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These are the slides for the talk presented at UIST 2026 by Wen Li.
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You can watch the demo video here: https://www.youtube.com/watch?v=iwoeuEEQqQg
If you need a PPTX/editable version for your class, email us hci@uchicago.edu
More information on this paper: https://lab.plopes.org/#electro-thermal-referral



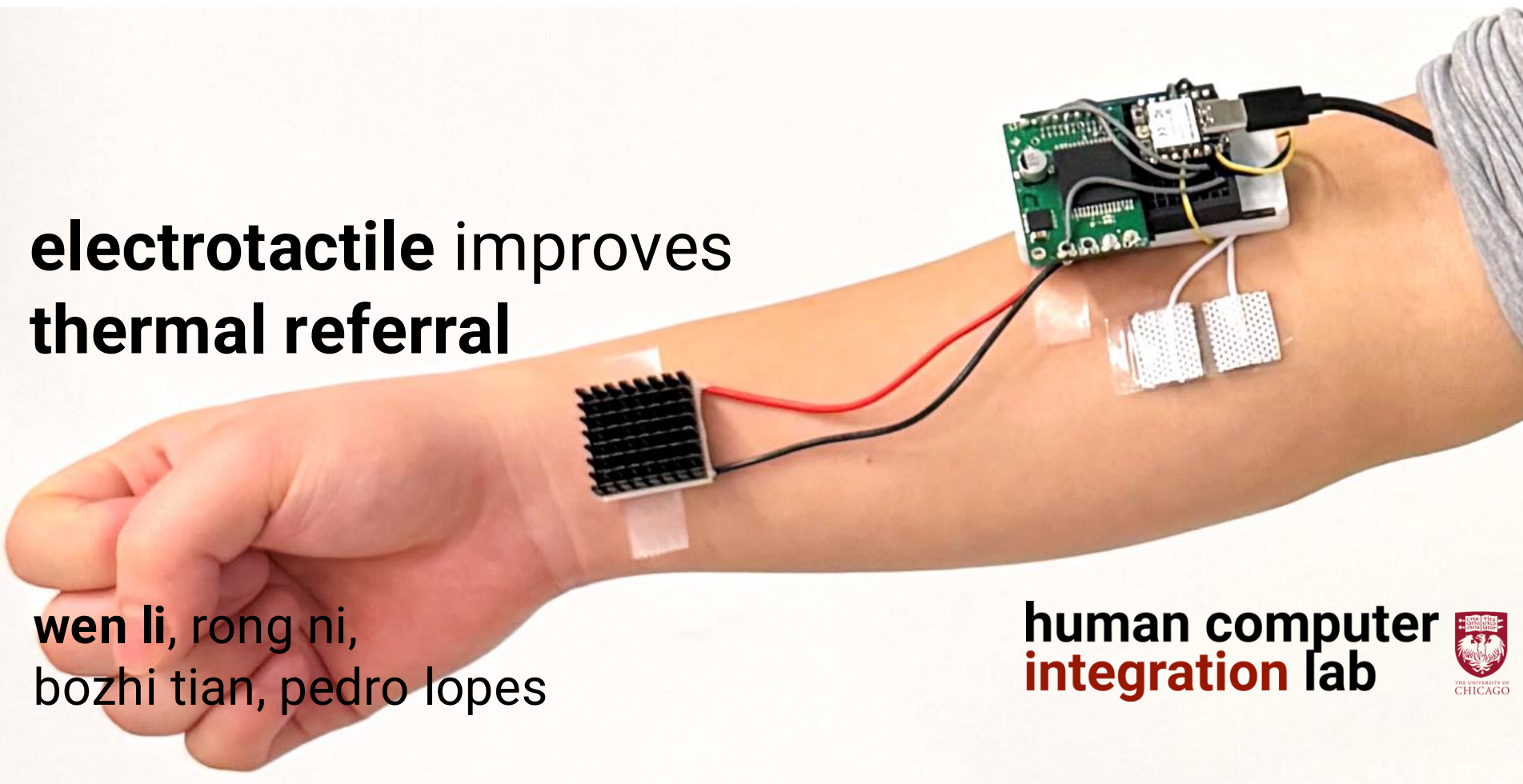
Electrotactile Improves Thermal Referral

Wen Li, Rong Ni, Bozhi Tian, Pedro Lopes. In Proc. UIST'26 (paper)

Thermal referral enables thermal sensations at locations lacking thermal actuators by using vibrations to redirect a nearby thermal sensation. This allows systems to replace some thermal actuators with smaller, lower-power vibration motors. However, we found that relying on vibration introduces two limitations: it struggles to reliably produce cold referral, and its strong tactile “buzz” makes it unsuitable for simulating non-contact thermal events (imagine the experience of a cold chill as you open a freezer in a virtual simulation). We propose a shift from vibrotactile to electrotactile stimulation. Our results confirm that electrotactile thermal referral significantly improves cold-referral rates and perceived thermal quality while minimizing distracting tactile sensations, dramatically expanding thermal referral’s applicability.

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electrotactile improves **thermal referral**

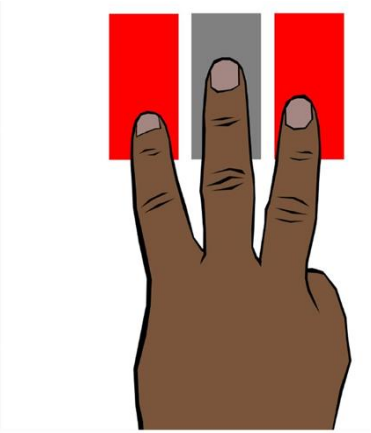


wen li, rong ni,
bozhi tian, pedro lopes

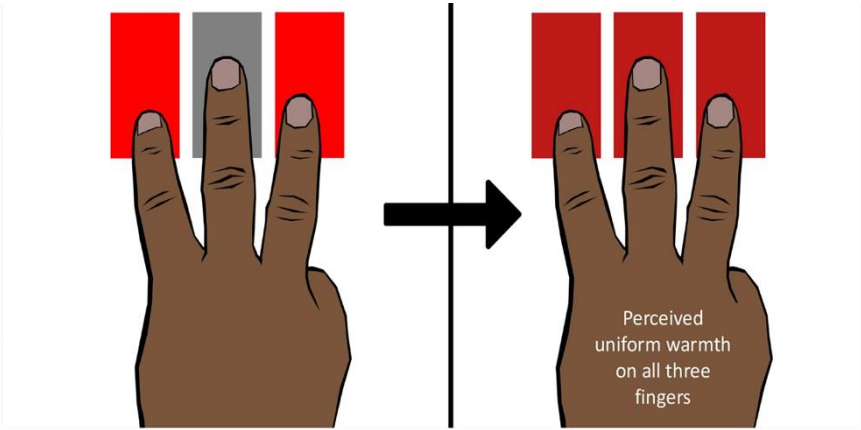
human computer
integration lab
THE UNIVERSITY OF CHICAGO

1. related work

thermal referral

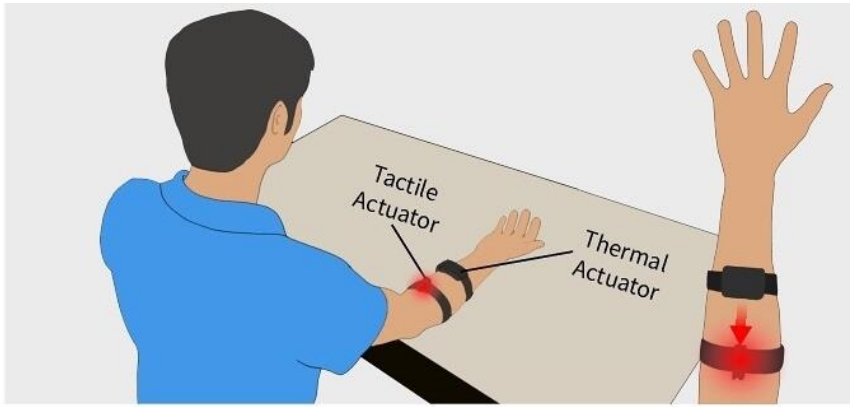


Karmakar et al., *Front. Hum. Neurosci.*, 2023



Karmakar et al., *Front. Hum. Neurosci.*, 2023

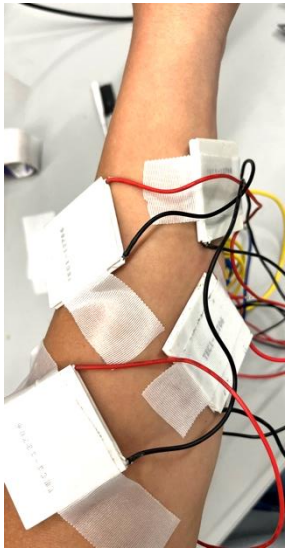
Karmakar et al., *Front. Hum. Neurosci.*, 2023



Wang et al., *CHI*, 2024

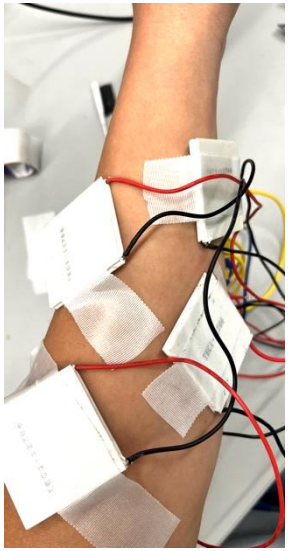
power-hungry, bulky



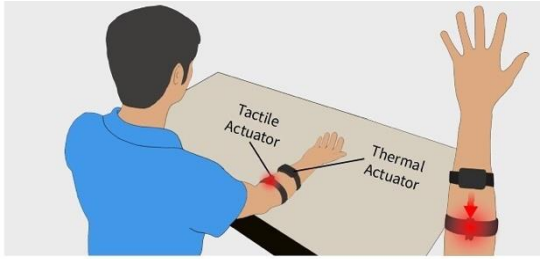


power-hungry, bulky

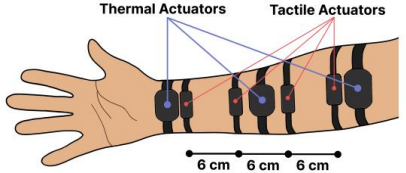




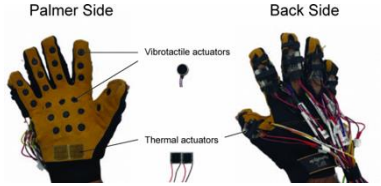
with thermal referral



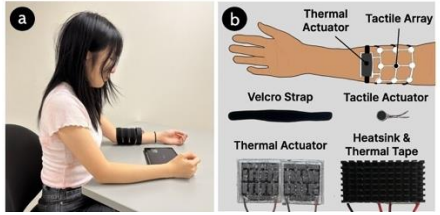
Wang et al., *CHI*, 2024



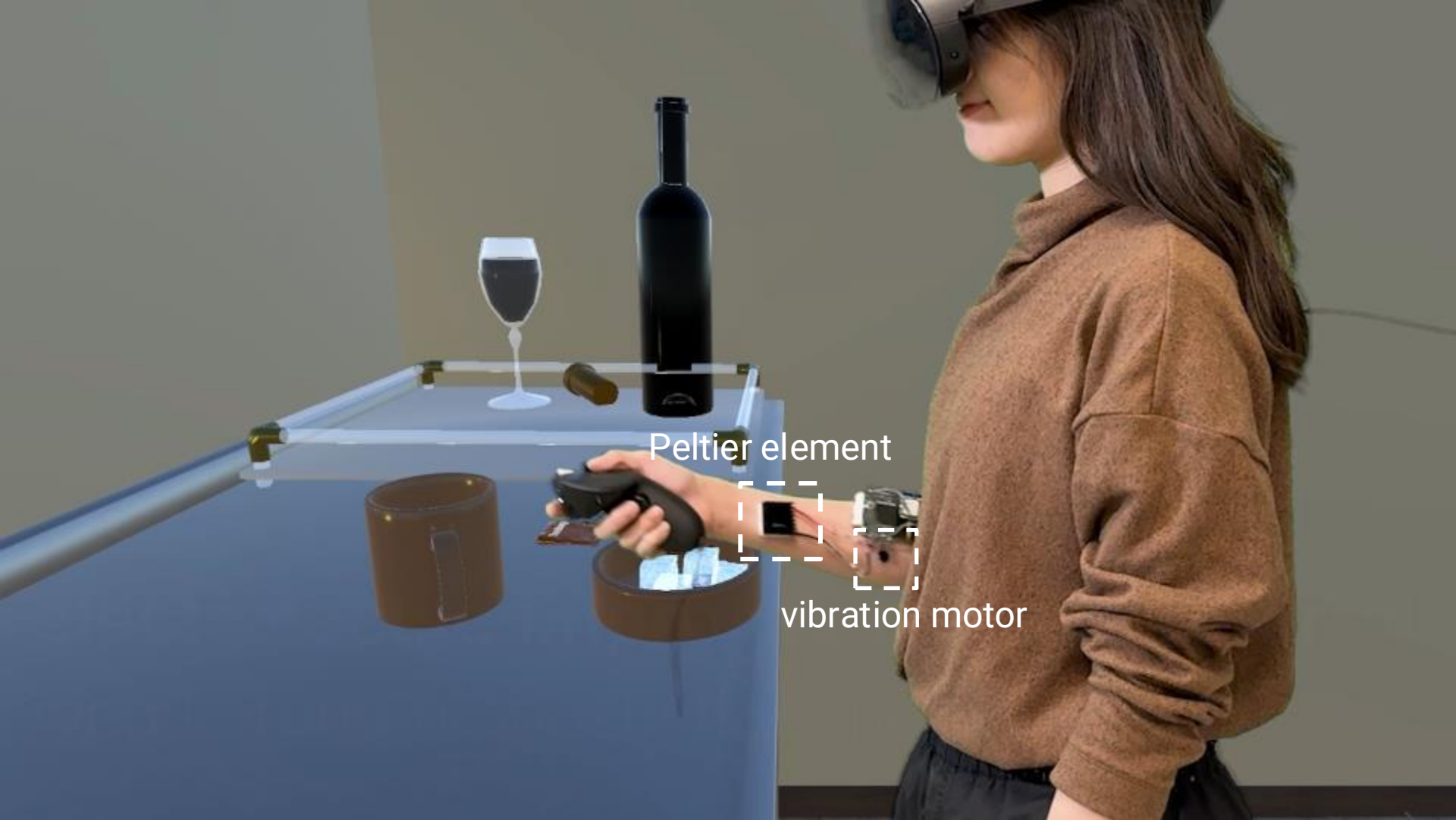
Singhal et al., *UIST*, 2024



Wang et al., *ISMAR*, 2024



Singhal et al., *UIST*, 2025


Peltier element
vibration motor



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Watch: https://www.youtube.com/watch?v=iwoeuEEQqQg

2. our approach

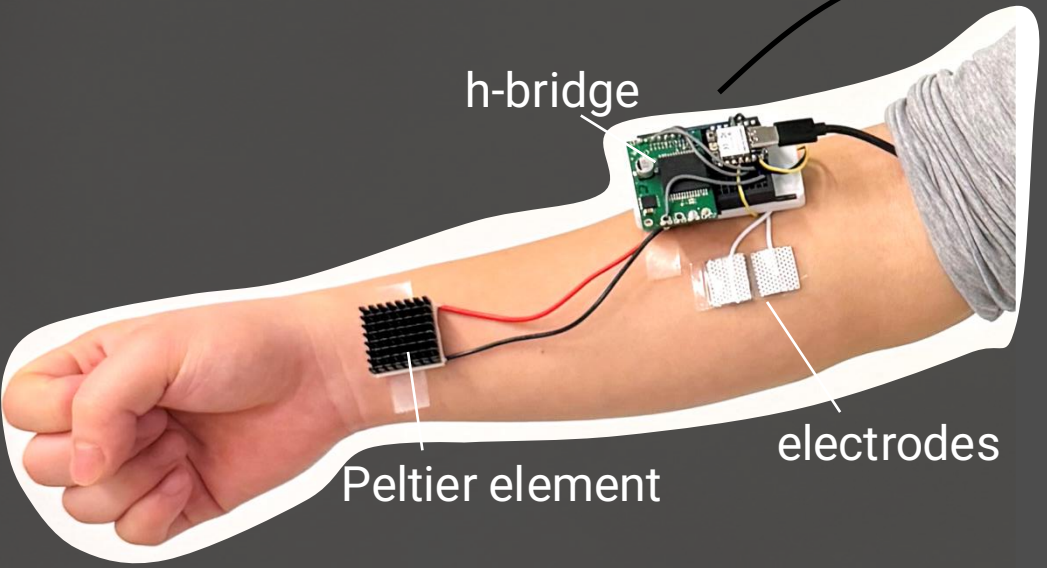


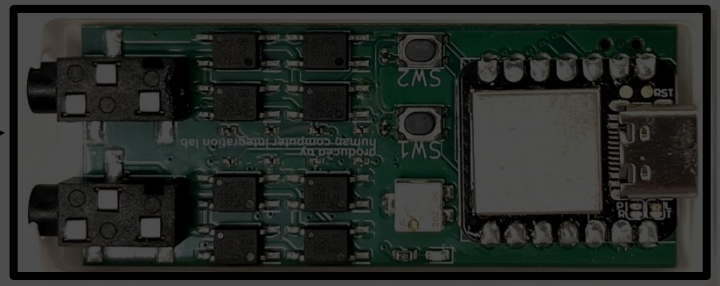
Watch: https://www.youtube.com/watch?v=iwoeuEEQqQg



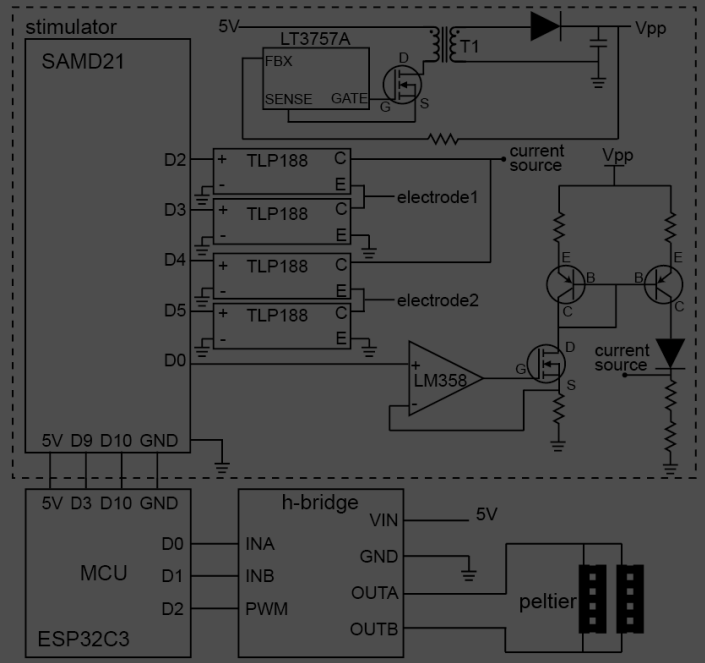
Watch: https://www.youtube.com/watch?v=iwoeuEEQqQg

3. implementation

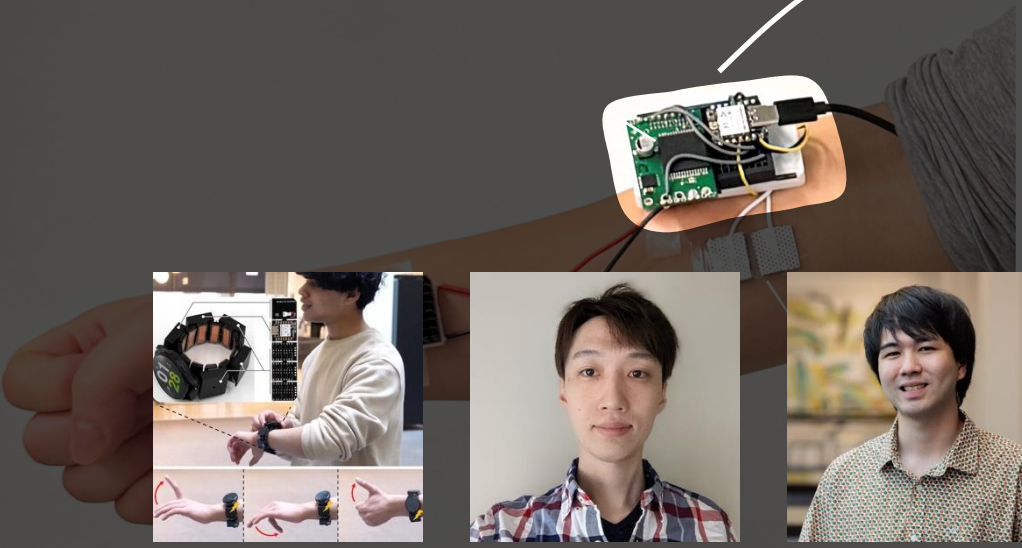




custom stimulator



on the back



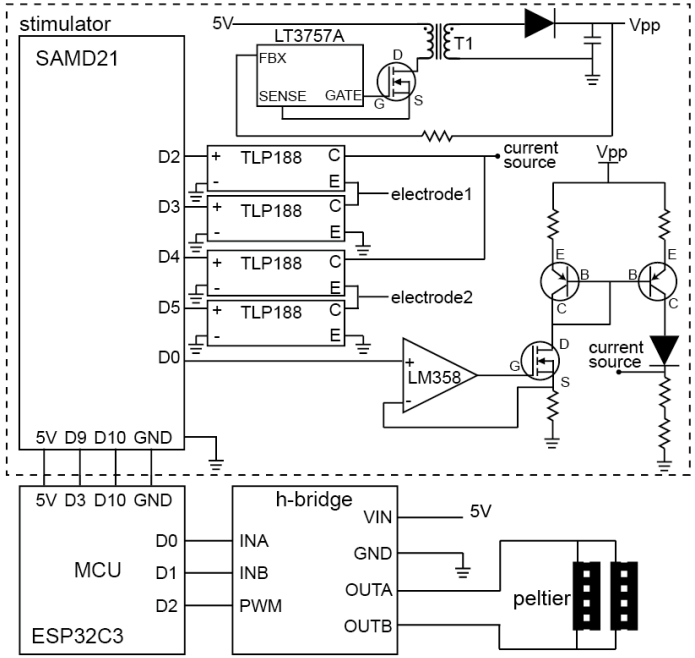
Takahashi et al. UIST, 2024

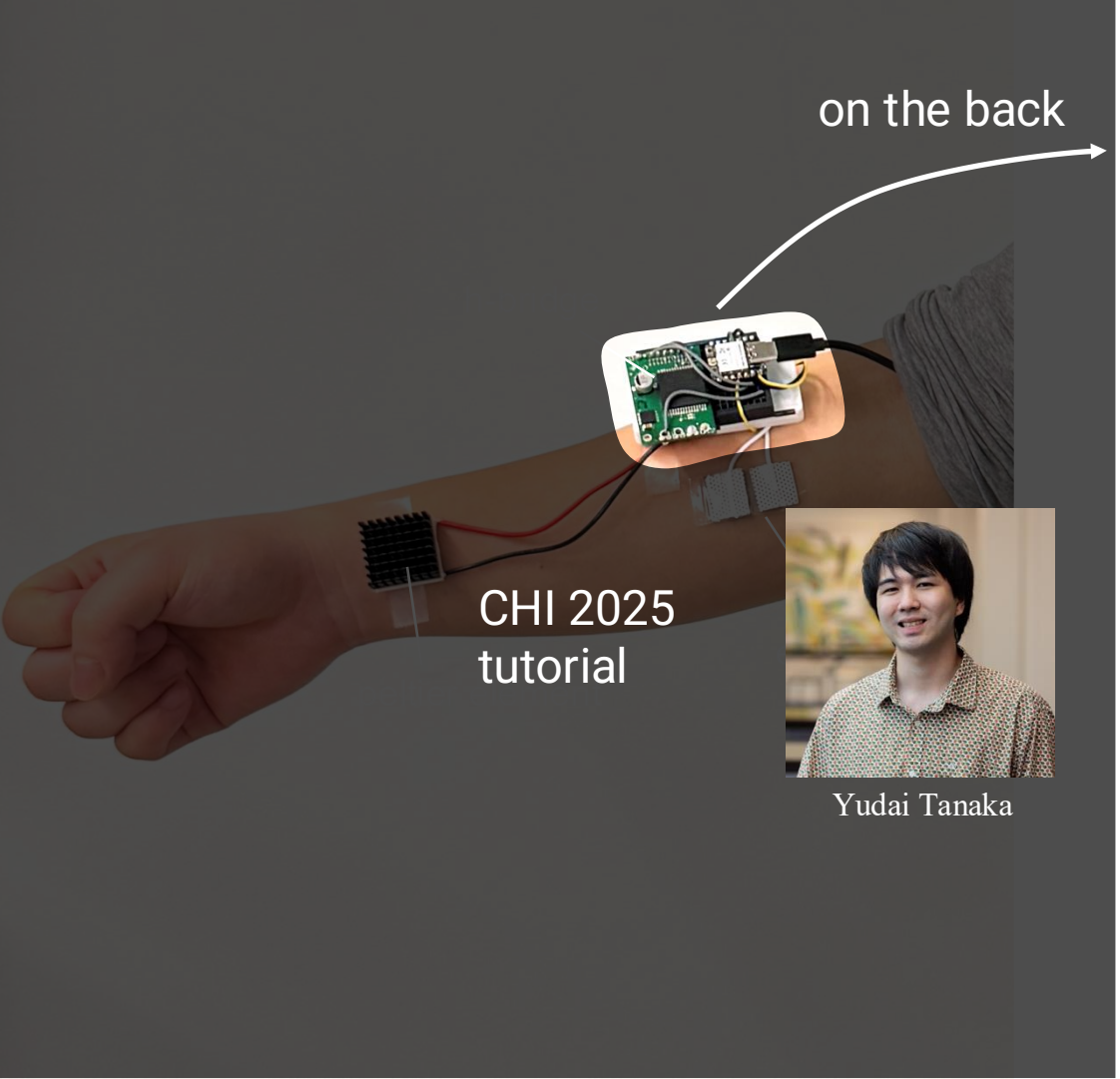
Akifumi Takahashi

Yudai Tanaka



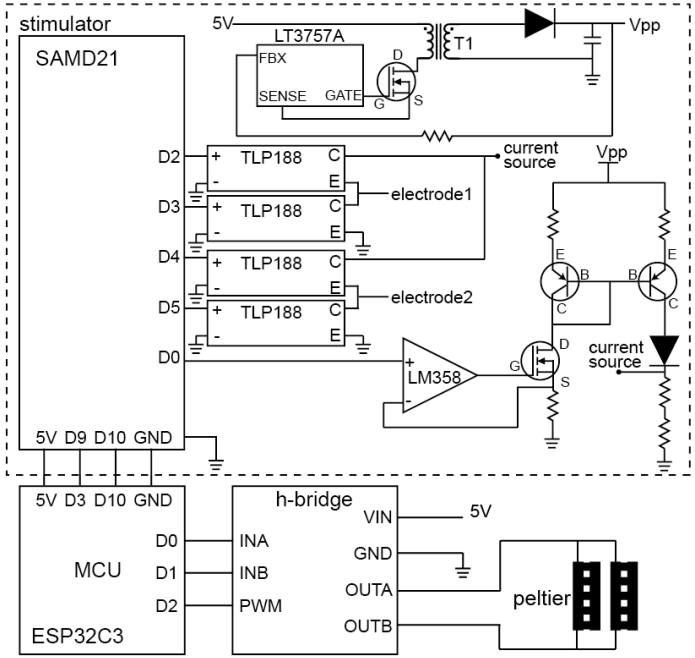
custom stimulator







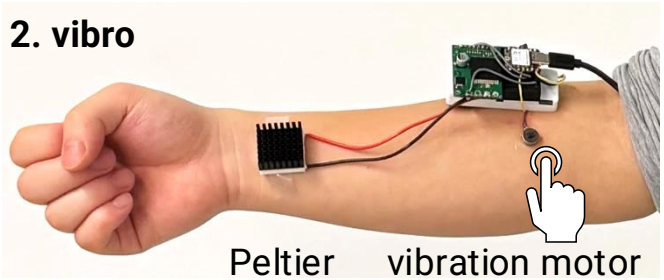
custom stimulator

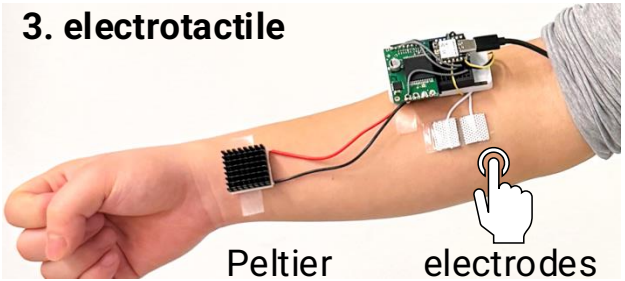


4. user studies

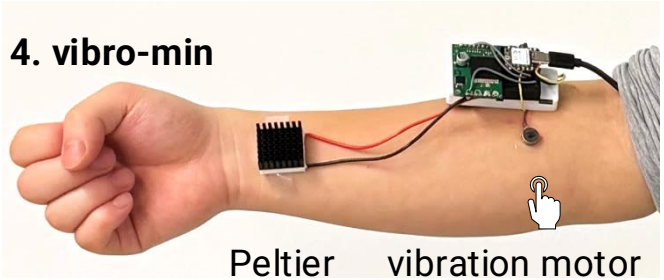
study 1: psychophysics

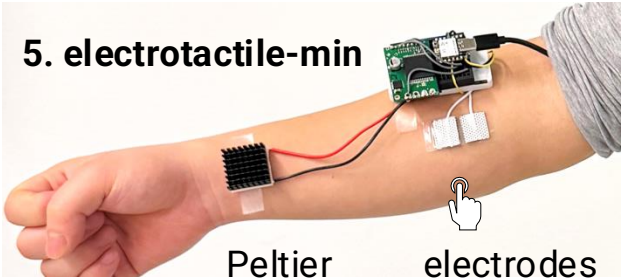
1. no tactile



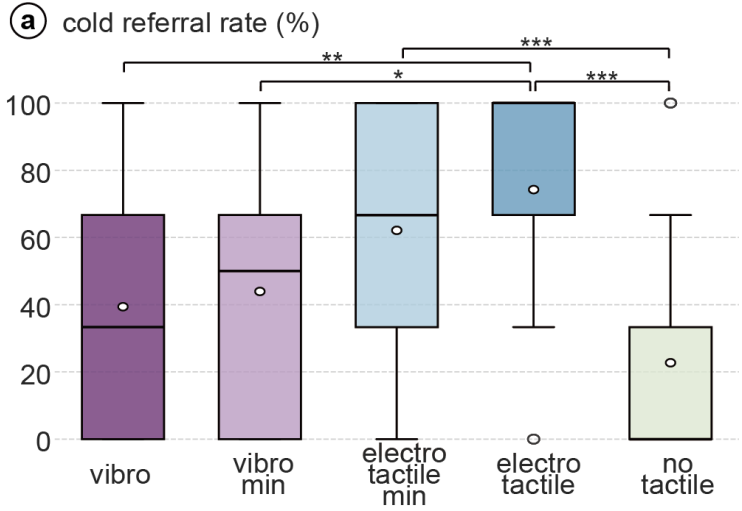


how much tactile stimulation do we actually need?

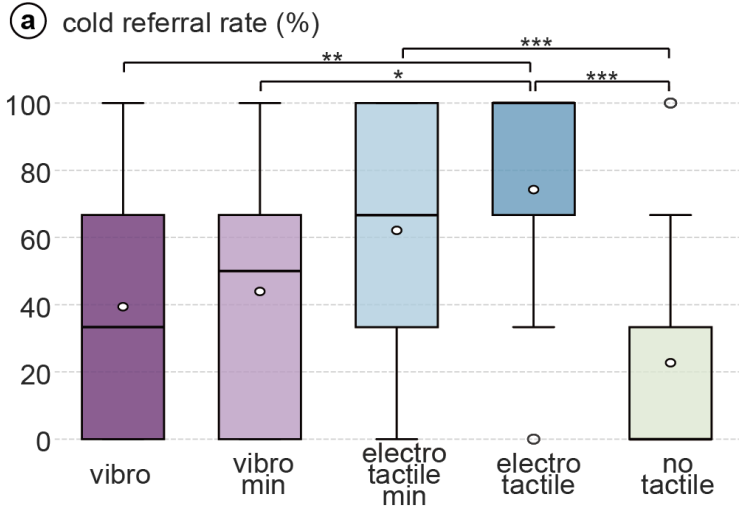




referral rate: how often people reported thermal at the tactile location

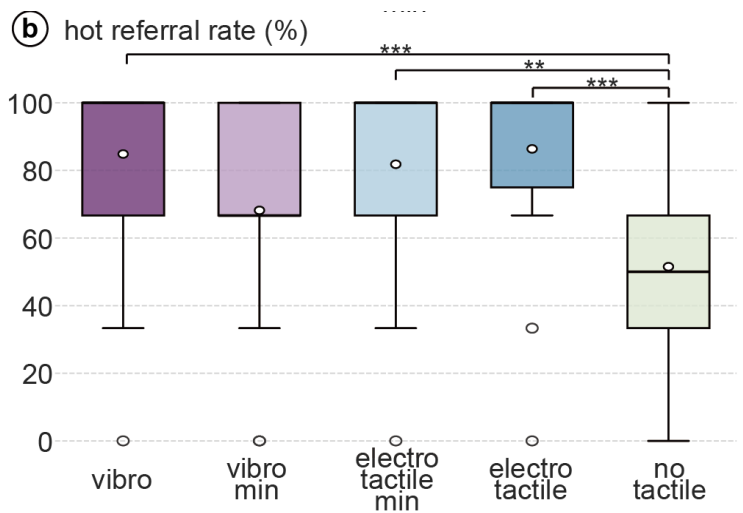


referral rate: how often people reported thermal at the tactile location

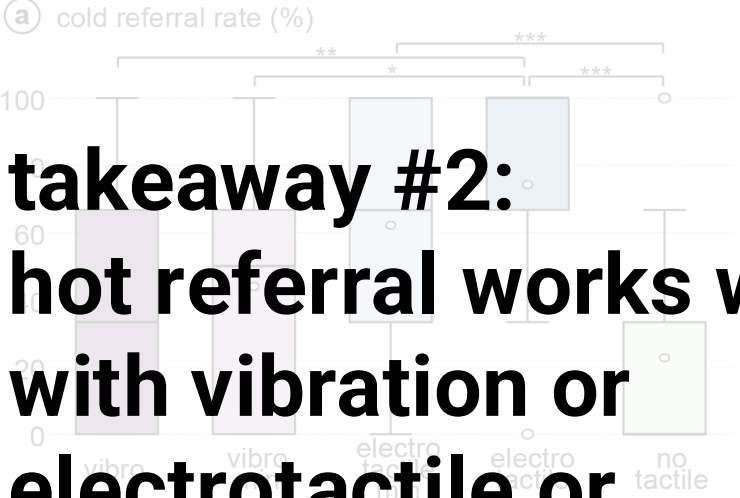


takeaway #1: electrotactile enables better cold referral

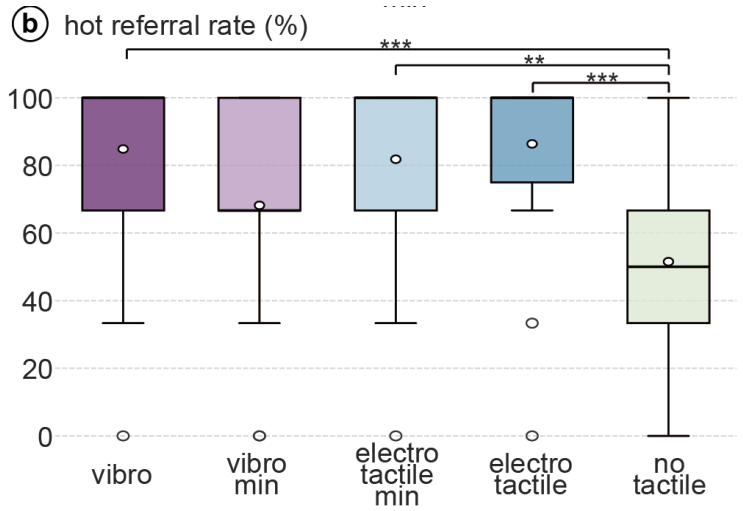
referral rate: how often people reported thermal at the tactile location



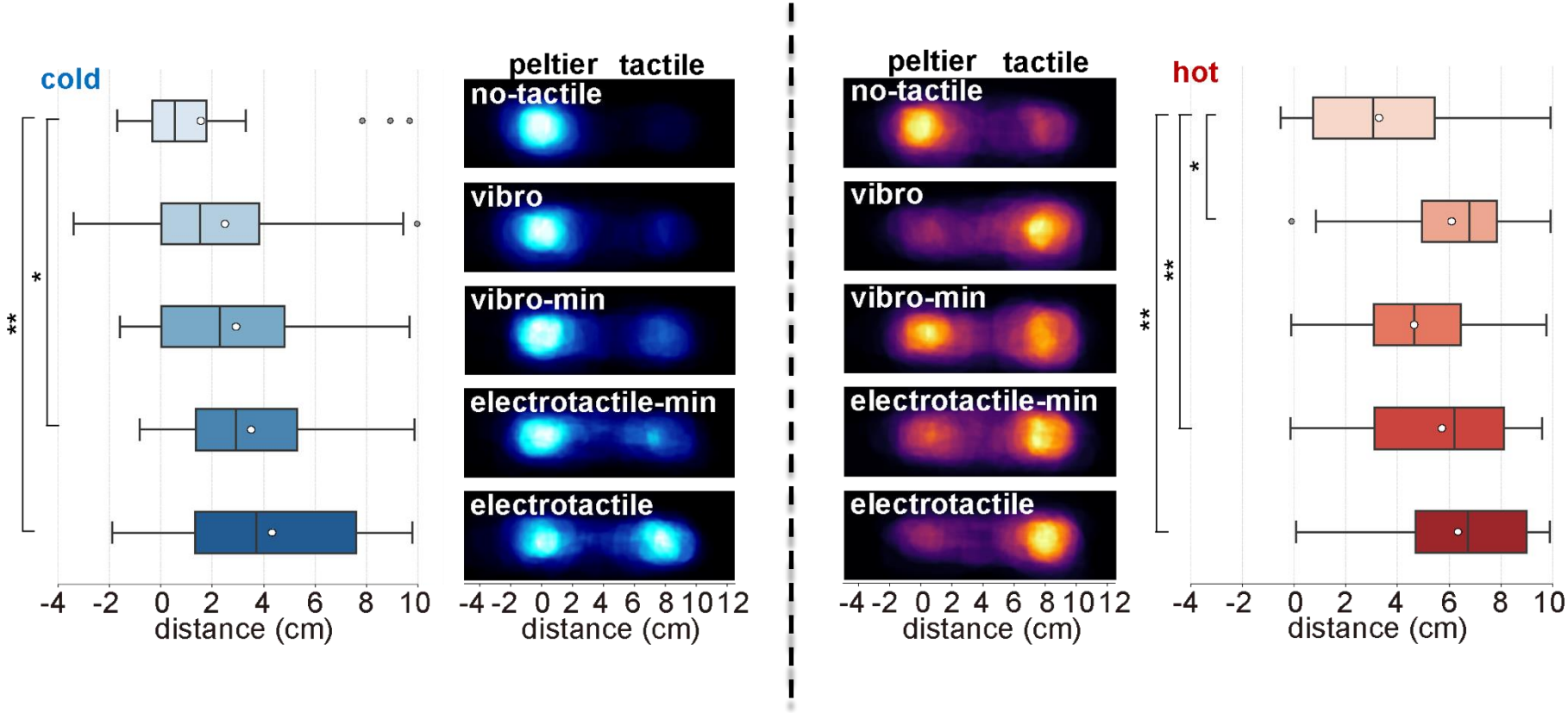
referral rate: how often people reported thermal at the tactile location



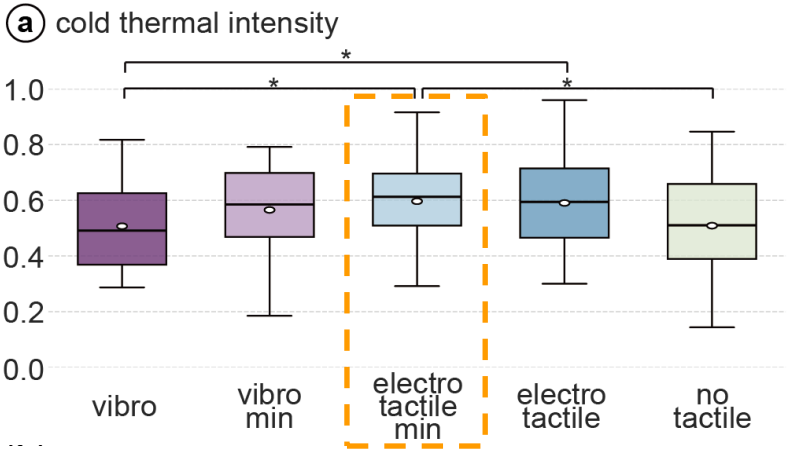
takeaway #2: hot referral works well with vibration or electrotactile or electrotactile-min

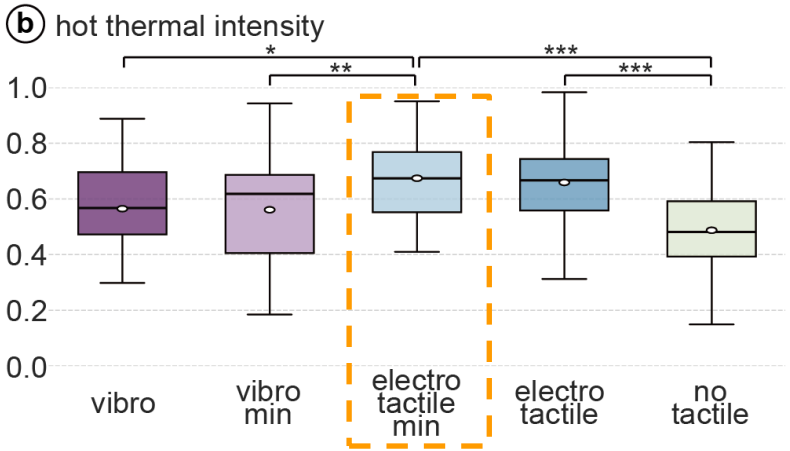


electrotactile moves cold sensation closer to tactile

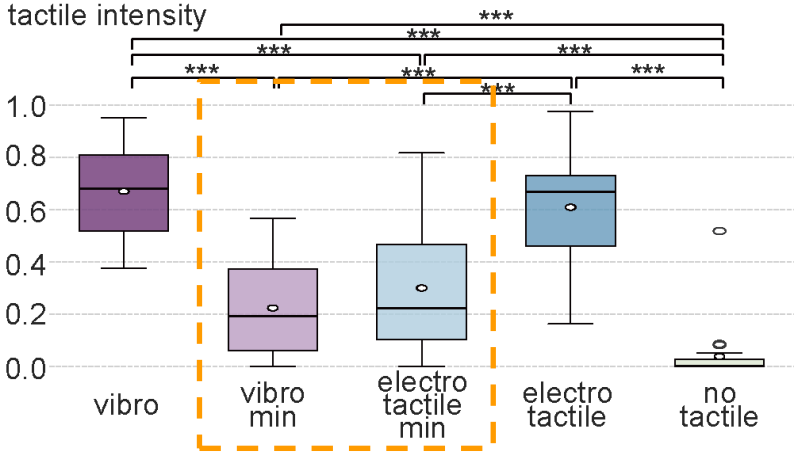


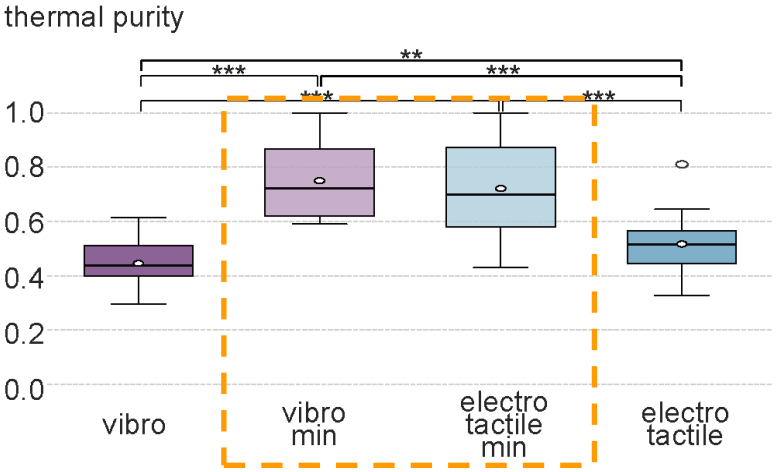
electrotactile improves the perceived thermal intensity



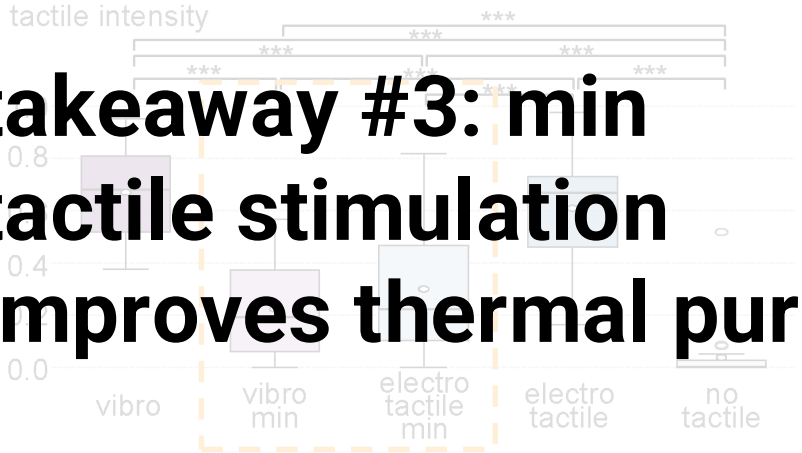


$$thermal\ purity = \frac{thermal\ intensity}{thermal\ intensity + tactile\ intensity}$$

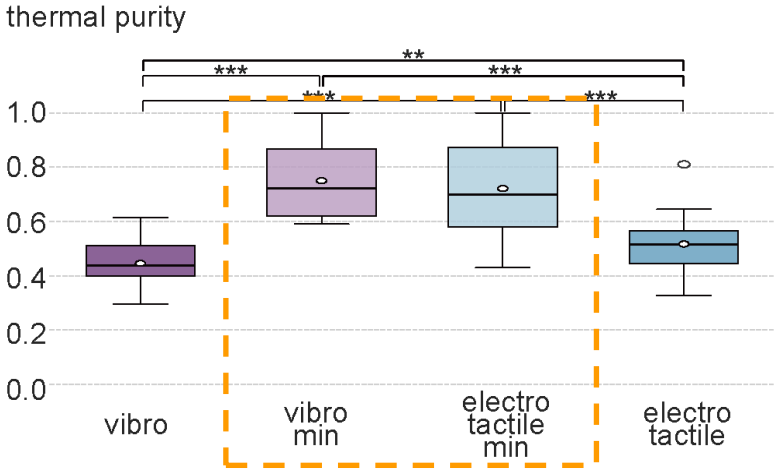




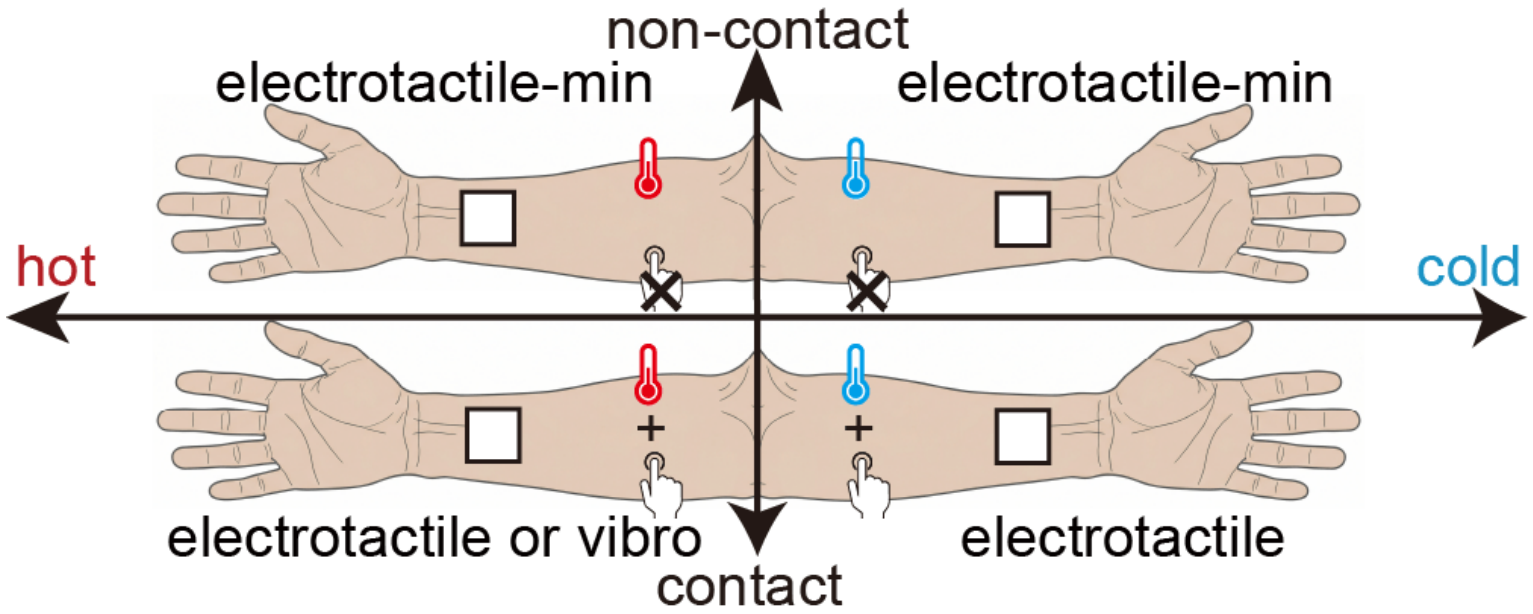
$$thermral\ purity = \frac{thermal\ intensity}{thermal\ intensity + tactile\ intensity}$$



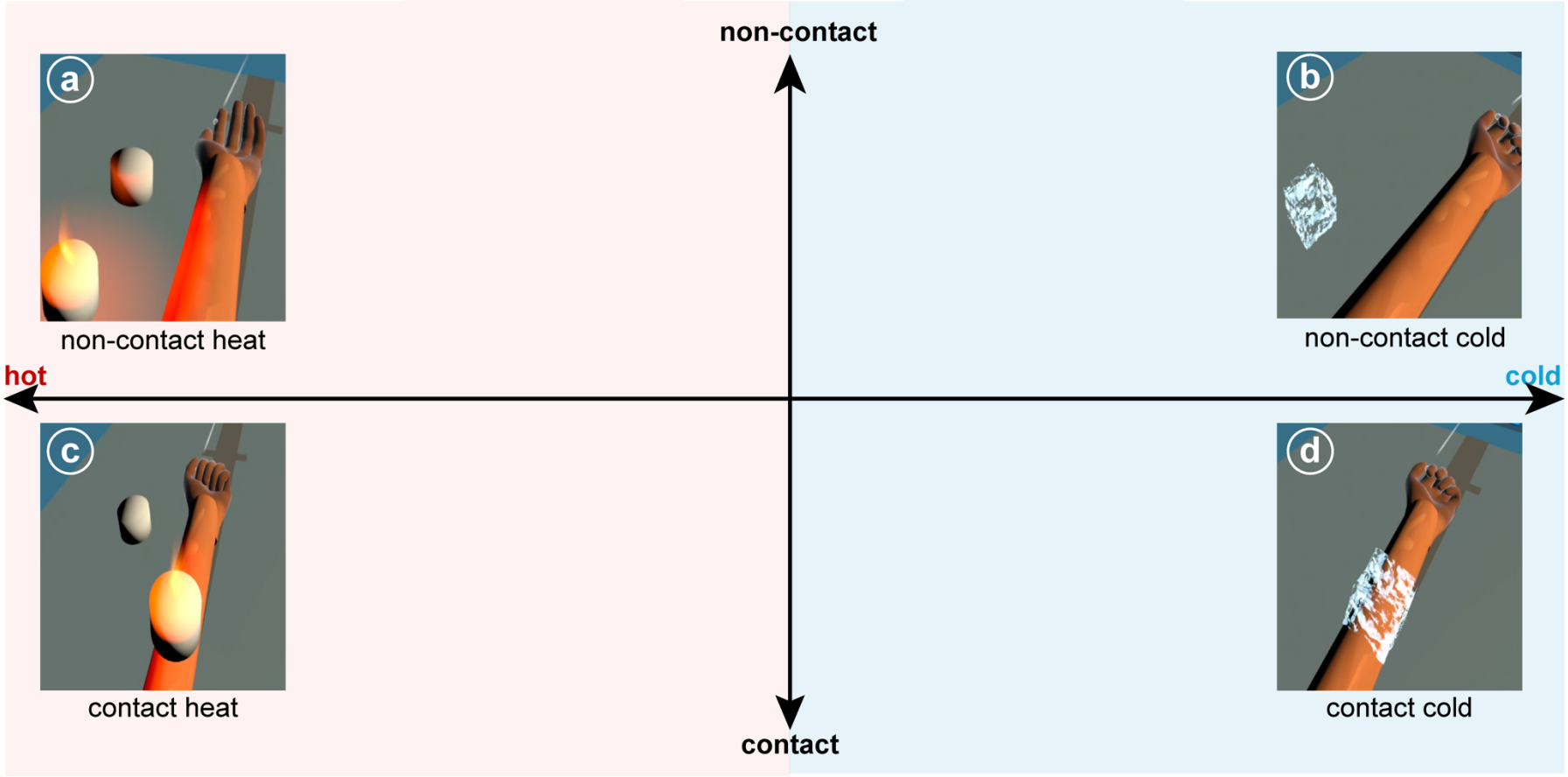
takeaway #3: min tactile stimulation improves thermal purity



takeaway #4: in combination = new guidelines

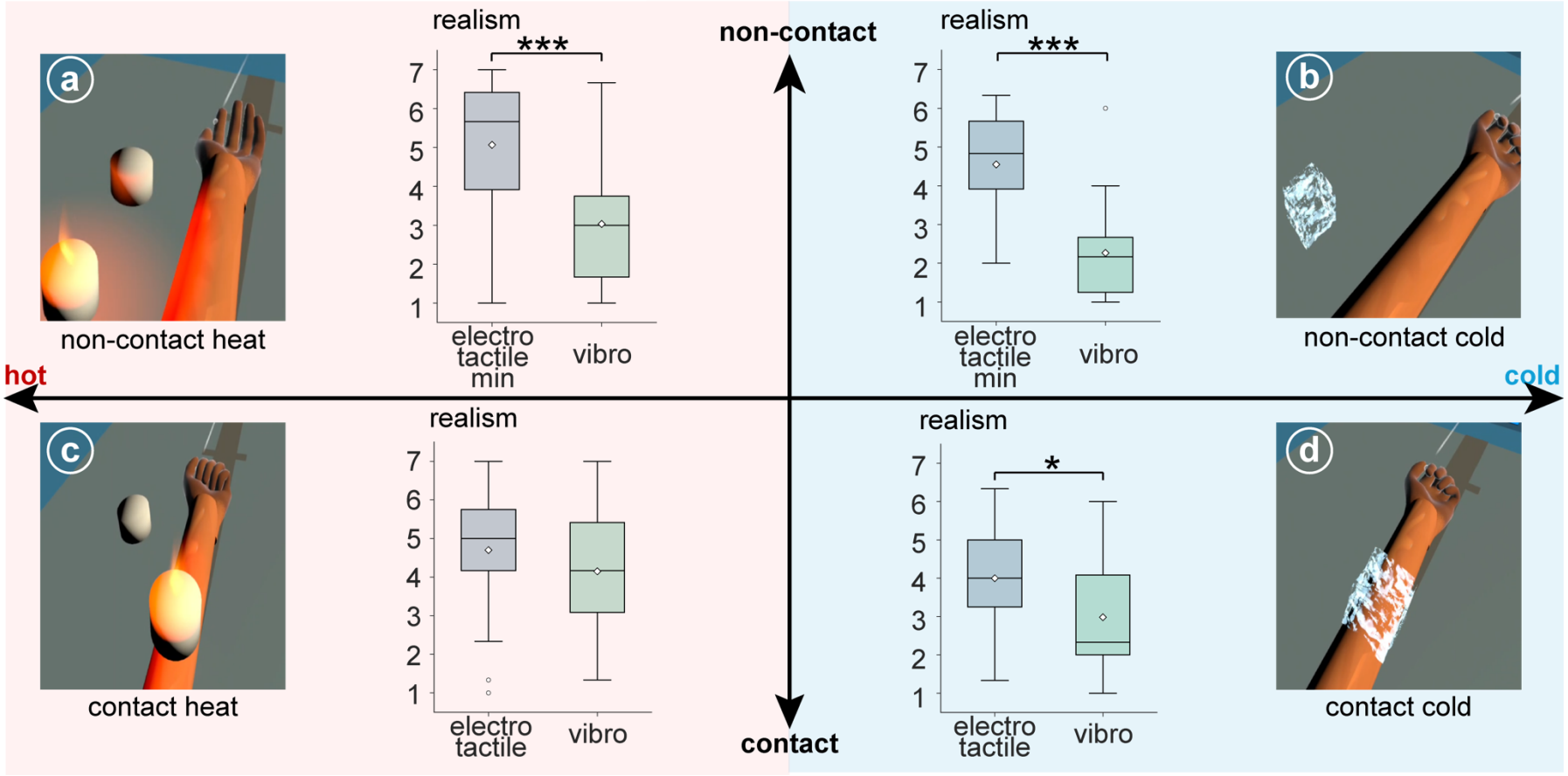


study 2: VR


non-contact
a
b
non-contact heat
non-contact cold
hot
cold
c
d
contact heat
contact cold
contact

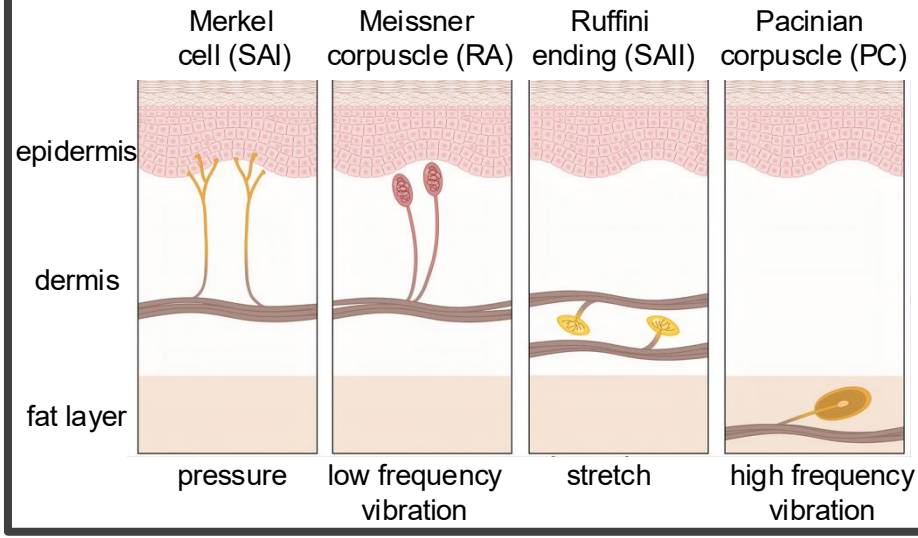
study 2: VR

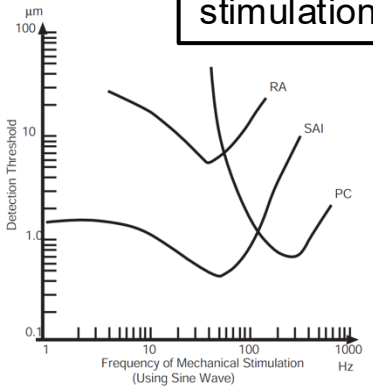
takeaway #5: increased realism



5. (side note on neuroscience)

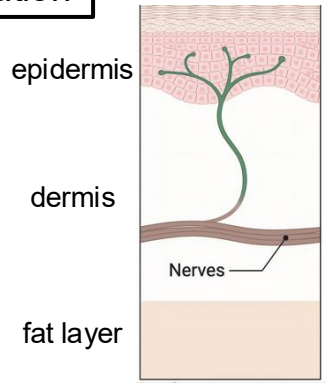
1. broad mechanoreceptor stimulation





Kajimoto et al., *IROS*, 2004

2. A-δ fiber stimulation





local anesthetic cream and electrotactile produce cold sensation

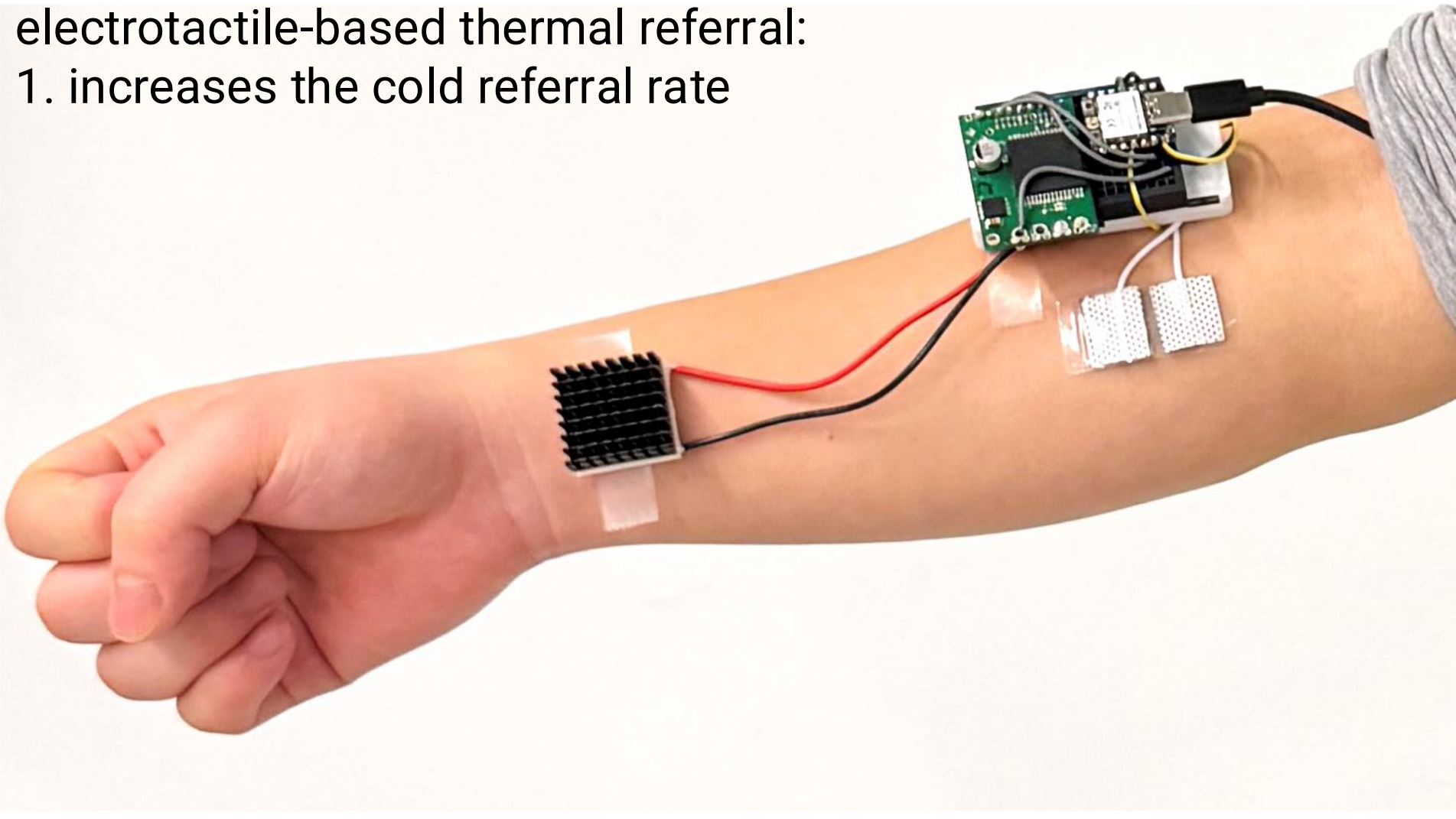
Saito et al., *AHs*, 2023

6. applications


Watch: https://www.youtube.com/watch?v=iwoeuEEQqQg

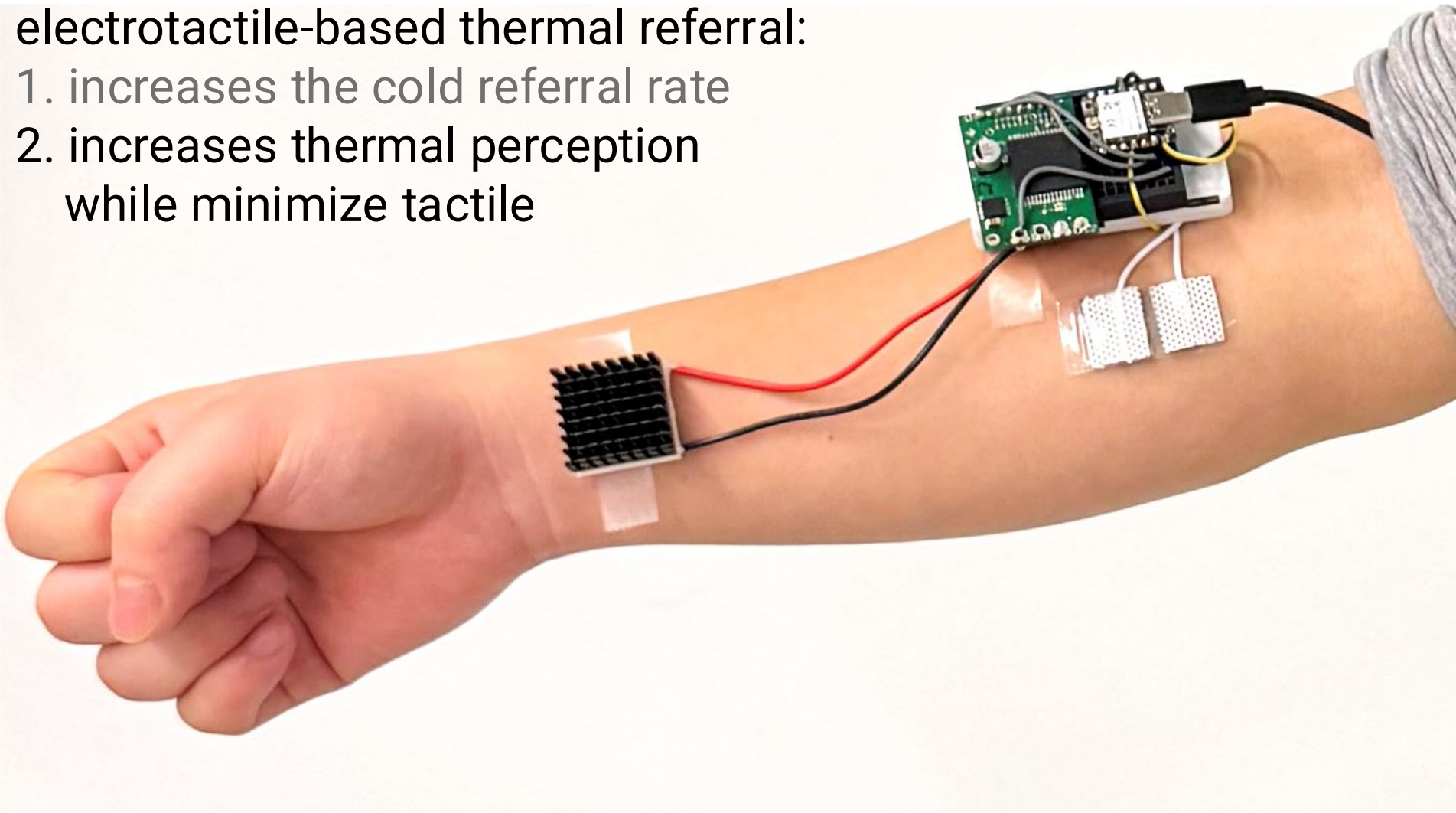
7. conclusions

electrotactile-based thermal referral:
1. increases the cold referral rate



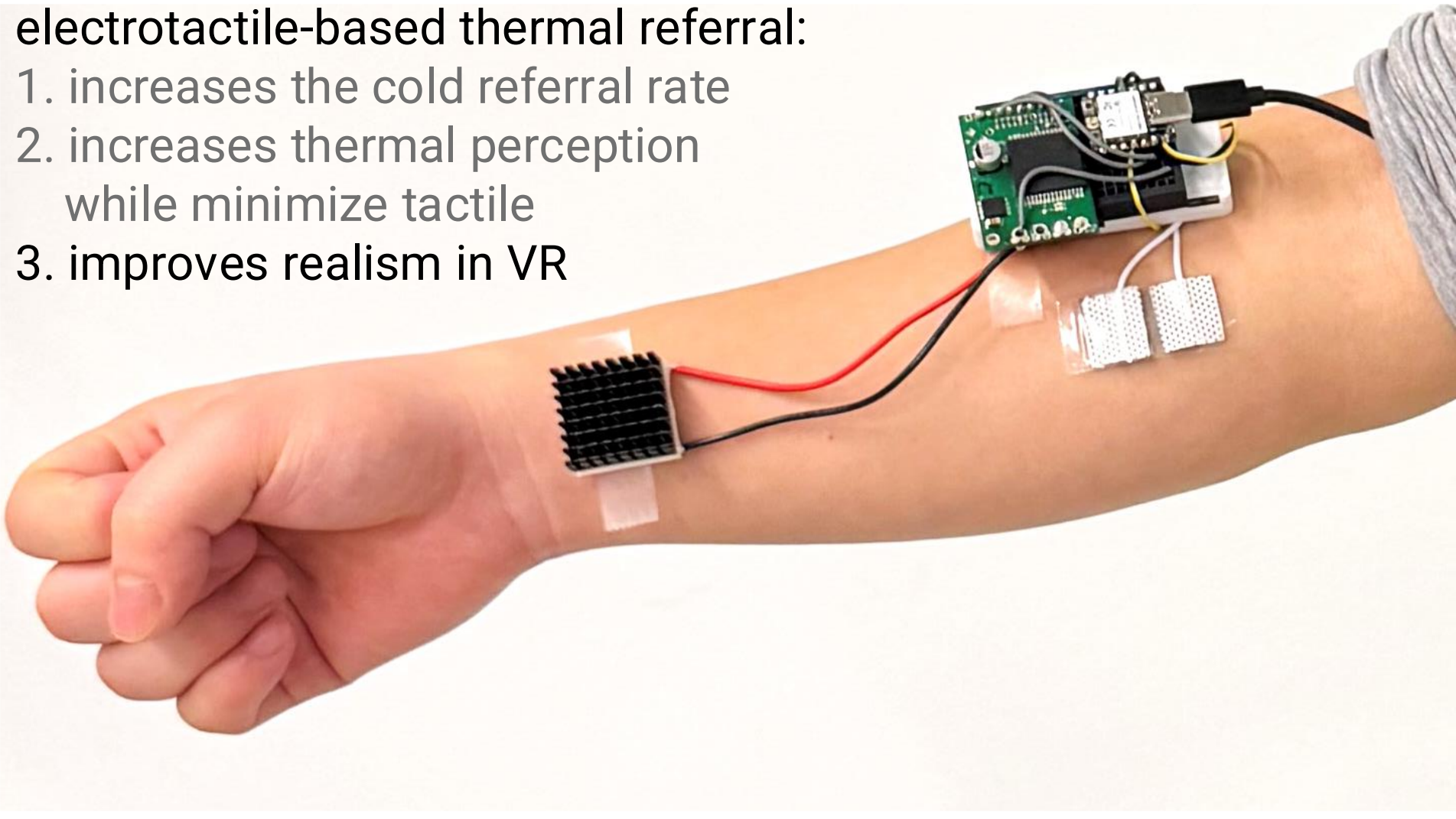
electrotactile-based thermal referral:

1. increases the cold referral rate
2. increases thermal perception
   while minimize tactile

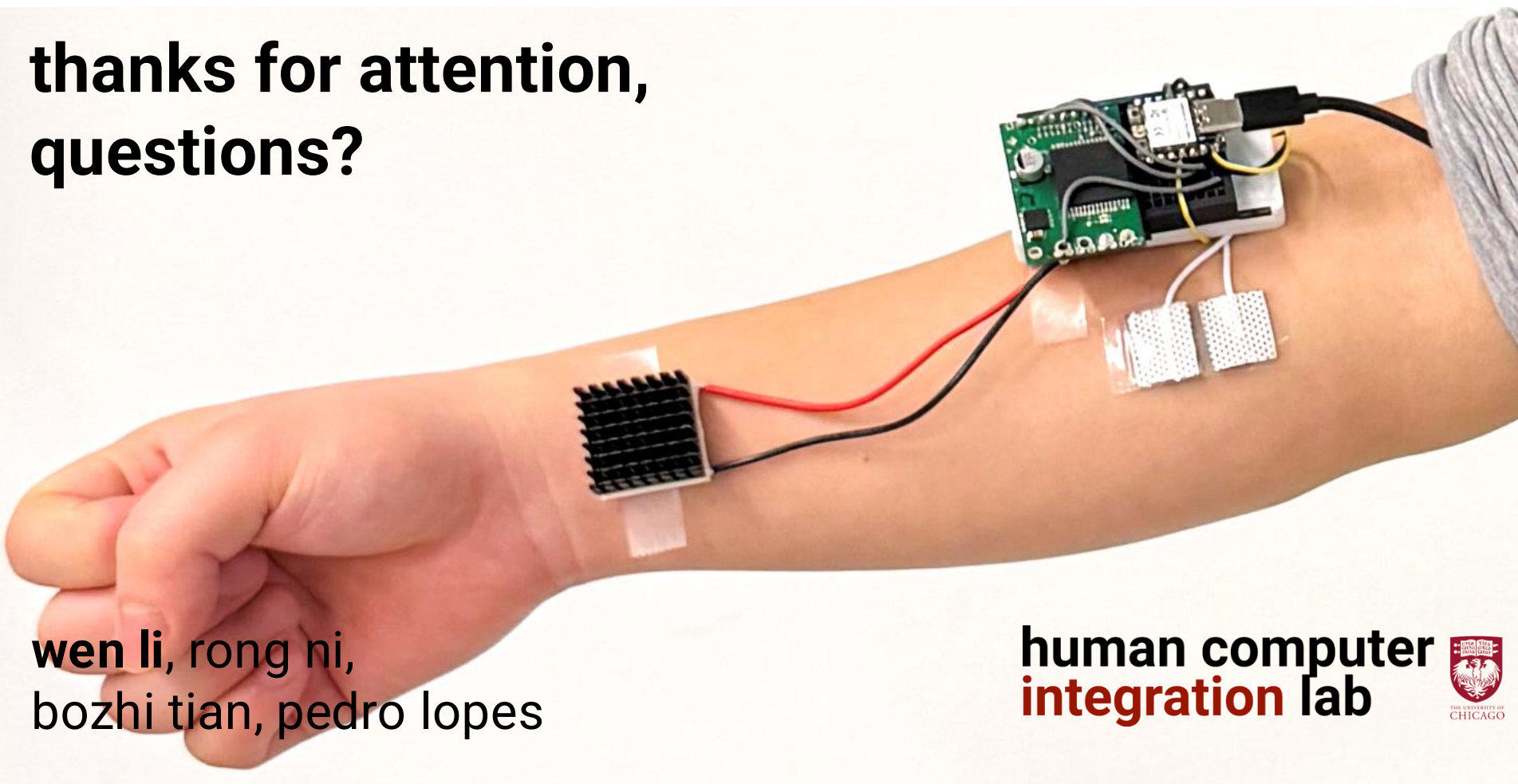


electrotactile-based thermal referral:

1. increases the cold referral rate
2. increases thermal perception
   while minimize tactile
3. improves realism in VR



thanks for attention, questions?



wen li, rong ni,
bozhi tian, pedro lopes

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integration lab
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If you need a PPTX/editable version for your class, email us hci@uchicago.edu
More information on this paper: https://lab.plopes.org/#electro-thermal-referral



Electrotactile Improves Thermal Referral

Wen Li, Rong Ni, Bozhi Tian, Pedro Lopes. In Proc. UIST'26 (paper)

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