects of neuroscience more through neuroimaging.

Sensory substitution systems may help people by restoring their ability to perceive certain defective sensory modality by using sensory information from a functioning sensory modality.

History [edit]

The idea of sensory substitution was introduced in the '80s by Paul Bach-y-Rita as a means of using one sensory modality, mainly taction, to gain environmental information to be used by another sensory modality, mainly vision.[1][2] Thereafter, the entire field was discussed by Chaim-Meyer Scheff in "Experimental model for the study of changes in the organization of human sensory information processing through the design and testing of non-invasive prosthetic devices for sensory impaired people".[3] The first sensory substitution system was developed by Bach-y-Rita et al. as a means of brain plasticity in congenitally blind individuals.[4] After this historic invention, sensory substitution has been the basis of many studies investigating perceptive and cognitive neuroscience. Sensory substitution is often employed to investigate predictions of the embodied cognition framework. Within the theoretical framework specifically the concept of sensorimotor contingencies [5] is investigated utilizing sensory substitution. Furthermore, sensory substitution has contributed to the study of brain function, human cognition and rehabilitation.[6]

Intent detection and somatosensory feedback

Sensor: This part of the system detects stimuli from the environment.

For instance, a camera might act as the sensor by capturing visual information.

Coupling System: This system interprets the signals received by the sensor

and translates them into a different form that another sense can perceive.

In the camera example, the visual information would be converted into sound or tactile signals.

Stimulator: This component delivers the converted signals to the user.

If the visual information was turned into sound, the stimulator would be a speaker or headphones.

How it works – sound to vibrations

External Sounds: The system begins by capturing sounds from the environment using a microphone.

Microphone: The microphone picks up these sounds and converts them into electrical signals.

Microcontroller: These electrical signals are then processed by a microcontroller, which is a small computer that interprets the sounds and converts them into patterns of vibrations.

Array of Vibration Motors: The processed signals are sent to an array of small vibrational motors embedded in the vest. These motors can create different vibration patterns on the wearer's skin.

Indenting - **This means gently pressing into the skin to create a feeling**

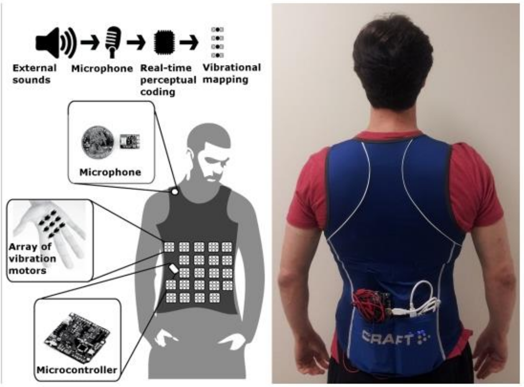
Bach-y-Rita P. Tactile sensory substitution studies. Ann N Y Acad Sci. 2004 May;1013:83-91.

https://eagleman.com/science/sensory-substitution

Sensory substitution

- what is it useful for?

Yes and yes. *Sensory substitution* is a non-invasive technique for circumventing the loss of one sense by feeding its information through another channel. We leveraged this technique to develop a non-invasive, low-cost method to allow people with deafness or hearing impairments to perceive auditory information via small vibrations on their skin.



The original form factor in my laboratory was a vest with vibratory motors stitched into it. It captured sounds and converted them to patterns of vibration on the skin. We had great results in the laboratory and scientific community, which led to my presentation at TED:

ABSTRACT: Forty years ago a project to explore late brain plasticity was initiated that was to lead into a broad area of sensory substitution studies. The questions at that time were: Can a person who has never seen learn to see as an adult? Is the brain sufficiently plastic to develop an entirely new sensory system? The short answer to both questions is *yes*, first clearly demonstrated in 1969 (Bach-y-Rita *et al.*, 1969). To reach that conclusion, it was first necessary to find a way to get visual information to the brain. That took many years and is still the most challenging aspect of the research and the development of practical sensory substitution and augmentation systems. The sensor array is not a problem: a TV camera for blind persons; an accelerometer for persons with vestibular loss; a microphone for deaf persons. These are common and fully developed devices. The problem is the brain–machine interface (BMI). In this short report, only two substitution systems are discussed, vision and vestibular substitution.

Somatosensory feedback

- essentially two ways of doing sensory substitution:
  - **mechanical (vibrotactile, indenting) – use vibrations/press on the skin to create patterns on the skin**
  - electrical (small currents through the skin) – use current to create patterns

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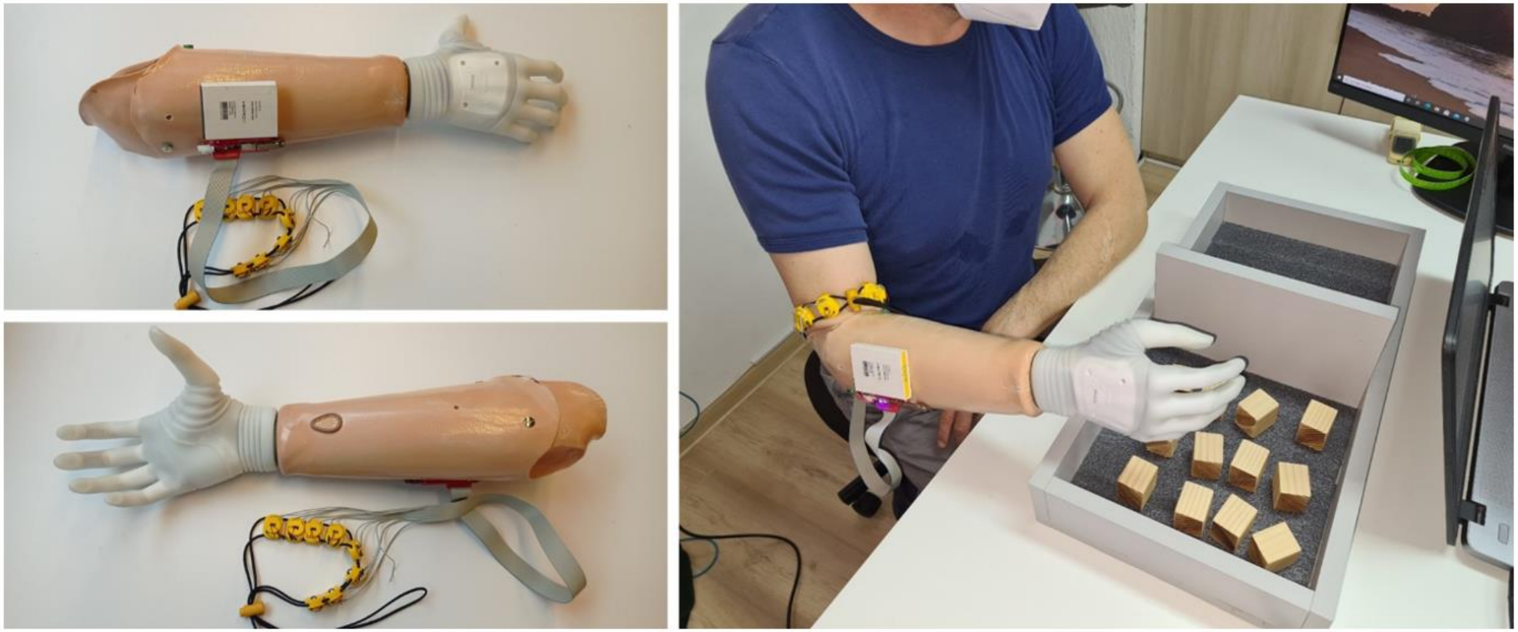


Somatosensory feedback

Raveh, Portnoy, Friedman, "Adding vibrotactile feedback to a myoelectric-controlled hand improves performance when online visual feedback is disturbed.," *Hum. Mov. Sci.*, 2018.

- does it work? does it improve control? If no visual feedback, then we rely on vibrotactile one

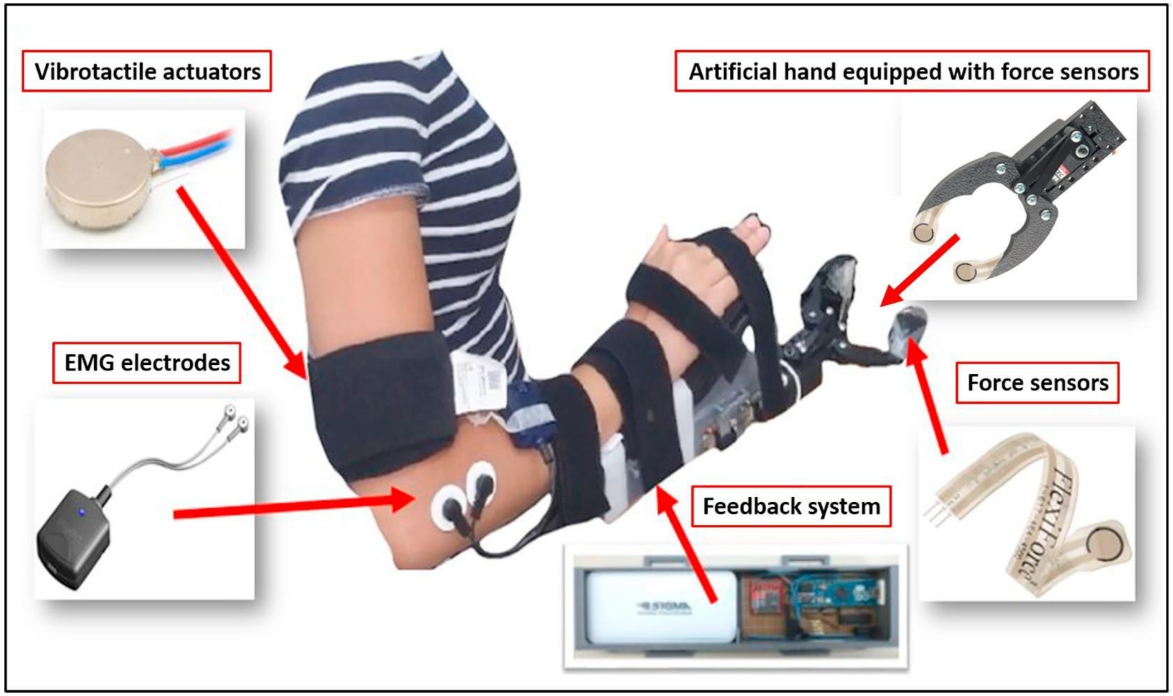
A B S T R A C T

We investigated whether adding vibrotactile feedback to a myoelectric-controlled hand, when visual feedback is disturbed, can improve performance during a functional test. For this purpose, able-bodied subjects, activating a myoelectric-controlled hand attached to their right hand performed the modified Box & Blocks test, grasping and manipulating wooden blocks over a partition. This was performed in 3 conditions, using a repeated-measures design: in full light, in a dark room where visual feedback was disturbed and no auditory feedback – one time with the addition of tactile feedback provided during object grasping and manipulation, and one time without any tactile feedback. The average time needed to transfer one block was measured, and an infrared camera was used to give information on the number of grasping errors during performance of the test. Our results show that when vibrotactile feedback was provided, performance time was reduced significantly, compared with when no vibrotactile feedback was available. Furthermore, the accuracy of grasping and manipulation was improved, reflected by significantly fewer errors during test performance. In conclusion, adding vibrotactile feedback to a myoelectric-controlled hand has positive effects on functional performance when visual feedback is disturbed. This may have applications to current myoelectric-controlled hands, as adding tactile feedback may help prosthesis users to improve their functional ability during daily life activities in different environments, particularly when limited visual feedback is available or desirable.

Somatosensory feedback

Raveh, Portnoy, Friedman, “Adding vibrotactile feedback to a myoelectric-controlled hand improves performance when online visual feedback is disturbed.,” *Hum. Mov. Sci.*, 2018.

- does it work? does it improve control? Force converted to vibrations



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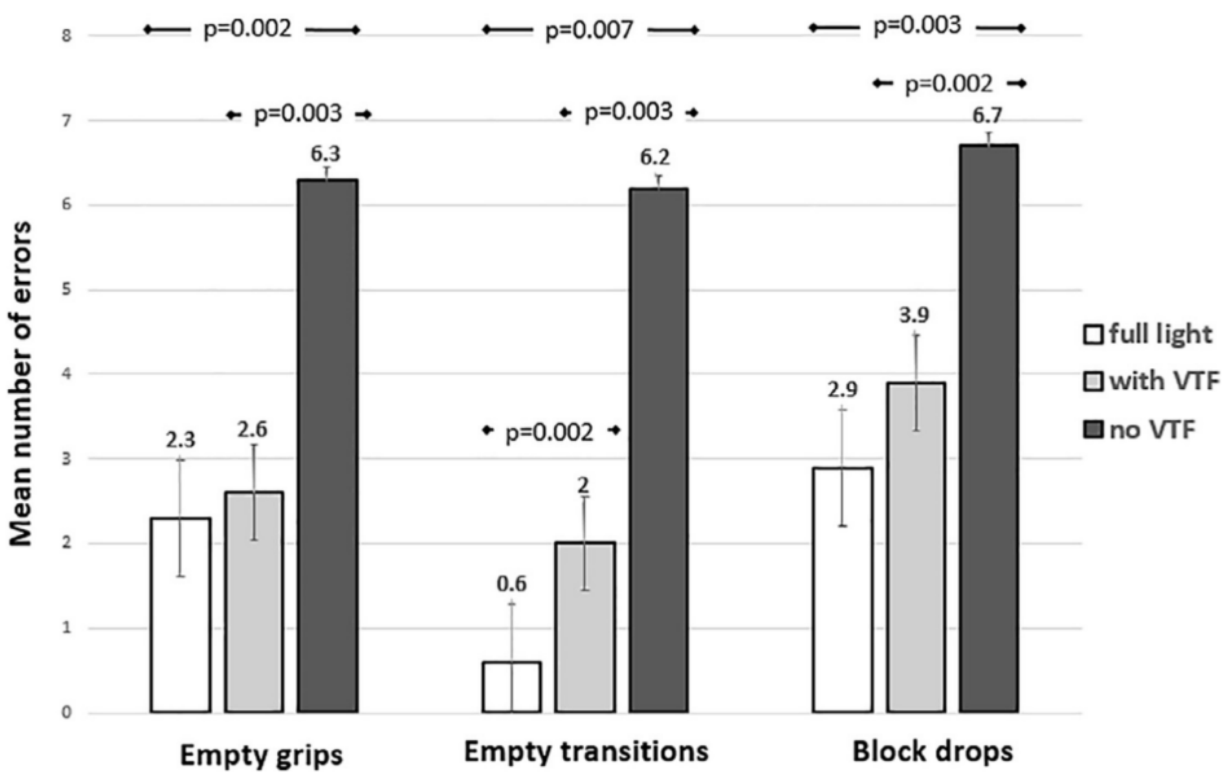
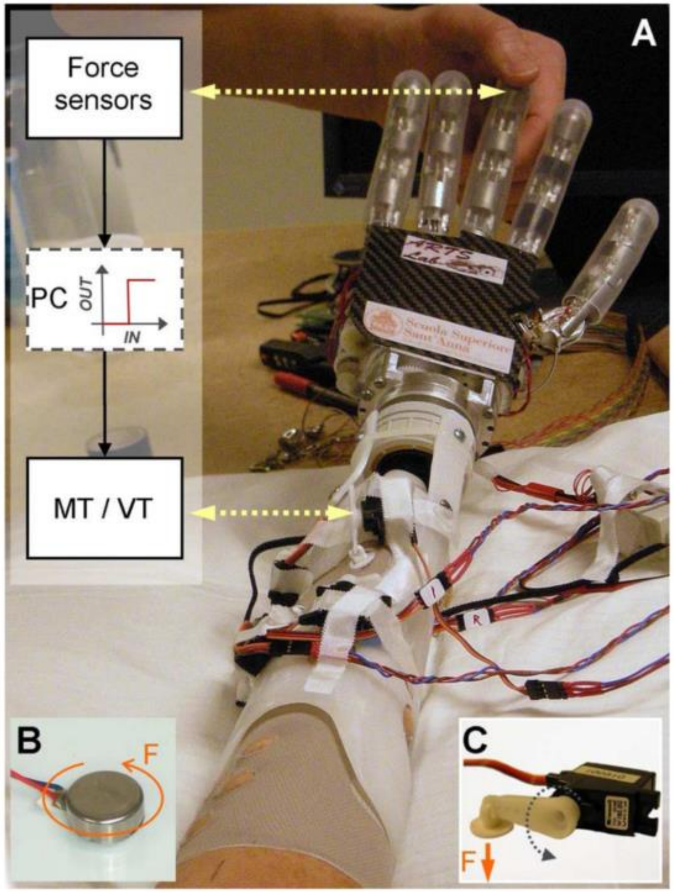


C. Antfolk et al., "Artificial Redirection of Sensation From Prosthetic Fingers to the Phantom Hand Map on Transradial Amputees: Vibrotactile Versus Mechanotactile Sensory Feedback," in IEEE Transactions on Neural Systems and Rehabilitation Engineering, 2013

Somatosensory feedback

- does it work? does it improve control? Intent and vibro

Abstract—**This work assesses the ability of transradial amputees to discriminate multi-site tactile stimuli in sensory discrimination tasks. It compares different sensory feedback modalities using an artificial hand prosthesis in: 1) a modality matched paradigm where pressure recorded on the five fingertips of the hand was fed back as pressure stimulation on five target points on the residual limb; and 2) a modality mismatched paradigm where the pressures were transformed into mechanical vibrations and fed back. Eight transradial amputees took part in the study and were divided in two groups based on the integrity of their phantom map; group A had a complete phantom map on the residual limb whereas group B had an incomplete or nonexisting map. The ability in localizing stimuli was compared with that of 10 healthy subjects using the vibration feedback and 11 healthy subjects using the pressure feedback (in a previous study), on their forearms, in similar experiments. Results demonstrate that pressure stimulation surpassed vibrotactile stimulation in multi-site sensory feedback discrimination. Furthermore, we demonstrate that subjects with a detailed phantom map had the best discrimination performance and even surpassed healthy participants for both feedback paradigms whereas group B had the worst performance overall. Finally, we show that placement of feedback devices on a complete phantom map improves multi-site sensory feedback discrimination, independently of the feedback modality.**



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Somatosensory feedback

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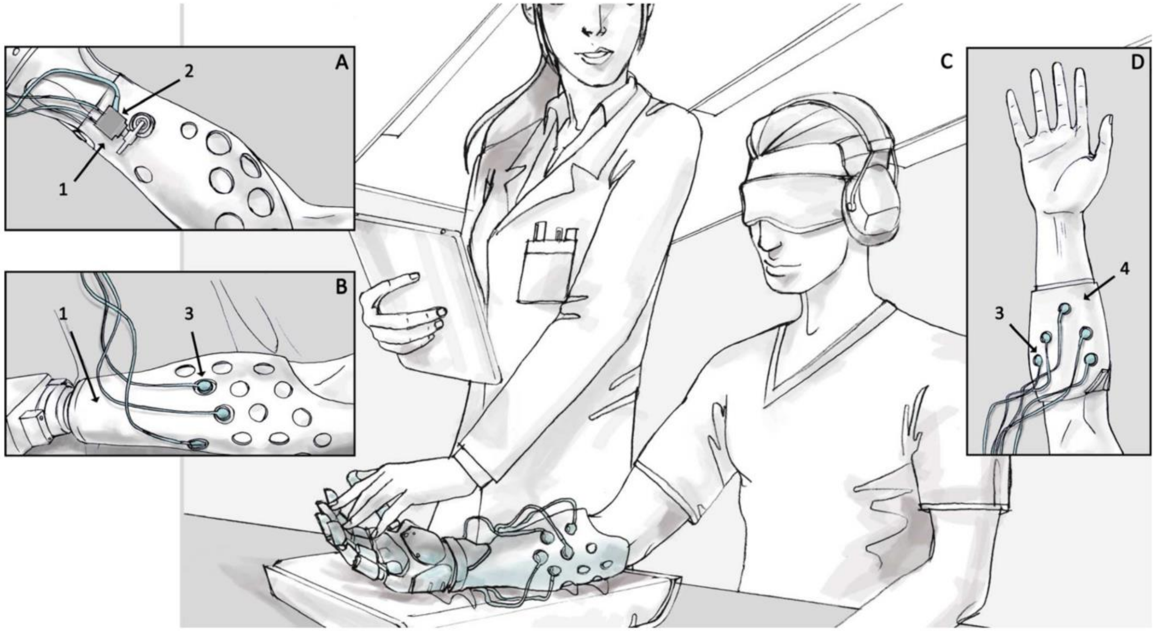

Fig. 3. A: Representative placement on amputee's residual limb of one of the mechanotactile stimulators (2) in the holes of the customized socket (1). B: Representative placement of a vibrotactile stimulator (3) in the holes of the customized socket (1). C: Experimental setup while subject was wearing earmuffs and blindfolded (during the reinforced learning and evaluation sessions). The feedback systems were held on the socket by means of an elastic bandage (not shown); during the whole experiment the subject kept his/her residual limb in a supine position on the table. D: Representative placement on healthy subject's forearm of vibrotactile stimulators (3) within the holes of the rigid mask that mimicked the socket (4). This setup was evaluated with non-amputees.

C. Antfolk et al., "Artificial Redirection of Sensation From Prosthetic Fingers to the Phantom Hand Map on Transradial Amputees: Vibrotactile Versus Mechanotactile Sensory Feedback," in IEEE Transactions on Neural Systems and Rehabilitation Engineering, 2013

Somatosensory feedback

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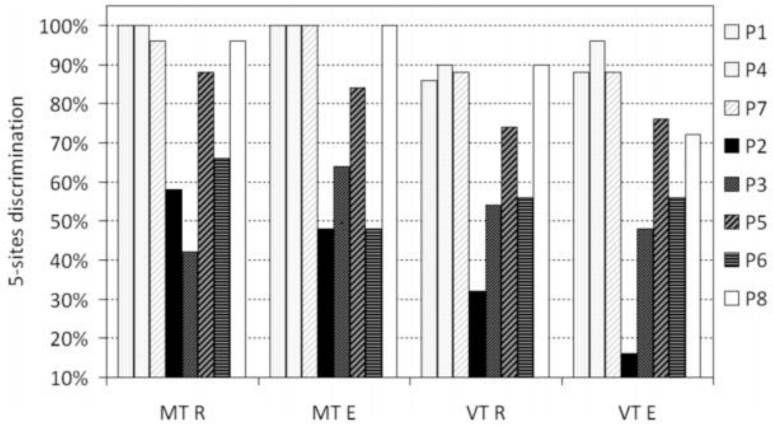


Fig. 4. Five-sites discrimination accuracy for each subject and experimental session (R: reinforced learning; E: evaluation) with the mechanotactile (MT) and vibrotactile (VT) system. The dark and light coloration of the bars highlights subjects belonging to different groups.

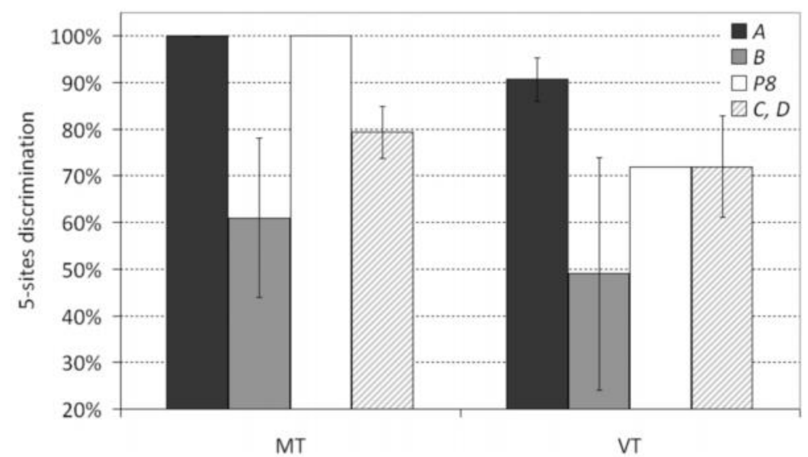
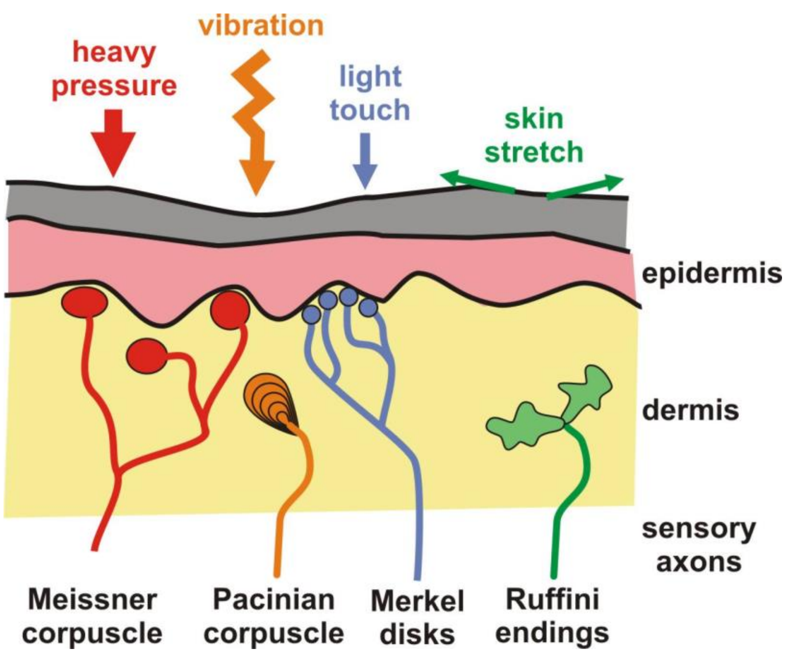
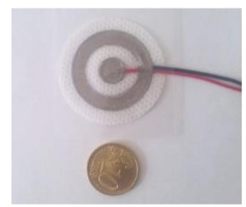


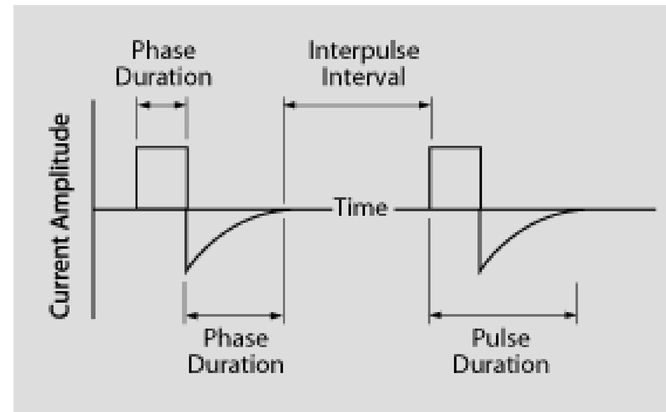
Fig. 5. Mean five-site discrimination percentage for each group (amputees: A, B; non-amputees: C, D) and P8.

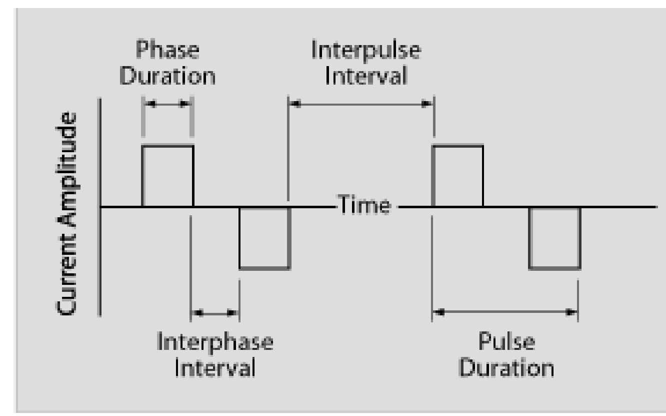
Somatosensory feedback

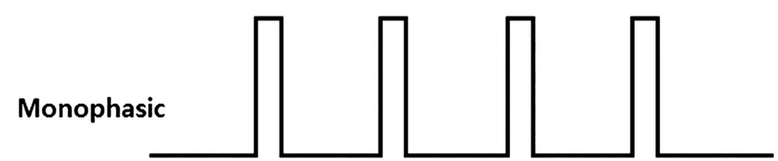
- essentially two ways of doing that:
  - mechanical (vibrotactile, indenting)
  - **electrical (small currents through the skin)**











M. A. Schweisfurth, M. Markovic, S. Dosen, F. Teich, B. Graimann, and D. Farina, “Electrotactile EMG feedback improves the control of prosthesis grasping force,” J. Neural Eng., vol. 13, no. 5, p. 056010, Oct. 2016.

Somatosensory feedback

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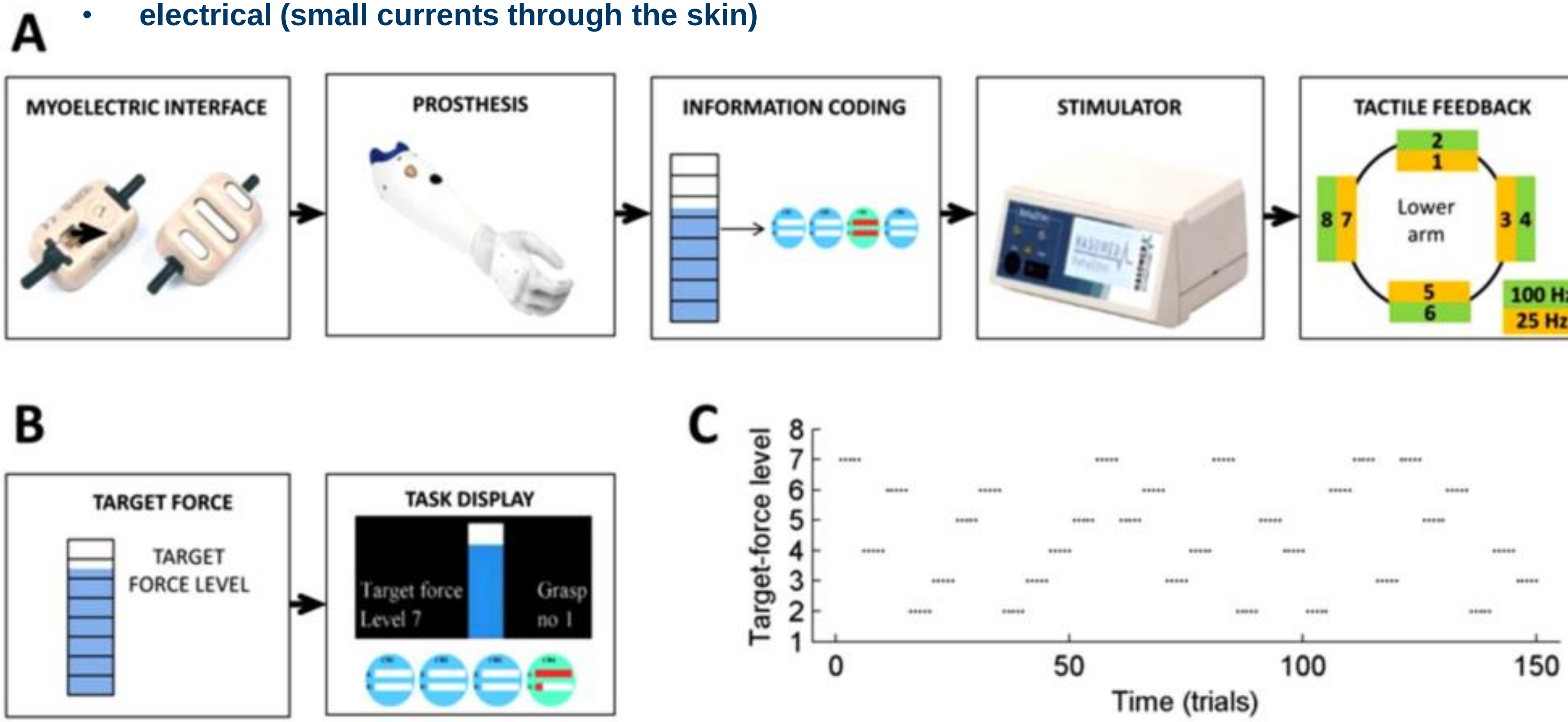

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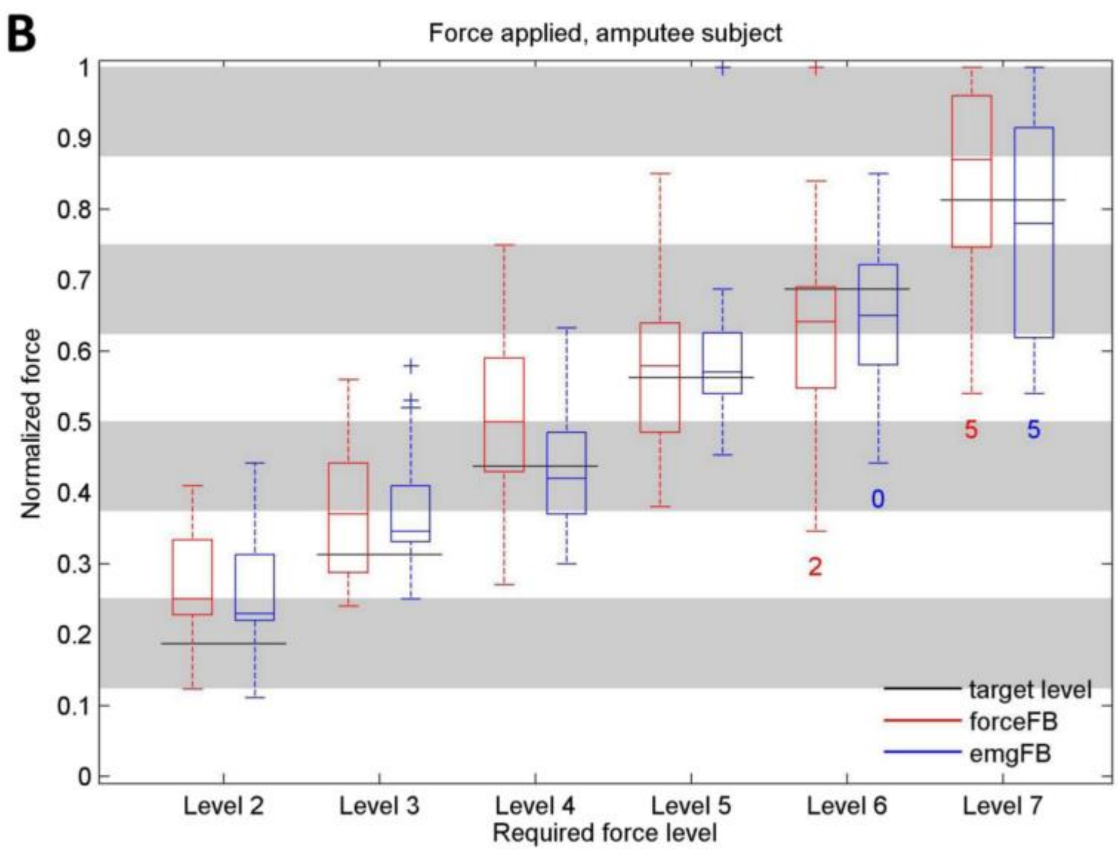
Somatosensory feedback



Conclusion

The present study demonstrated that the novel approach for closing the loop in prosthetics (EMG feedback) can be implemented using a practical electrotactile interface in a realistic task (i.e., randomized grasping with six different force levels) to improve the precision and AE of EMG and force control with respect to the classic force feedback. This EMG-feedback implementation offers one possible, clinically-relevant and applicable solution for closing the loop in the context of myoelectric prosthesis control. In principle, the novel approach could be regarded as rather general and with many possible applications. Regardless of the prosthesis control algorithm, the principle would be identical, i.e., the novel feedback informs the user about the exact input he/she sends to the prosthesis, where this input can be a processed myoelectric signal, as in the present study, or even the output of a pattern recognition/regression method. The connection

Sensory feedback in prosthetics: a story with a twist

Strahinja Dosen

Dept. of Health Science and Technology

The Faculty of Medicine

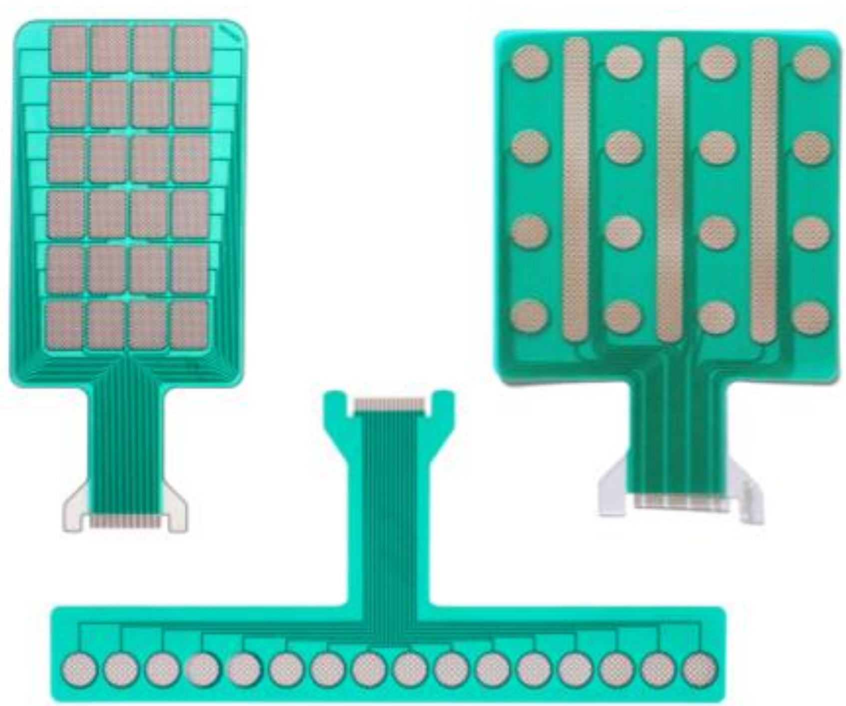
Aalborg University

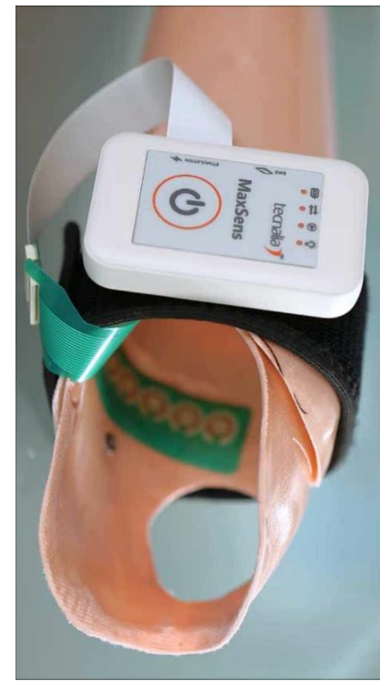
Aalborg, Denmark

New York Times 52 Places to Go in 2019

by Patti | Jan 9, 2019 | Travel News | 1 comment

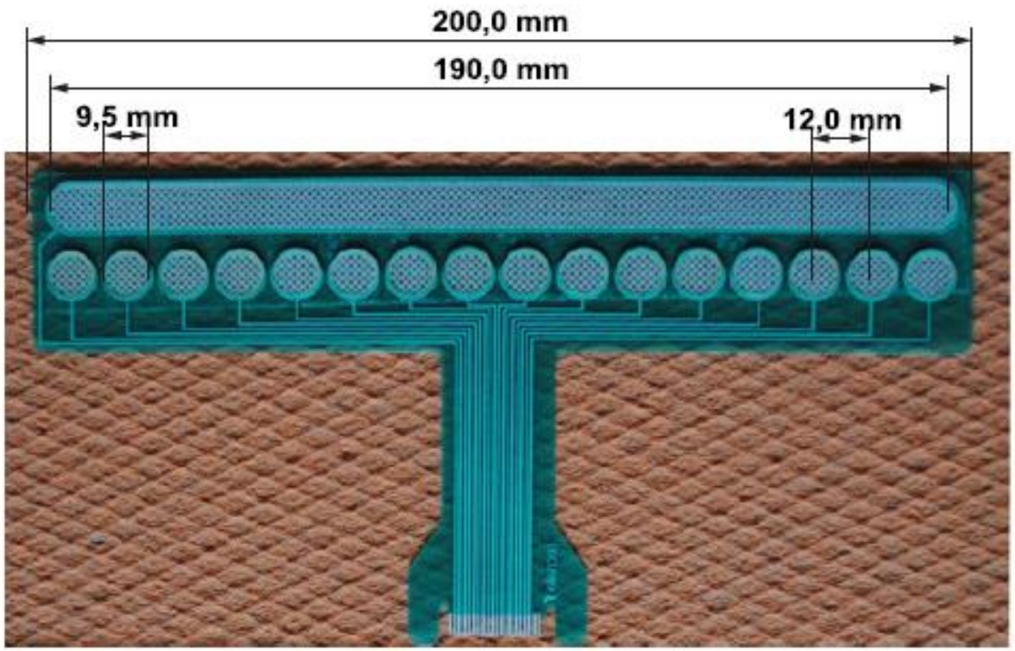
Multichannel electrotactile stimulation using electrode arrays and matrices



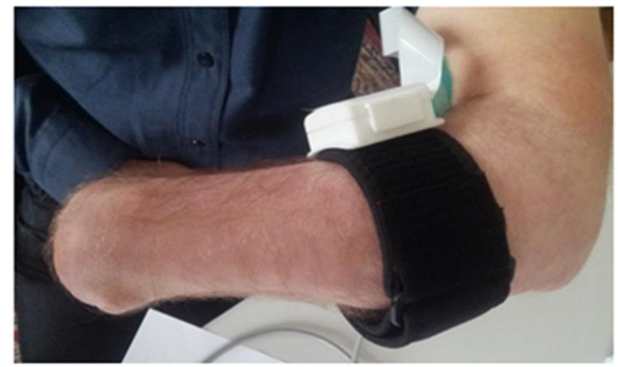


Štrbac M *et al.*, “Integrated and flexible multichannel interface for electrotactile stimulation,” *J. Neural Eng.*, vol. 13, no. 4, p. 046014, Aug. 2016.

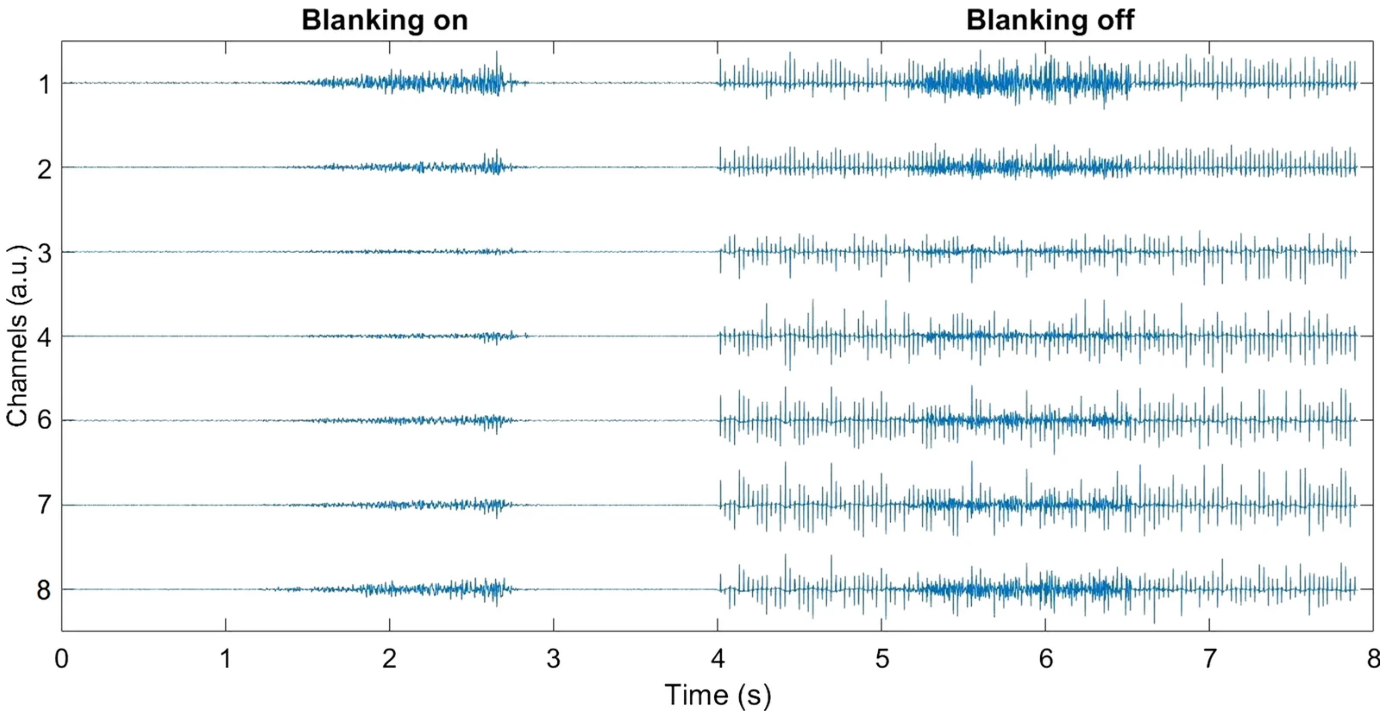
Compact system for multichannel stimulation



Štrbac M, Belić M, Isaković M, Kojić V, Bijelić G, Popović I, Radotić M, Došen S, Marković M, Farina D and Keller T 2016 Integrated and flexible multichannel interface for electrotactile stimulation *J. Neural Eng.* **13** 046014



Simultaneous recording and stimulation



M. A. Garenfeld, N. Jorgovanovic, V. Ilic, M. Strbac, M. Isakovic, J. Dideriksen and S. Dosen "A compact system for simultaneous stimulation and recording for closed-loop myoelectric control," *J. Neuroeng. Rehabil.*, vol. 18, no. 1, p. 87, 2021

Feedback from a multifunctional prosthesis

M. A. Garenfeld, C. K. Mortensen, M. Strbac, J. L. Dideriksen, and S. Dosen, “Amplitude versus spatially modulated electrotactile feedback for myoelectric control of two degrees of freedom,” *J. Neural Eng.*, vol. 17, no. 4, p. 046034, Aug. 2020.

Hand aperture feedback

Courtesy of Tecnalia

Force feedback

Courtesy of Tecnalia

Wrist rotation feedback

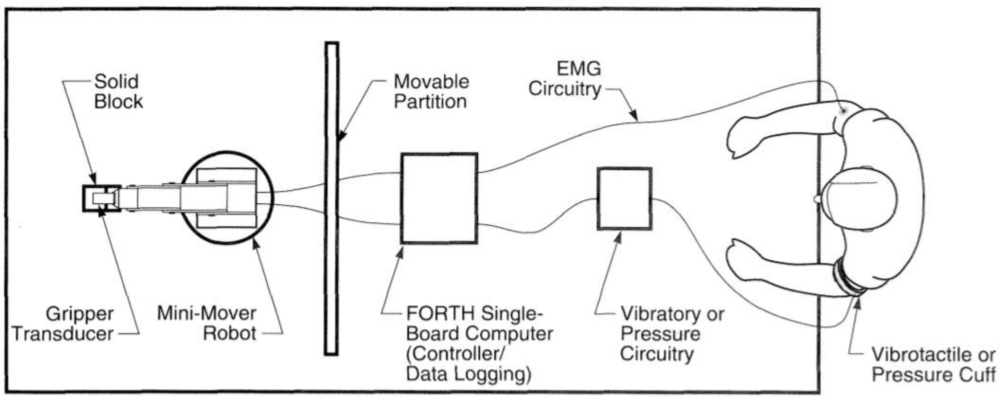
Courtesy of Tecnalia

Sensory feedback improves function

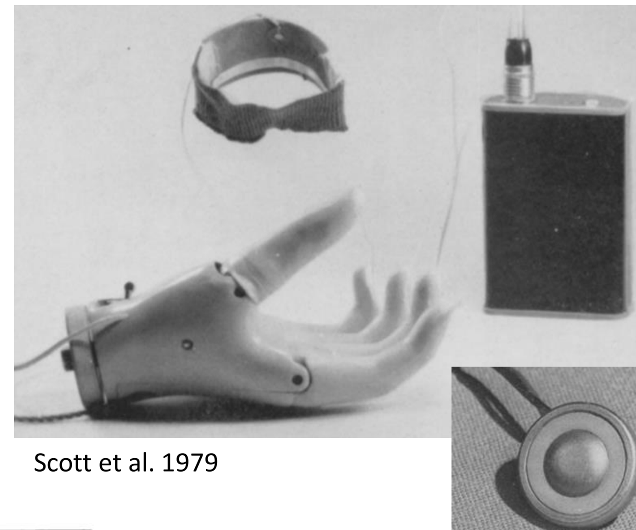
Courtesy of Tecnalia

An interesting twist!

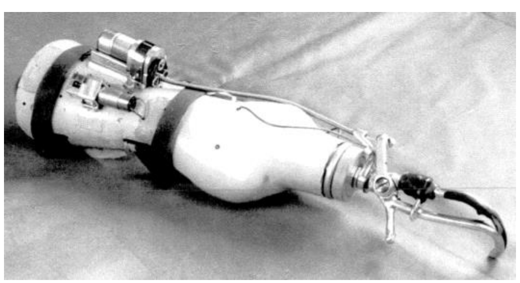
Stimulation methods in the past

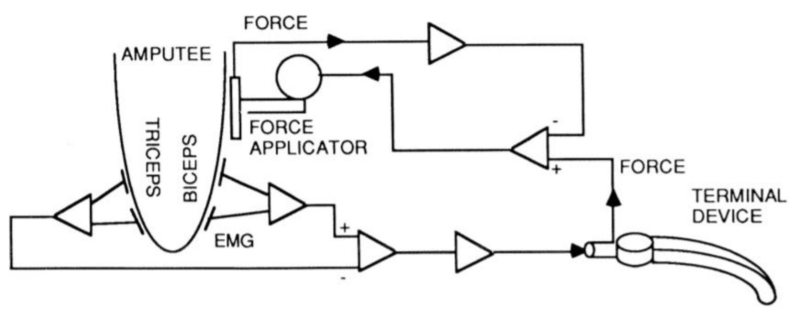


Patterson et al. 1992



Scott et al. 1979





Meek et al. 1989

Sensory feedback – a really old story

Annals of Biomedical Engineering, Vol. 8, pp. 293-303, 1980
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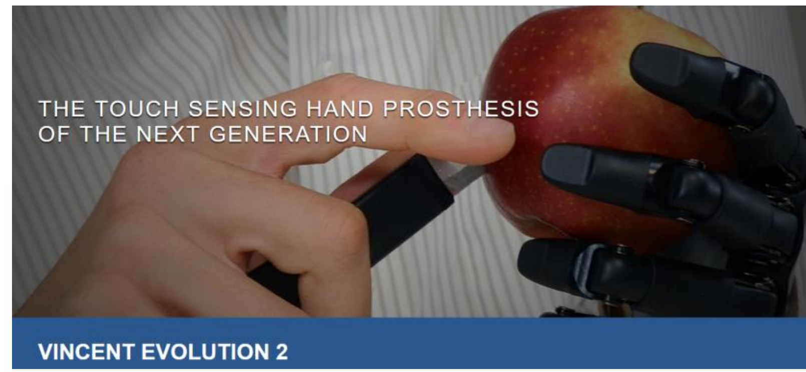
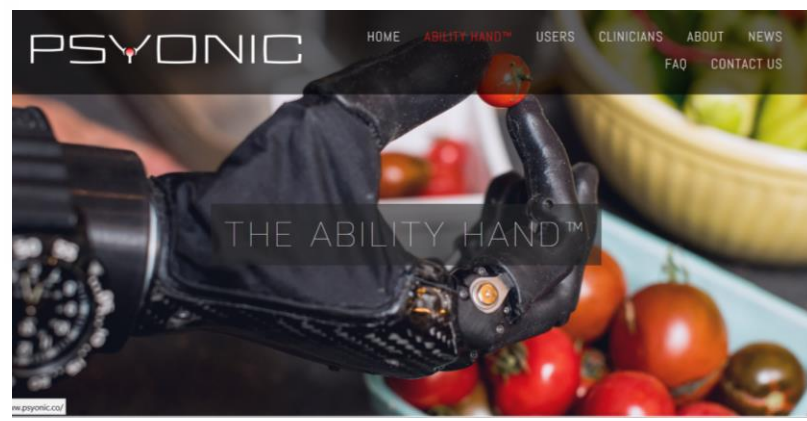
CLOSED-LOOP CONTROL IN PROSTHETIC SYSTEMS: HISTORICAL PERSPECTIVE*

Dudley S. Childress

Prosthetics Research Laboratory
Northwestern University
Chicago, Illinois

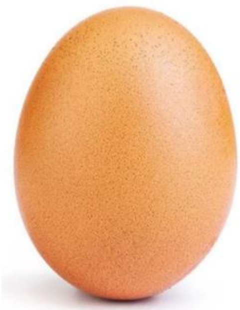


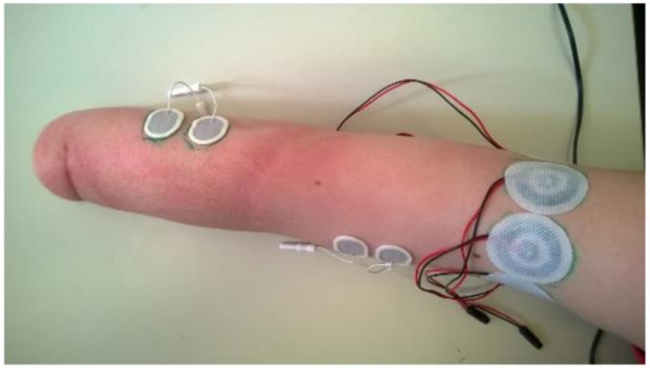


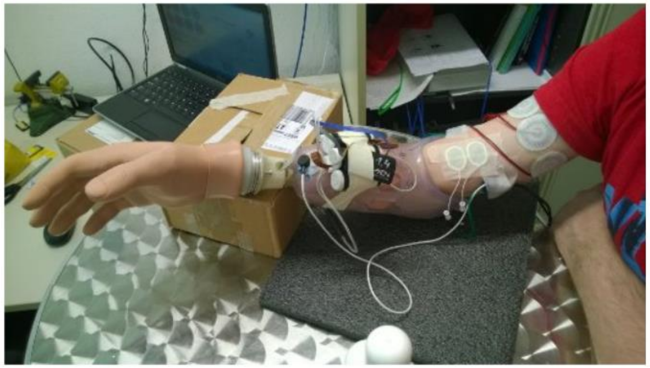
Surprising results in literature

- “Moreover, the experiments showed that when grasping tasks are performed under visual control, **the enhanced proprioception offered by a vibrotactile system is practically not exploited**.” Cipriani C, *IEEE Trans. Robot.*, vol. 24, no. 1, pp. 170–184, Feb. 2008.
- “This was performed with and without vibrotactile feedback in a counter-balanced order of two conditions … **No significant differences were found in visual attention or in performance time between the two conditions.**” Raveh E., *Assist. Technol.*, vol. 30, no. 5, pp. 274–280, 2018.
- “Performance on the SHAP, a measure of hand mechanical function and control, was **similar with and without sensory feedback**” Schiefer M et al., *J. Neural Eng.*, vol. 13, no. 1, p. 016001, Feb. 2016.

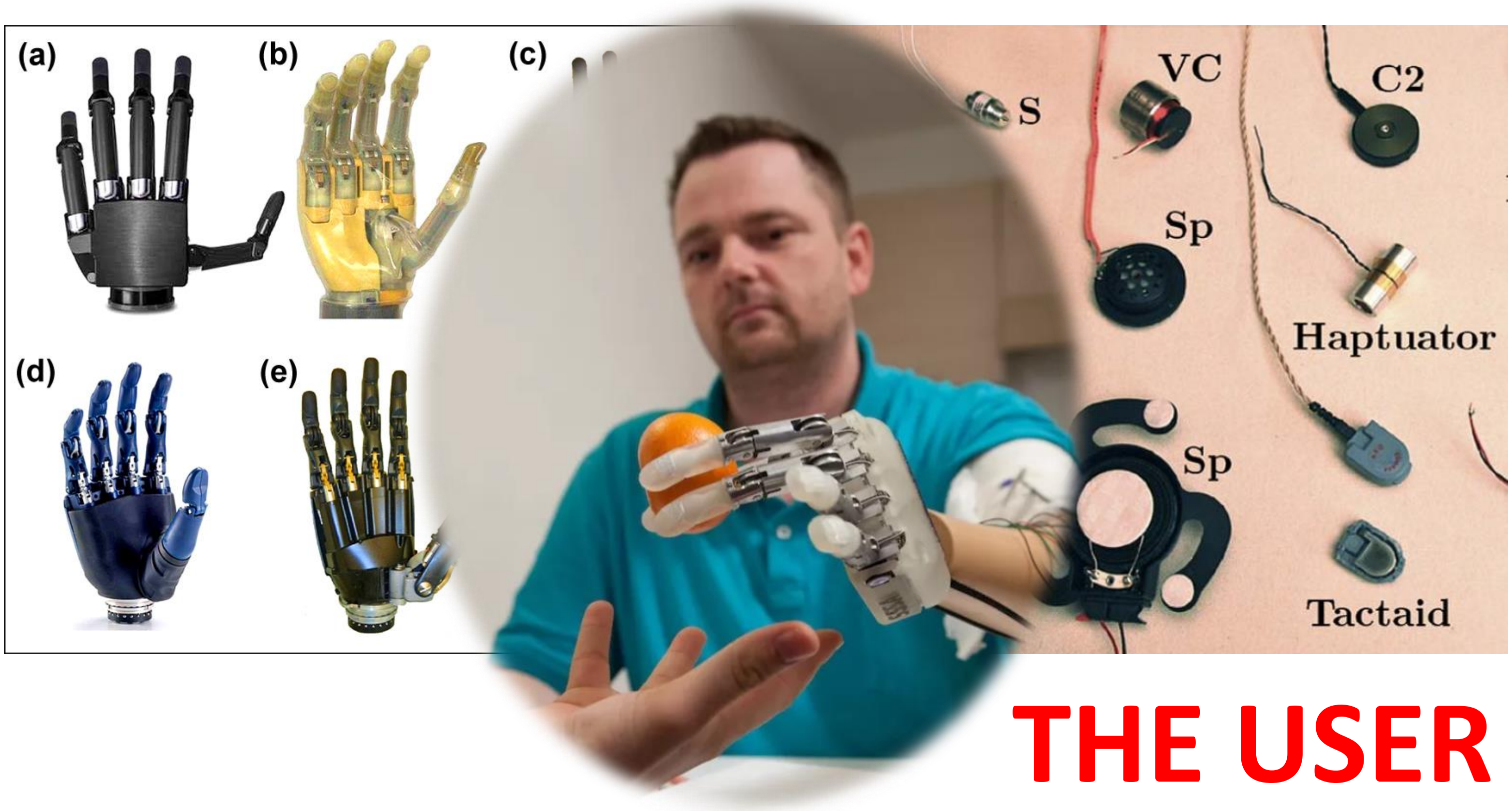
The Magician’s hat (but the magic is missing)







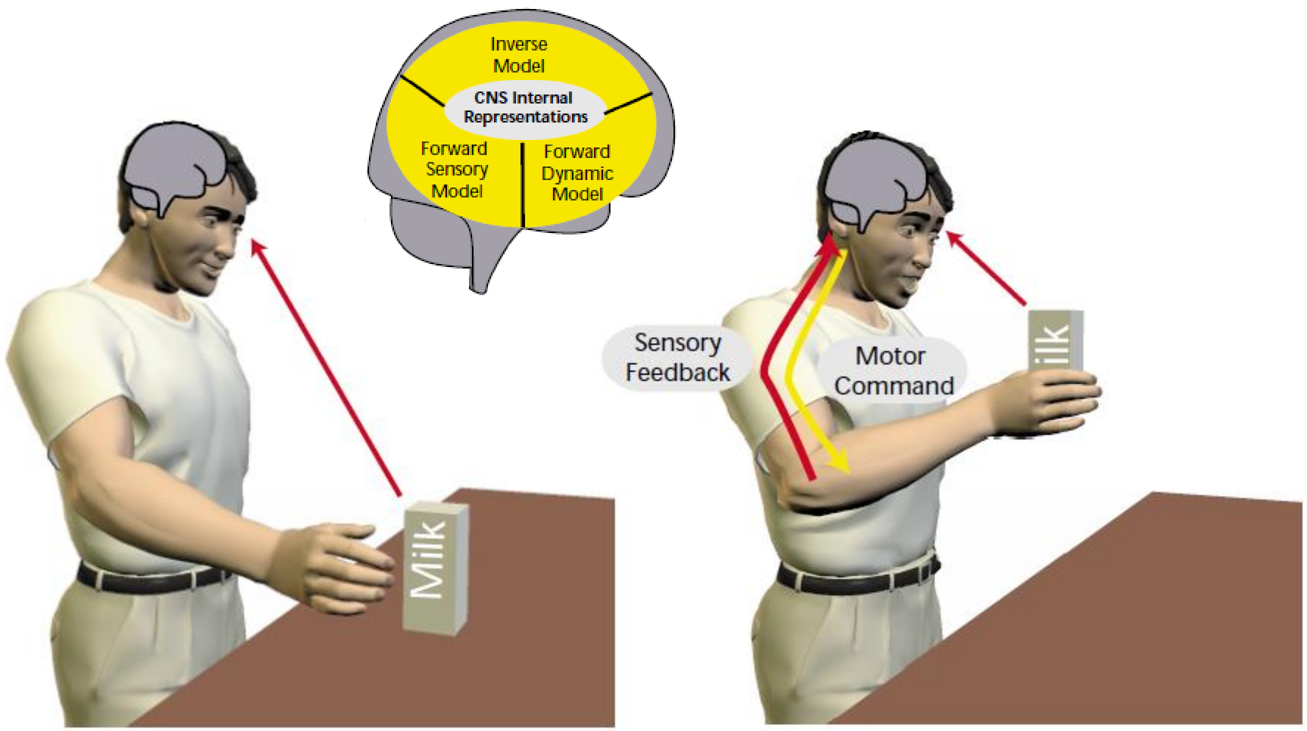
The most crucial thing to understand ....



THE USER

J. T. Belter et al., “Mechanical design and performance specifications of anthropomorphic prosthetic hands: a review.,” *J. Rehabil. Res. Dev.*, vol. 50, no. 5, Jan. 2013.

How do you use feedback when grasping?



D. M. Wolpert and Z. Ghahramani, “Computational principles of movement neuroscience,” *Nat. Neurosci.*, vol. 3, no. S11, pp. 1212–1217, Nov. 2000.

A man who lost his body

Ian Waterman – a man without somatosensory feedback

Courtesy of BBC

However, Ian Waterman in real life

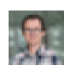
Courtesy of BBC

REVIEW ARTICLE

Front. Neurosci., 23 June 2020 | https://doi.org/10.3389/fnins.2020.00345

Check for updates

A Review of Sensory Feedback in Upper-Limb Prostheses From the Perspective of Human Motor Control

Jonathon W. Sensinger[1*†] and  Strahinja Dosen[2*†]

[1]Institute of Biomedical Engineering, University of New Brunswick, Fredericton, NB, Canada

[2]Department of Health Science and Technology, The Faculty of Medicine, Integrative Neuroscience, Aalborg University, Aalborg, Denmark

REVIEW ARTICLE
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A Review of Sensory Feedback in Upper-Limb Prostheses From the Perspective of Human Motor Control

Jonathon W. Sensinger[1*†] and Strahinja Dosen[2*†]

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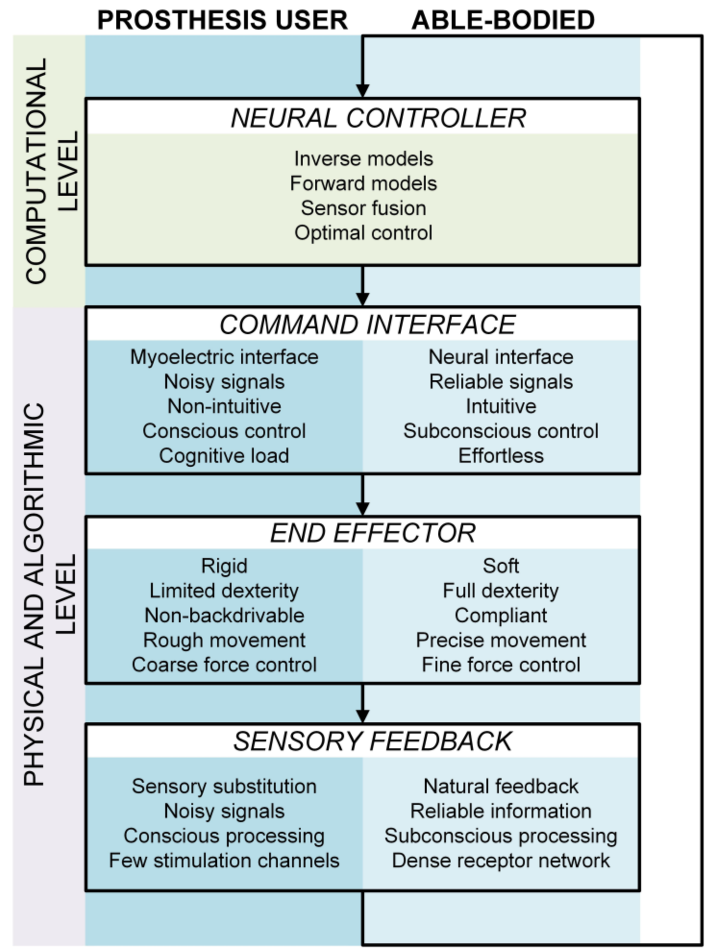
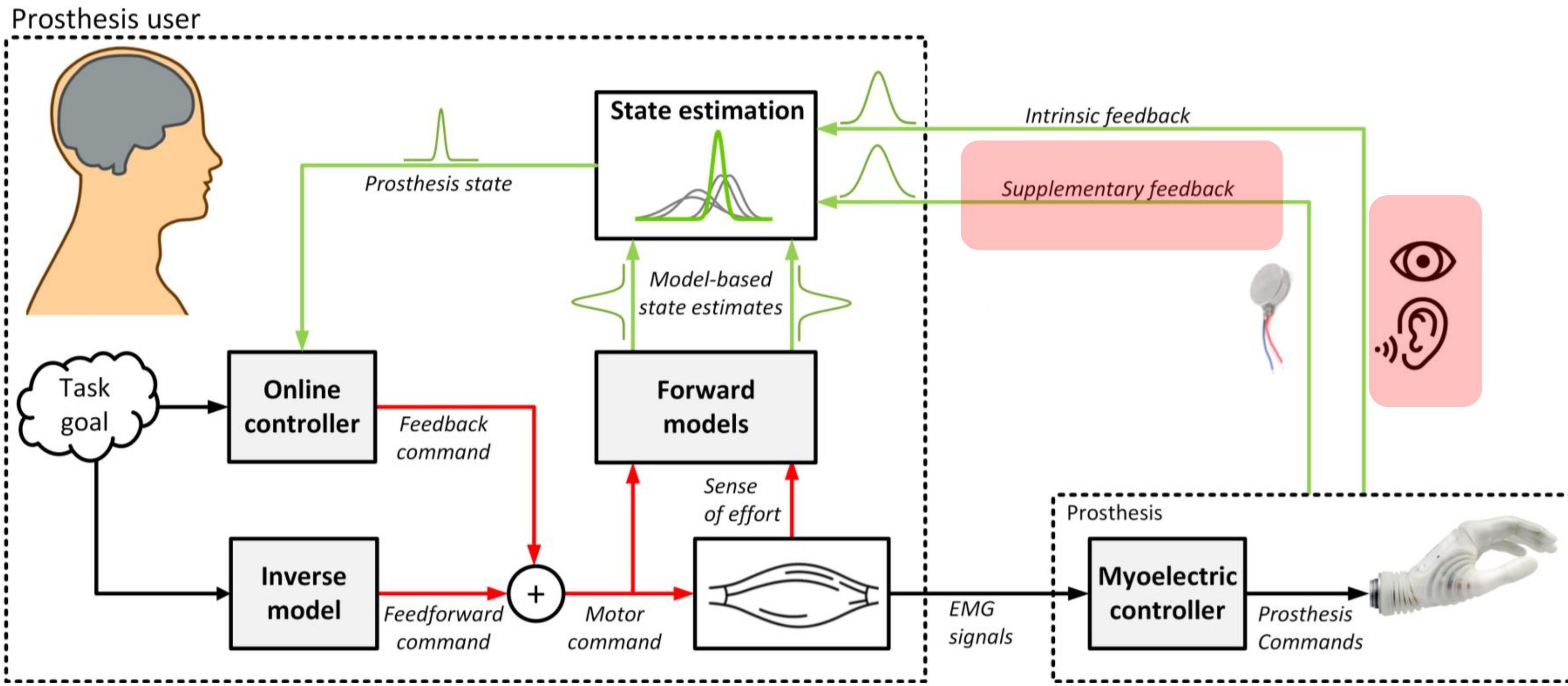
[2]Department of Health Science and Technology, The Faculty of Medicine, Integrative Neuroscience, Aalborg University, Aalborg, Denmark



J. W. Sensinger and S. Dosen, “A review of sensory feedback in upper-limb prostheses from the perspective of human motor control,” *Front. Neurosci.*, vol. 14, Jun. 2020.

Holistic approach to sensory feedback

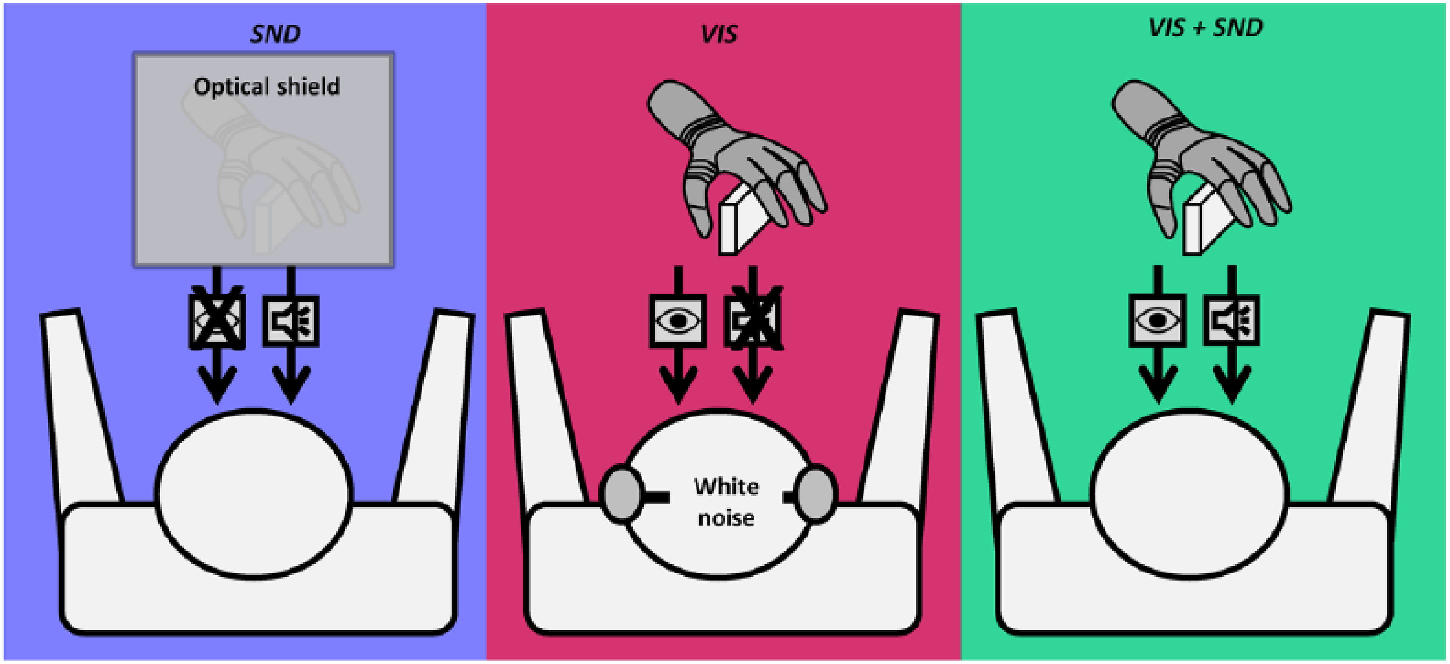


J. W. Sensinger and S. Dosen, "A review of sensory feedback in upper-limb prostheses from the perspective of human motor control," *Front. Neurosci.*, Jun. 2020.

Incidental feedback

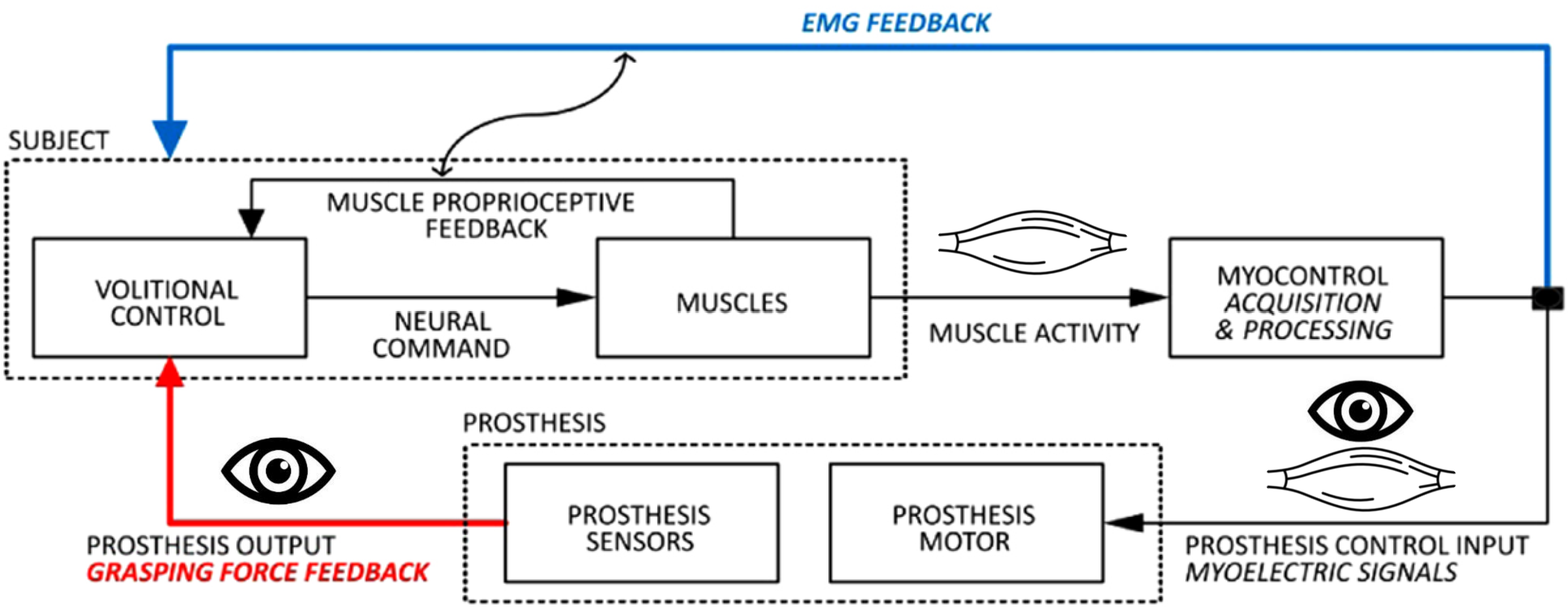
Courtesy of Dr. Sebastian Amsuess

The power of incidental feedback



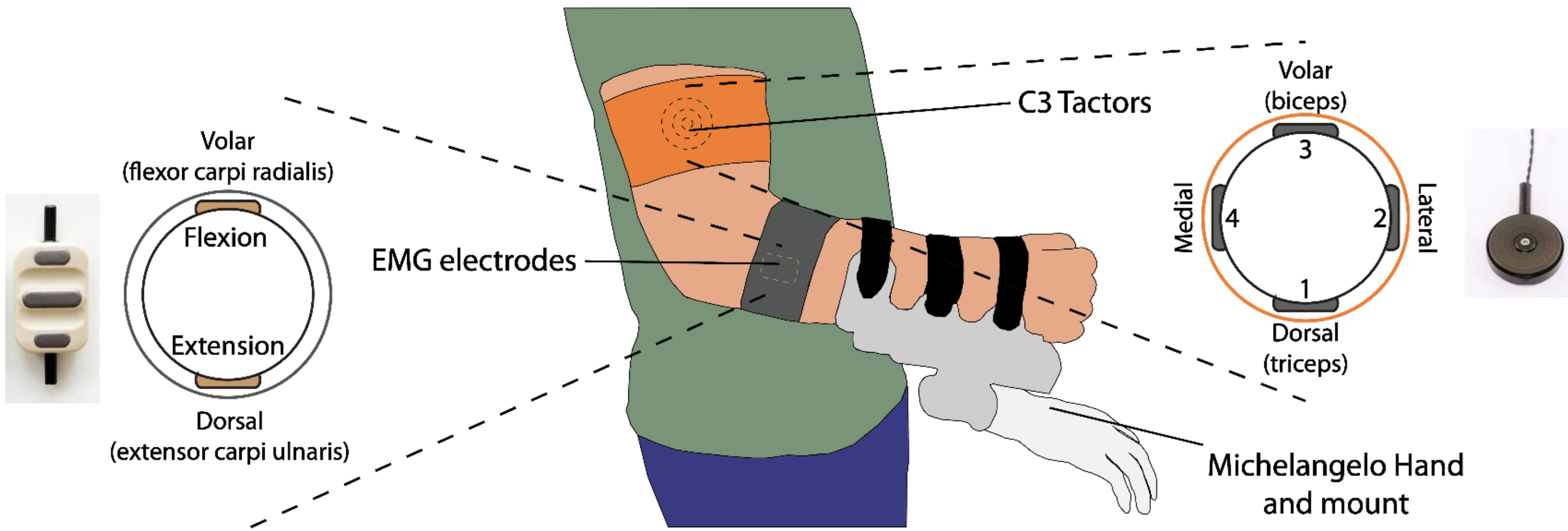
M. A. Schweisfurth, C. Niethammer, B. Meyer, D. Farina, and S. Dosen, "Psychometric characterization of incidental feedback sources during grasping with a hand prosthesis," *J. Neuroeng. Rehabil.*, vol. in press, 2019.

A novel concept: EMG feedback



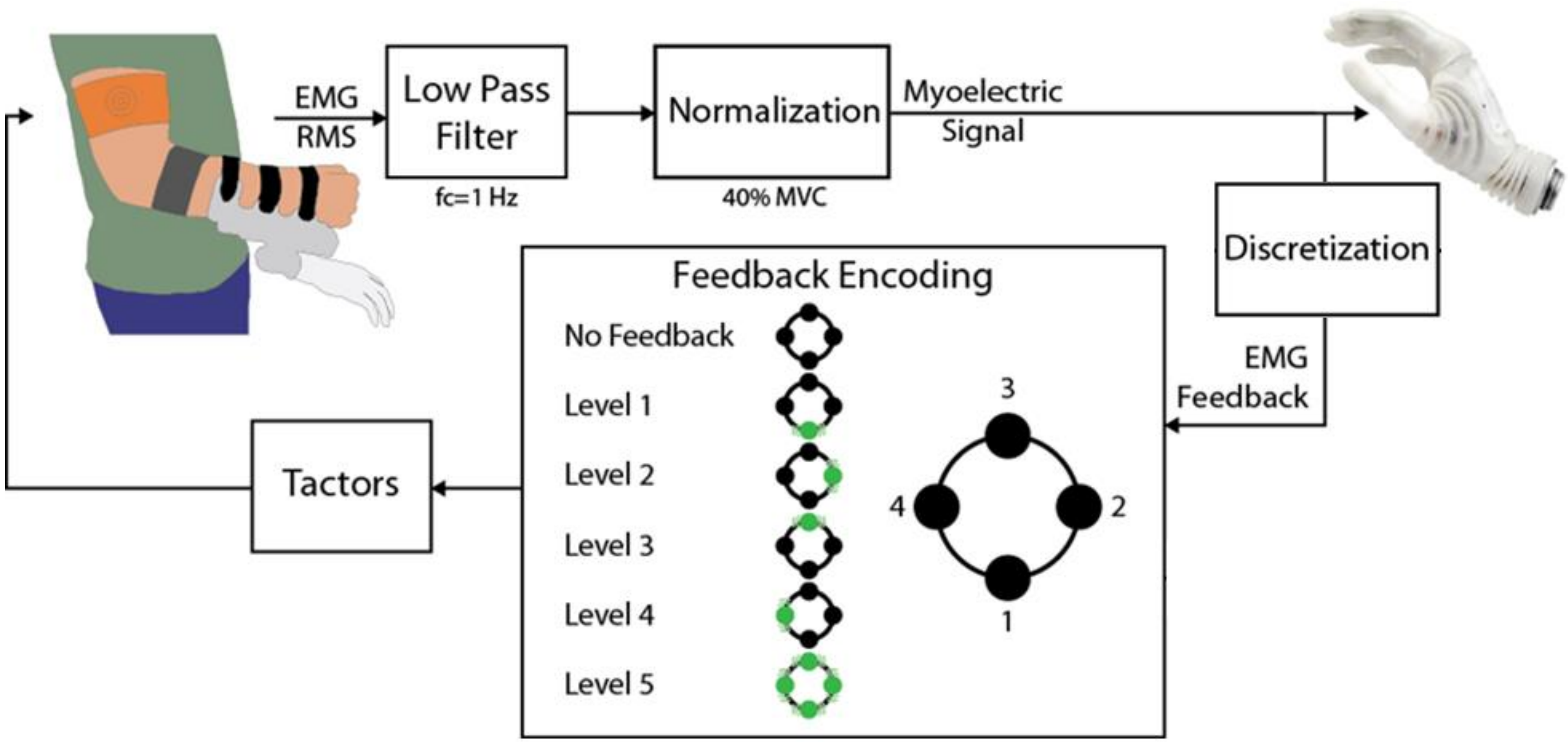
S. Dosen et al., "EMG Biofeedback for online predictive control of grasping force in a myoelectric prosthesis.," J. Neuroeng. Rehabil., vol. 12, no. 1, p. 55, Jun. 2015.

An example implementation



J. Tchimino, M. Markovic, J. L. Dideriksen, and S. Dosen, “The effect of calibration parameters on the control of a myoelectric hand prosthesis using EMG feedback,” *J. Neural Eng.*, vol. 18, no. 4, p. 046091, Aug. 2021.

An example implementation



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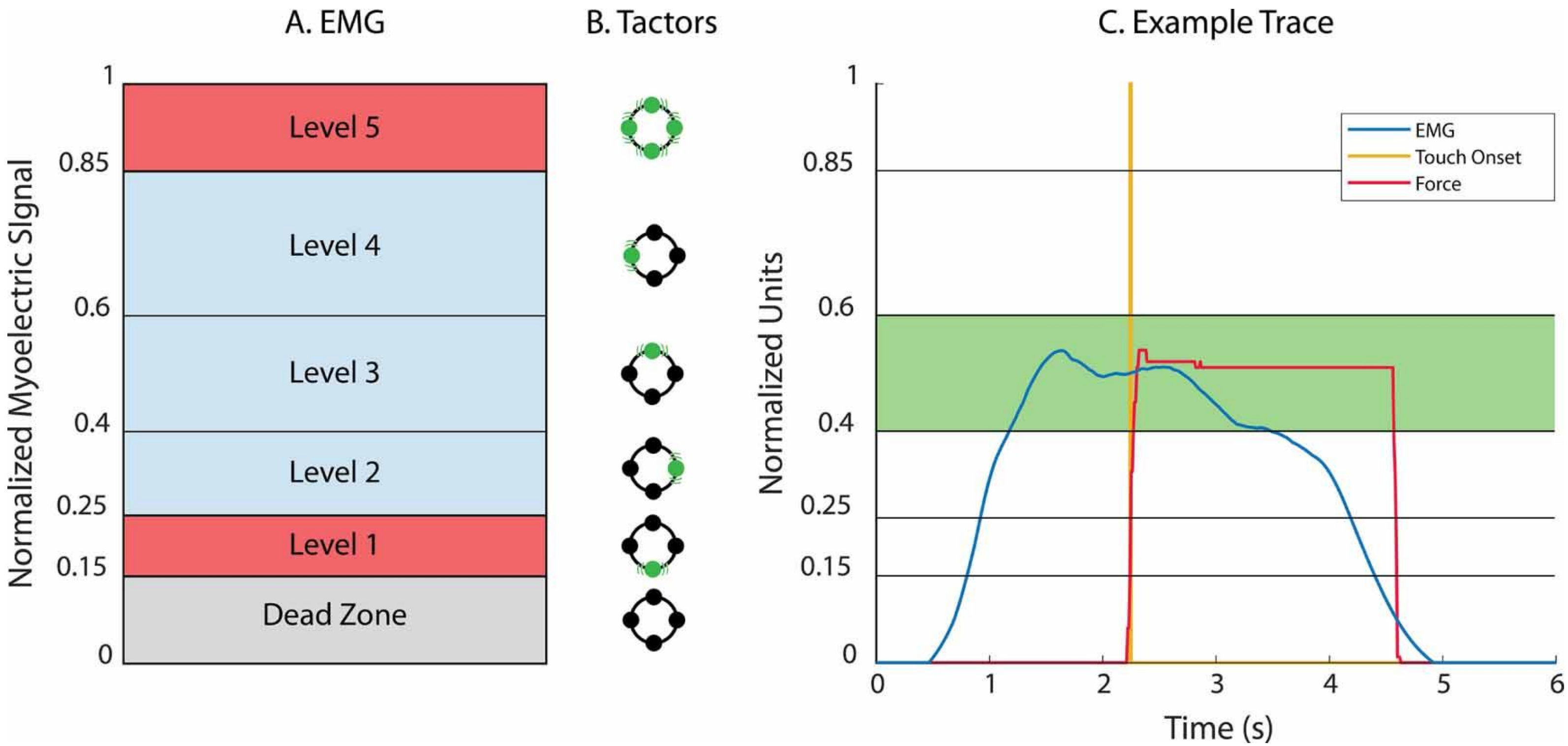
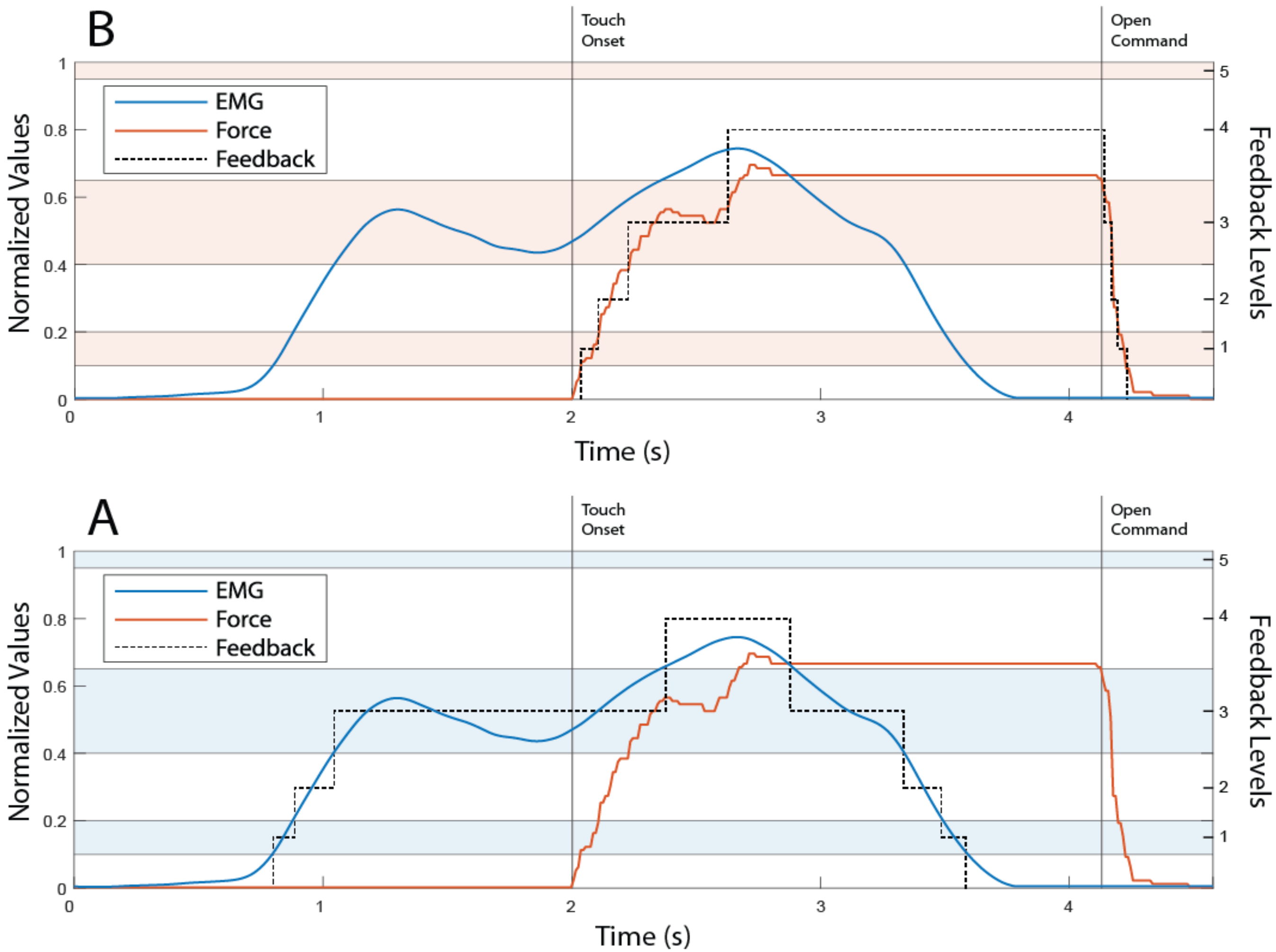
Prosthesis control using EMG feedback



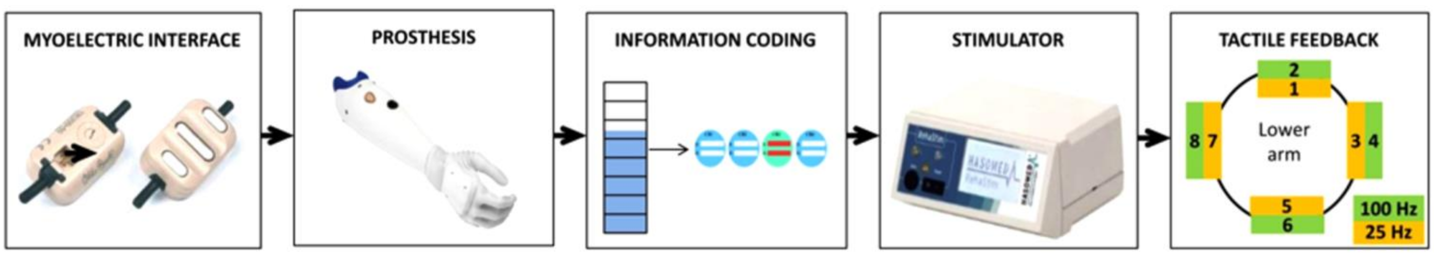
J. Tchimino, M. Markovic, J. L. Dideriksen, and S. Dosen, "The effect of calibration parameters on the control of a myoelectric hand prosthesis using EMG feedback," *J. Neural Eng.*, vol. 18, no. 4, p. 046091, Aug. 2021.

EMG
vs
FORCE
feedback



EMG feedback outperforms force feedback

- M. A. Schweisfurth, M. Markovic, S. Dosen, F. Teich, B. Graimann, and D. Farina, “Electrotactile EMG feedback improves the control of prosthesis grasping force,” J. Neural Eng., vol. 13, no. 5, p. 056010, Oct. 2016.
- J. Tchimino, M. Markovic, J. L. Dideriksen, and S. Dosen, “The effect of calibration parameters on the control of a myoelectric hand prosthesis using EMG feedback,” *J. Neural Eng.*, vol. 18, no. 4, p. 046091, Aug. 2021.



Take home messages

- To design effective feedback, we need to approach it from a broader perspective (**human motor control**)
- This means understanding the mechanisms and strategies used by prosthesis users
- Feedback will be beneficial if it has a positive effect on the totality of the human motor control loop
- Providing a variable that **cannot be assessed** using intrinsic feedback sources
- Conveying information that **can facilitate natural mechanisms** (e.g., predictive control of grasping force)

Somatosensory feedback

- the answer is, in general, yes…
- …as long as there is no or little visual feedback.

- but the story isn‘t over.

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