

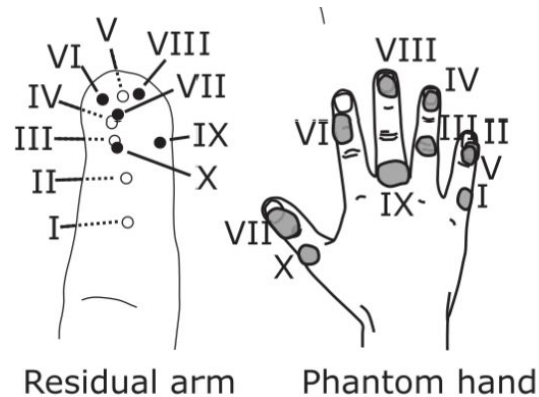
RESEARCH**BIOENGINEERING**

Restoration of natural thermal sensation in upper-limb amputees

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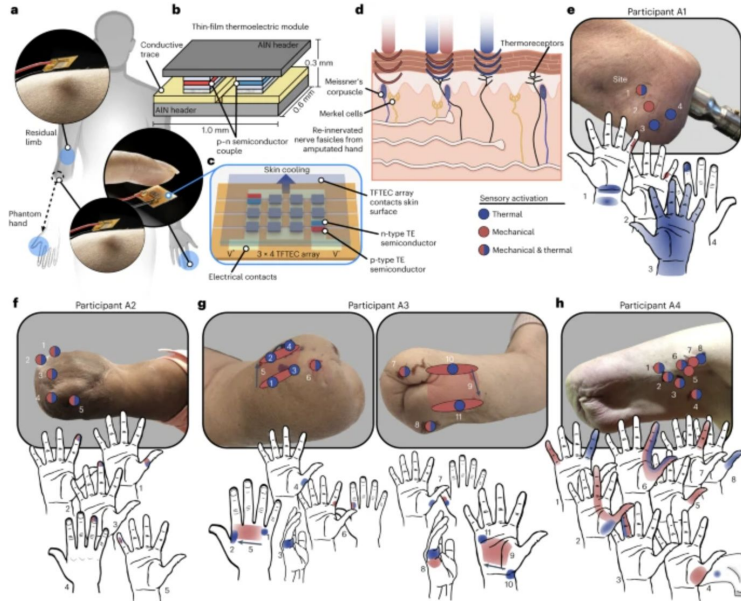
The use of hands for gathering rich sensory information is essential for proper interaction with the environment; therefore, the restoration of sensation is critical for reestablishing the sense of embodiment in hand amputees. Here, we show that a noninvasive wearable device can be used to provide thermal sensations on amputees' phantom hands. The device delivers thermal stimuli to specific regions of skin on their residual limb. These sensations were phenomenologically similar to those on the intact limbs and were stable over time. Using the device, the subjects could successfully exploit the thermal phantom hand maps to detect and discriminate different thermal stimuli. The use of a wearable device that provides thermal sensation can increase the sense of embodiment and improve life quality in hand amputees.

Sofia Yeremeieva
Leonardo Silvagni
Joana Pires



Esper Bionics hand prosthesis.

Fig. 1: Mapping thermal sensations in the phantom hand.

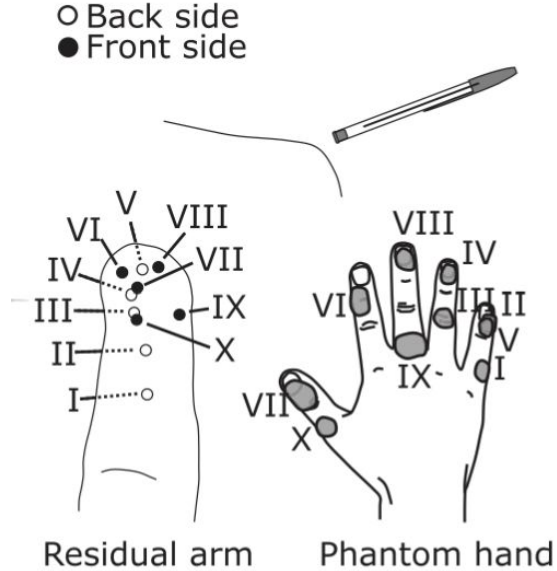


Osborn et al. at the John Hopkins University (natural thermal perceptions, 1).



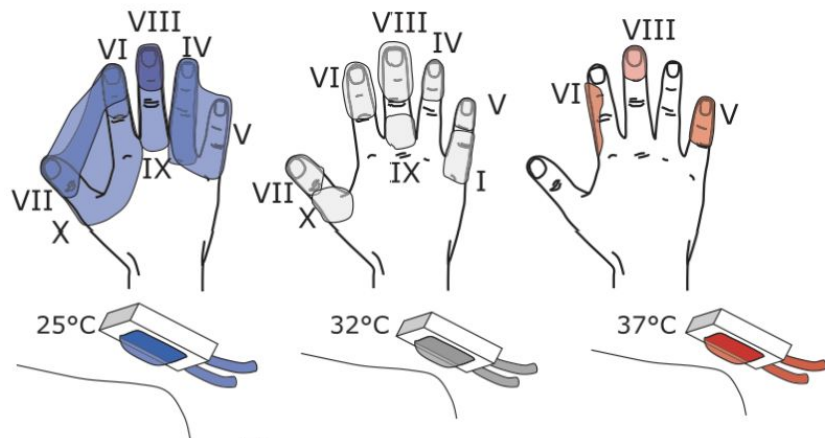
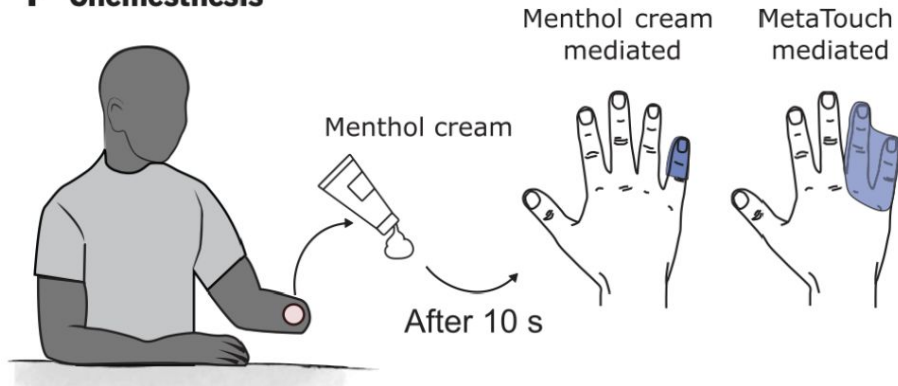
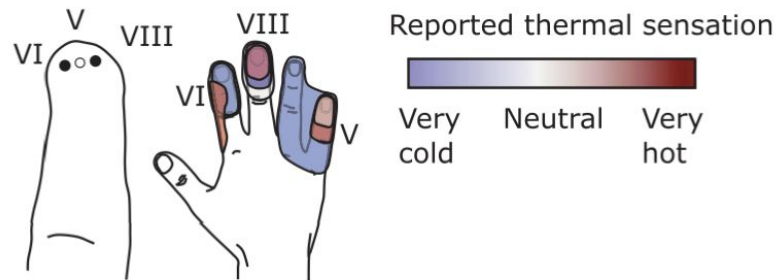
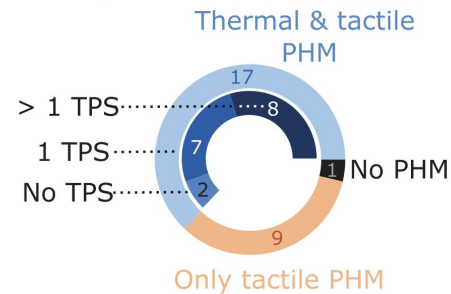
Daekyo, Triolo, Charkhkar (Plantar somatosensory restoration, 2).

Research participants



- Twenty-seven adult (24 to 65 years old; four female)
- Projected sensation was found in 26 of the 27 participants.

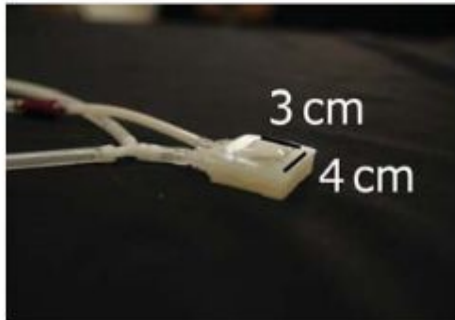
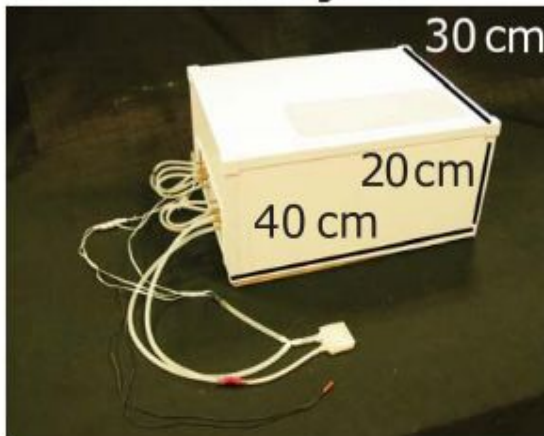


C Example of thermal phantom hand map**F Chemesthesis****D Example of thermal phantom spots****E Group statistics**

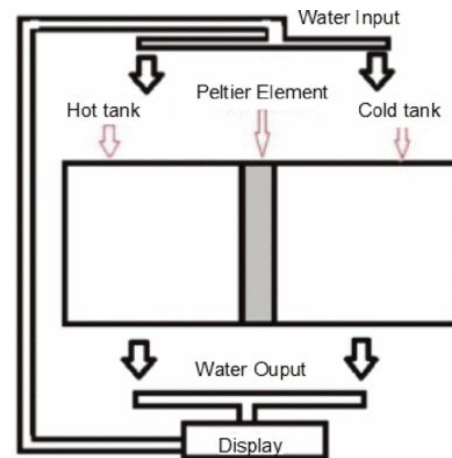
TPS: Thermal phantom spot

PHM: Phantom hand map

Meta touch system



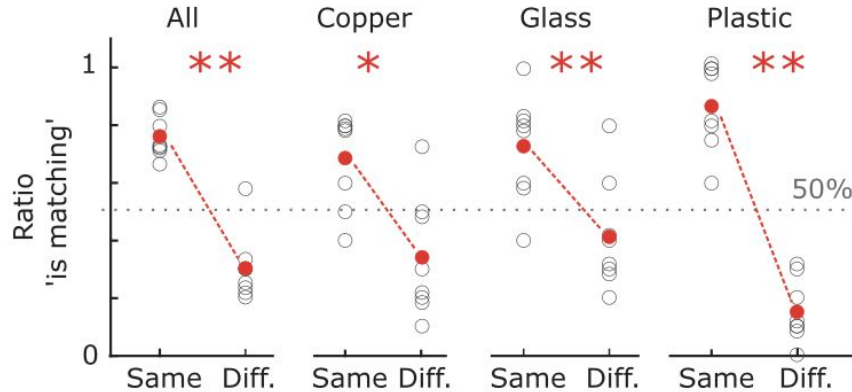
- Custom made hydraulic thermal device
 - Hydraulics provide both thermal, pressure and vibrotactile stimuli
 - Water tanks heated and cooled by Peltier element



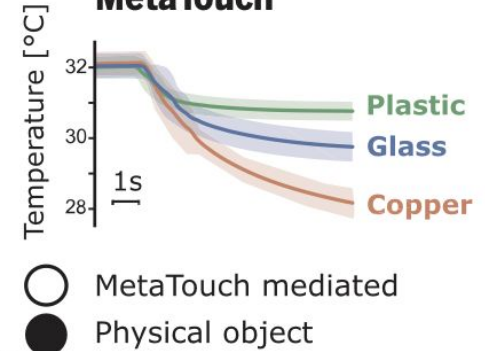
Matching sensations on nonamputee

- 8 nonamputee subjects, lower abdomen
- Matching rate: plastic > glass > copper
- Overall stimuli matched at 76.4%

B Matching sensation on the abdomen (nonamputee participants, n=8)



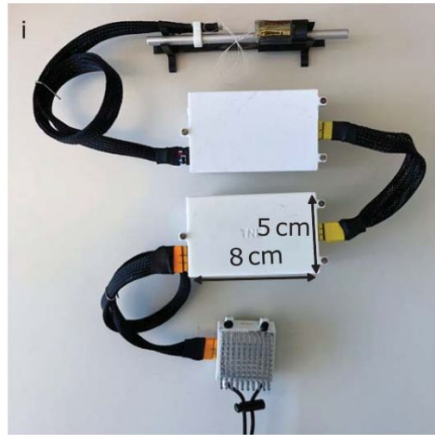
A Materials' signature thermal drops with the MetaTouch



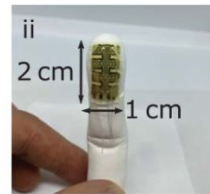
Novelty - MiniTouch

- Thermal phantom sensation through wearable device (320g)
 - active thermal skin (ATS) sensor
 - control unit
 - thermal display on the user's skin

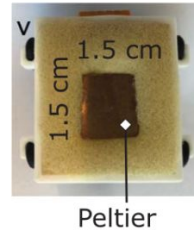
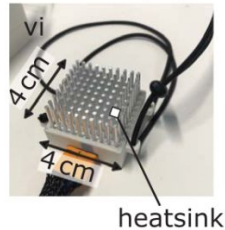
A The MiniTouch system



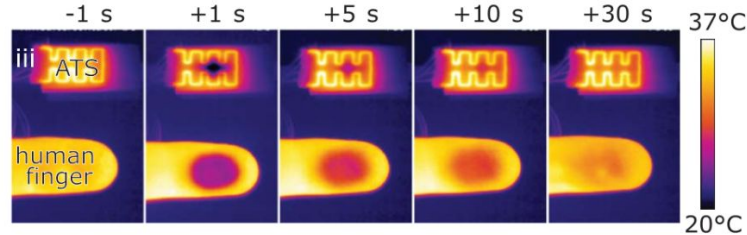
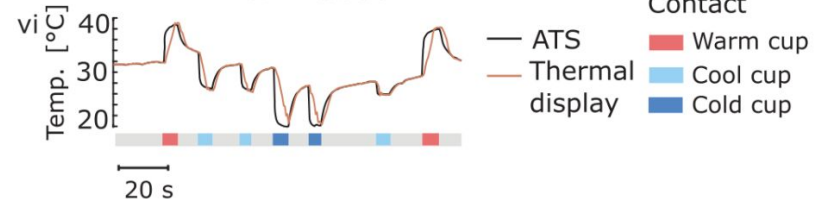
Active thermal skin (ATS)



Thermal display



Time after contact with a cold object

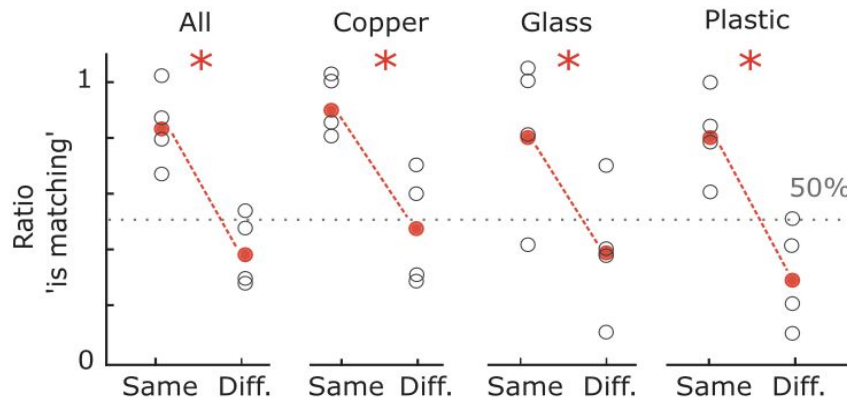

 $R^2 = 0.784$


Matching sensations on amputee

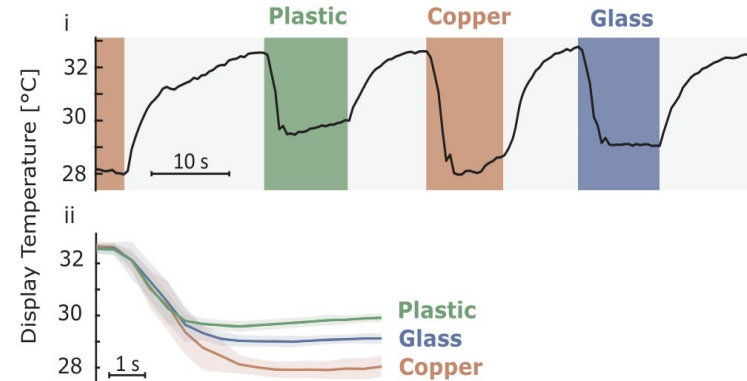
- 4 amputees with at least one thermal spot
- matching rate: copper > plastic > glass
- overall stimuli matched at 83.3%

➤ Thermal phantom sensations are phenomenologically similar to intact hand

C Matching sensation on a thermal phantom spot (amputee participants, n=4)



D MiniTouch-mediated stimulation



Discrimination task

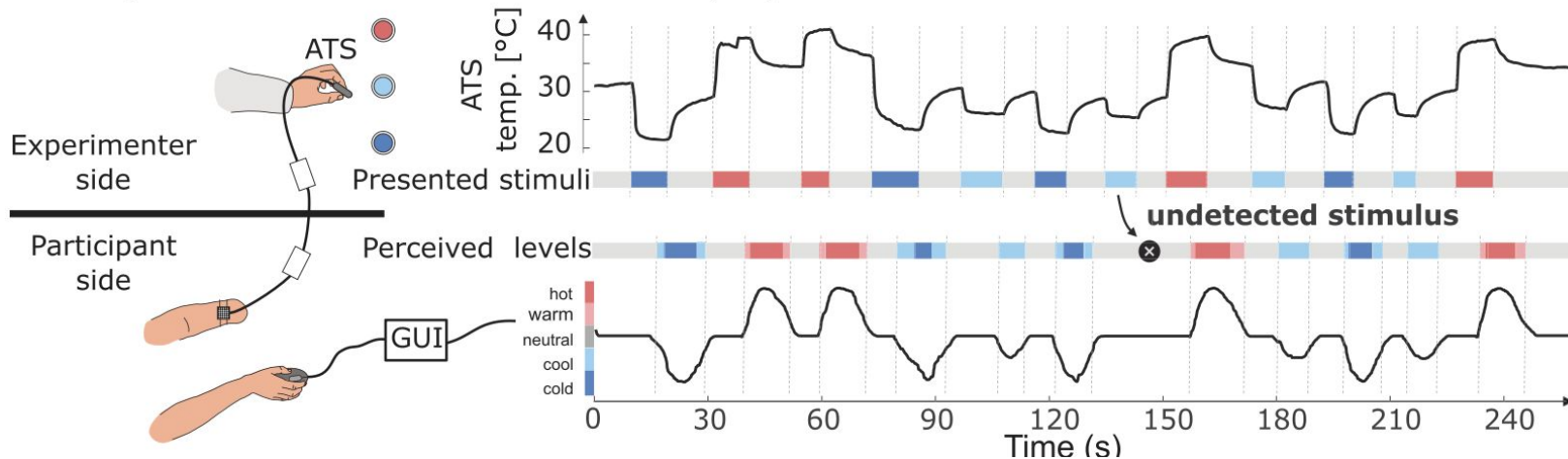
- Thermal discrimination with objects at 15°(cold), 24°(cool) or 40°(hot)
- Hot stimuli : 97.2%
- Cold stimuli : 61.1%

C Group average
(amputee participants, n=9)

Presented stimuli	Hot cup	Cool cup	Cold cup	
	97.2	55.6	36.1	
	2.8	11.1	61.1	
	hot warm	cool	cold	neutral

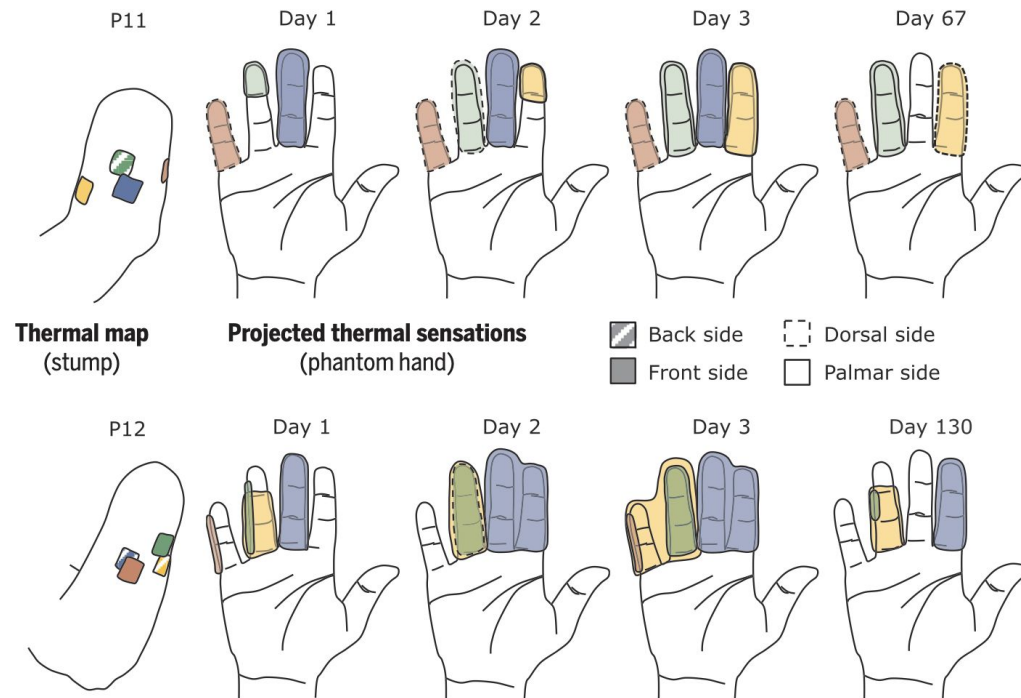
Perceived level

B Example of uncued thermal discrimination task (P12)



Partially stable projections

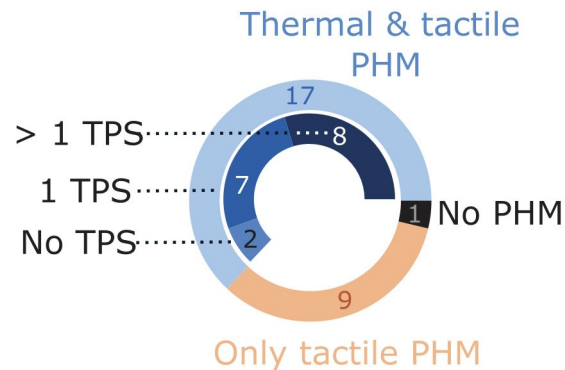
- MiniTouch set on 25°
- Two patients (P11 and P12)
 - P11: 67 days evaluation
 - P12: 130 days evaluation
 -
- P11 has 11/37 overlap
- P12 has 3/12 overlap
- yes/no questionnaire



Limitations & Challenges

- Thermal maps are specific to each patient
 - no general prosthesis
- Sample size is small
 - Stability assessment only has 2 patients
- Finding patients willing to be followed for long periods is hard

E Group statistics



TPS: Thermal phantom spot

PHM: Phantom hand map

Open Questions

- Can this thermal map be found in other type of amputee?
- How stable are the thermal maps?
 - Is the sample size big enough?
- Are thermal prosthesis viable?
 - 2024: Prosthesis with integrated thermal feedback (5)

1. <https://www.nature.com/articles/s41551-023-01070-w> (thermal sensation)
2. <https://www.science.org/doi/10.1126/scirobotics.adf8997> (plantar sensation)
3. <https://iopscience.iop.org/article/10.1088/1741-2552/ac4e1b> (tacticle sensation)
4. <https://iopscience.iop.org/article/10.1088/1741-2552/ac8c38> (review)
5. <https://www.sciencedirect.com/science/article/pii/S266663402300404X> (prosthesis with integrated thermal feedback)