Thermal Masking in VR

Multisensory Haptics Research: Perceptual HCI Study
Can a moving visual stimulus in VR reshape a thermal-masking illusion?

MSC SEMESTER PROJECT | STOCKHOLM UNIVERSITY, DSV

Andreas Franke | Embedded Systems / Unity VR / HCI Research

6 PARTICIPANTS FULLY COUNTER-BALANCED

3 CONDITIONS: COMBINED, HAPTIC, VISUAL

26 PAGE PAPER ACM/CHI FORMAT

4 THEMES REFLEXIVE THEMATIC ANALYSIS

THE RESEARCH GAP

The thermal masking illusion causes vibrotactile stimulation at one skin location to displace the perceived location of a simultaneous thermal stimulus — typically experienced as an abrupt "teleportation" of warmth. Prior work established the illusion under static, non-immersive conditions.

This project asked: **can a continuous moving visual cue in immersive VR reshape that abrupt jump into a perceived gradual movement?** The combination of thermal masking, dynamic visual stimulus, and VR had not been studied before.

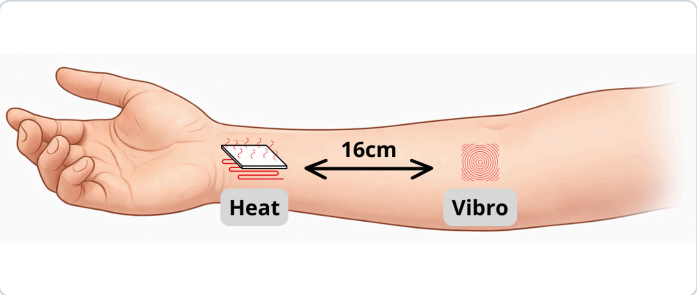
THE APPROACH

A custom Arduino haptic device delivered synchronized thermal (Peltier element, at wrist) and vibrotactile (vibration motor, 16 cm proximal) stimulation. A Unity VR cabin scene showed a candle-like point of light traveling wrist-to-elbow over 5 seconds, temporally aligned with the haptic stimulation via serial trigger.

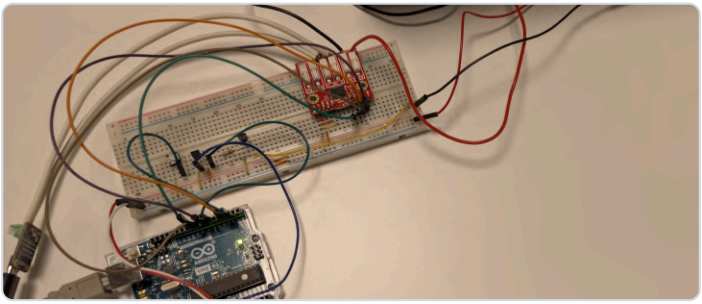
Six participants experienced three conditions (combined, haptic-only, visual-only) in a fully counterbalanced within-subjects design. Post-experience semi-structured interviews were analysed with reflexive thematic analysis.

MY ROLE

Primary technical owner and sole author of the final ACM-style report: hardware circuit design and Arduino firmware, Unity VR scene implementation, user study design and execution (participant recruitment, consent, all three conditions), audio transcription, qualitative coding and reflexive thematic analysis, and final writeup in ACM conference format.



Stimulus placement: Peltier (wrist) and vibration motor (16 cm proximal); the standard configuration for the thermal masking illusion



Built haptic device: Arduino Uno, TB6612FNG motor driver, TMP36 thermistor, Peltier element, vibration motor; foam-boxed for user study sessions

HAPTIC DEVICE

- **MCU:** Arduino Uno, timing, PWM control, serial sync to Unity
- **Thermal:** TEC1-12706 Peltier at wrist; HUSB238 USB-C PD power
- **Tactile:** 5V coin vibration motor, 16 cm proximal (near elbow)
- **Driver:** TB6612FNG H-bridge, PWM Peltier direction control
- **Safety:** TMP36 42°C cutoff; burst PWM (0.2 s on / 0.1 s off); 30 s cooldown

VR ENVIRONMENT (UNITY)

- **Scene:** Dim cabin; grill table; forearm surrogate aligned per session
- **Visual:** Candle-like light wrist → elbow, 5 s; serial Timeline sync
- **Presence:** Edge vignette on head rotation; wrist occluded with box
- **Runtime:** Meta Quest (OpenXR)
- **Conditions:**
  - A — Combined: visual + haptic
  - B — Haptic-only
  - C — Visual-only
- **Ethics:** Ethical approval; hardware cutoff switch present throughout

Arduino C++ | Peltier Element | Vibrotactile Haptics | TB6612FNG H-Bridge | TMP36 Safety Cutoff | Unity C# | Meta Quest | OpenXR | VR / XR | Within-subjects Design | Reflexive Thematic Analysis | Multisensory Integration | Perceptual Illusion | HCI / CHI

SYSTEM ARCHITECTURE

HAPTIC DEVICE
- Peltier thermal (wrist)
- Vibration motor (elbow)
- TMP36 42°C safety cutoff

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ARDUINO FIRMWARE
- TB6612FNG H-bridge driver
- PWM burst + 30s cooldown
- Serial sync trigger to Unity

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UNITY VR SCENE
- Candle light wrist → elbow, 5 s
- Static forearm surrogate
- Vignette + occlusion presence

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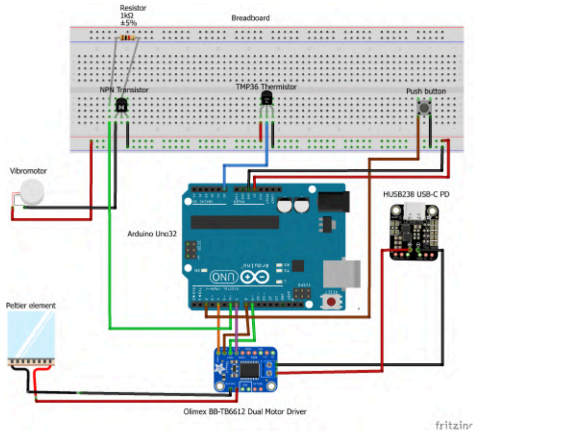
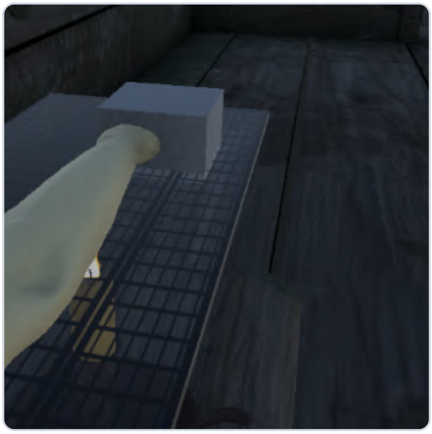
STUDY & ANALYSIS
- N=6 fully counterbalanced
- Semi-structured interviews
- 4 themes derived (RTA)



Circuit diagram: Arduino Uno, TB6612FNG driver, TMP36 thermistor, HUSB238 USB-C PD, Peltier element, vibration motor



Unity VR scene: candlelight travels wrist → elbow over 5 seconds, synced to the haptic device via serial trigger

STUDY DESIGN

	A — COMBINED	B — HAPTIC-ONLY	C — VISUAL-ONLY
Heat	✓ Active	✓ Active	— Off
Vibr.	✓ Active	✓ Active	— Off
Light	✓ Moving	— Off	✓ Moving

- All 6 permutations assigned (fully counterbalanced)
- Sessions 20–30 min, with ~15–20 min interview each
- Participants kept unaware of actuator positions
- Hardware cutoff switch used throughout all trials

FOUR THEMES: THEMATIC ANALYSIS

THEME 1
Sensory Characteristics
Heat quality, vibration texture; whether sensation felt continuous or discrete.

THEME 2
Spatial Perception
Perceived forearm direction and trajectory; some reported wrist-to-elbow movement.

THEME 3
Visual-Haptic Integration
Visual cue enhanced haptic input; could not generate sensation alone (4 / 6 felt nothing in the visual-only condition).

THEME 4
Cognitive Sense-Making
Expectations and attention shaped variability in the illusion experience.

KEY FINDINGS

- 2 participants (P1, P2) reported wave-like or continuous wrist-to-elbow movement in the combined condition
- 1 participant (P3) reported an initial jump followed by continuity, a distinct and notable transition pattern
- Visual cue acted as an *interpretive aid* for existing haptic input, not as an independent generative stimulus
- Strong individual differences in multisensory integration susceptibility were observed across participants
- Combined condition consistently produced richer, more "real" participant descriptions than haptic-only
- Continuous visual motion in VR can *support* but does not reliably *produce* perceived gradual thermal movement; the qualitative approach appropriately mapped the phenomenological range before quantitative hypotheses are formed

DESIGN IMPLICATIONS FOR VR HAPTICS

- **Temporal sync matters:** visual-haptic alignment is the critical variable for perceptual fusion
- **Visual cues guide sparse haptics:** dynamic VR elements can compensate for hardware-limited actuator arrays
- **Adaptive systems needed:** individual differences mean uniform mappings will not work for all users
- **Two-point rigs can produce movement percepts:** dense arrays are not required if visual-haptic congruence is high

Future Research Directions

- Quantitative follow-up: spatial localisation tasks and continuous rating scales with a larger and more diverse sample
- Dense Peltier array and hand / arm tracking for stronger embodiment and cleaner spatial localisation results
- Systematic variation of animation speed, visual form, and individual-difference measures across participants
- Adaptive visual-haptic mappings for broader body locations; mixed-methods extension at scale