Cortical Activation Patterns During Visual and Vibrotactile Emotion Stimulation: A Comparative fNIRS Study

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Lena Schubart received the master's degree in Digital Business Systems from the Technical University of Applied Sciences Würzburg-Schweinfurt, Germany, in 2026. She is currently working as a research assistant (HiWi) at the Technical University of Applied Sciences Würzburg-Schweinfurt, contributing to a project led by doctoral researcher Marie Herz on an emotion-sensing glove, which also forms part of her research work.

Her research interests lie in the intersection of accessibility, neuroscience, and psychology, with a particular focus on human-centered applications of emerging technologies.

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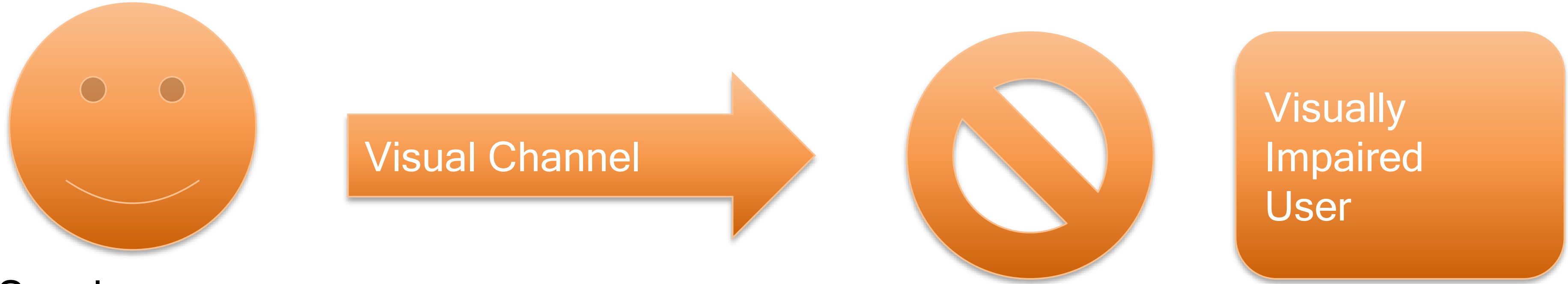
Problem: Emotional Information is Visual



Speaker
(Facial expressions)

- > 50% of emotional information in conversations is conveyed through non-verbal signals
- 2.2 billion people worldwide live with visual impairments (36 million blind)

Background

Theoretical Background

- Emotions can be communicated through touch
- Vibrotactile systems enable emotion transmission
- Emotion processing may be modality-independent

Research Gap

Previous research demonstrates the behavioral effectiveness of haptic emotion communication. However, it remains unclear whether haptic emotional stimuli evoke similar neural activation patterns as visual stimuli. To the best of our knowledge, direct neurophysiological comparisons between these modalities remain limited.

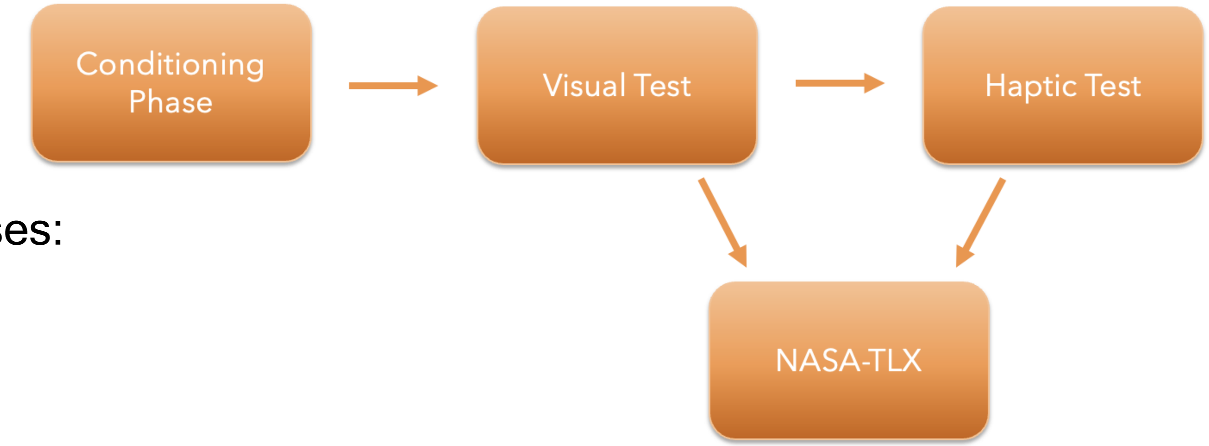
Research Question & Hypotheses

Research Question: Does emotional processing differ between haptic and visual modalities of information transmission?

H1: H1: Haptic emotional stimuli lead to comparable prefrontal activation as visual stimuli.

H2: Haptic emotional stimuli lead to higher cognitive load than visual emotional stimuli.

Study Design



The experiment consists of three consecutive phases:

1. Conditioning Phase

2. Visual Test Phase

3. Haptic Test Phase

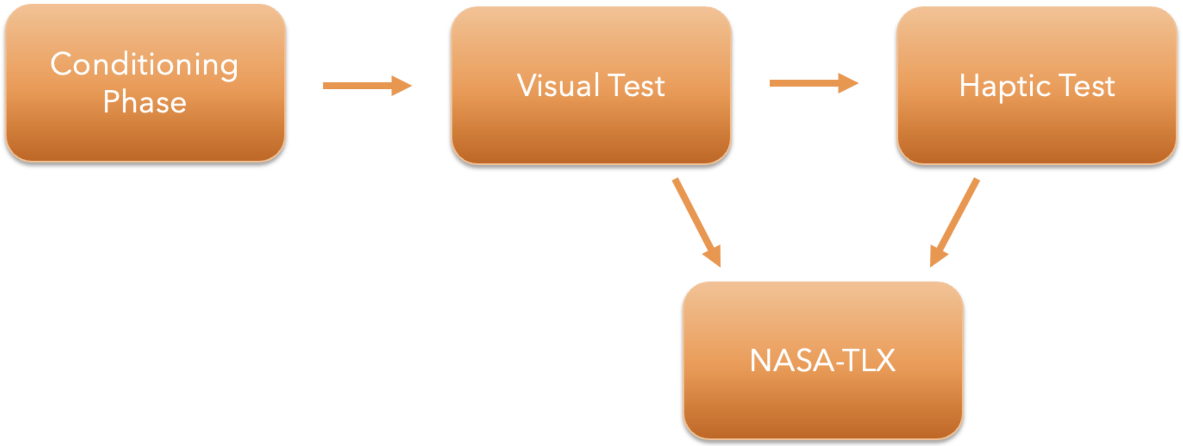
After each test phase, subjective cognitive workload is assessed using the NASA-TLX questionnaire.

Conditioning Phase

Participants learn the association between visual emotional stimuli and vibrotactile patterns.

- Visual stimuli: FACES database (6 emotions)
- Each image: 4 s → followed by vibration (specific finger)
- Repeated presentations to strengthen emotion-vibration mapping
- 5 s pause between stimuli (hemodynamic response)
- Memory Check: Participants must correctly recall the emotion-finger mapping

Study Design



Visual Test Phase

- Same facial stimuli as in conditioning
- 5 s pause between stimuli
- Randomized order
- Participants report perceived emotion

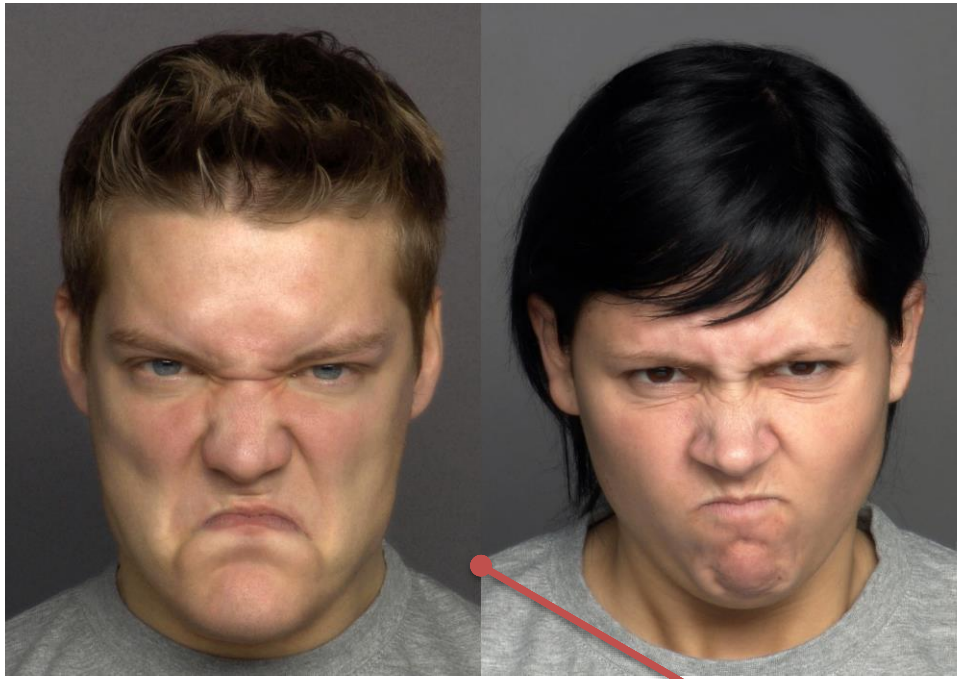
Haptic Test

- Only vibration stimuli (200 ms)
- Delivered to specific fingers
- 5 s pause between stimuli
- Participants report perceived emotion

Cognitive Load

- NASA-TLX after each phase

Visual Stimuli



Happiness

Anger

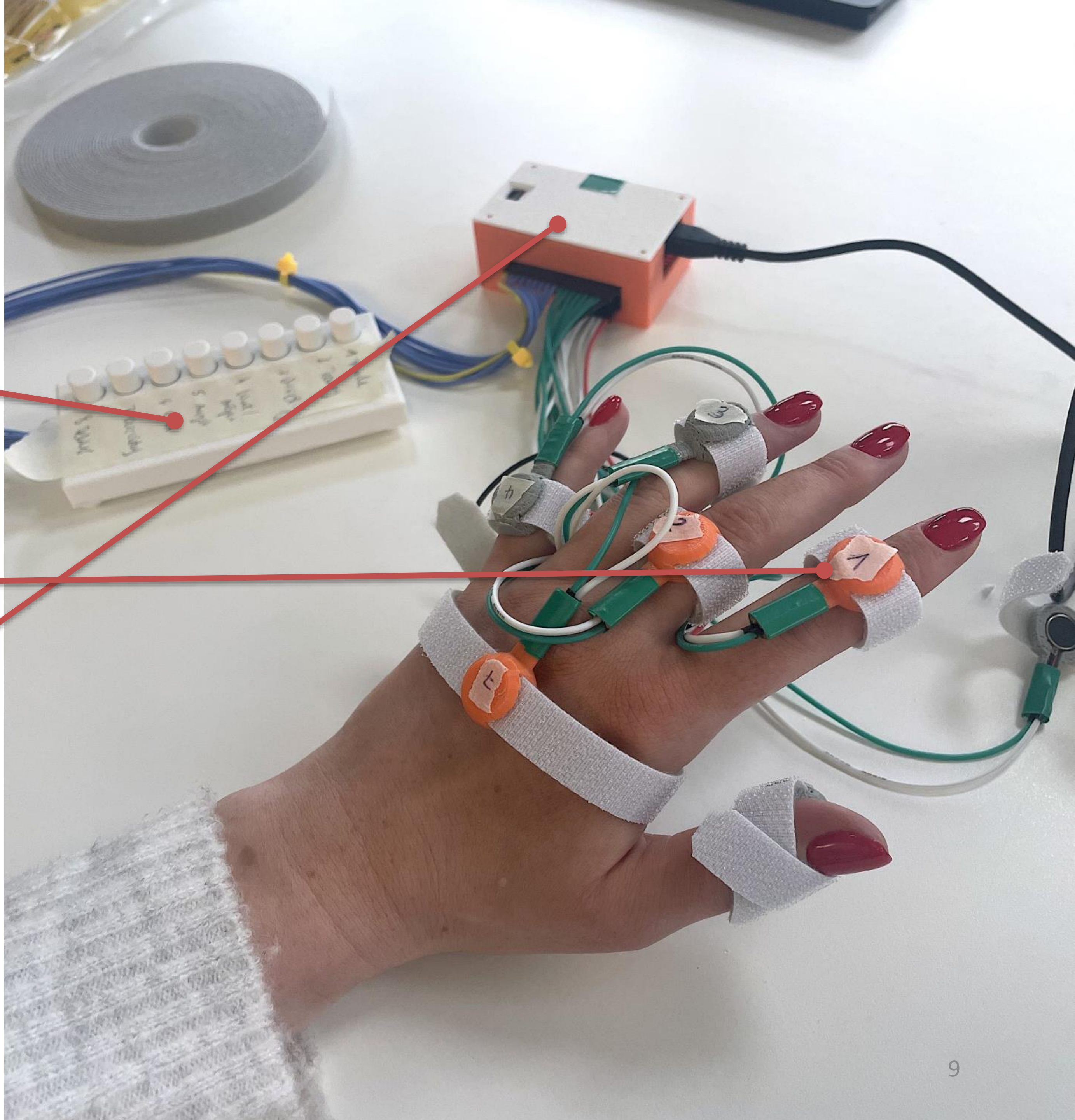
Two examples of visual stimuli from the FACES database
Source: Ebner et al. (2010)

laptic System

Button box / control unit

8 vibration motors

Microcontroller



Neurophysiological Measurement: fNIRS

fNIRS is a non-invasive neuroimaging method that measures changes in blood oxygenation in the brain.

How does fNIRS work?

When a brain region becomes active, it requires more oxygen. As a result, more oxygen-rich blood flows to this area.

This leads to:

- an increase in oxygenated hemoglobin (HbO)
- a decrease in deoxygenated hemoglobin (HbR)

fNIRS uses near-infrared light to detect these changes in blood oxygenation.

What does this mean?

An increase in HbO indicates higher neural activity in the measured brain region.

In this study, activity is measured in the prefrontal cortex, which is involved in:

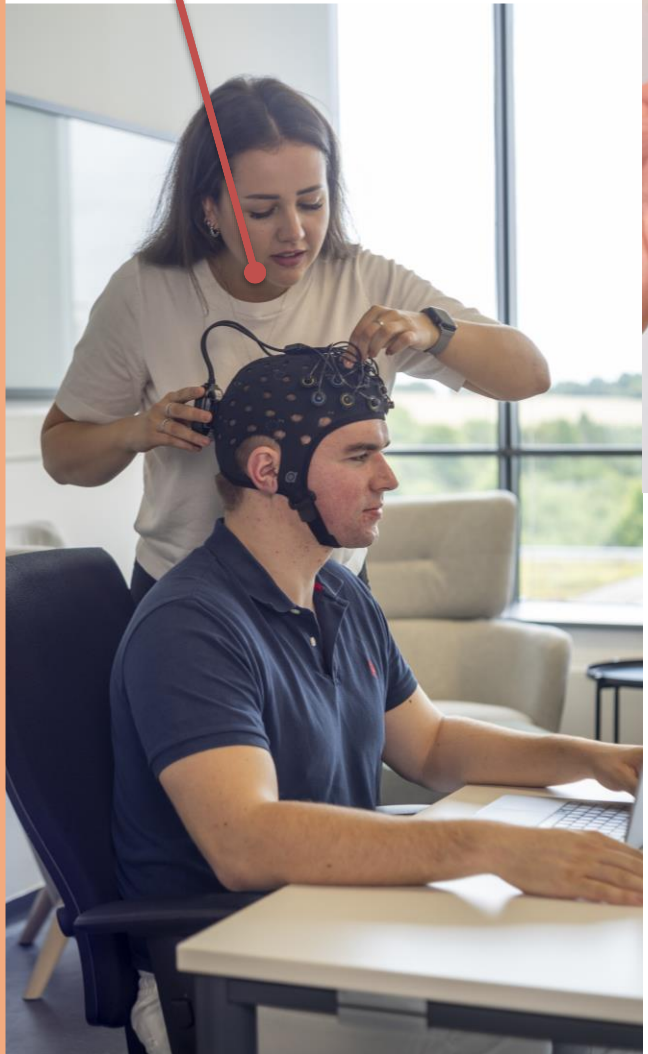
- emotional evaluation
- cognitive control
- decision-making

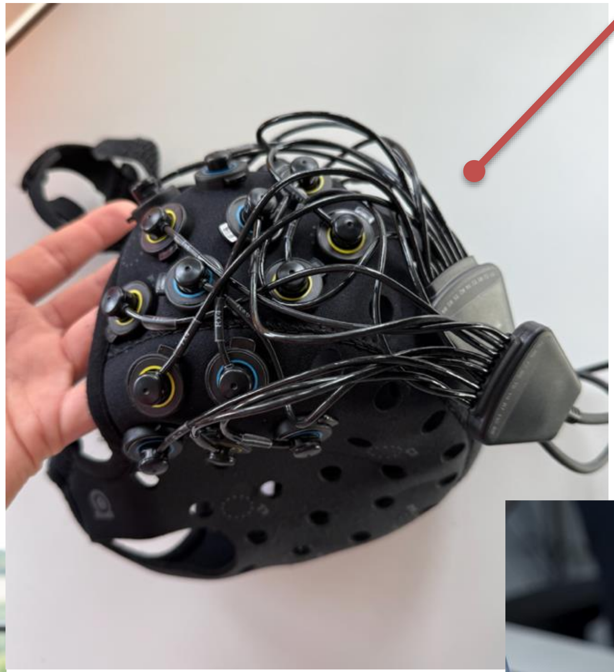
Artinis Brite24 product images
Source: Artinis Medical Systems (2020) Brite24 - wearable fNIRS system
https://www.artinis.com/nirs-eeg-package

Experimental Setup

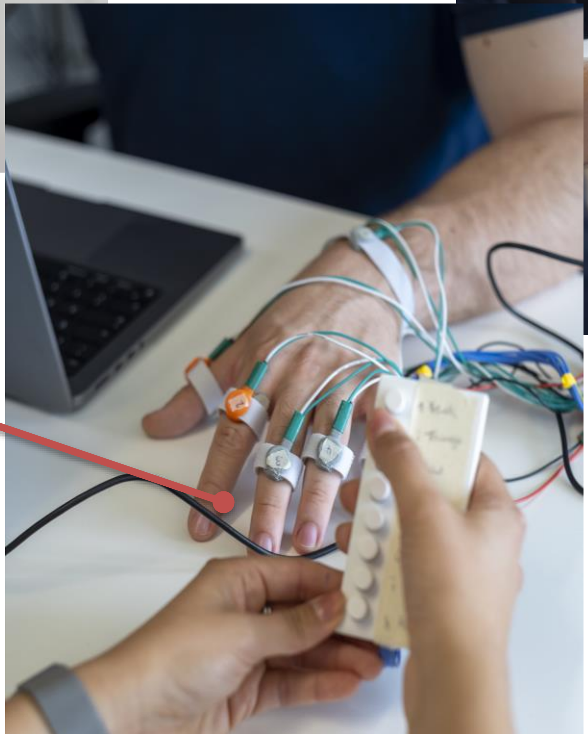
Placement of the optodes

Setup of the fNIRS measurement system (Brite24)





Setup and testing of the vibrotactile stimulation system



Attach vibration motors to the hand

fNIRS Results: Prefrontal Activation

- Functional near-infrared spectroscopy (fNIRS) measured changes in oxygenated hemoglobin (HbO) in the prefrontal cortex (PFC)
- An increase in HbO indicates higher neural activity relative to baseline

Stimulation	N	Mean HbO (µmol/L)	SD
Visual	32	- 0,85	10,41
Haptic	32	5,93	15,74

- The Wilcoxon signed-rank test revealed no significant difference between visual and haptic stimulation: **$Z = -0.47$, $p = .640$**
- Interpretation → Haptic emotional stimulation activates the prefrontal cortex at a level comparable to visual stimuli

Emotion Recognition

- Emotion recognition was assessed using verbal responses after each emotion block
- Participants identified the perceived emotion in both conditions
- The difference between conditions was only 1 percentage point
- Highest recognition rates were observed for: Neutral: 100% in both phases, Happiness: 100% visual, 96.9% haptic

Emotion	Visual correct/total	Visual (%)	Haptic correct/total	Haptic (%)
Sadness	28/32	87,5 %	27/32	84,4 %
Anger	31/32	96,9 %	31/32	96,9 %
Neutral	32/32	100,0 %	32/32	100,0 %
Fear	28/32	87,5 %	28/32	87,5 %
Happiness	32/32	100,0 %	31/32	96,9 %
Disgust	31/32	96,9 %	31/32	96,9 %
Total	182/192	94,8 %	180/192	93,8 %

- Interpretation → The high recognition rates confirm successful conditioning and reliable emotion identification in both modalities

Subjective Cognitive Load (NASA-TLX)

- Subjective workload was measured using the NASA-TLX questionnaire, which includes six subscales:

Mental Demand | Physical Demand | Temporal Demand | Performance | Effort | Frustration

- The total NASA-TLX score showed no significant difference between conditions: Z = 1.81, p = .070
- However, the Mental Demand subscale revealed a highly significant difference: Z = 3.21, p = .001, r = .57
- Additional finding: 24 of 32 participants (75%) reported higher mental demand during haptic stimulation
- Interpretation → Processing haptic emotional stimuli requires significantly higher cognitive effort than visual emotion recognition

Conclusion & Future Work

Conclusion

- The results suggest that haptic emotion stimulation can activate the prefrontal cortex similarly to visual emotional stimuli, indicating modality-independent emotion processing after conditioning
- Although neural activation patterns were comparable, haptic emotion processing required higher cognitive effort, suggesting that decoding haptic signals involves additional cognitive processing
- Overall, the findings demonstrate that haptic emotion communication is neurally feasible and can achieve emotion recognition accuracy comparable to visual perception

Future Work

- Investigate blind and visually impaired participants
- Examine long-term training effects on cognitive load
- Implement automated stimulus presentation for higher temporal precision
- Combine fNIRS with fMRI to capture deeper brain structures involved in emotion processing