Evaluating Angular Accuracy of Wrist-based Haptic Directional Guidance for Hand Movement

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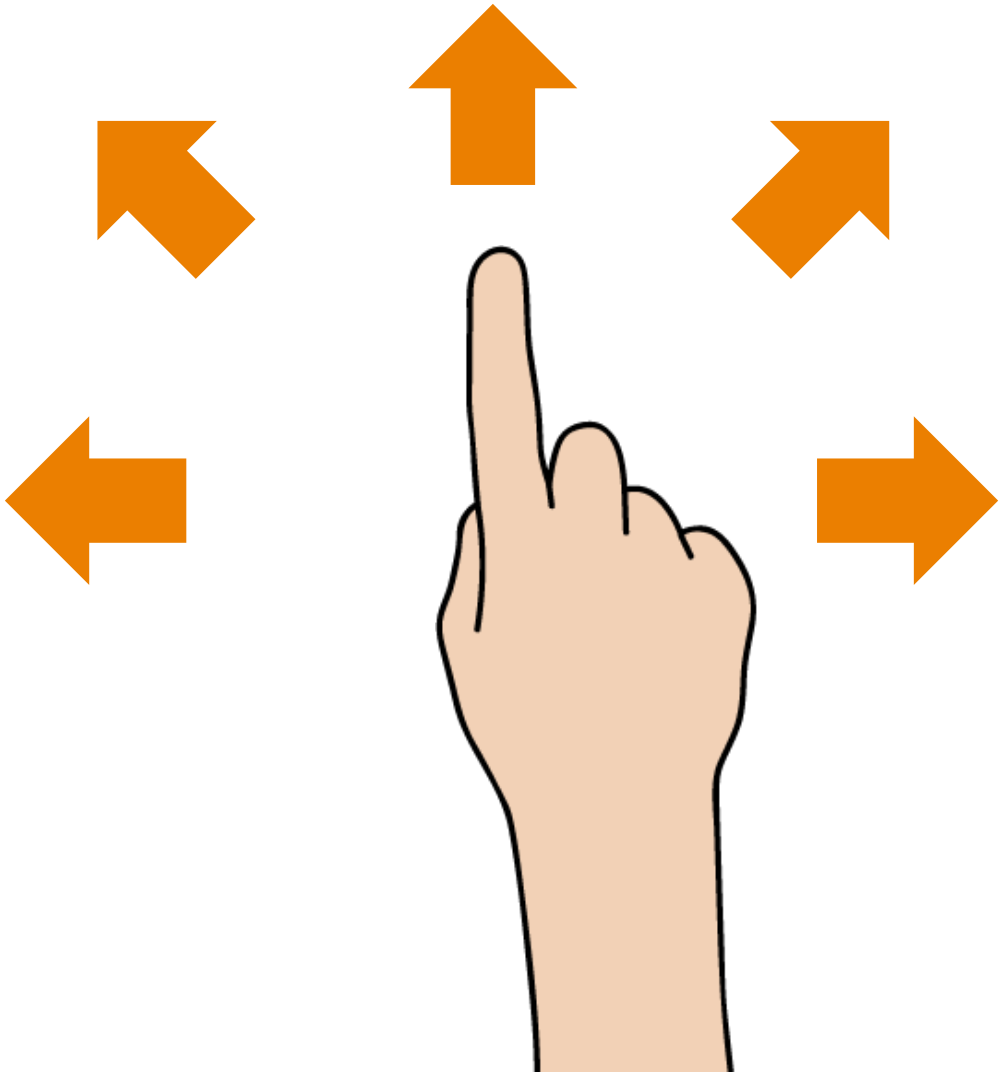
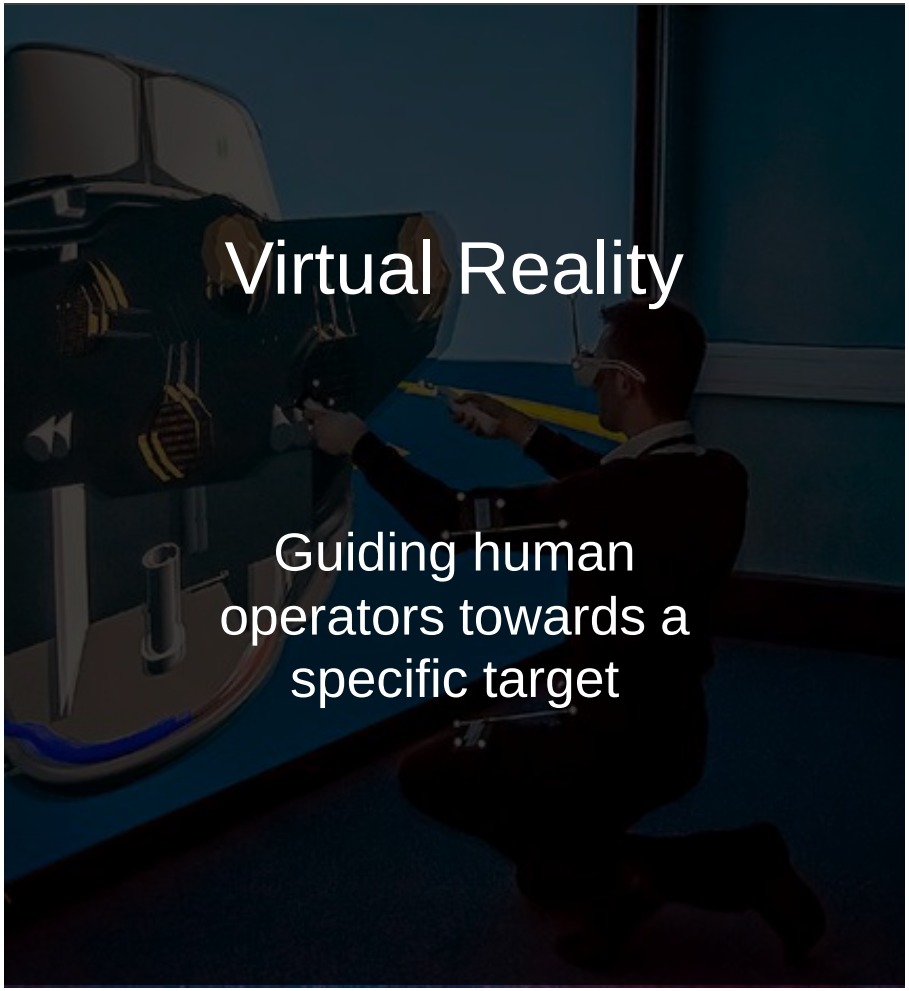
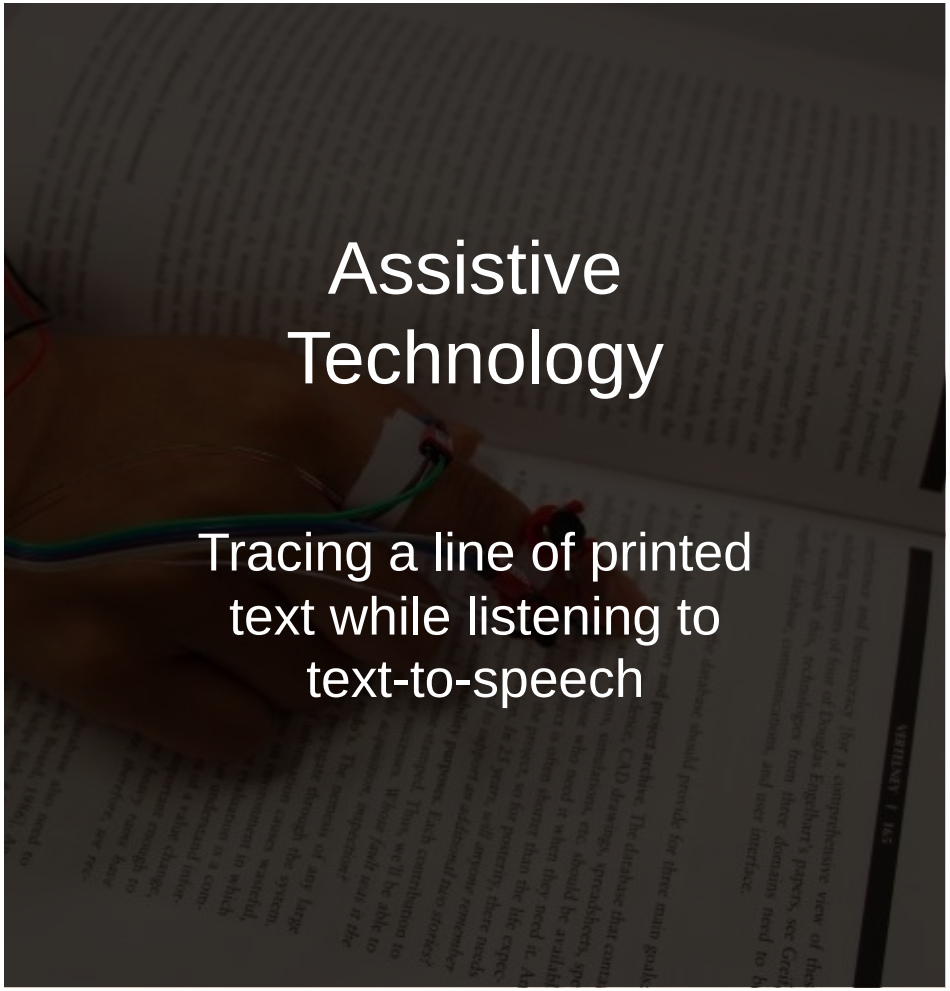
Directional Guidance for Hand Movement



When is the hand guidance needed?

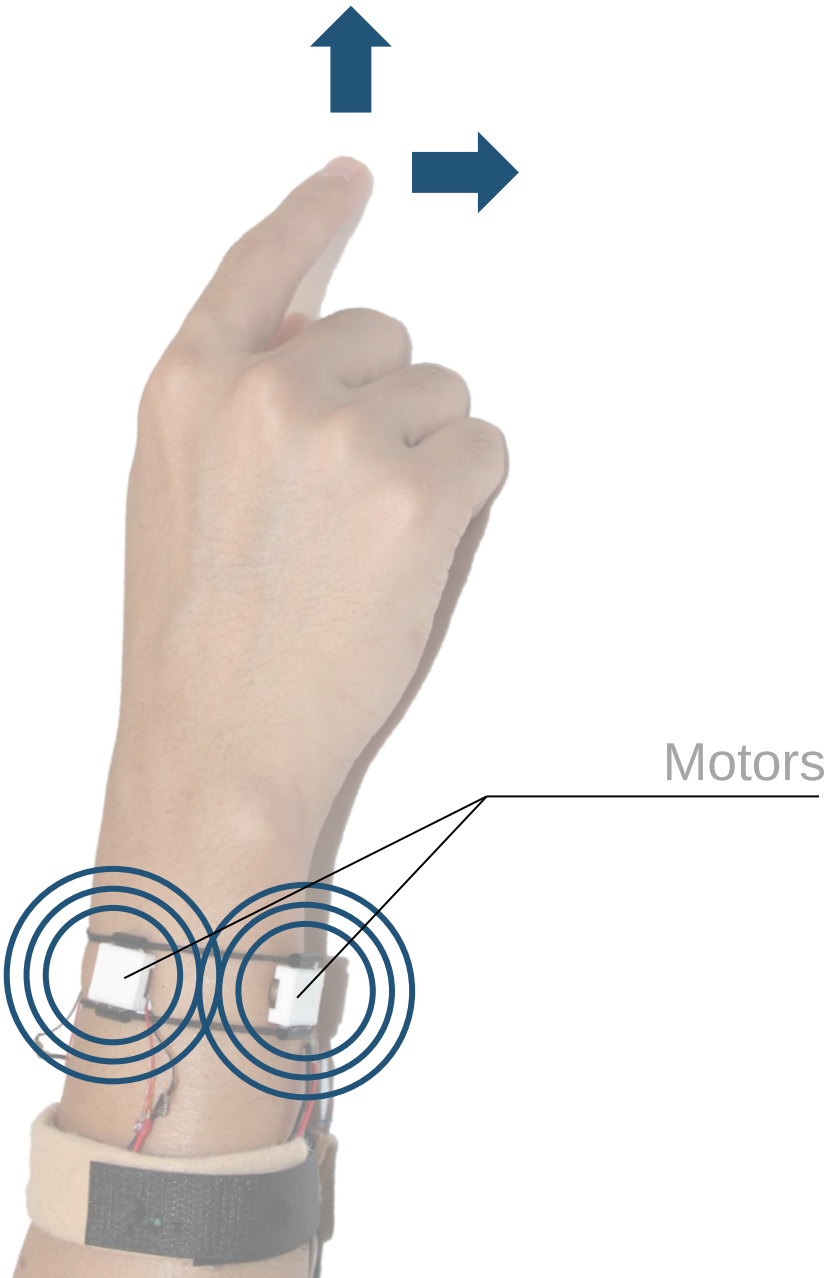




Problem

Visual or audio information channels are **overloaded or inaccessible** due to environmental factors.

One Solution: Wrist-Based Haptic Feedback



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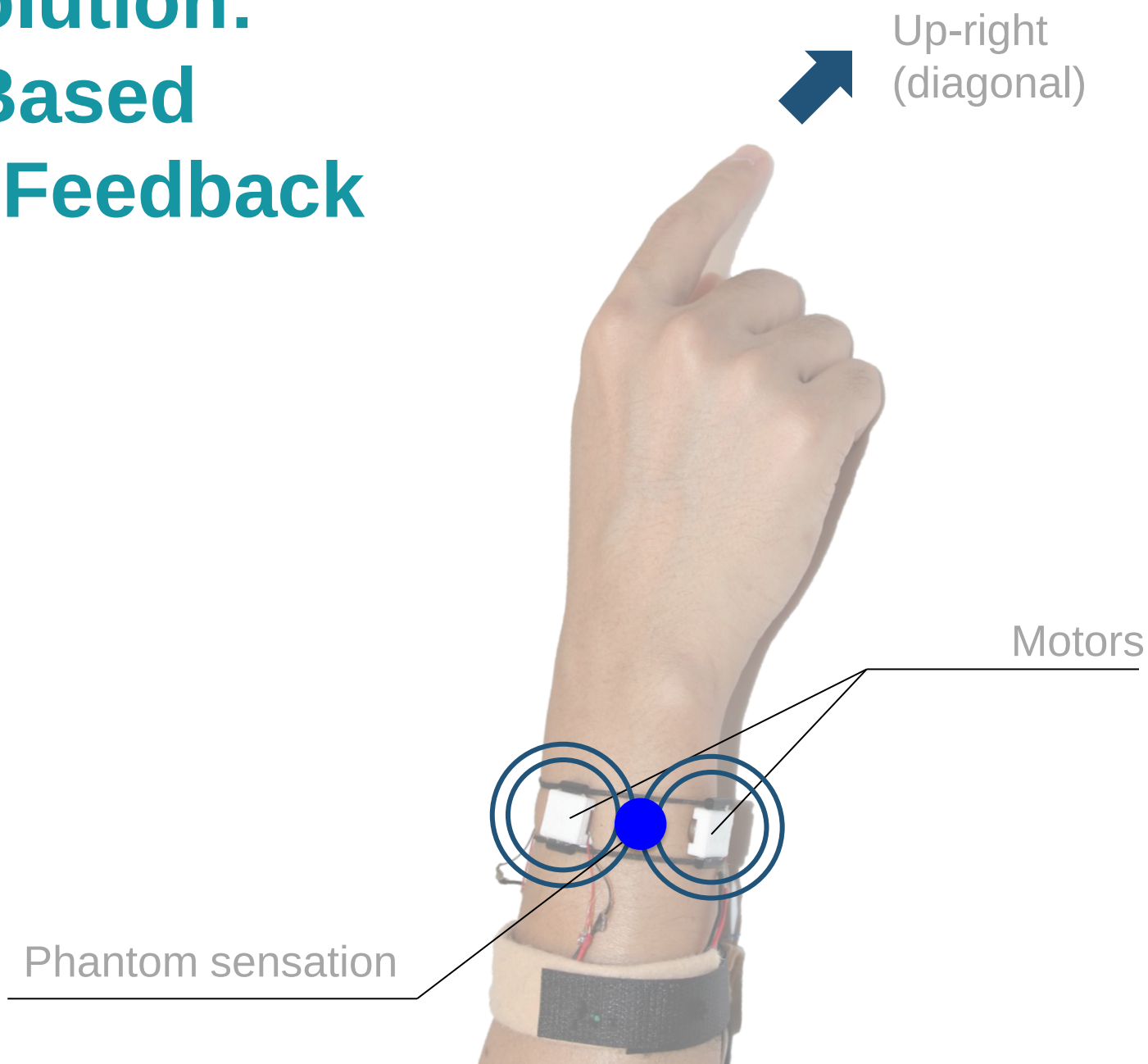
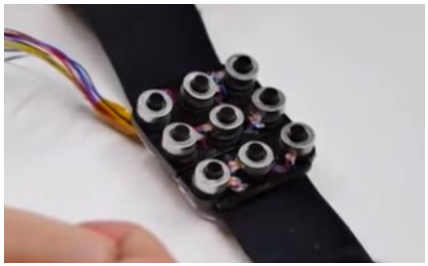


Existing studies: Wrist-based feedback

Grid layouts



Can be used for coarse-grained direction (e.g., cardinal directions)

Lee *et al*. (2015)

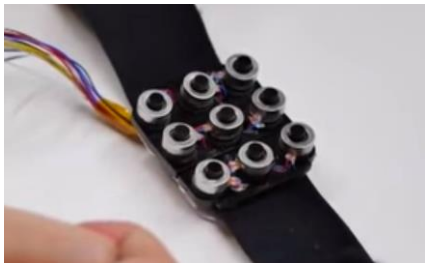
Grid layouts offer lower tactile perception compared to motors placed on a band

Matscheko *et al*. (2010)

Band layouts

Existing studies: Wrist-based feedback

Grid layouts



Can be used for coarse-grained direction (e.g., cardinal directions)

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Grid layouts offer lower tactile perception compared to motors placed on a band

Matscheko *et al*. (2010)

Band layouts

Have been used to guide translation and rotation of the arm using four or six motors

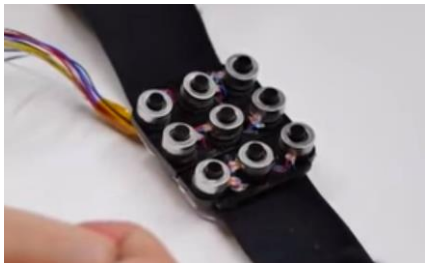
Six motors were more accurate than four motors and verbal guidance.

By Weber *et al*. (2011)

The study only included at most six angles of movement, not higher precision

Existing studies: Wrist-based feedback

Grid layouts

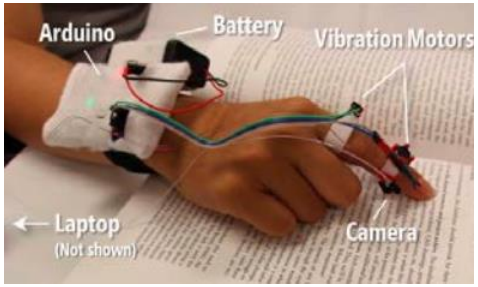


Band layouts

Fine-grained directional guidance has received less attention

Existing studies: Finger-based feedback

By Horvath *et al.*



By Stearns *et al*.

Motors on the finger have been explored to guide visually impaired users in tracing a line or reading text

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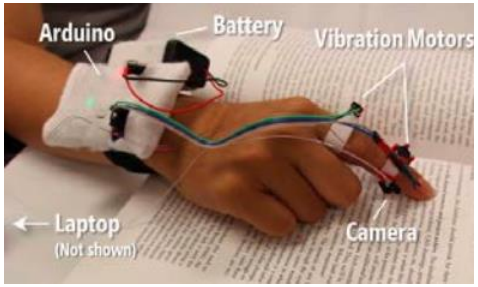

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Motors on the finger have been explored to guide visually impaired users in tracing a line or reading text

In contrast, a wrist-based approach:

Can be incorporated into a smartwatch band

Balances proximity to the finger, sensitivity, surface area, and social acceptability

Research Questions

How accurately can people move their hand given fine-grained haptic guidance on a wristband?

How many motors are needed to achieve this level of accuracy?

Wristband Prototypes

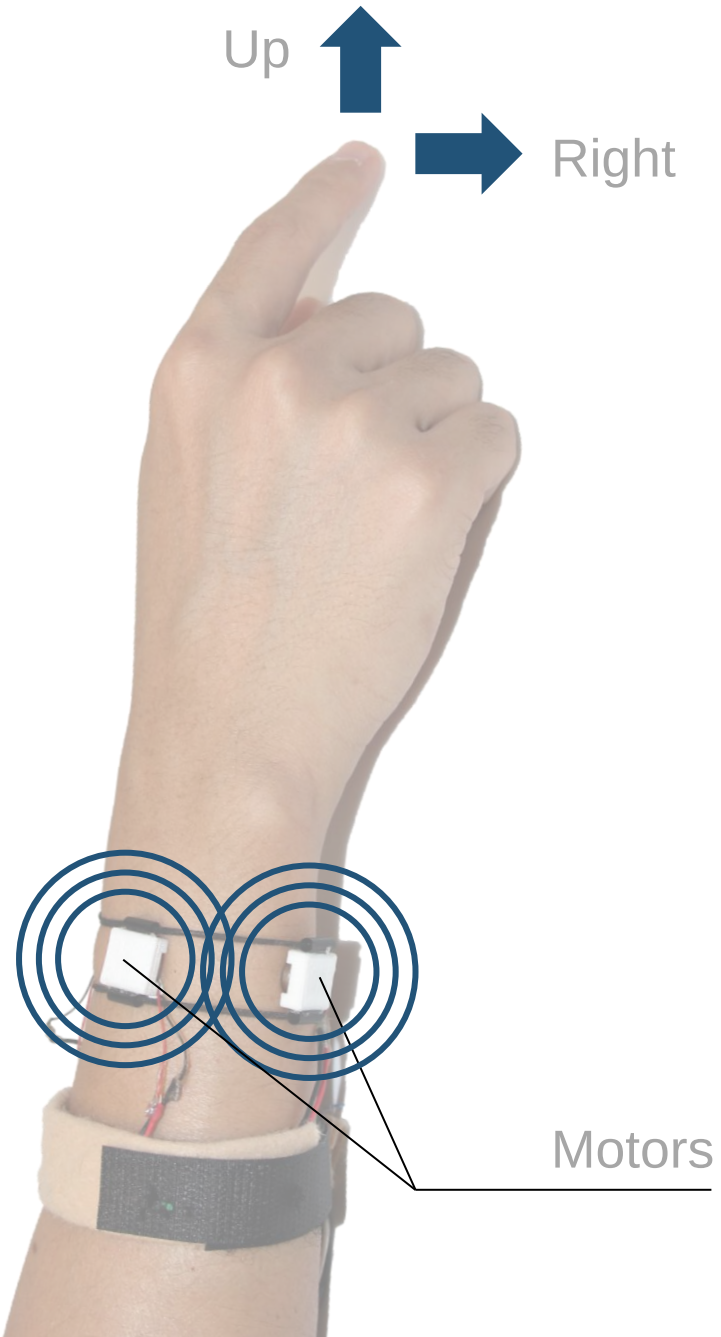
Providing fine-grained directional guidance

4-motor wristband

8-motor wristband

Mapping the Vibration to a Direction

How to indicate angles of direction *between* motors?

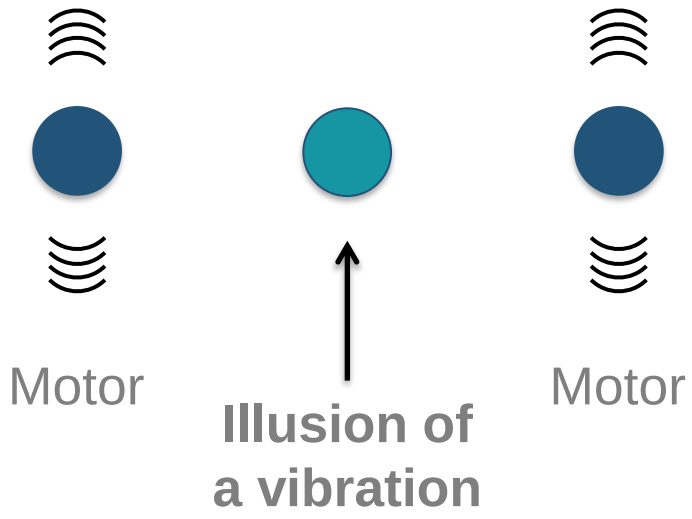


Phantom Sensation

Two vibrotactile actuators placed closely together on the skin create the **illusion of a single vibration** between the two actuators.

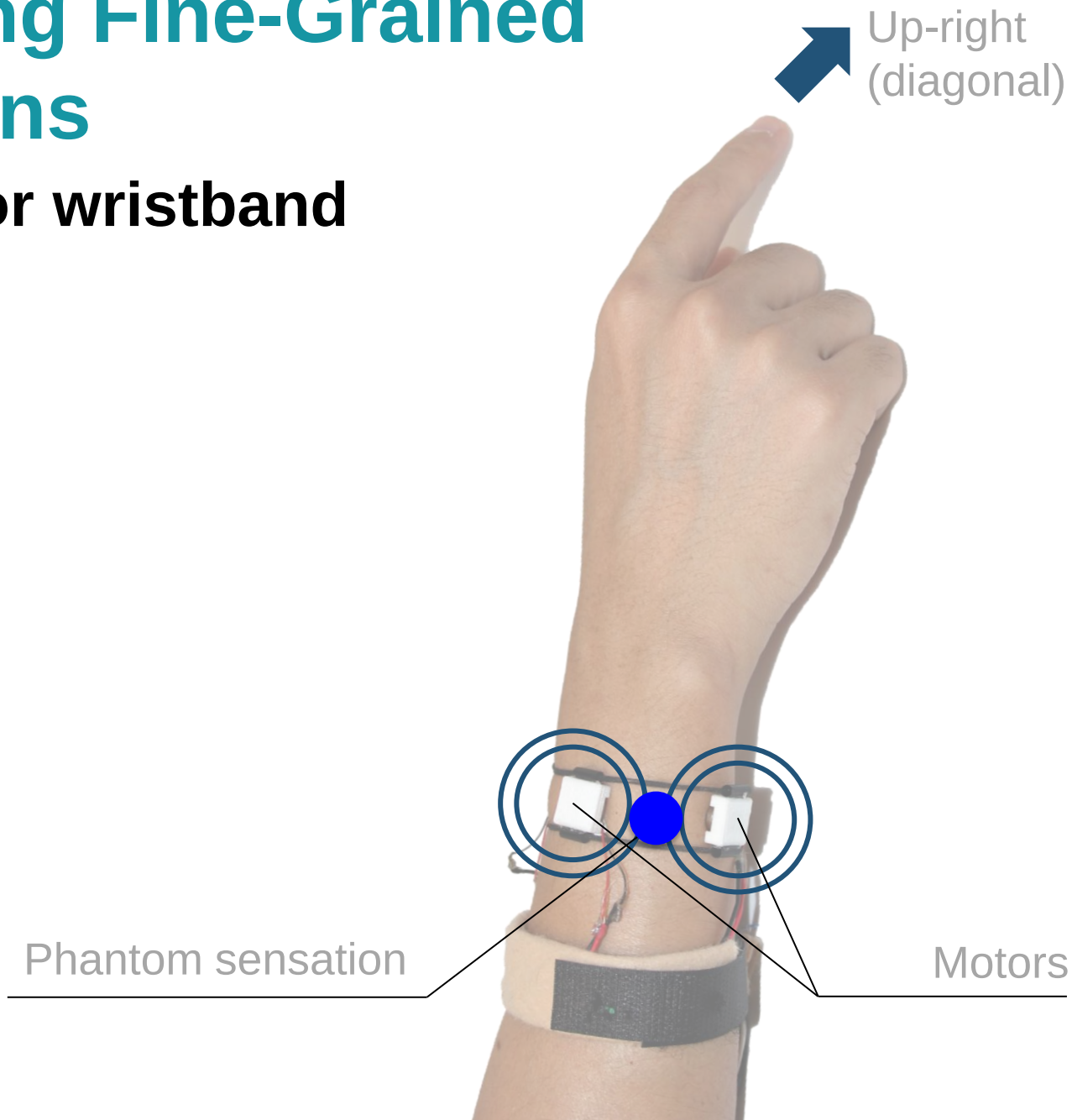
The location of the phantom sensation is determined by the amplitude of the two vibrations.

[Alles, 1970]



Providing Fine-Grained Directions

Four-motor wristband



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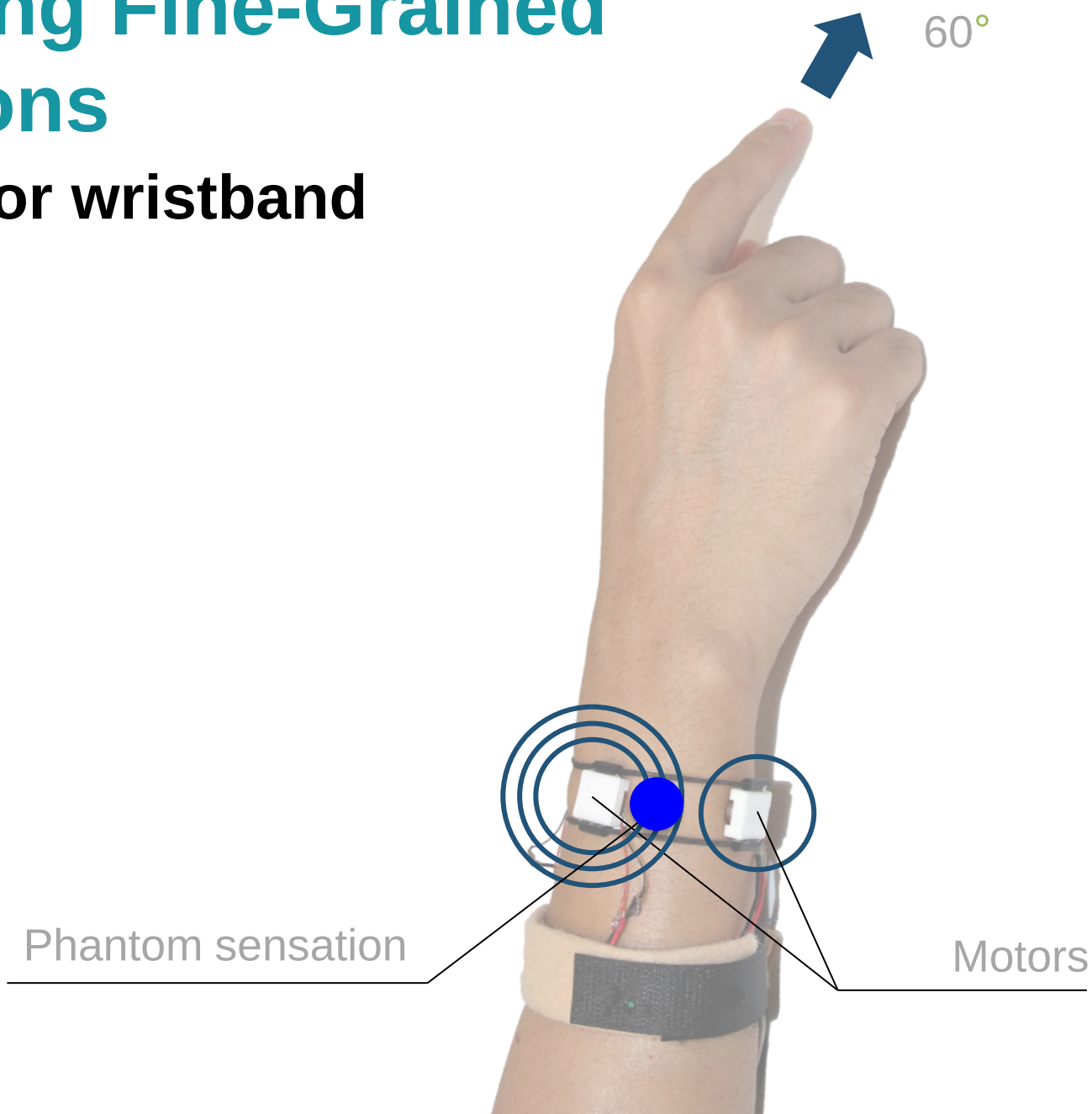

Providing Fine-Grained Directions

Eight-motor wristband

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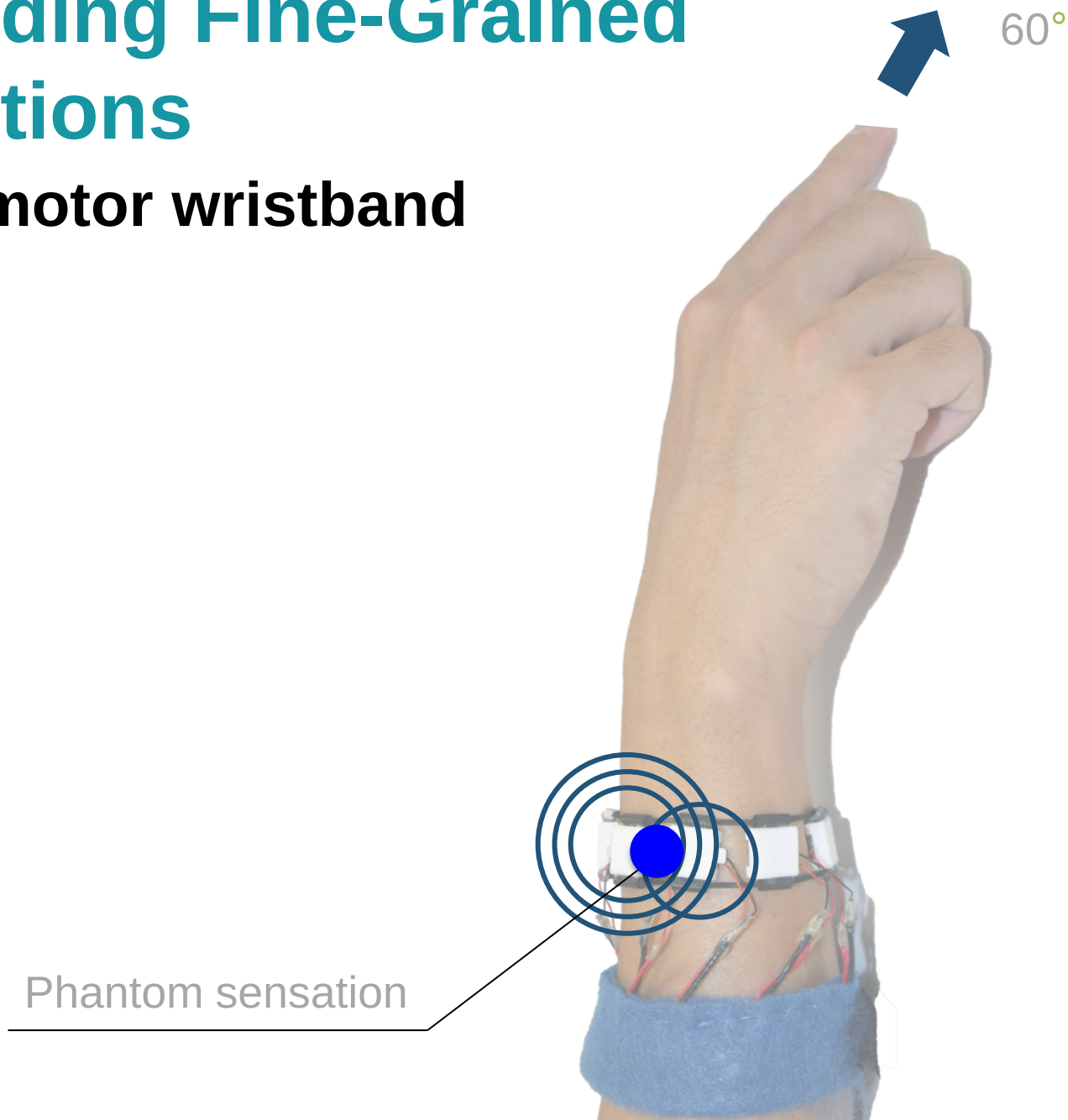
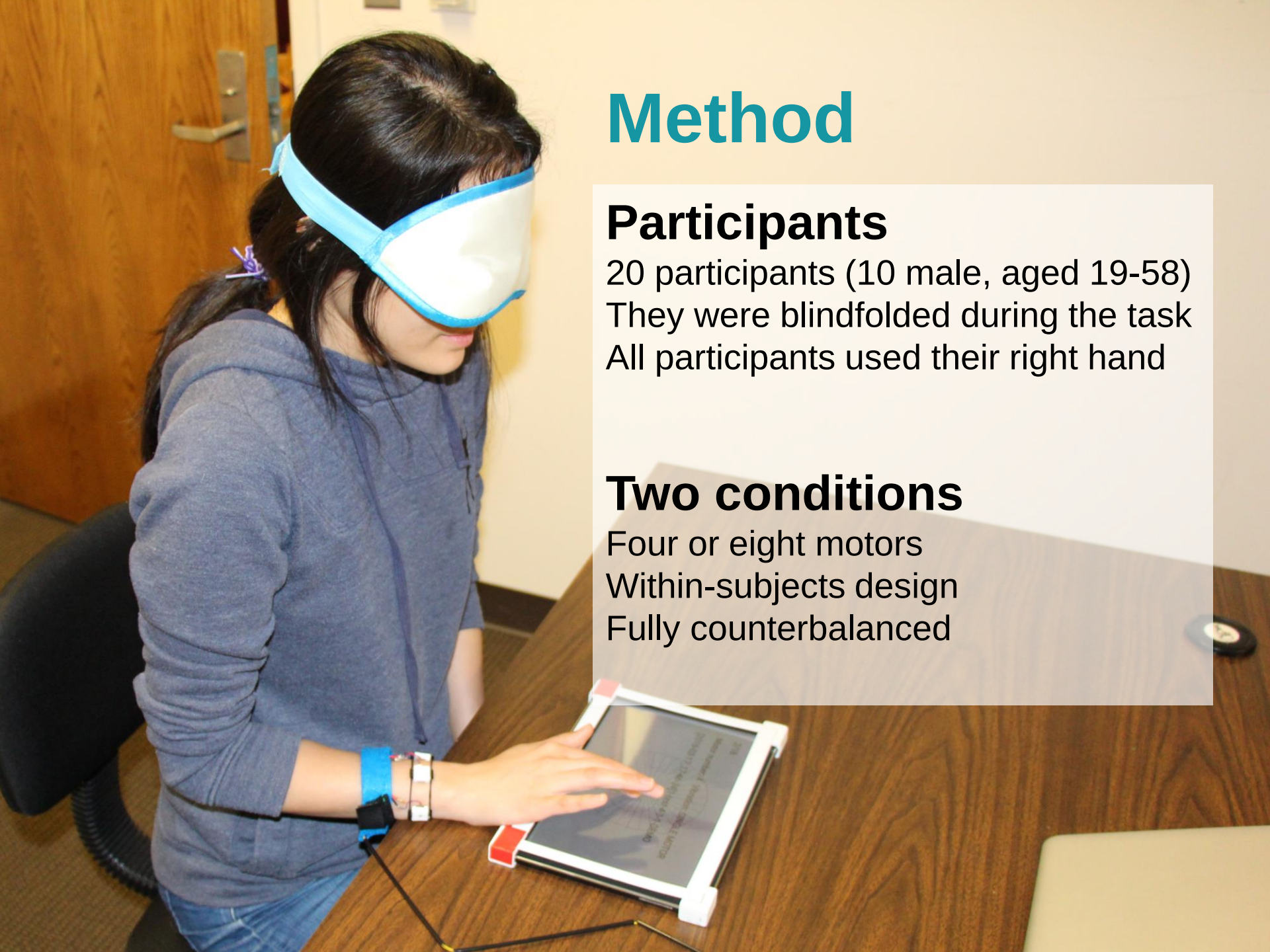
Eight-motor wristband



User Study

Comparing haptic feedback with four or eight motors around the wrist



Method

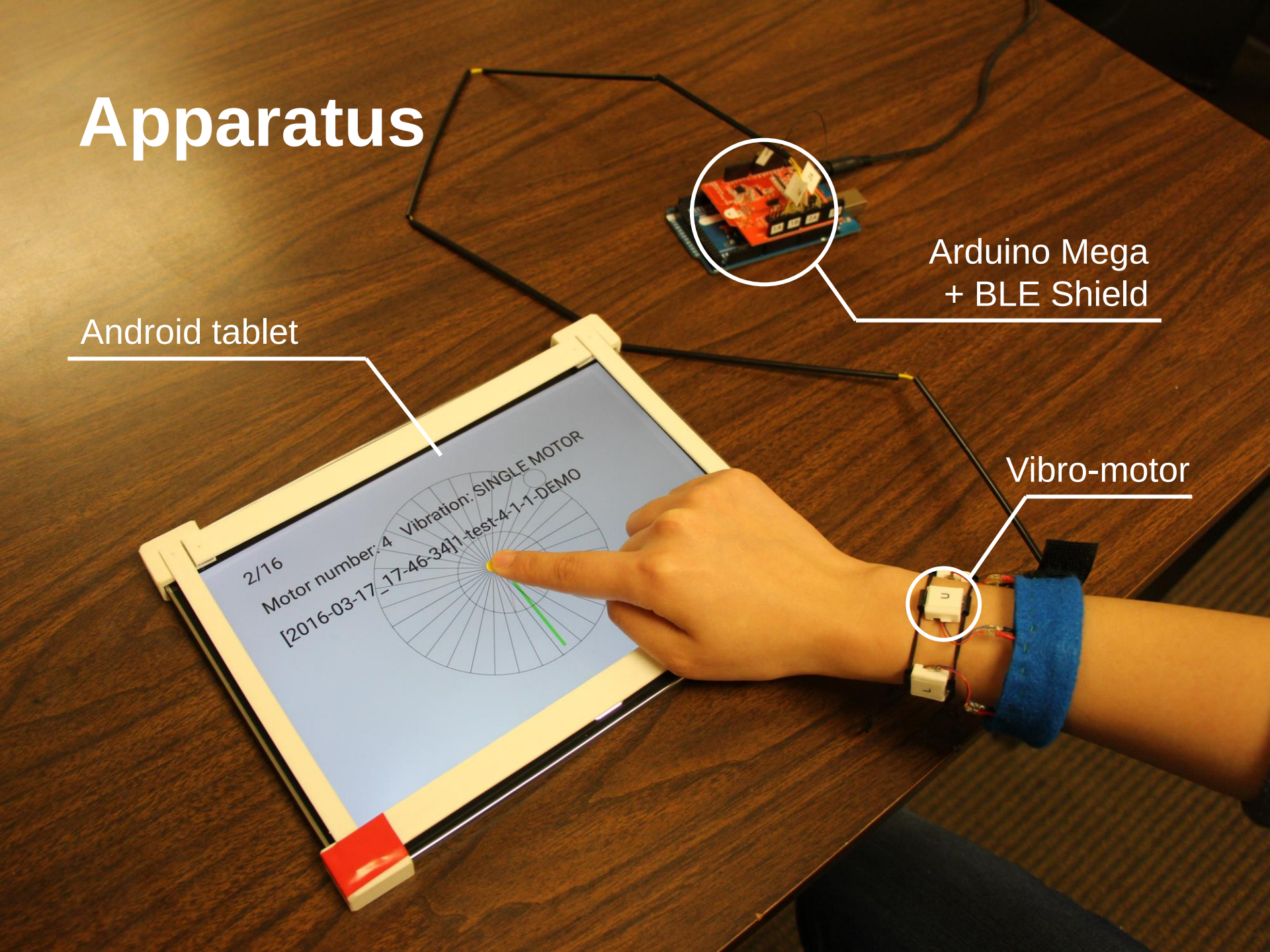
Participants

20 participants (10 male, aged 19-58)
They were blindfolded during the task
All participants used their right hand

Two conditions

Four or eight motors
Within-subjects design
Fully counterbalanced

Apparatus


Arduino Mega
+ BLE Shield
Android tablet
Vibro-motor
2/16
Motor number: 4
Vibration: SINGLE MOTOR
[2016-03-17_17-46-34]1-test-4-1-1-DEMO

Procedure

1. Background survey

Age, gender, experience in using a touchscreen device and haptic feedback.

2. Completing a task in two conditions

Moving the hand in the direction of the vibration.

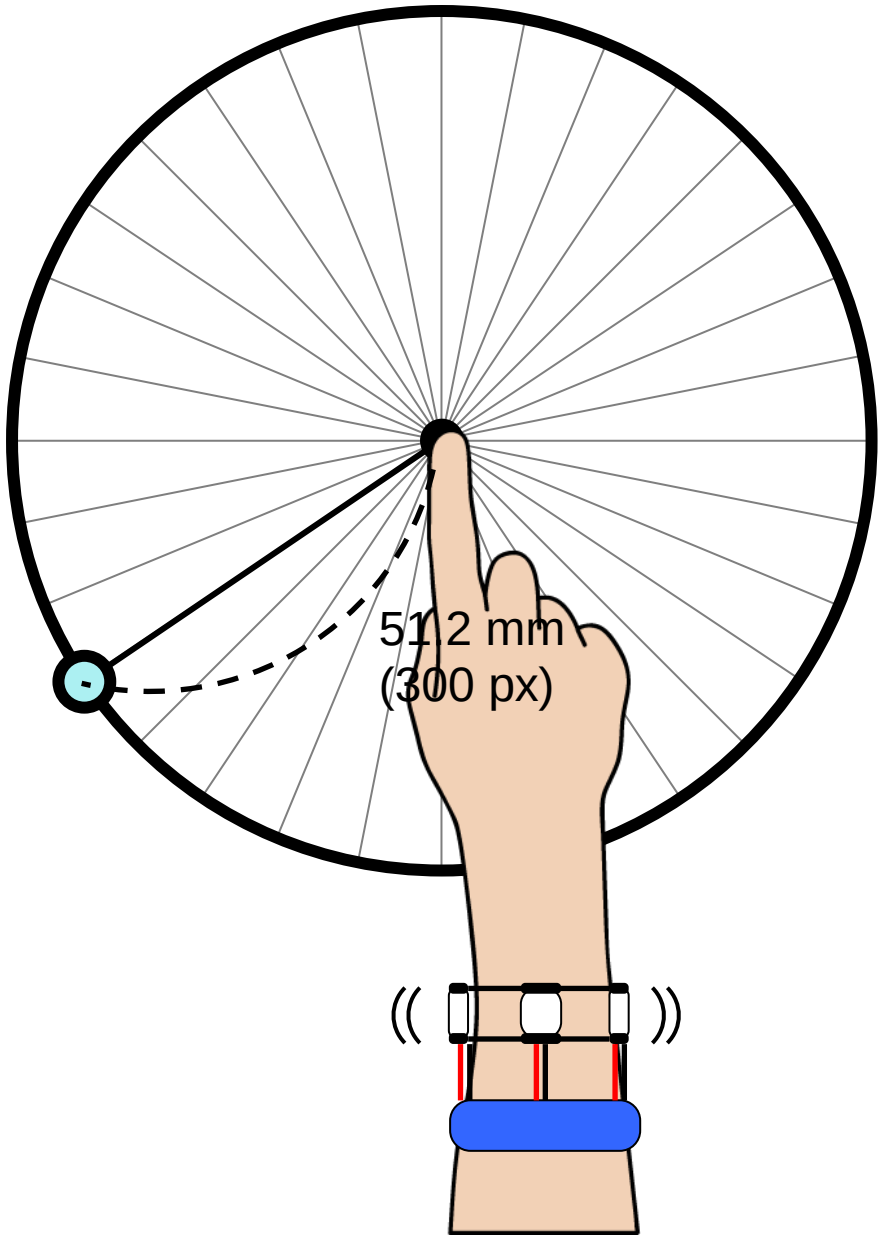
3. Questionnaire

Comparing ease of use, accuracy, and preference between the two conditions.

Task

Each trial: move in one of 32 directions

(11.25° intervals)



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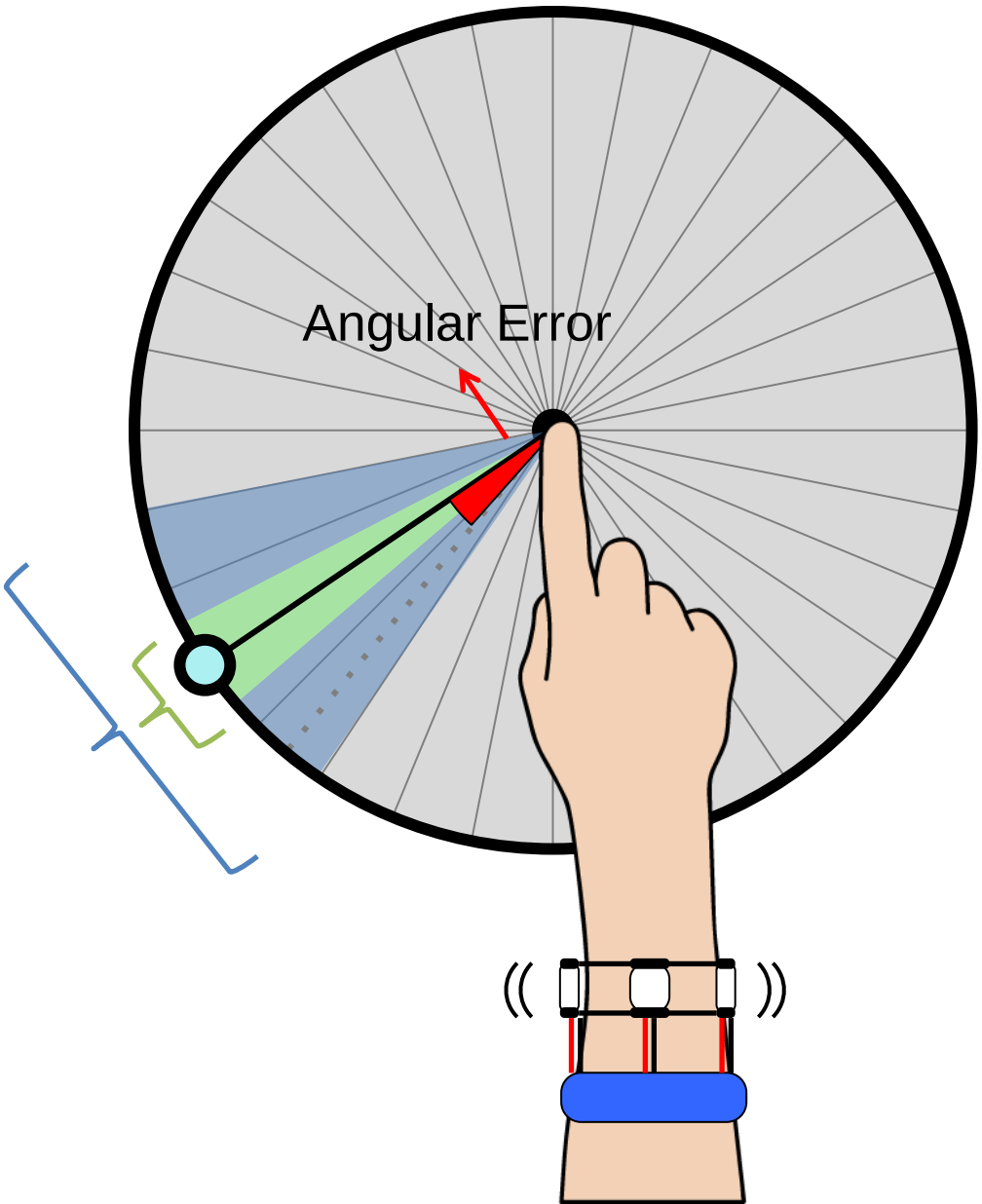


Audio Feedback

Exact (11.25° interval)
Chime + “Perfect!”

Approximate (45° interval)
Chime

Incorrect (Error > 45°)
Beep

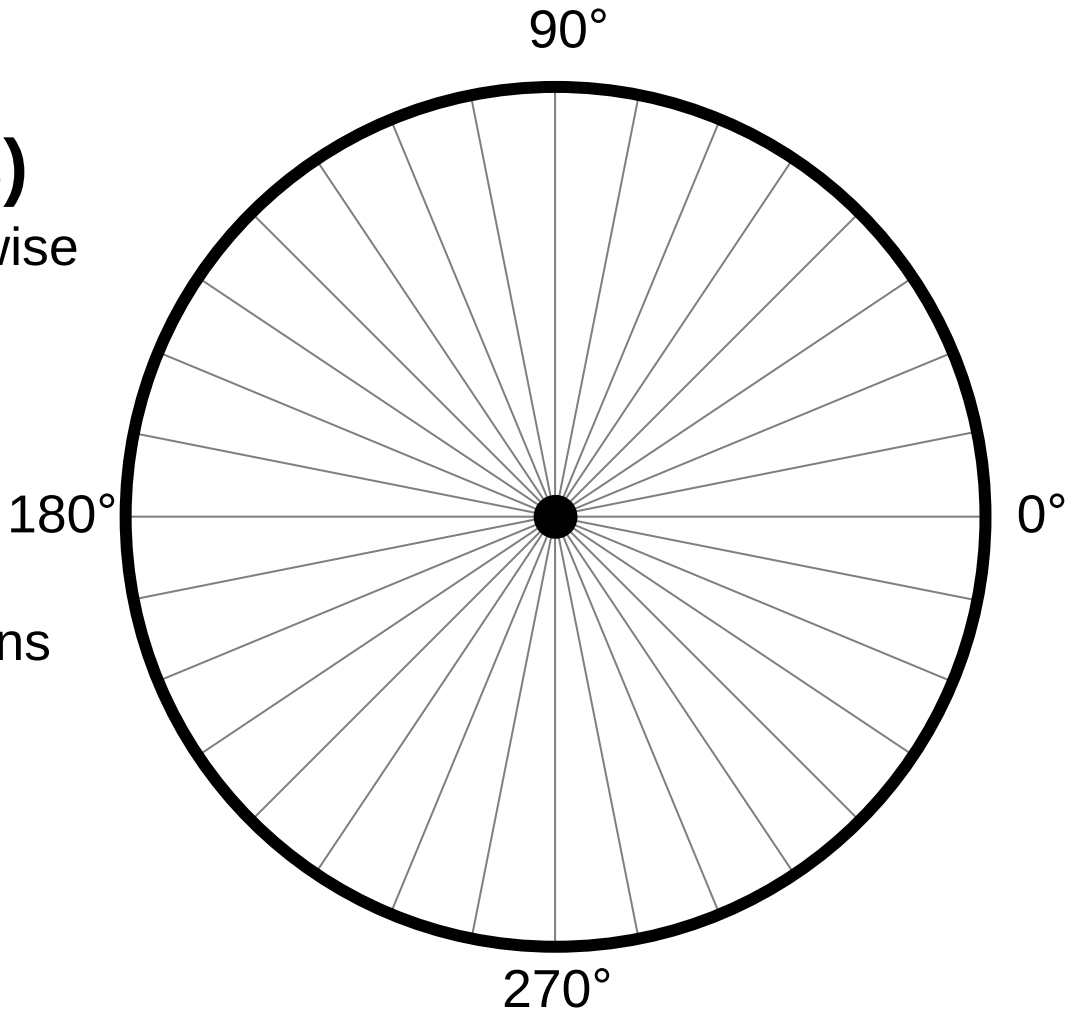
Task

Practice (16 trials)

8 directions counterclockwise
+ 8 random directions

Test (96 trials)

3 repetitions of 32 directions
in randomized order



Hypotheses

H1

The 8-motor condition will be more accurate than the 4-motor condition.

Eight motors provide twice the fidelity of information.

H2

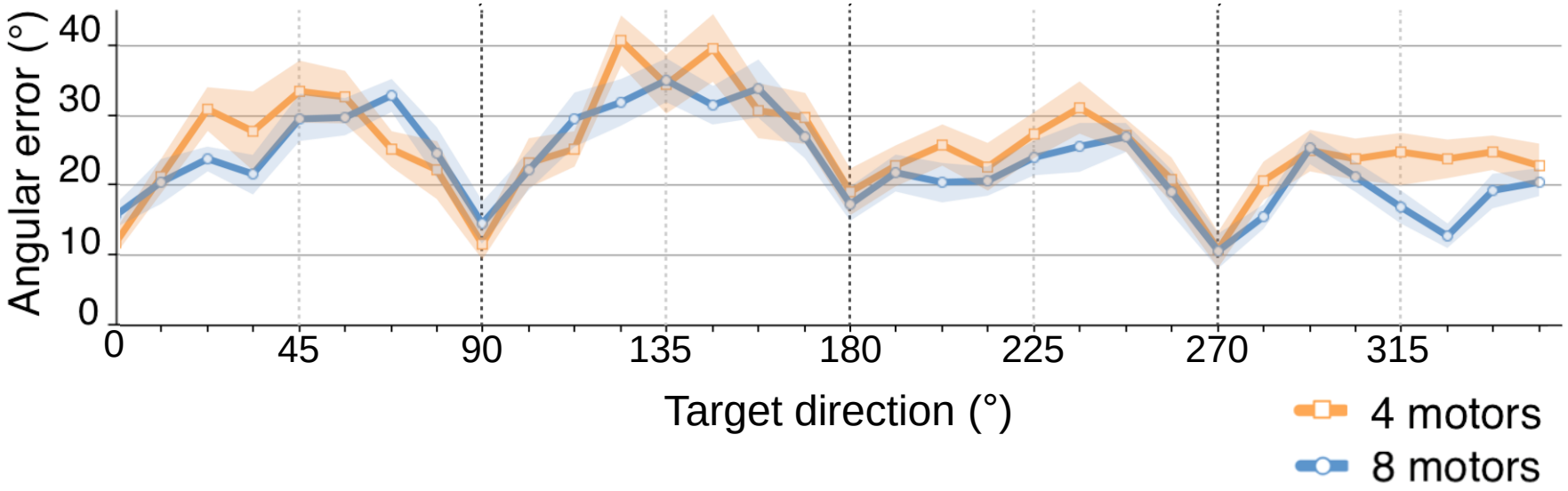
The 8-motor and 4-motor conditions will impact trial completion time differently.

The 4-motor condition is simpler but the 8-motor condition may offer clearer intercardinal information.

Results

Accuracy, time, and subjective responses

Cardinal Directions Most Accurate



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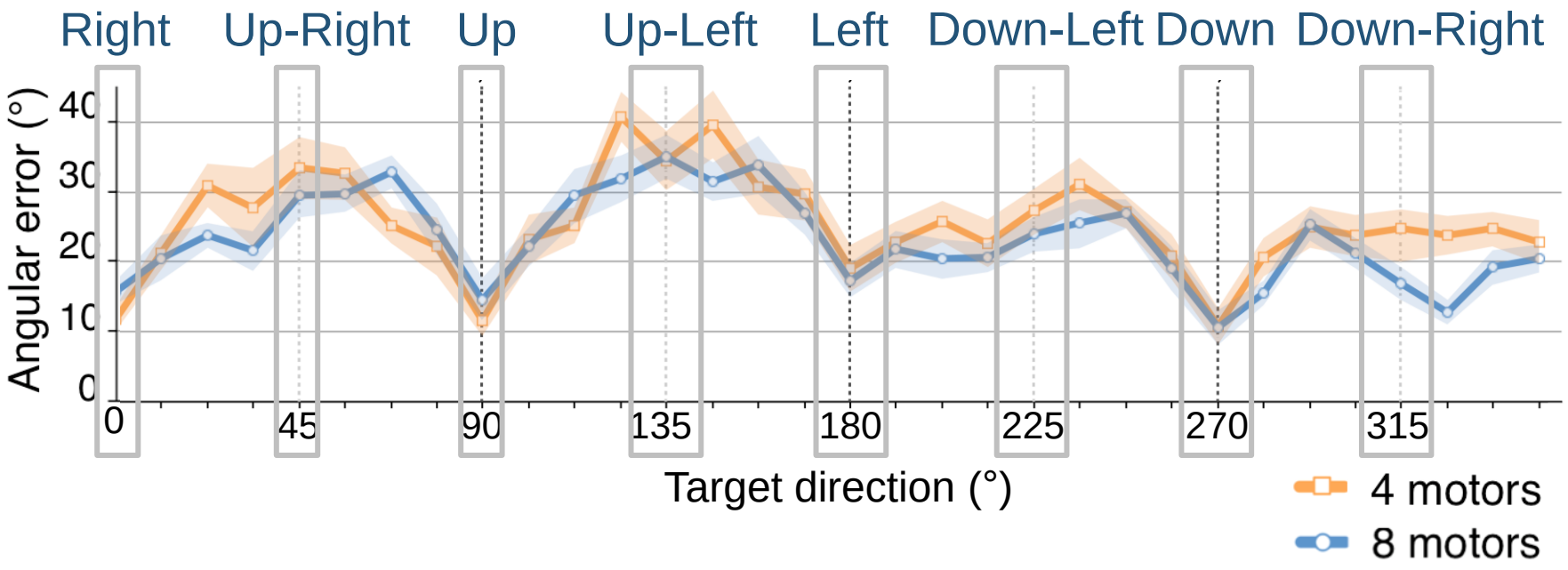
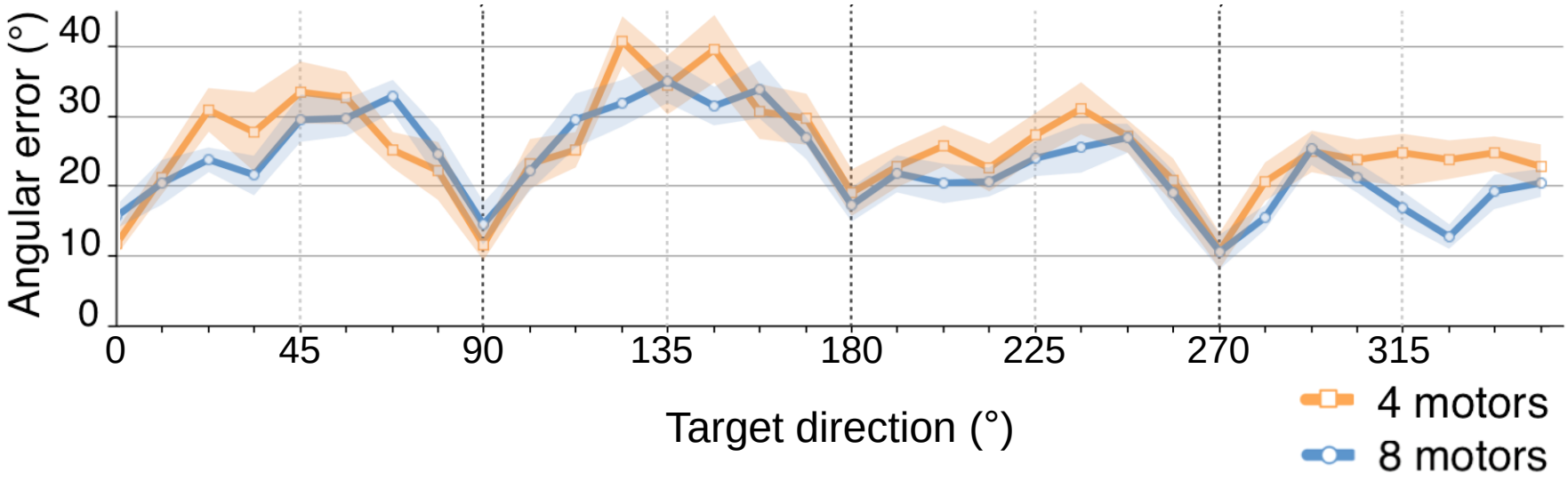


8-motors More Accurate Than 4-motors



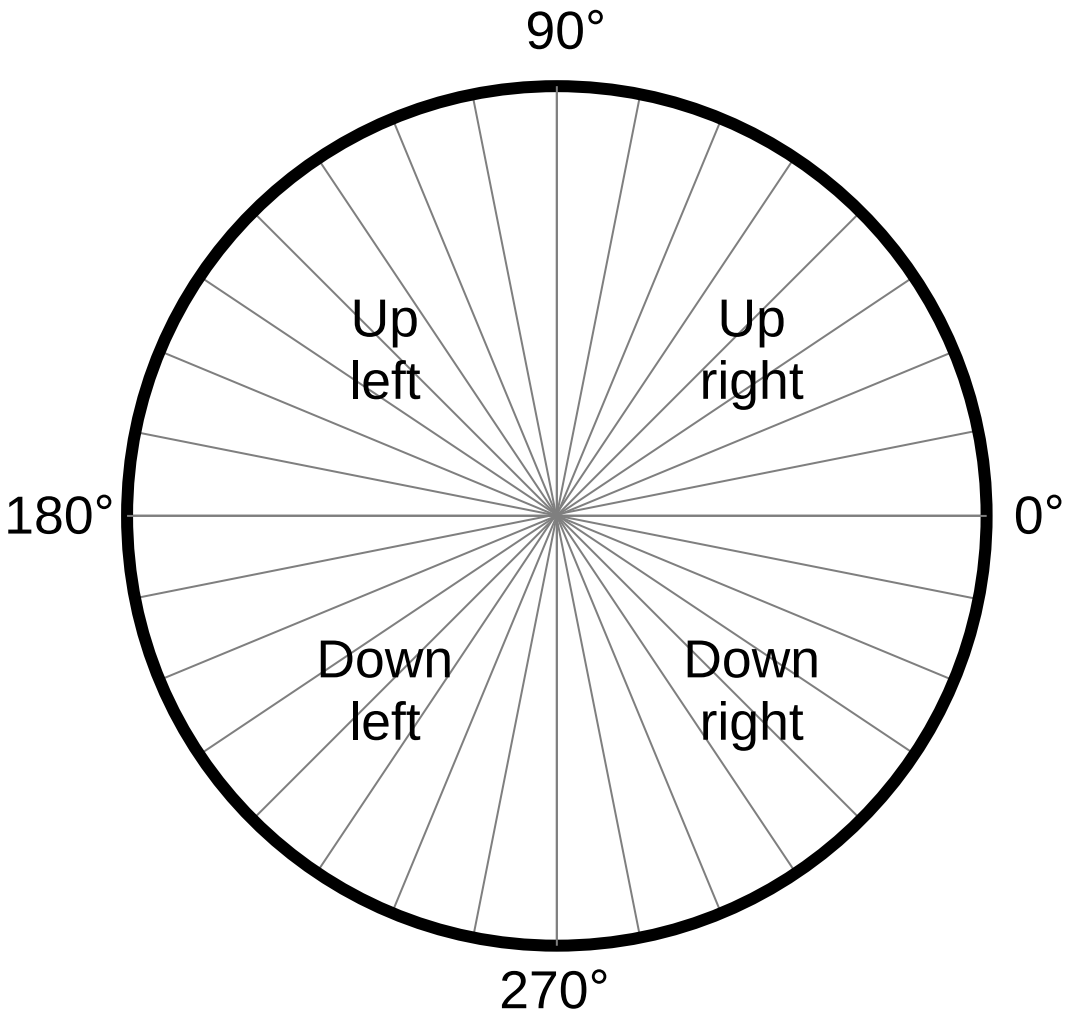
Average angular error across *all* directions

4-motor	**8-motor**
25.4°	23.2°

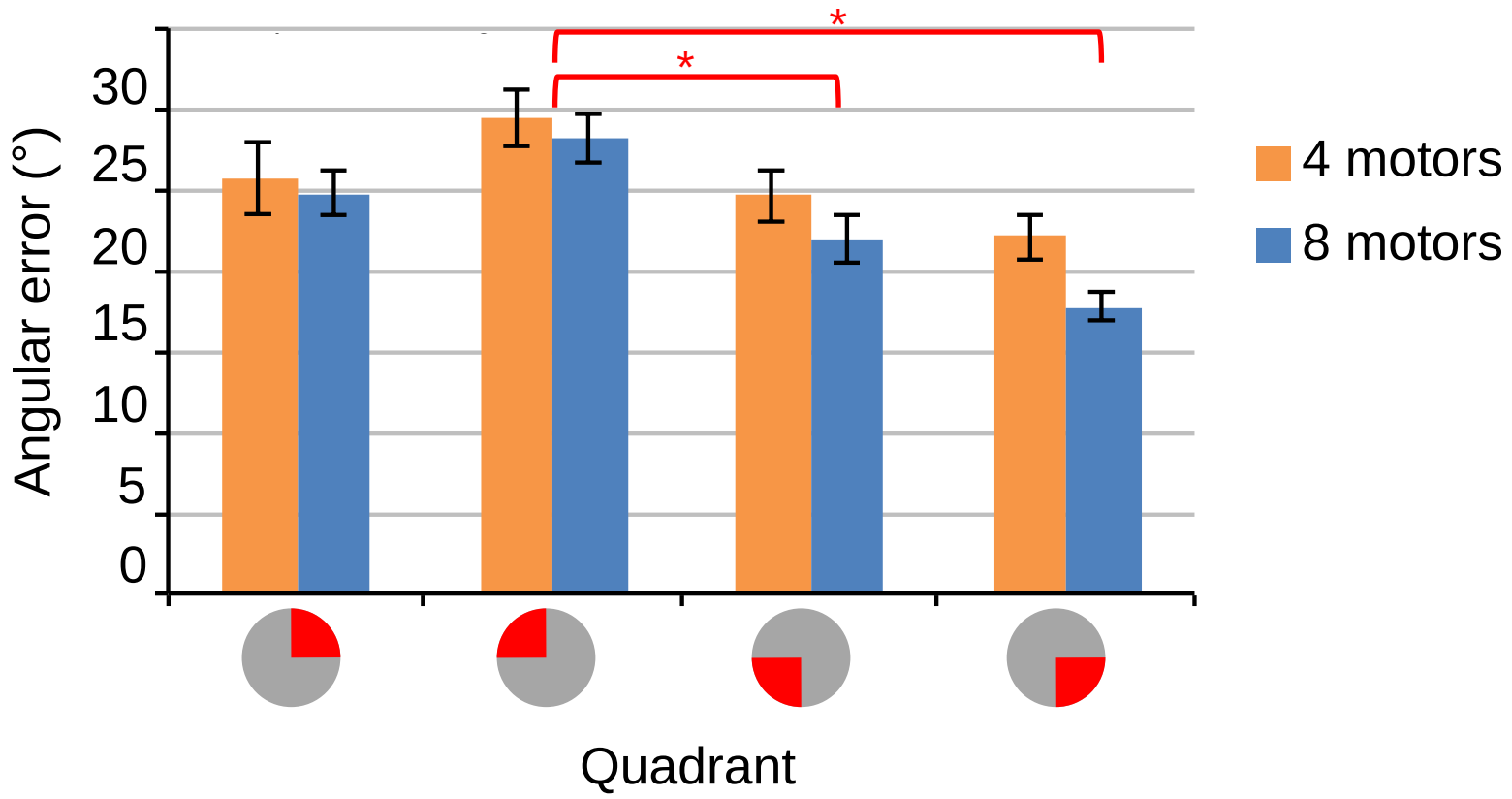
Statistically significant difference (p = .034, one-tailed t-test)

Hypothesis 1 is supported

Angular Accuracy by Quadrant

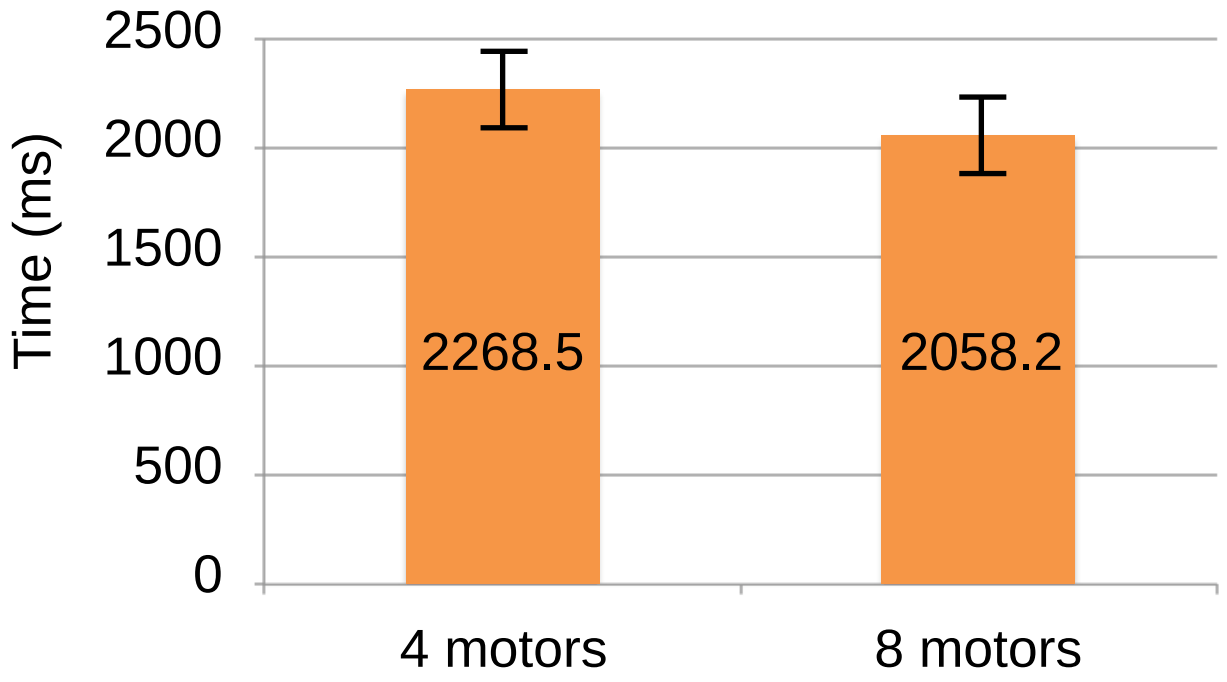


Upper-left Quadrant was Least Accurate



Upper-left quadrant was significantly worse than the two downward quadrants ($p < .05$)

No Differences in Trial Completion Time



No significant difference found between conditions using a Wilcoxon signed ranks test ($Z = -.89$, $p = .372$)

Hypothesis 2 is not supported

Subjective Response

	Answer	
Question	4-motor	8-motor

Recap and Discussion

1. Doubling the number of haptic motors increased accuracy, but not speed.

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2. Empirically identified a potential lower bound on angular error: about 23-25°.

3. Movements in the upper-left quadrant were less accurate than other quadrants, perhaps because all participants used their right hand.

Future Work

1. **Further investigate identified angular error limit** such as how it affects more realistic tasks with continuously updated directional guidance (e.g., tracing a path)

2. **Extend these findings to users with visual impairments** such as for finger-based reading of printed text or to gain spatial layout information of a printed page

Questions?

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This work was supported by the Office of the Assistant Secretary of Defense for Health Affairs under Award W81XWH-14-1-0617