Belt Project Literature Review

Ben Falandays

9/13/22

Guidelines for the Use of Vibro-Tactile Displays in Human Computer Interaction

van Erp 2002

- Stimulus detection: lowest thresholds when…
  - On glabrous skin (no hair)
  - Vibration frequencies 200-250hz
  - Stimulus duration increases (temporal summation)
- Tactile coding:
  - By subjective magnitude
    - No more than 4 levels
  - By frequency
    - No more than 9 levels
    - Difference of 20% b/w levels
  - By temporal patterns
    - Pulses or gaps of at least 10ms

- Potential pitfalls:
  - Temporal masking
    - Occurs when stimuli are in same location (only relevant w/ environmental coding)
    - Can be avoided by using different locations or different frequencies
  - Sensory adaptation
    - Increases detection threshold (up to 20db) and lowers subjective magnitude (up to 7db)
    - Takes up to 25 min
    - Recovery time is half of adaptation time
    - Can be avoided by switching b/w frequencies (e.g. 80db and 100db)

A Meta-Analysis of Vibrotactile and Visual Information Displays for Improving Task Performance

Prewett, Elliott, Walvoord, & Coovert 2012

- Concluded that “vibrotactile *alerts* are an effective replacement for visual alerts, but vibrotactile direction cues are not effective when replacing visual direction cues.”

My thoughts on the literature

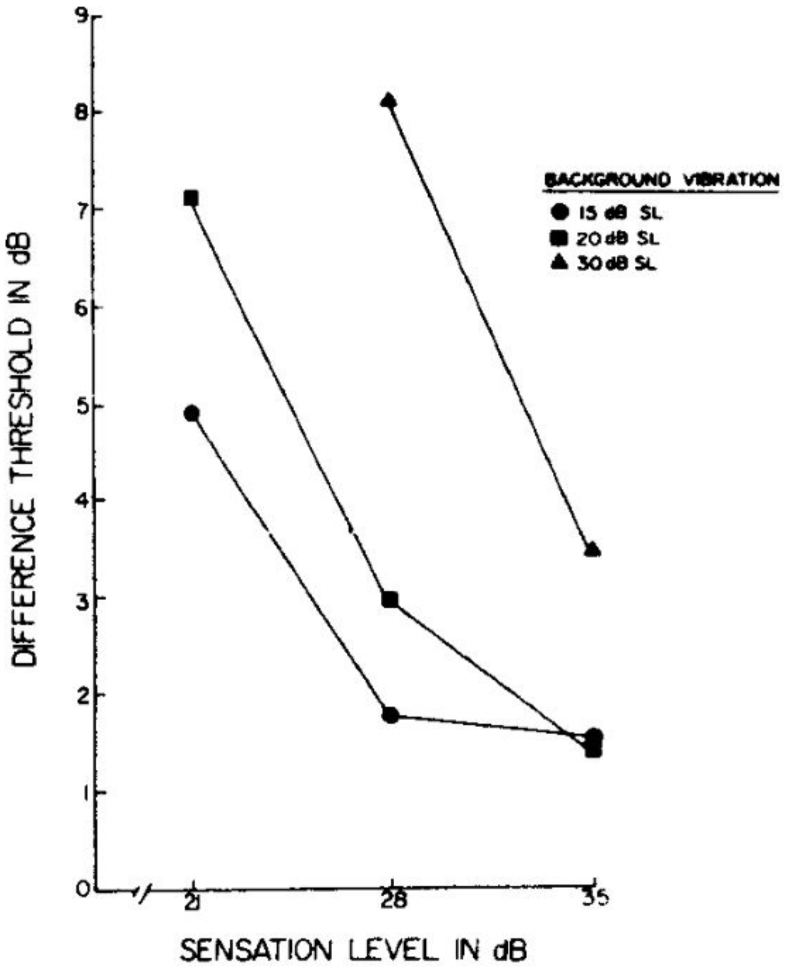
- We don’t know much about hyperacuity, besides that exists
    - I.e. how do we code it? What intensities to use? Does JND matter here?
    - This could be worth a dedicated experiment
- A lot of existing work has participants stationary, but walking can have an effect on detection thresholds, so we should use walking tasks where possible
    - Studies comparing active exploration vs stationary or yoked conditions finds that active exploration lowers detection thresholds and improves performance
- Sensory adaptation could be a major issue (although some work suggests adaptation can enhance detection -- not sure what to make of that yet)
    - We could try a coding where vibrations are cancelled out, i.e. only send a signal when the user is deviating from the intended trajectory
- Practice matters a lot. I worry that we could rule out an effective coding scheme based on early user responses

Detection Thresholds

Difference threshold for intensity of tactile stimuli

James, 1972

- Perception of vibration intensity/frequency
  - Vibration intensity and frequency are perceptually confounded
  - 16% change in intensity is just noticeable distance
  - 5-7 perceptually distinguishable levels for a typical motor
  - Background vibration increases detection threshold



Estimation of Torso Vibrotactile Thresholds Using Eccentric Rotating Mass Motors

Valle et al 2021

- Absolute threshold ≈ 75 hz
- Differential threshold ≈ 20%

Vibrotactile localization on the abdomen: Effects of place and space

Cholewiak, Brill & Schwab 2004

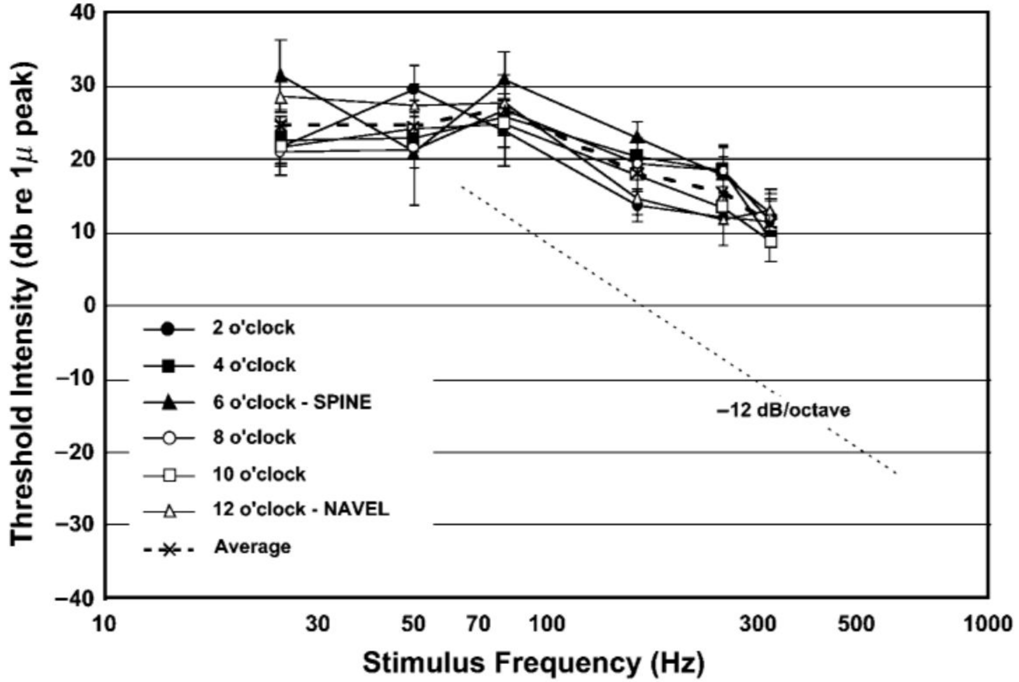


Figure 1. Vibrotactile detection thresholds, in decibels, relative to 1 μ of peak displacement as a function of stimulus frequency, measured at six sites around the abdomen at a level 25 mm above the navel. For reference, a line representing a slope of −12 dB/octave is also shown, representing the slope of high-frequency vibrotactile sensitivity functions on glabrous skin. The mean is also shown with standard errors about the data points.

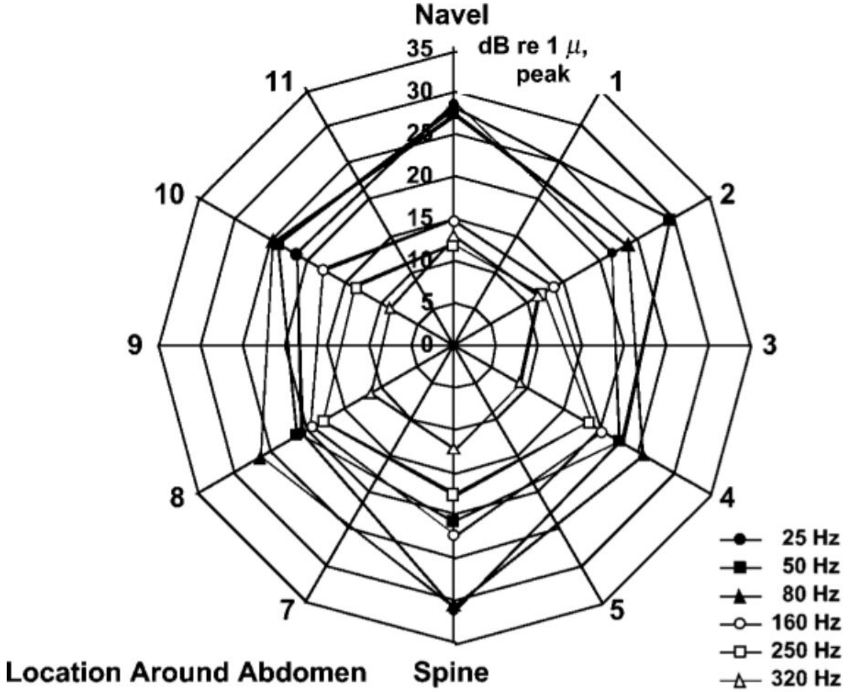


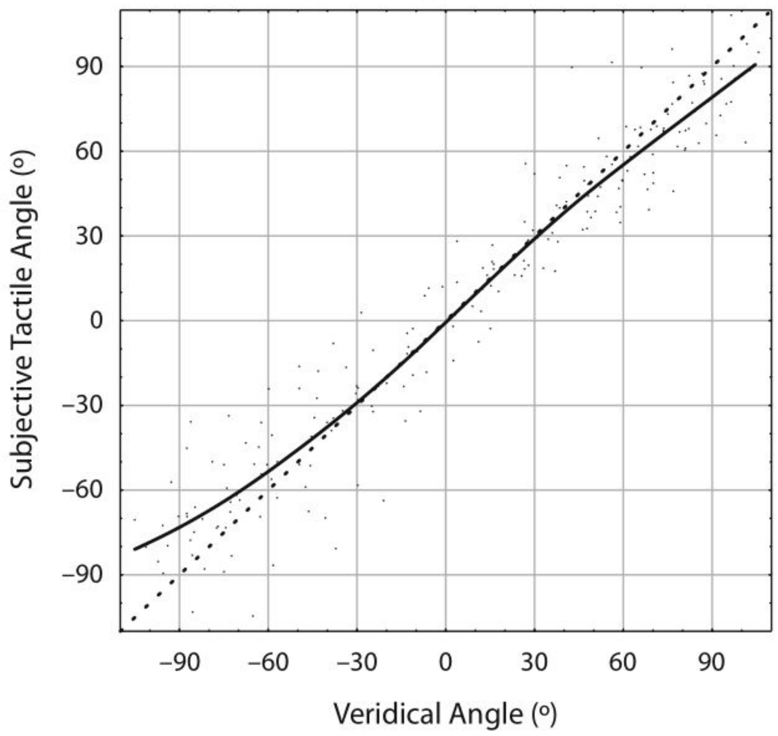
Figure 2. Vibrotactile detection thresholds, in decibels, relative to 1 μ of peak displacement for six stimulus frequencies, measured at six sites around the abdomen at a level 25 mm above the navel. The data were plotted on polar coordinates to illustrate the spatial distribution, with the numbers representing 12 locations circling the abdomen. Site 12 is located at the navel, whereas Site 6 is located at the spine. These data are identical to those in Figure 1, except for the graphic representation.

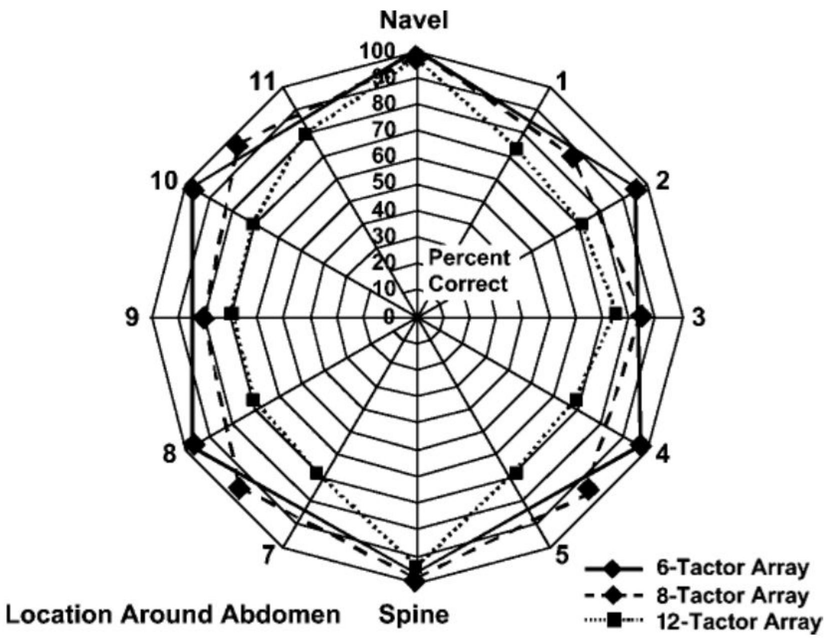
Localization/Acuity

Sensitivity to vibrations on the waist

van Erp (2008). Absolute localization of vibrotactile stimuli on the torso

- Localization
  - Absolute: 1.66 cm (size of the stimuli)





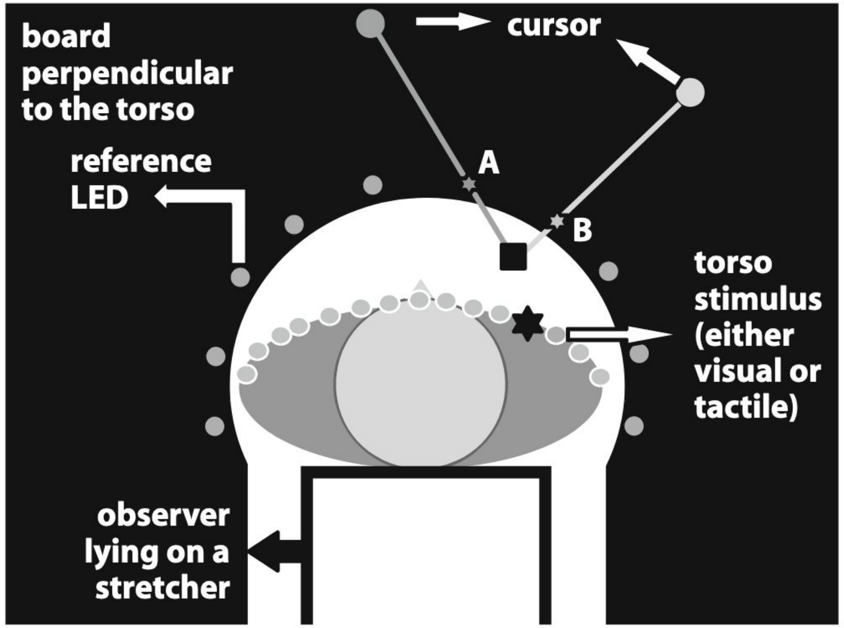
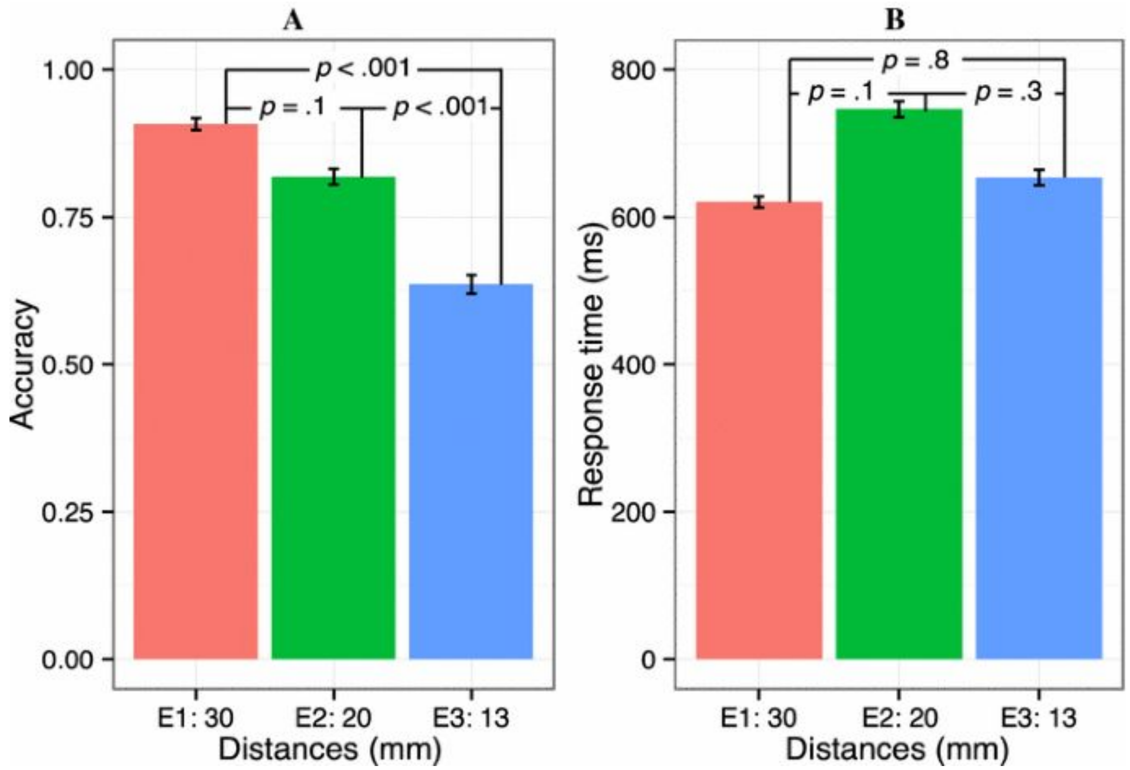


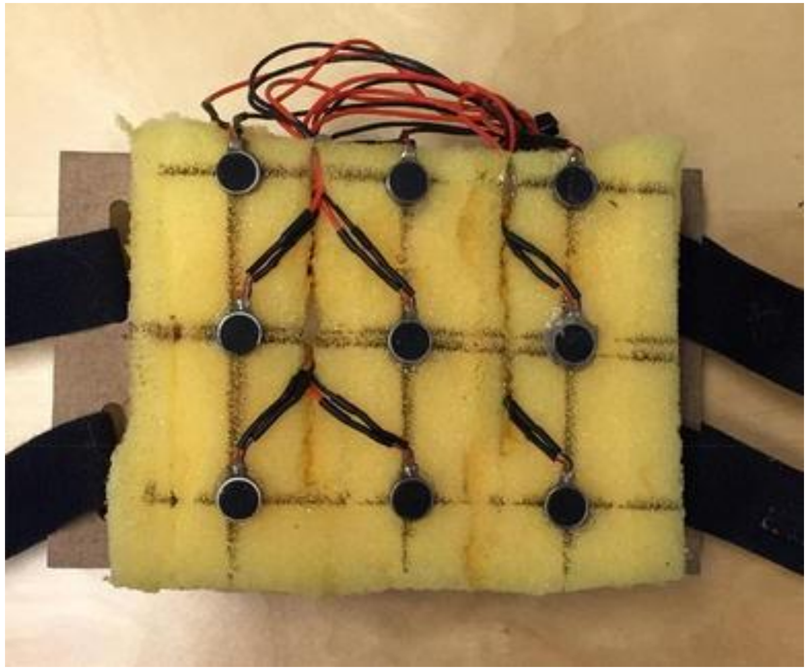
Figure 2. Layout of the experimental setup and the triangulation principle. The observer was lying on his back on a stretcher. A board was placed perpendicular to the body midaxis just below the observer's navel. Each trial consisted of three stimuli: a torso stimulus (a vibration or light-emitting diode [LED], indicated by the star), a reference LED mounted on the board, and a cursor. The observer's task was to position the cursor with a handheld dial such that the three stimuli were on a straight line. By using different reference LEDs, on different trials (e.g., A and B) for each torso stimulus, the subjective location of the torso stimulus could be calculated, using triangulation.

Relative vibrotactile spatial acuity of the torso

Johannesson et al, 2017

- Localization
  - Left/right relative: 13 mm (size of the stimuli)

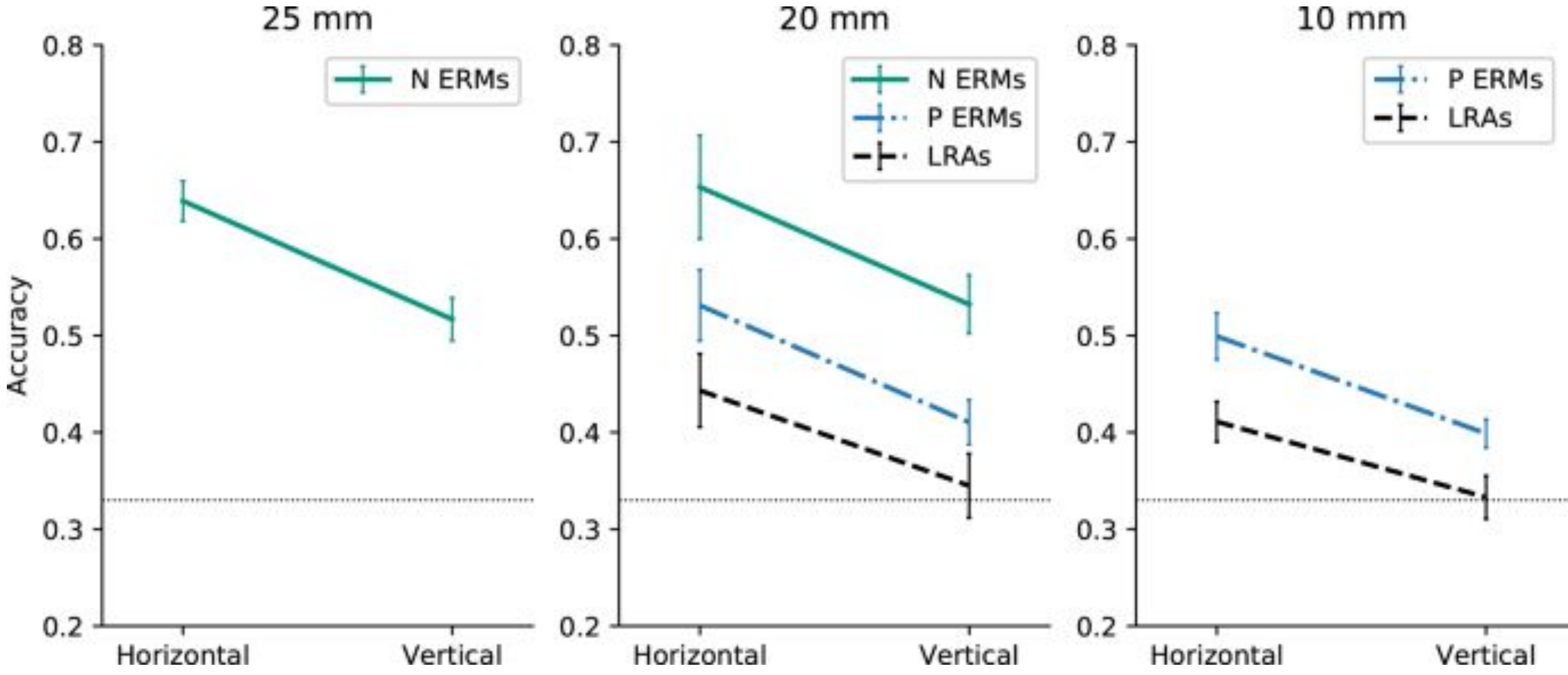




Measuring relative vibrotactile spatial acuity: effects of tactor type, anchor points and tactile anisotropy

Hoffman et al, 2018

- Accuracy by motor type:
  - N ERMS >
  - P ERMS >
  - LRAs

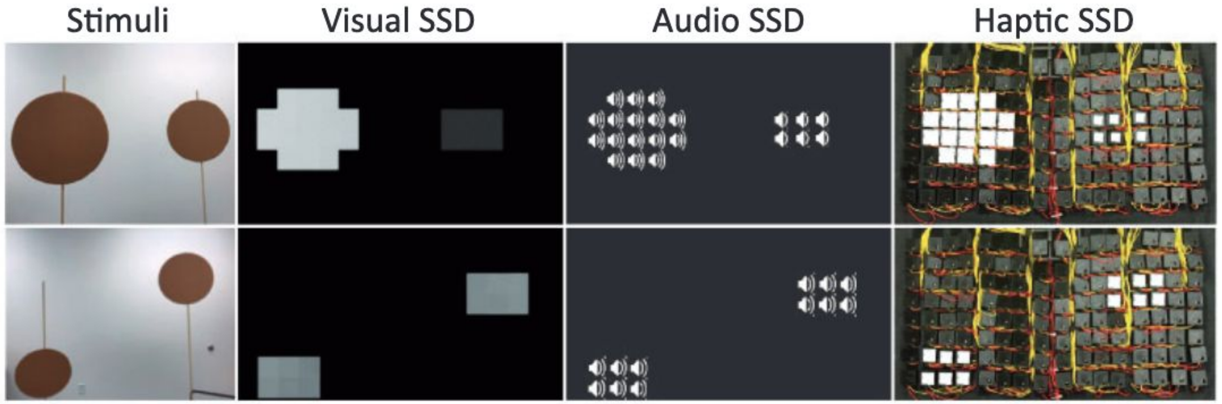


How Much Spatial Information Is Lost in the Sensory Substitution Process? Comparing Visual, Tactile, and Auditory Approaches

Richardson, et al 2018

- 16 x 8 tactor vest
- Active sensing task
- Vertical discrimination:
    - 21 degrees visual angle
- Distance discrimination:
    - 29cm

Figure 3. Left image shows a VibroVision vest user; the chest-mounted camera provides 3D information that is convey via spatialised vibrations arranged in a 16×8 matrix (right image). *Note:* Please refer to the online version of the article to view the figures in colour.



Localized Magnification in Vibrocatile HMDs for Accurate Spatial Awareness

Olveira, Nedel, Maciel & Brayda, 2016

- Tactor coverage of 45 degrees leads to fast but imprecise performance
- Increasing density locally ("tactile fovea") can optimize tradeoff b/w speed and precision

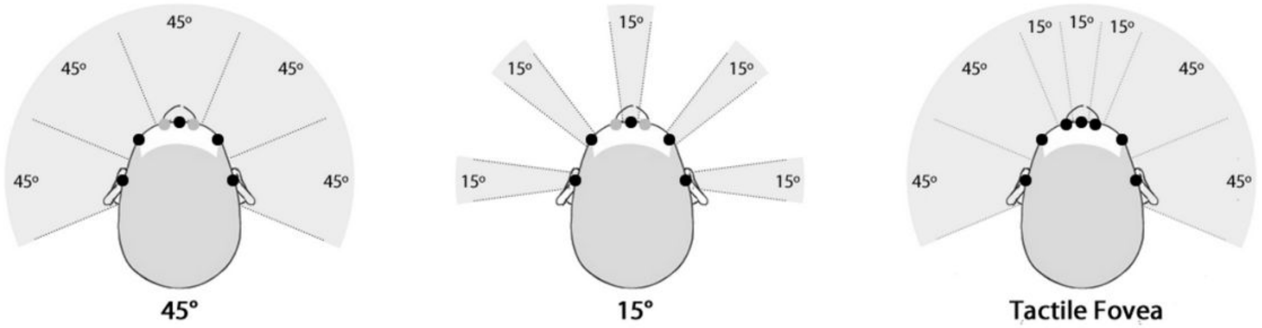


Fig. 1: The three modalities of directional cueing. The 45° modality is the baseline condition; Commonly, the density of the array is increased to reduce the angle covered by each tactor in this modality. The 15° is a proposed condition to increase precision without manipulation of vibration parameter and array density. The Tactile Fovea condition is a second proposal to achieve higher precision by locally increasing the array density.

Pitfalls to Avoid

The Intensity Order Illusion: Temporal Order of Different Vibrotactile Intensity Causes Systematic Localization Errors

Hoffman et al 2019

- Used 4x4 tactor array on lower back
- Strong followed by weak stim leads to perceived downward movement
- Weak followed by strong leads to upward shift

Vibrotactile Spatial Acuity and Intensity Discrimination on the Lower Back Using Coin Motors

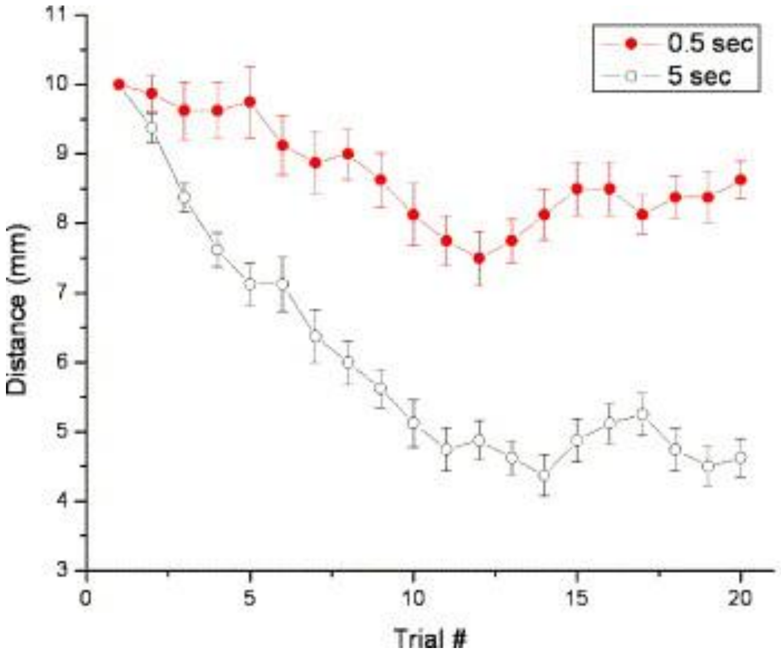
Stronks et al 2016

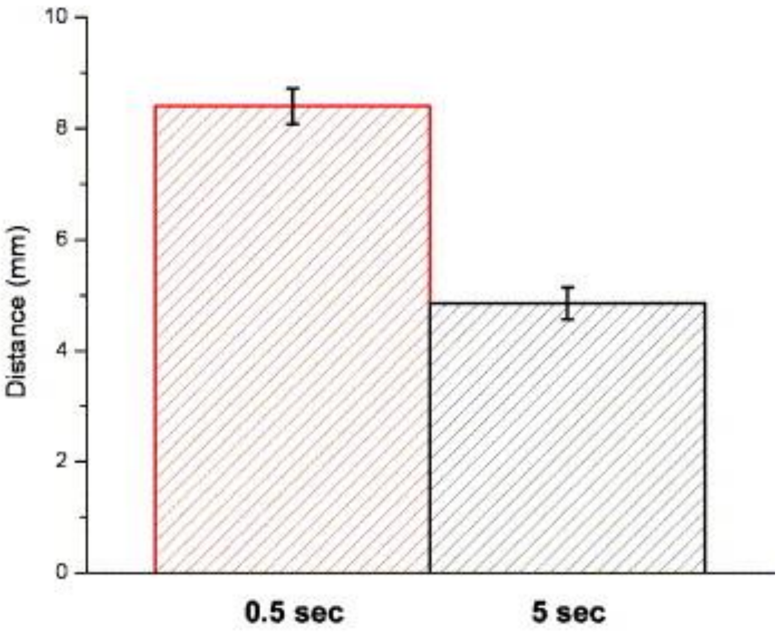
- Two-point discrimination threshold decreases with SOA
  - 52 mm at 0ms SOA
  - 28 mm at 200ms SOA
- Found intensity JND of 14%
  - Did not depend on SOA

Vibrotactile adaptation enhances spatial localization

Tannan, Whitsel, & Tommerdahl, 2006

- 5 seconds of 25hz flutter before stimulus resulted in 2-fold enhancement of spatial discrimination, relative to .5s of flutter
  - From ≈ 8mm to ≈ 4mm (on hand)
- Effect increased over trials

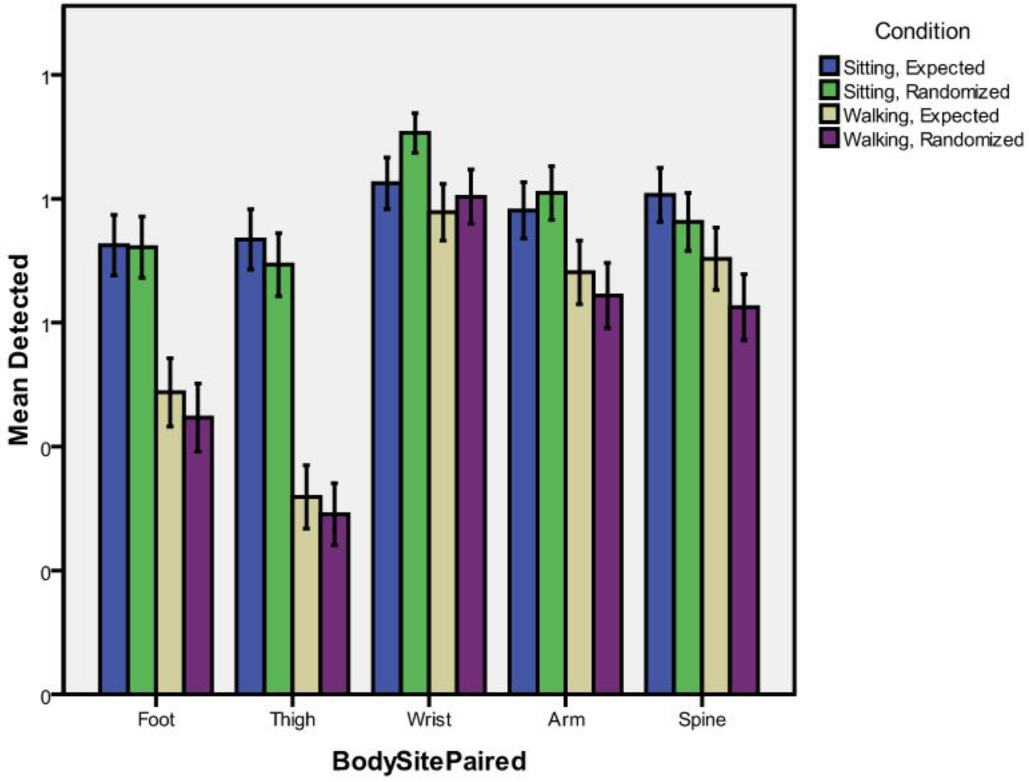


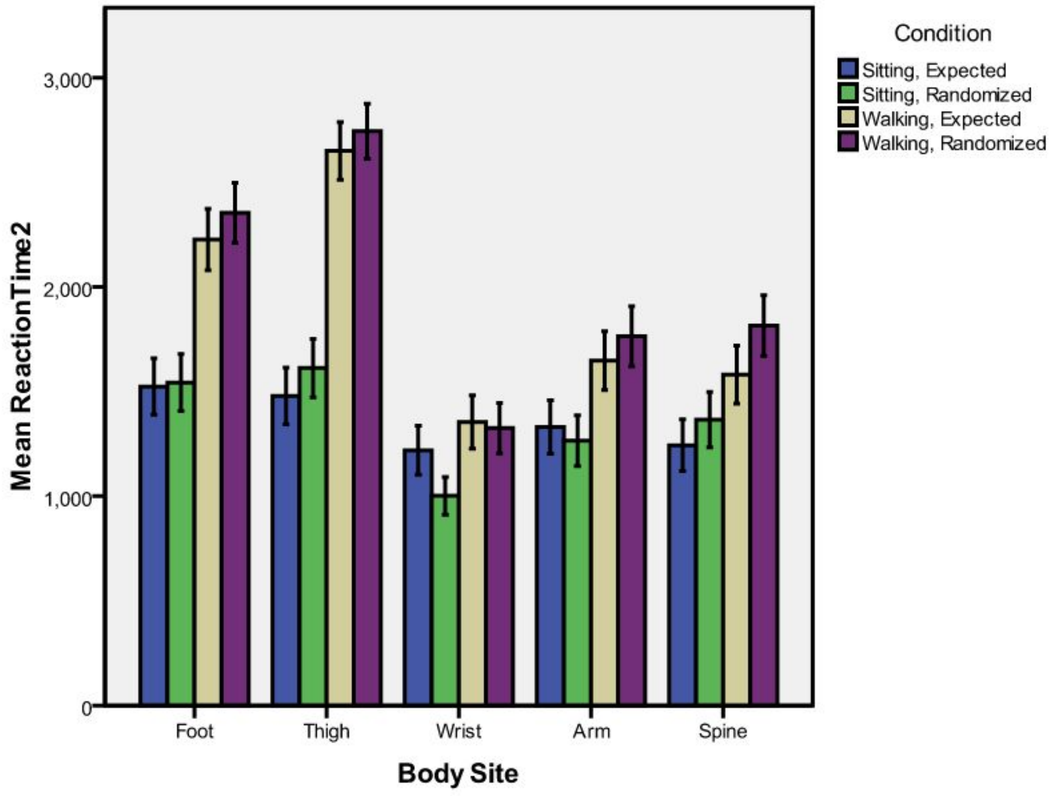


Detecting Vibrations Across the Body in Mobile Contexts

Karuei et al 2011

- Walking can decrease likelihood of detection and increase reaction time





Numerosity judgments for tactile stimuli distributed over the body surface

Gallece, Tan, & Spence 2005

- Error rates in numerosity judgments become very high (>50%) whenever more than 2 stimuli are presented

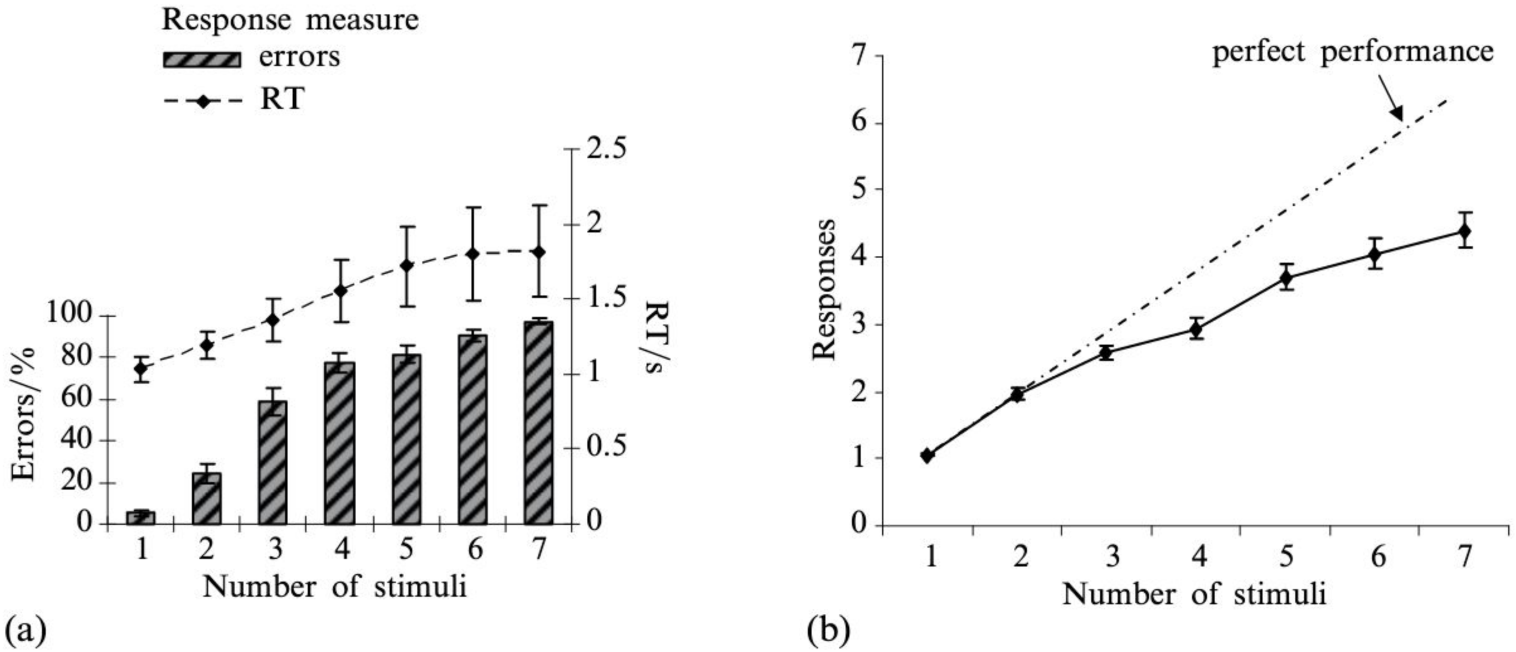


Figure 3. (a) Mean error rates and RTs in experiment 1 as a function of the number of tactors activated. (b) Mean number of tactors reported by participants in experiment 1 as a function of the number of tactors activated. Error bars represent ±1 SEM.

Do “mudsplashes” induce tactile change blindness?

Gallece, Tan, & Spence 2007

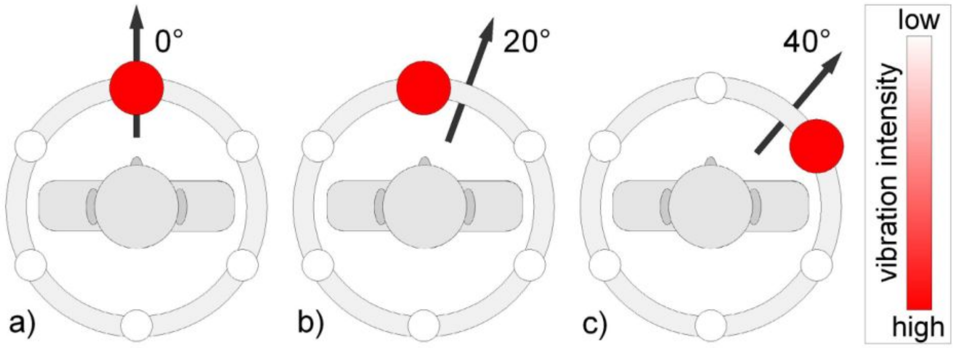
- Tactile change blindness can be induced by:
  - Tactile mask between events
  - “Mudsplash” – tactile distractor at time of change

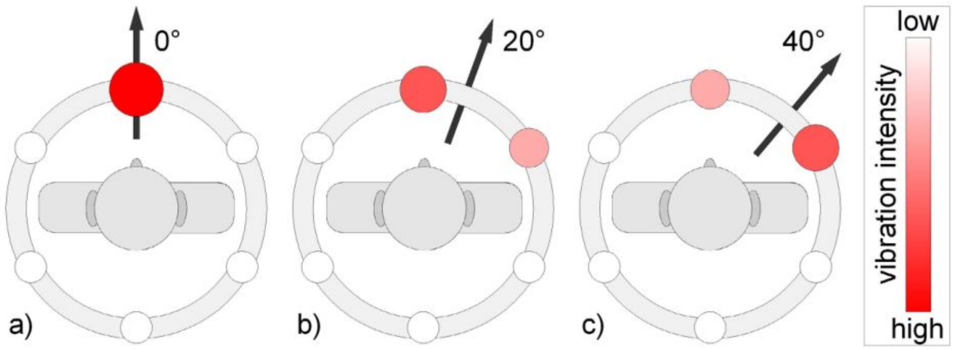
Hyperacuity

Evaluation of Continuous Direction Encoding with Tactile Belts

Pielot et al 2008

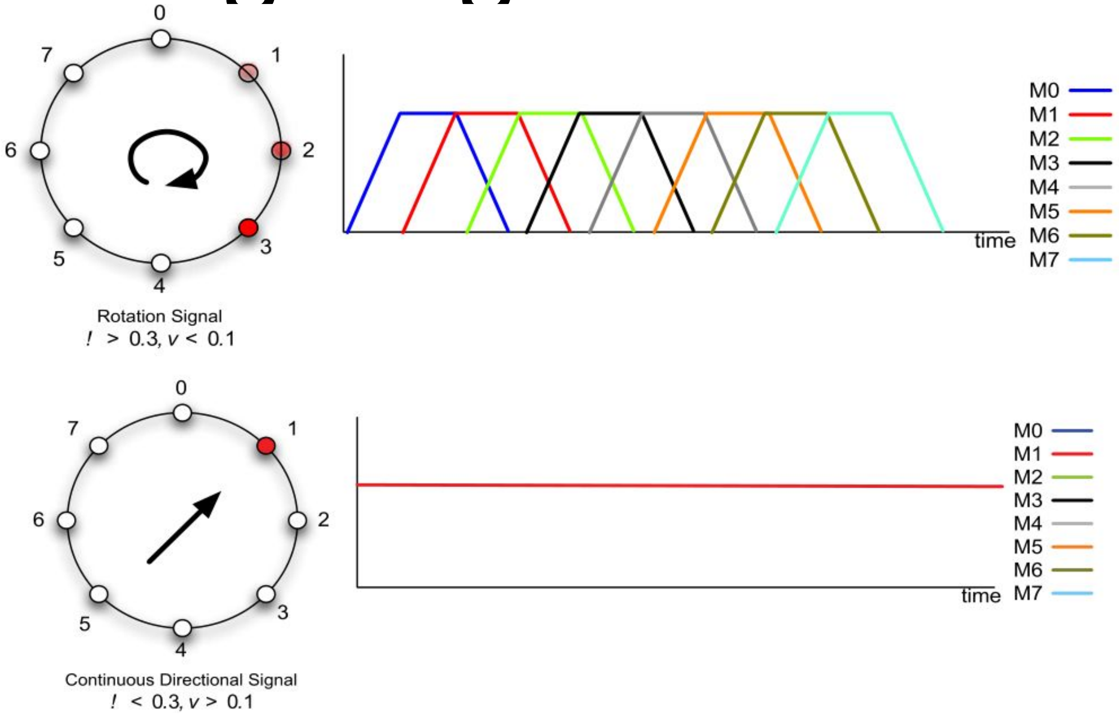
- Hyperacuity / Perceptual Interpolation
  - Discrete presentation error of 19.4deg
  - Interpolated presentation of 16.8deg.
- Interpolated presentation takes longer to process & performed worse in wayfinding task
  - DV was completion time in virtual wayfinding
  - 72.6 s for interpolated, 65.59 seconds for discrete

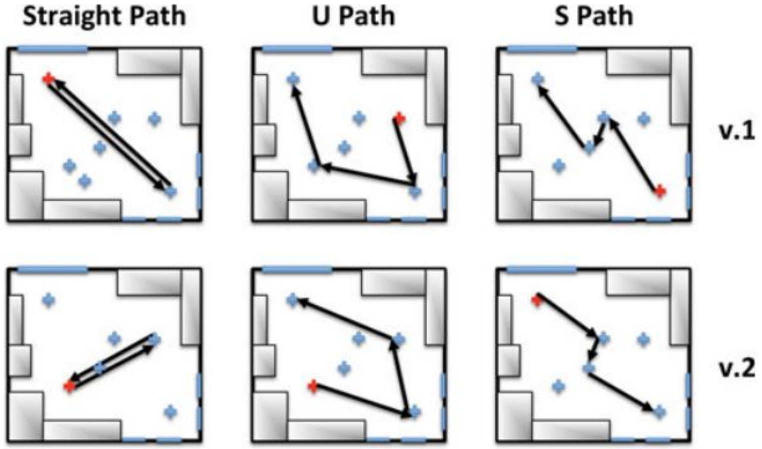




Wayfinding

Navigating with vibrations





- Audio guidance (left, right, straight, turn around, destination reached) compared to vibration queues (directional, rotational, stop)
- Waypoint navigation
- The belt guidance kept users closer to the desired path but took longer to complete compared to audio guidance.

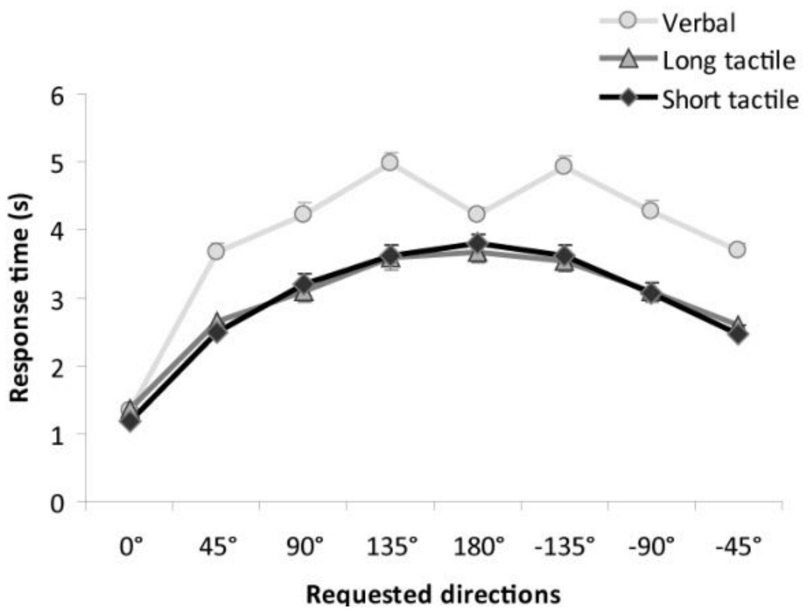
German Flores, Sri Kurniawan, Roberto Manduchi, Eric Martinson, Lourdes M Morales, and Emrah Akin Sisbot. *Vibrotactile guidance for wayfinding of blind walkers*. IEEE transactions on haptics, 8(3):306–317, 2015.

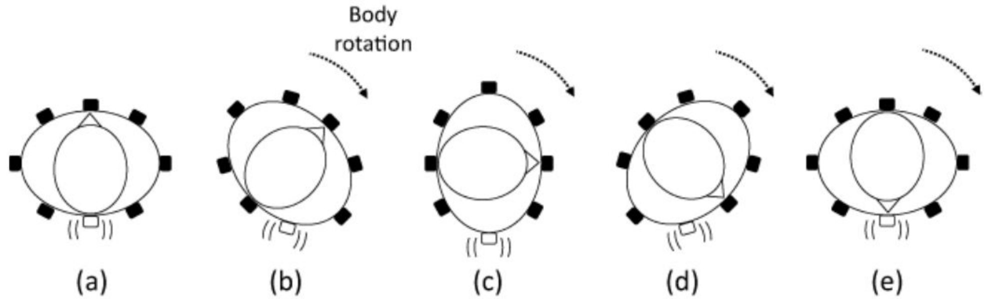
Navigating with vibrations

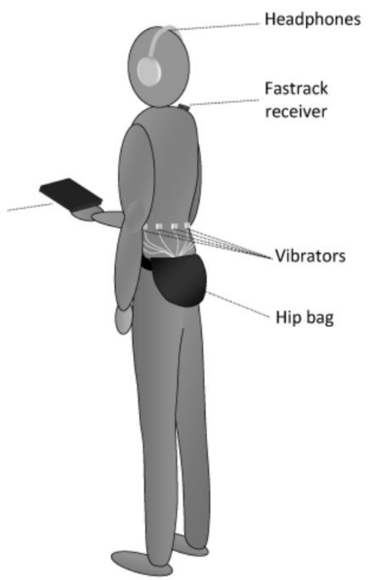
Table 1
Heading performance measures in the three guidance modes conditions.

Measure	Verbal mode		Long tactile mode		Short tactile mode	
	M (SE)	*95% CI*	*M (SE)*	*95% CI*	*M (SE)*	*95% CI*
CE	10.74 (2.22)	[5.85, 15.63]	10.04 (2.15)	[5.30, 14.78]	6.27 (1.05)	[3.95, 8.58]
AE	14.16 (1.71)	[10.40, 17.92]	13.59 (1.71)	[9.82, 17.35]	8.90 (0.89)	[6.94, 10.86]
VE	10.38 (0.79)	[8.65, 12.11]	9.53 (0.76)	[7.86, 11.21]	7.37 (0.46)	[6.35, 8.39]

Note. M = Mean; *SE* = standard error; *95% CI* = 95% confidence interval; *CE* = constant error; *AE* = absolute error; *VE* = variable error.



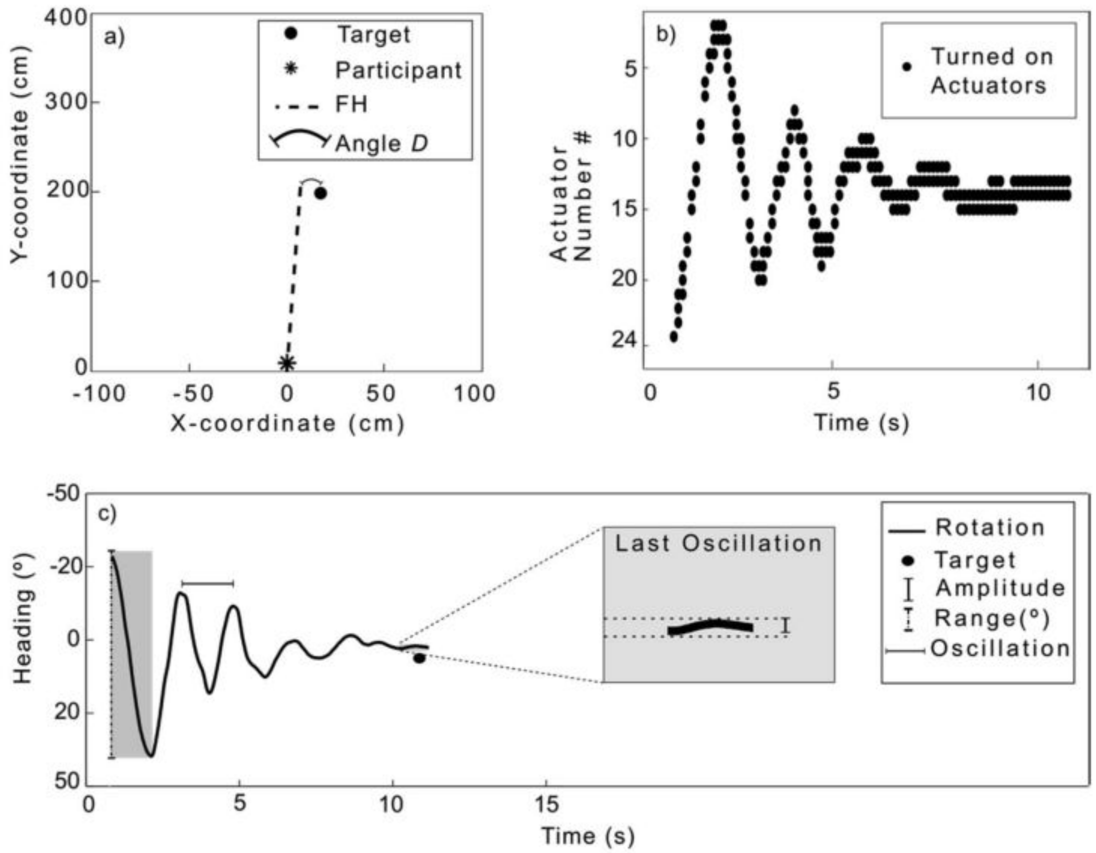


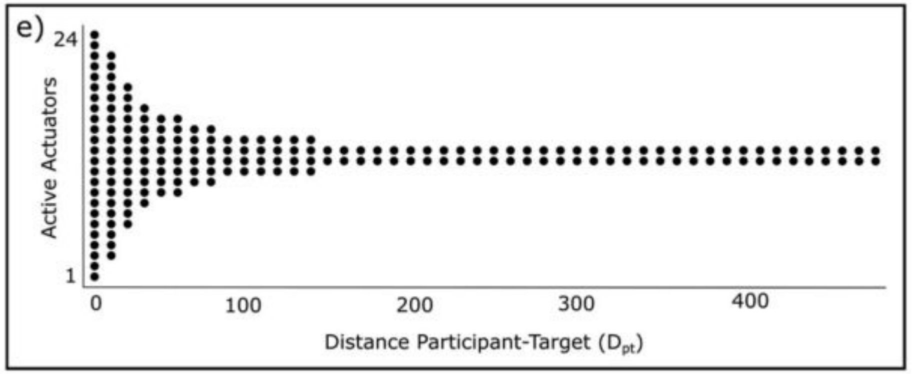


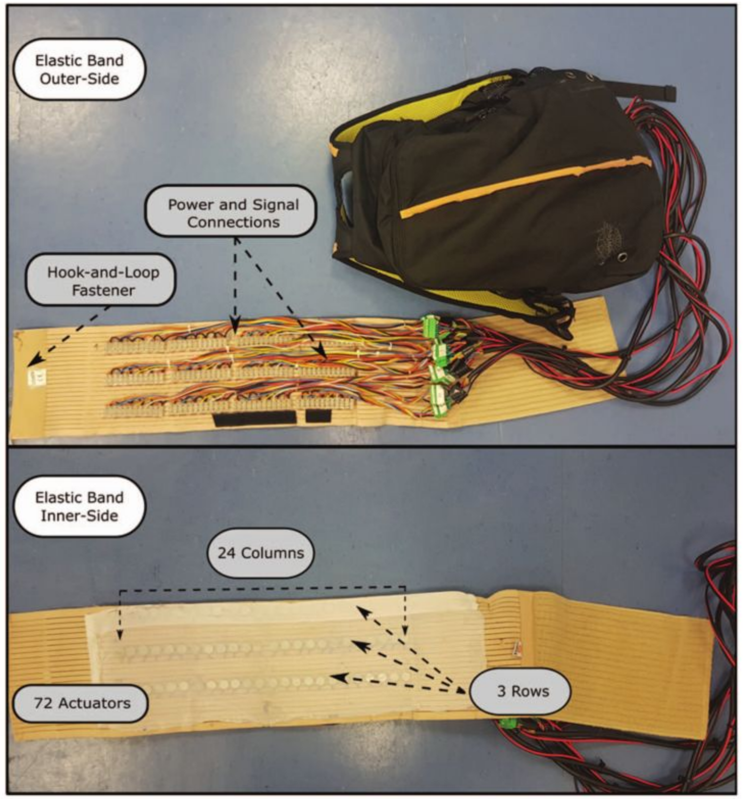
- Tested three schemes: verbal, one long vibration, short continuous vibrations
- Orientation only
- Online instructions are better than both other schemes

Elise Faugloire and Laure Lejeune. *Evaluation of heading performance with vibrotactile guidance*: The benefits of information–movement coupling compared with spatial language. Journal of Experimental Psychology: Applied, 20(4):397, 2014.

Navigating with vibrations



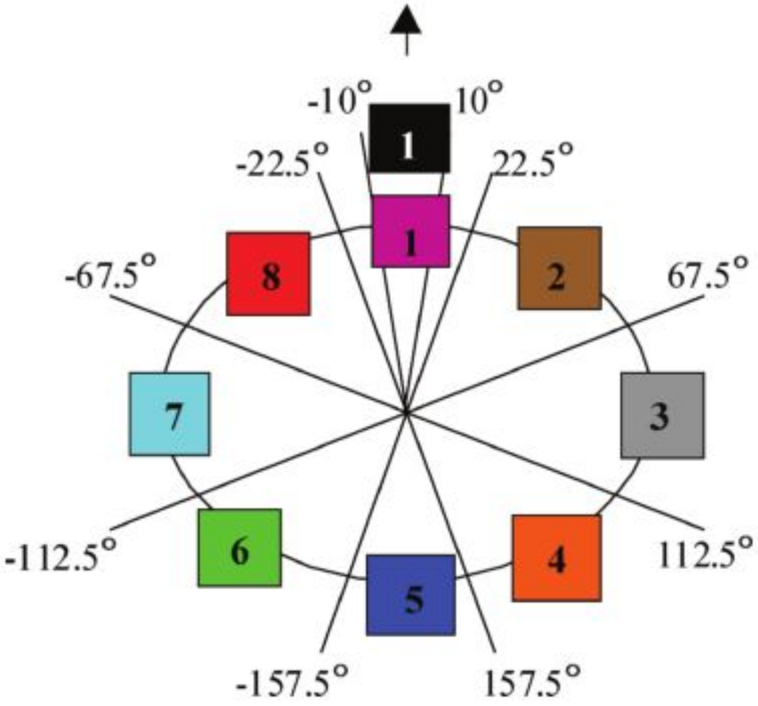


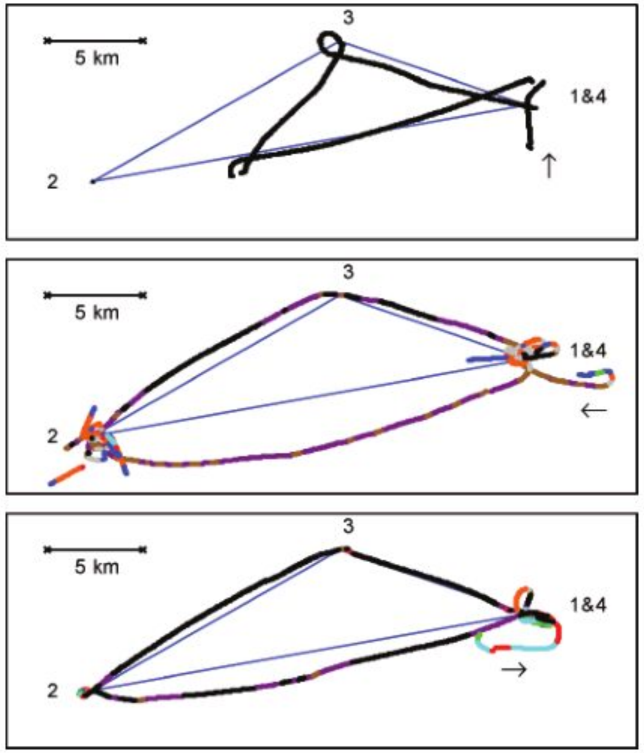


"For an accurate orientation performance, a large number of actuators (i.e., a good resolution of the sensory flow field) and a sufficiently direct perception–action coupling are both needed."

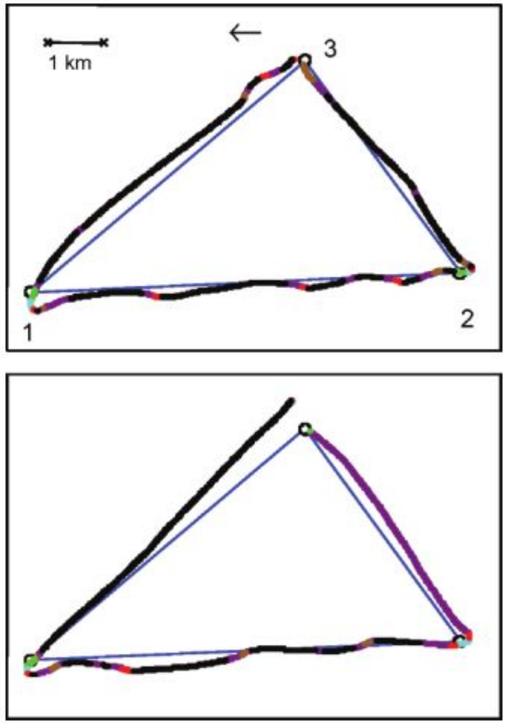
Lorena Lobo, David Travieso, David M Jacobs, Matthew Rodger, and Cathy M Craig. *Sensory substitution: Using a vibrotactile device to orient and walk to targets*. Journal of Experimental Psychology: Applied, 24(1):108, 2018.

Navigating with vibrations





Helicopter!



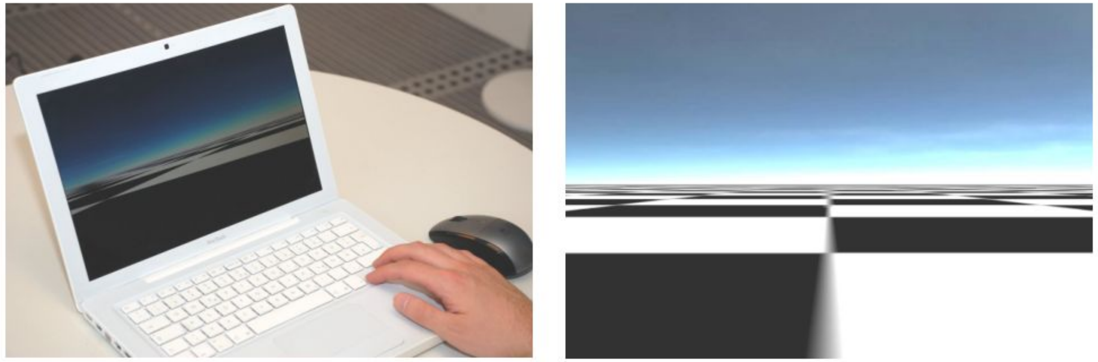
Boat!

- Direction to waypoint indicated by closest motor to direction of waypoint
- Tested 5 different distance coding schemes in pauses between vibrations
- Distance coding had no effect on performance (measured by walking speed)
- Also tested navigation for helicopters and boats!

Jan BF Van Erp, Hendrik AHC Van Veen, Chris Jansen, and Trevor Dobbins. Waypoint navigation with a vibrotactile waist belt. ACM Transactions on Applied Perception (TAP), 2(2):106–117, 2005.

Navigating with vibrations

(a) (b)



- “Our hypothesis was that adding distance information should improve walking speed and accuracy, however, similar results were obtained with and without distance information.”
- Modulated vibration frequency and pattern to code distance to waypoint

Markus Straub, Andreas Riener, and Alois Ferscha. *Distance encoding in vibro-tactile guidance cues*. In 2009 6th Annual International Mobile and Ubiquitous Systems: Networking & Services, MobiQuitous, pages 1–2. IEEE, 2009.