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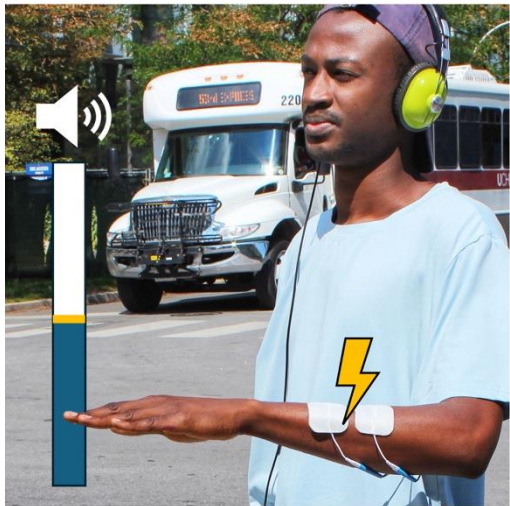
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More on this paper (or others of our lab) at: <https://lab.plopes.org/>



Increasing Input Accuracy of Embodied-devices via Electrical Muscle Stimulation

Lonnie Chien, Yudai Tanaka, Noor Amin, Jas Brooks, Pedro Lopes. In Proc. [CHI'26](#) (paper)

We propose interaction-techniques to increase input accuracy with embodied-devices—an emergent type of interactive-system where the user's body serves as both the input and output medium (e.g., gestural-input via cameras/IMUs; gestural-output via motors/muscle-stimulation). A critical shortcoming of existing embodied-devices is their failure to enforce alignment between the users' proprioceptive-inputs and interface-state. Thus, we turn to muscle-stimulation to enable embodied-devices to: recall previous interface-states; provide confirmation-cues to signal state transitions; and (3) constrain inputs to a valid range. We found that, compared to an embodied device without EMS-feedback, the combination of our techniques increased the inputs': absolute-accuracy; relative-accuracy; and confidence. Our approach enables this without resorting to non-gestural modalities (visuals/sound/vibrations)—respecting the proprioceptive nature of embodied-devices.



[click for paper PDF](#)



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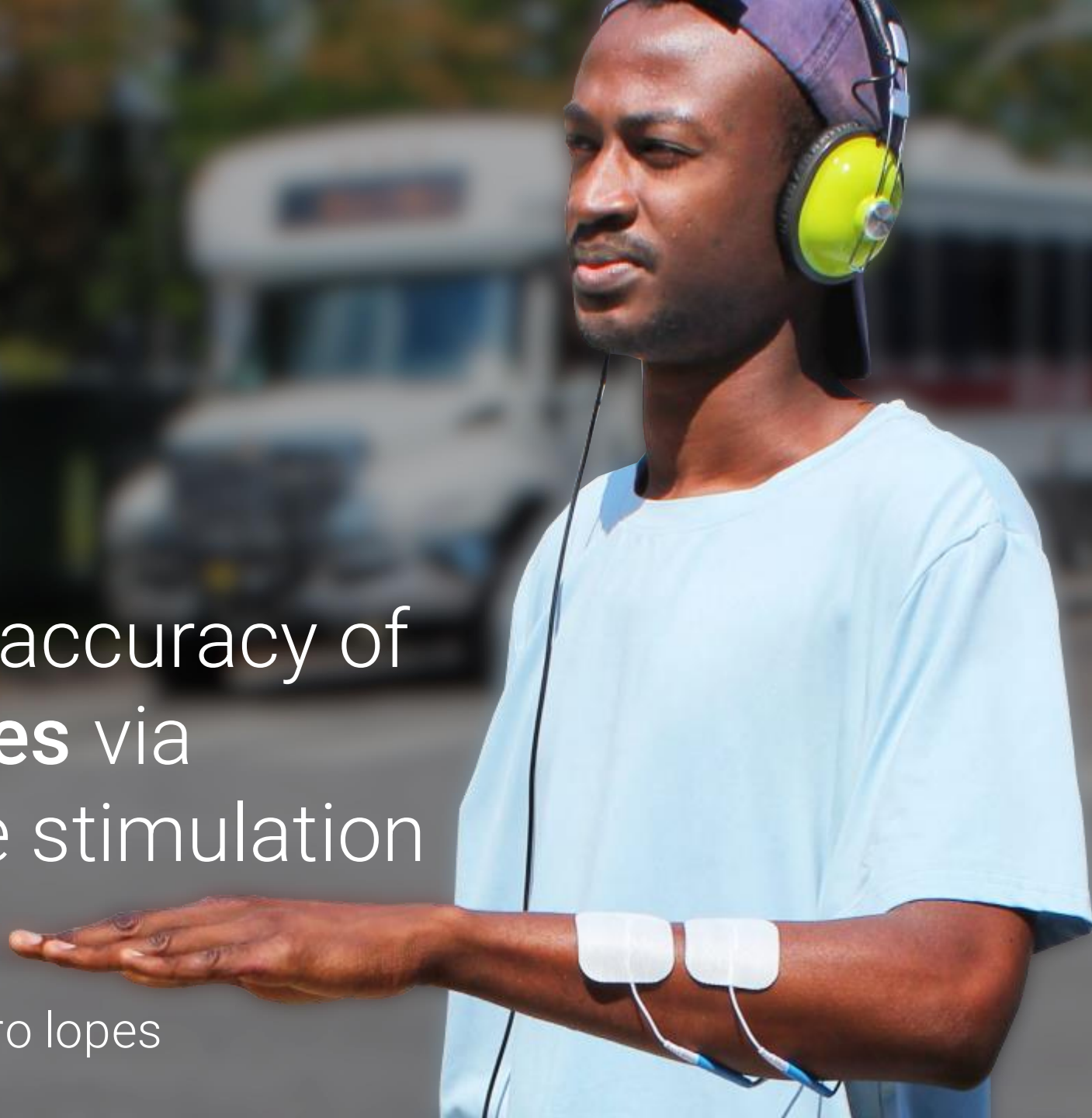
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increasing input accuracy of
embodied devices via
electrical muscle stimulation

lonnie chien, yudai tanaka,
noor amin, jas brooks, pedro lopes



1. related work

VIDEOPLACE (CHI '85)



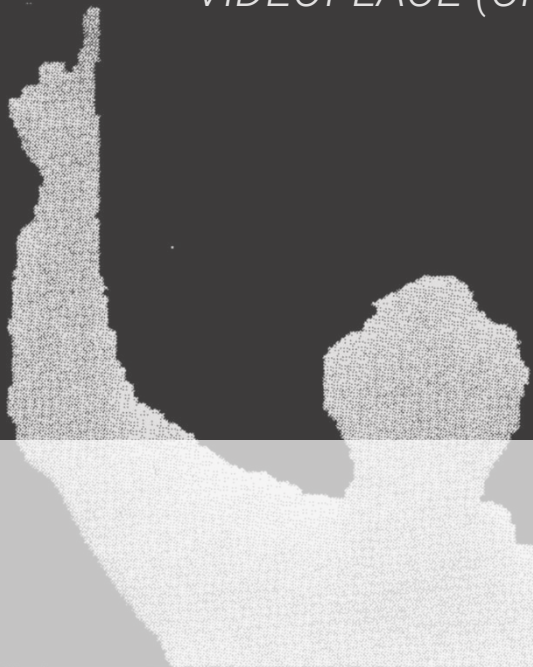
Kinect (2010)



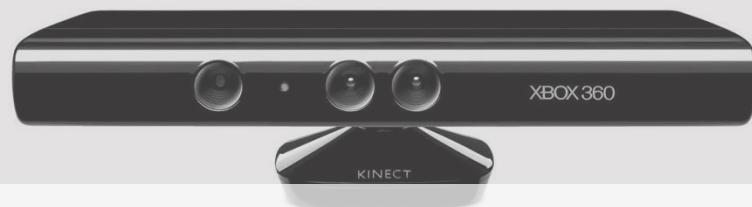
Apple (2023)



VIDEOPLACE (CHI '85)



Kinect (2010)



Apple (2023)

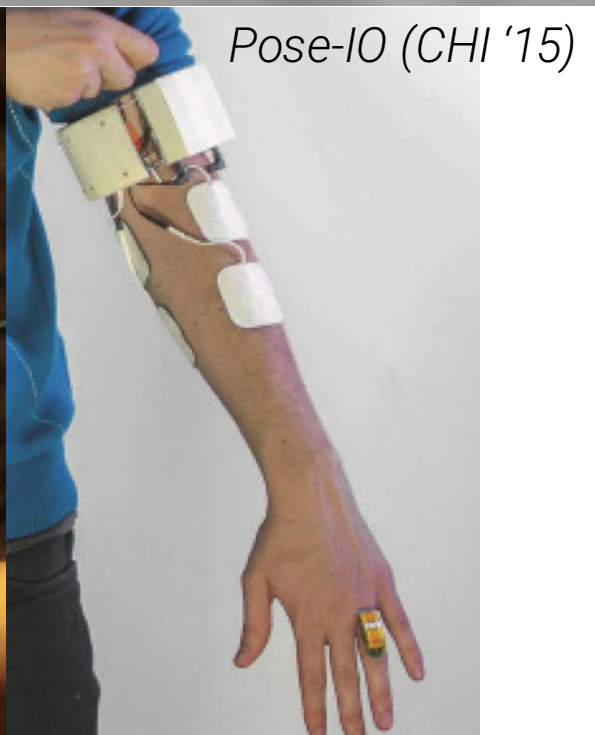
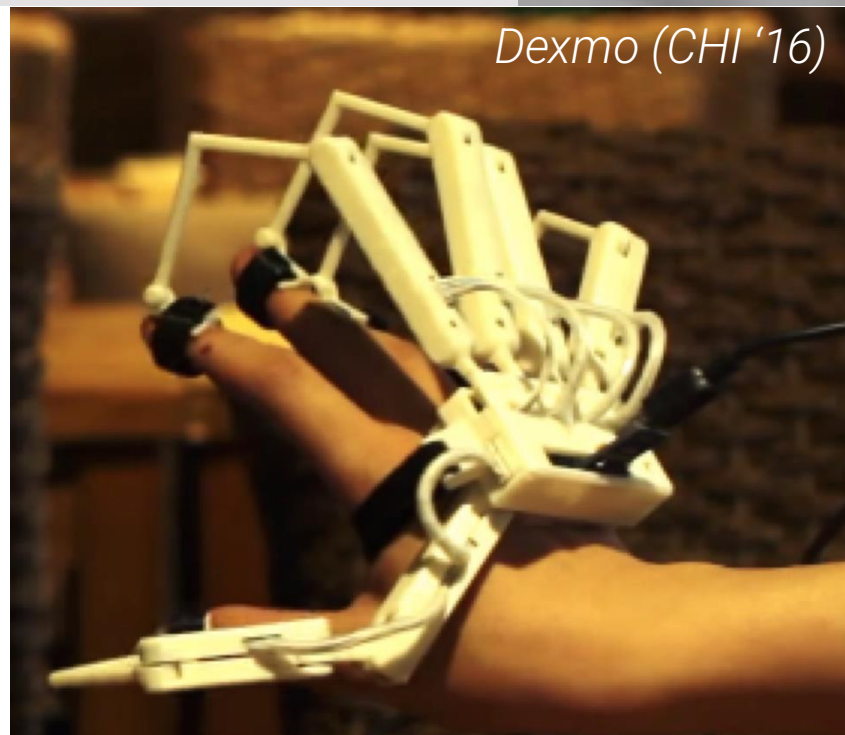
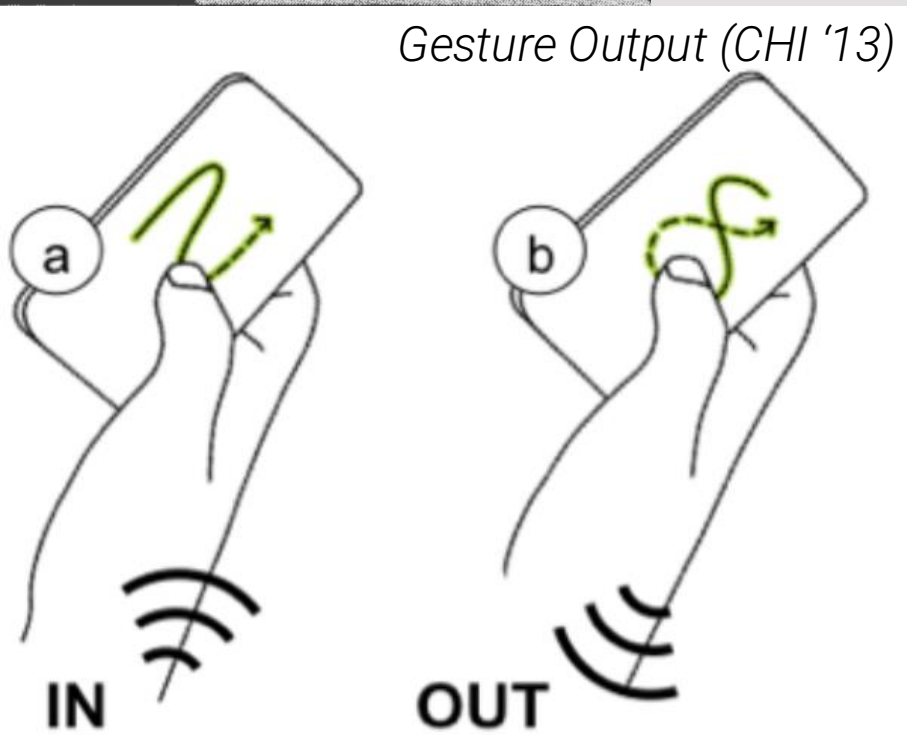


gestures as input

input

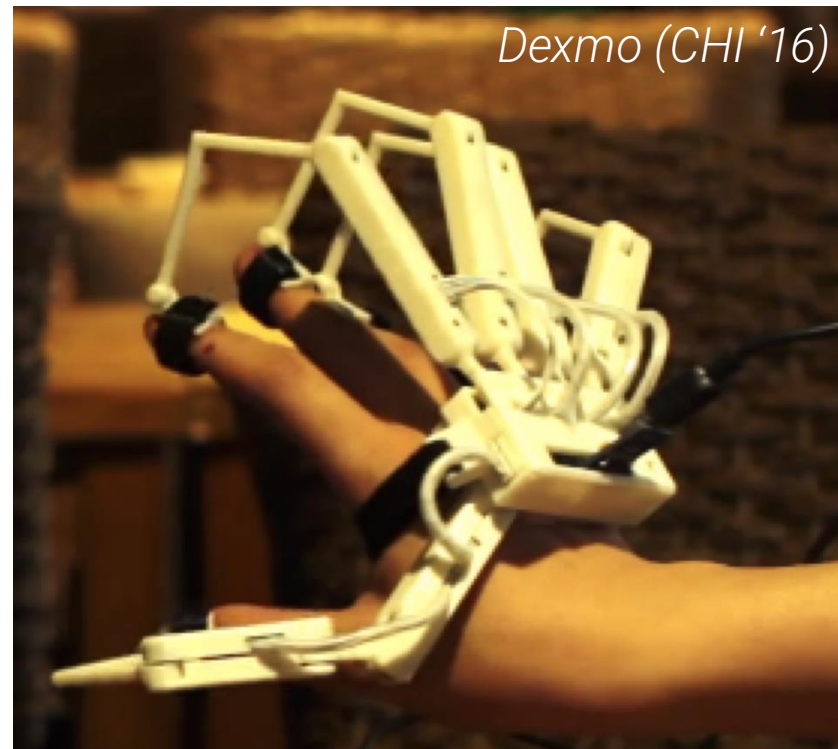
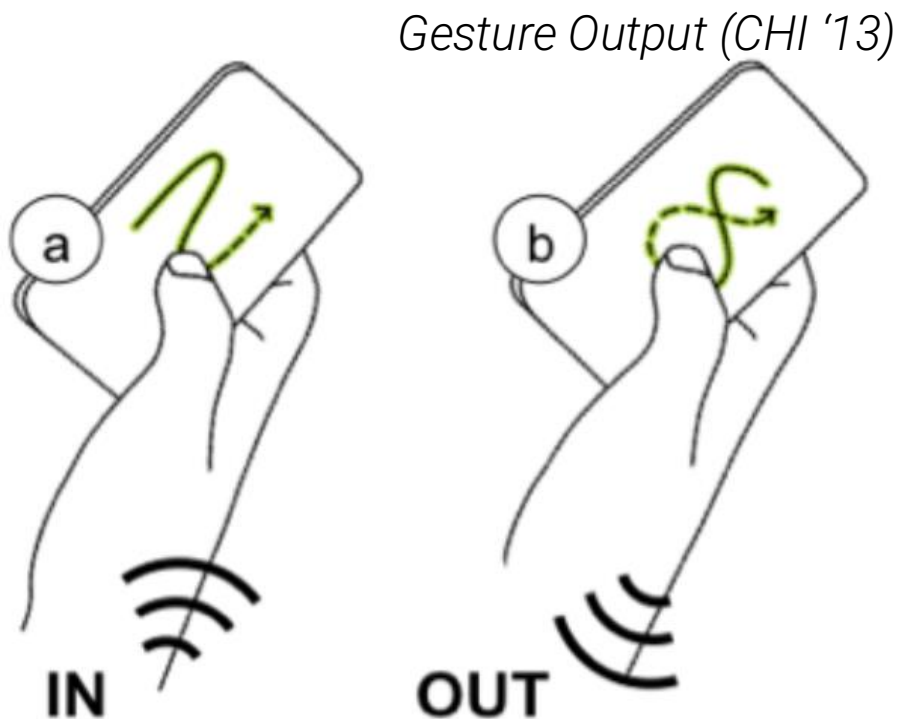


output



embodied devices

use the body for input *and* output



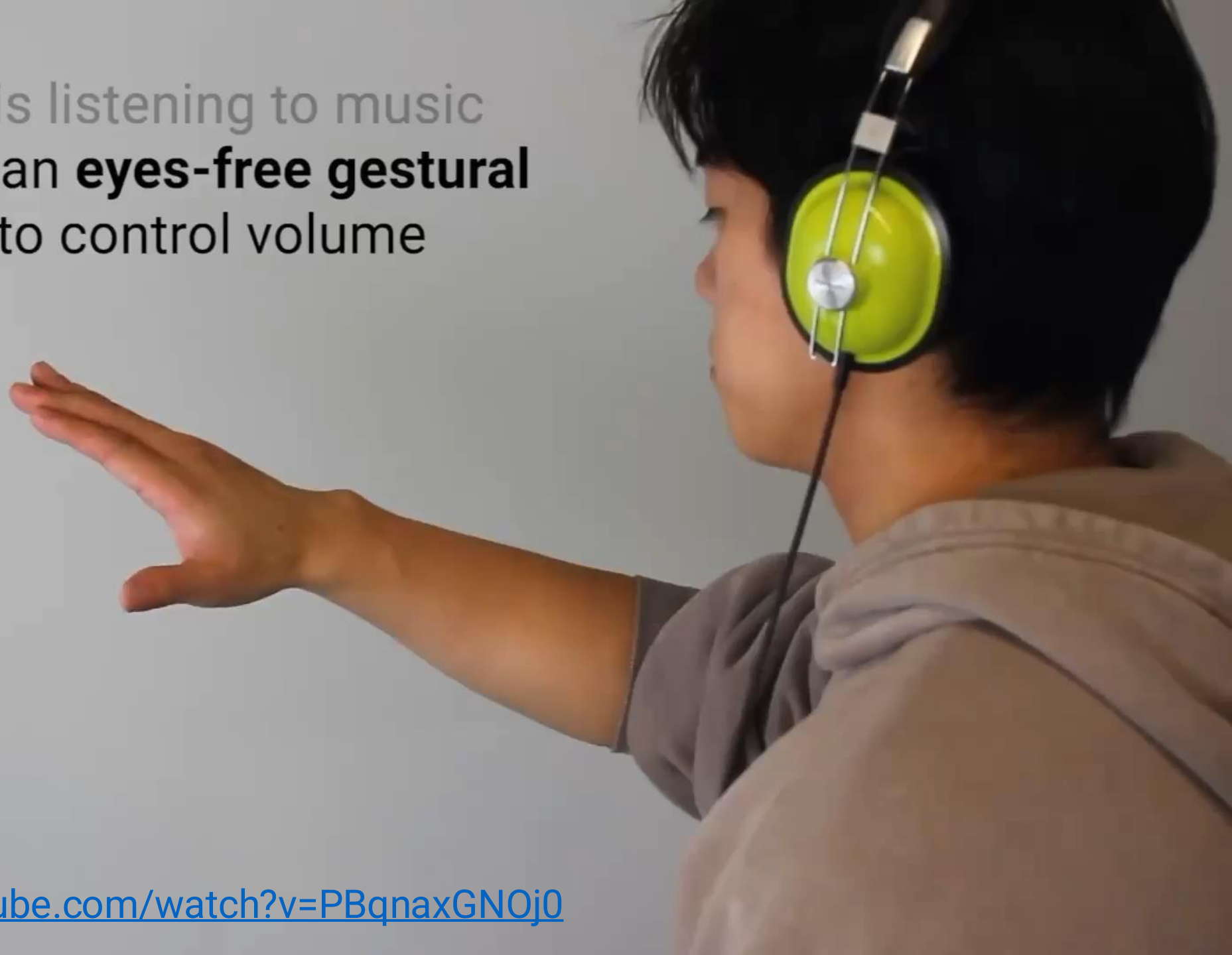
2. gestures as I/O
breaking down

this user is listening to music



watch: <https://www.youtube.com/watch?v=PBqnaxGNOj0>

this user is listening to music
and uses an **eyes-free gestural**
interface to control volume

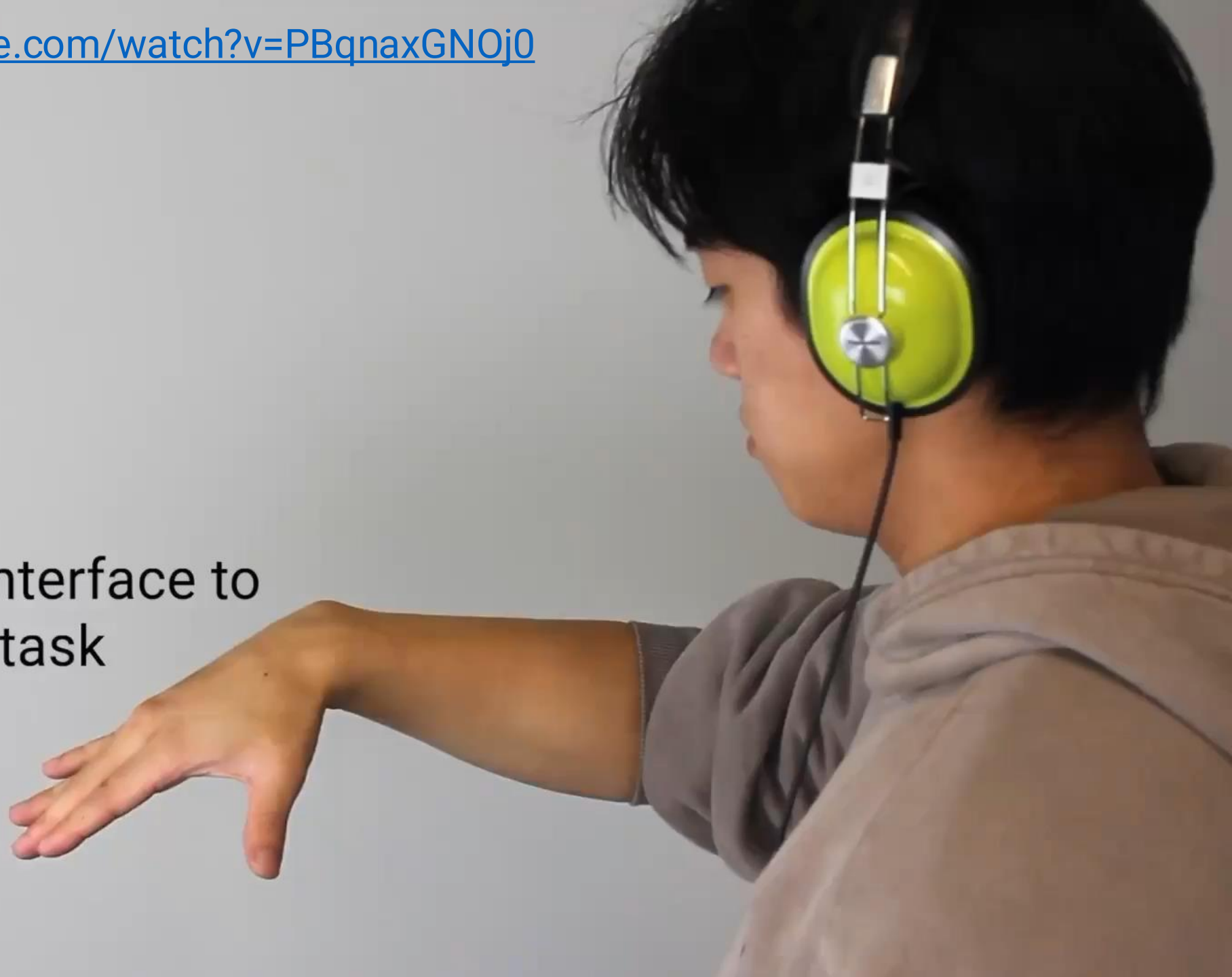


watch: <https://www.youtube.com/watch?v=PBqnaxGNOj0>

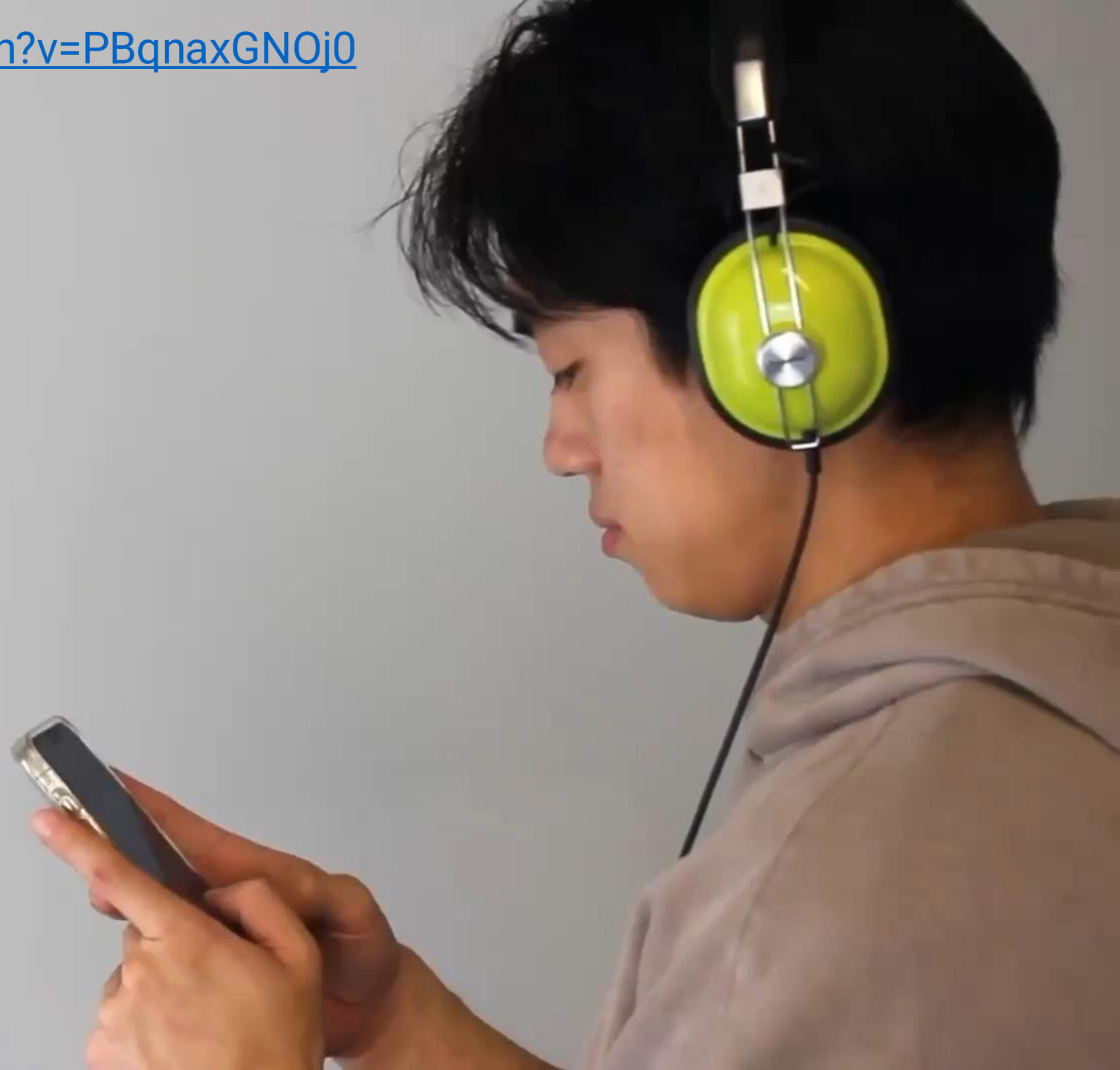
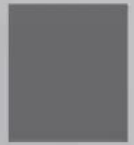
watch: <https://www.youtube.com/watch?v=PBqnaxGNOj0>



they dismiss the interface to
switch to another task



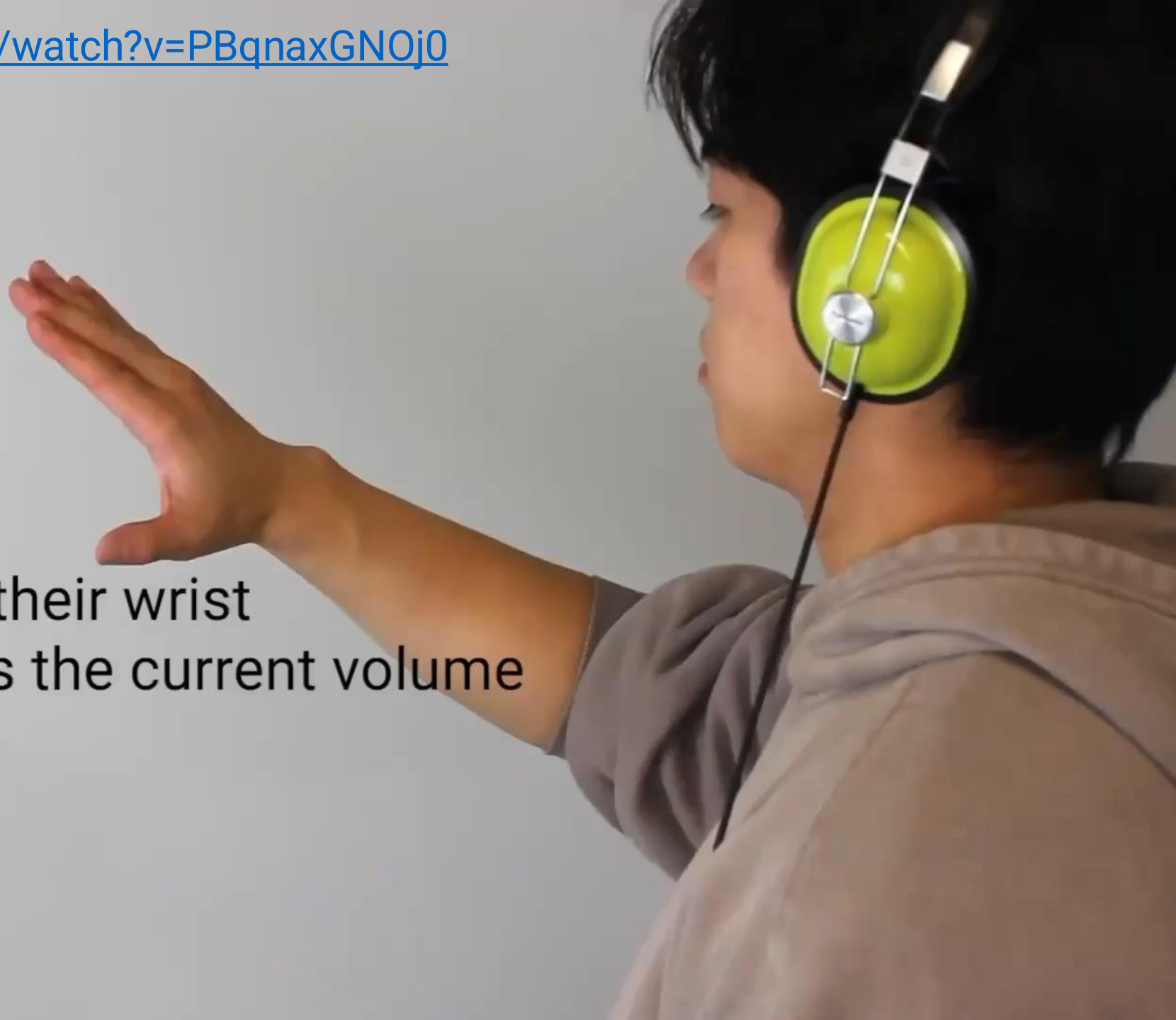
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watch: <https://www.youtube.com/watch?v=PBqnaXGN0j0>



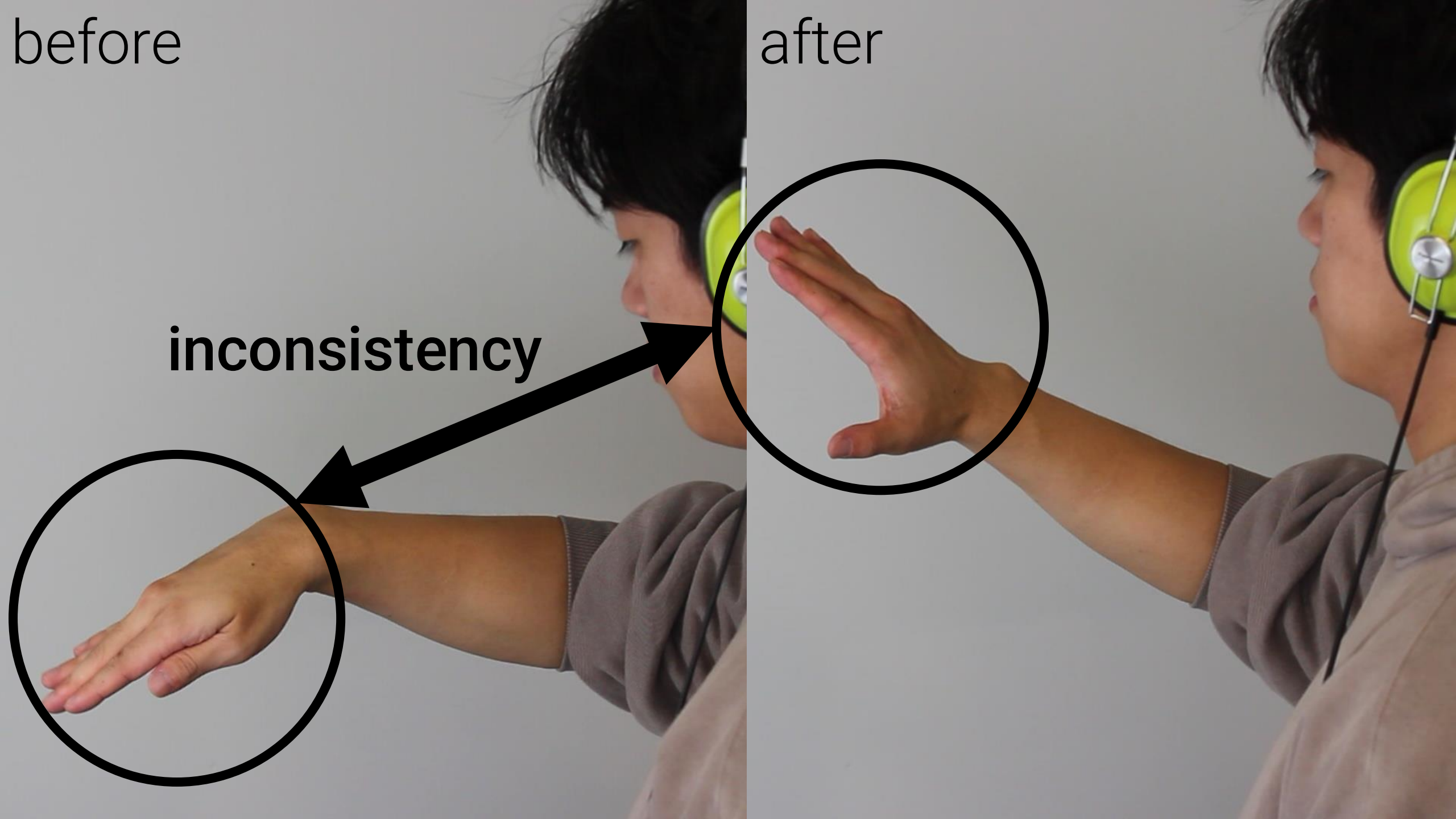
when they return, their wrist
no longer matches the current volume



before

after

inconsistency



3. our approach
to improving
accuracy

interaction techniques using **EMS**



3.1 our first technique
to improve accuracy:
muscle recall



1. recall

watch: <https://www.youtube.com/watch?v=PBqnaxGN0j0>



EMS will actuate their arm



nielsen's usability heuristic:
recognition rather than recall



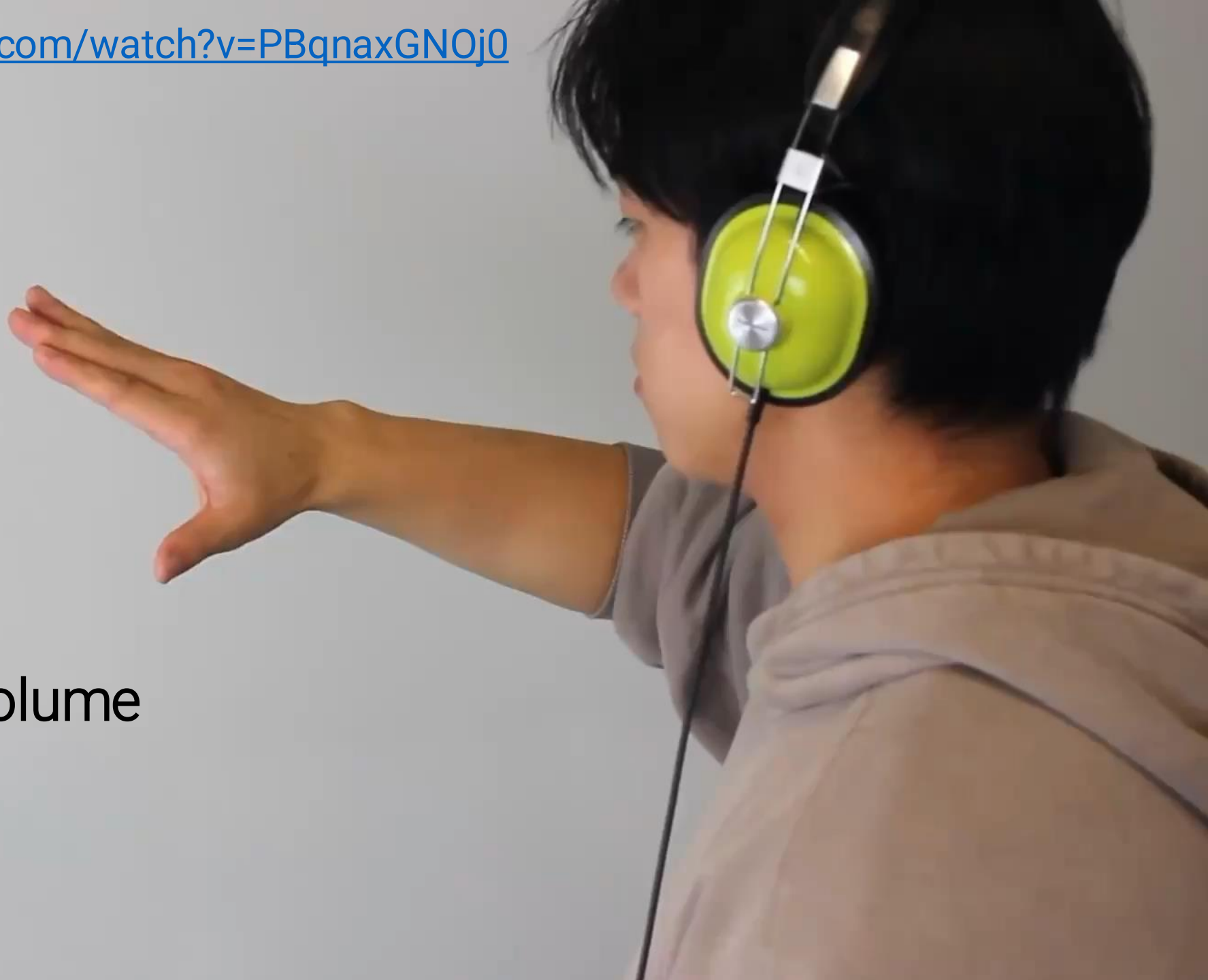
3.2 our second technique
to improve accuracy:
state confirmation



watch: <https://www.youtube.com/watch?v=PBqnaxGNOj0>



user sets a volume



2. confirmation

watch: <https://www.youtube.com/watch?v=PBqnaxGN0j0>

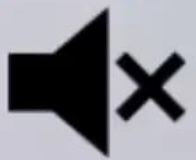


2. confirmation

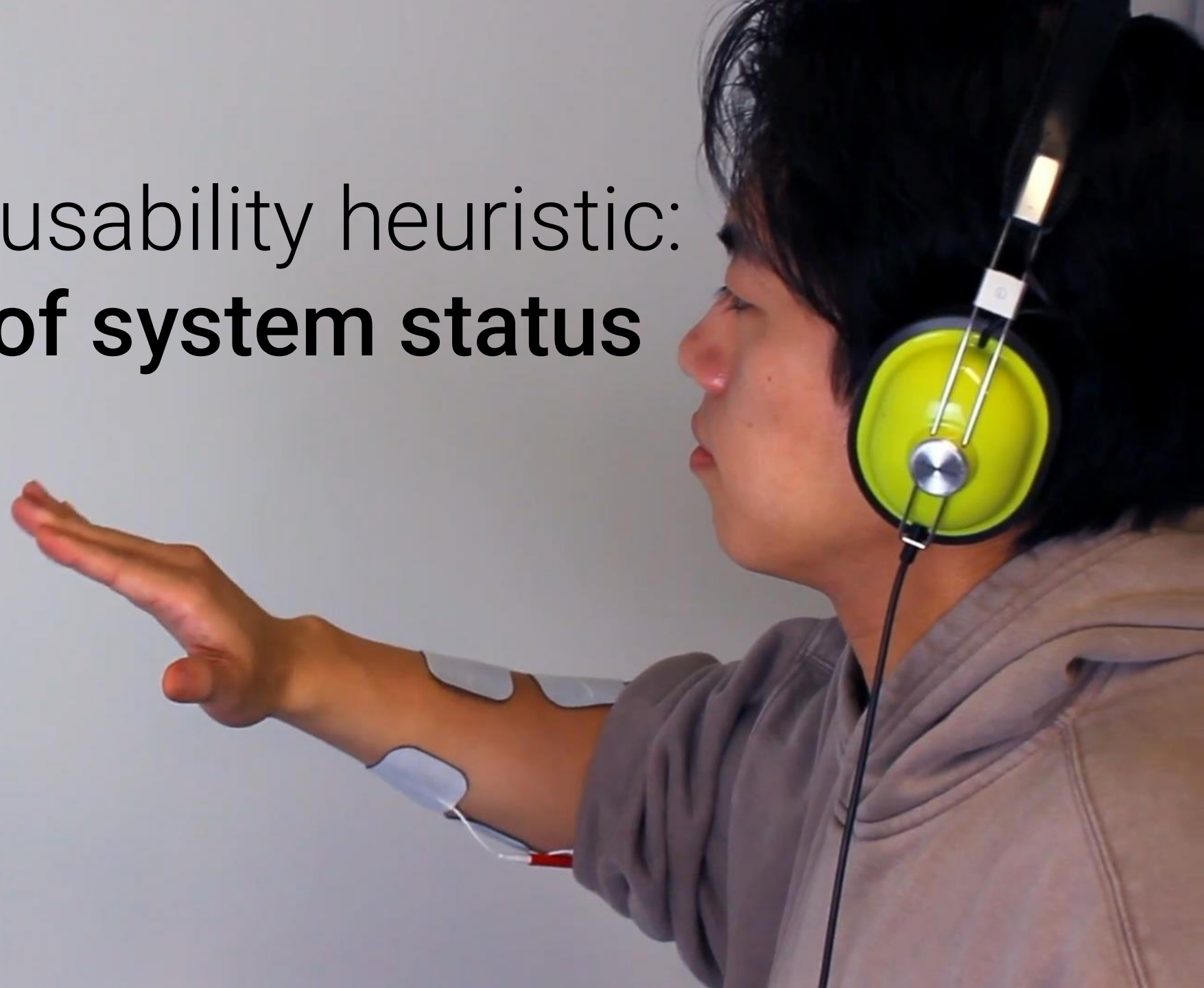
watch: <https://www.youtube.com/watch?v=PBqnaxGN0j0>



"ah, let me put this back"



nielsen's usability heuristic:
visibility of system status



watch: <https://www.youtube.com/watch?v=PBqnaxGN0j0>



3.3 our third technique
to improve accuracy:
constraint



3. constraint

watch: <https://www.youtube.com/watch?v=PBqnaxGN0j0>

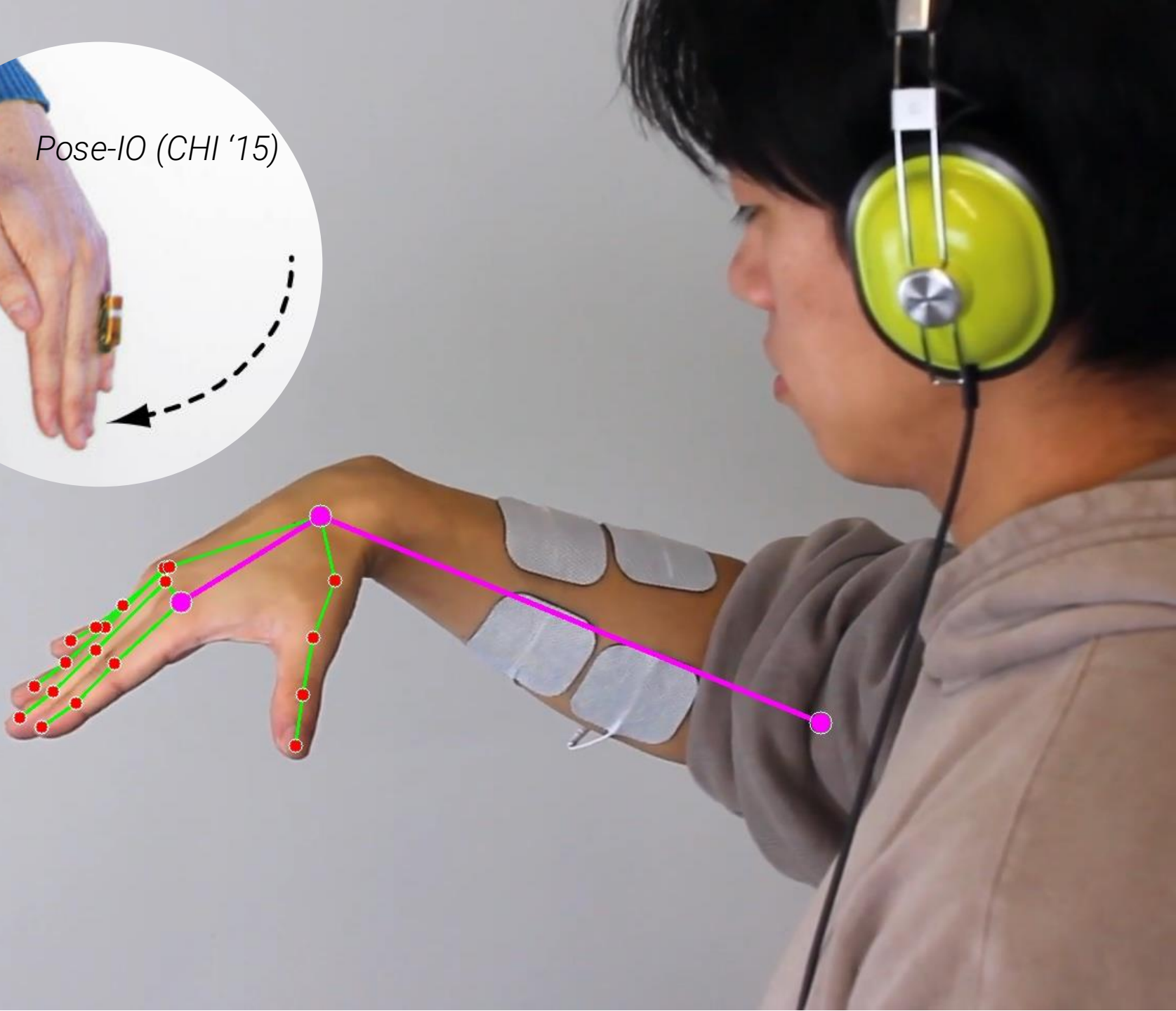
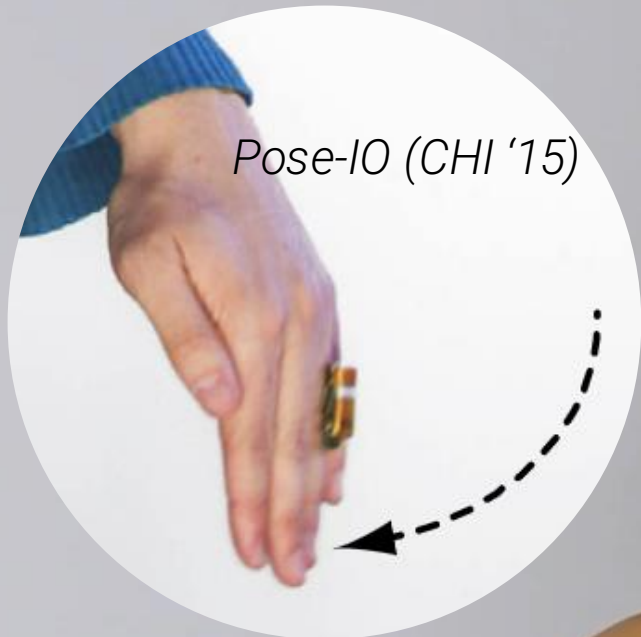




usability heuristic:
error prevention



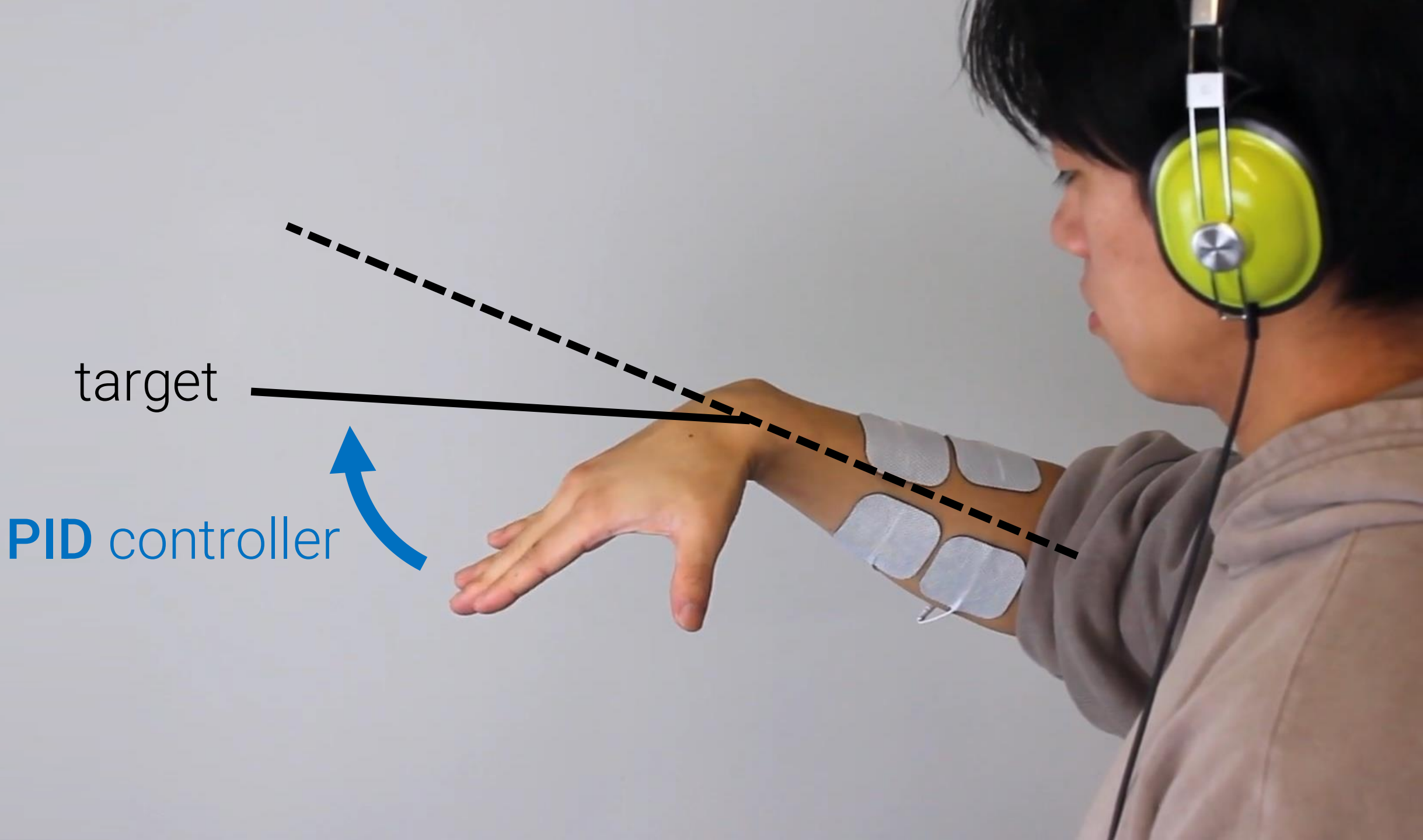
4. implementation



A side-profile photograph of a person with short dark hair wearing large, bright green headphones. On their left forearm, there are several white, rectangular adhesive electrodes connected by thin wires. The person's hand is extended forward and slightly downward. The background is a plain, light-colored wall.

extensor digitorum

flexor digitorum superficialis



target

PID controller

5. user study

passive joint position reproduction test while blindfolded
demonstration → distraction → input



passive joint position reproduction test

demonstration → distraction → input

new position

last position



passive joint position reproduction test

demonstration → distraction → input

new position

30 seconds: keyboard typing

last position



passive joint position reproduction test

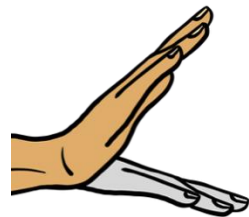
demonstration → distraction → input

new position



last position

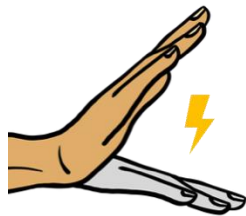
baseline



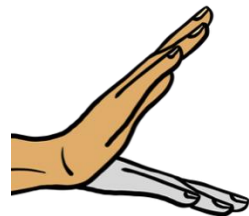
baseline



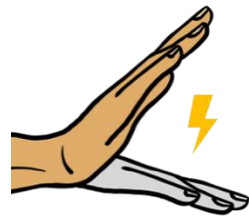
recall



baseline



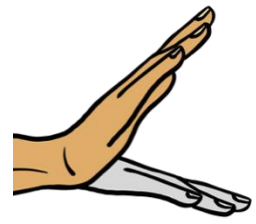
recall



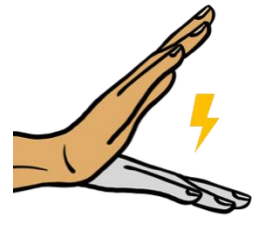
confirmation



baseline



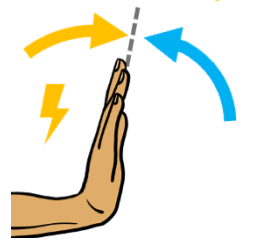
recall



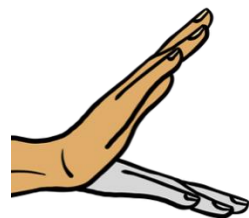
confirmation



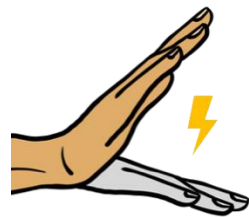
constraint



baseline



recall



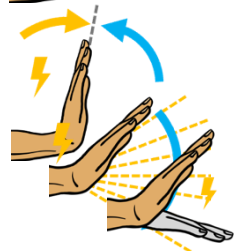
confirmation



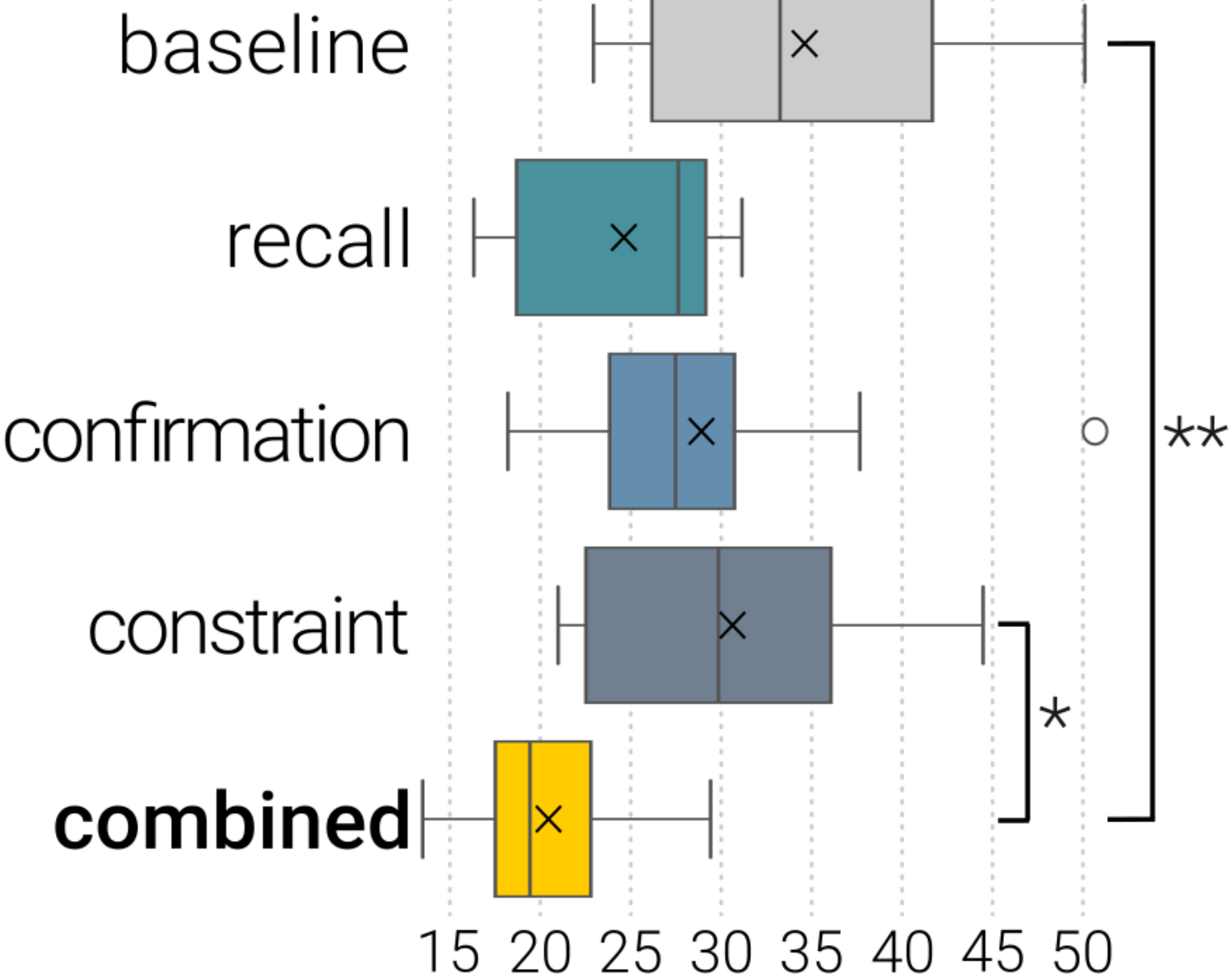
constraint



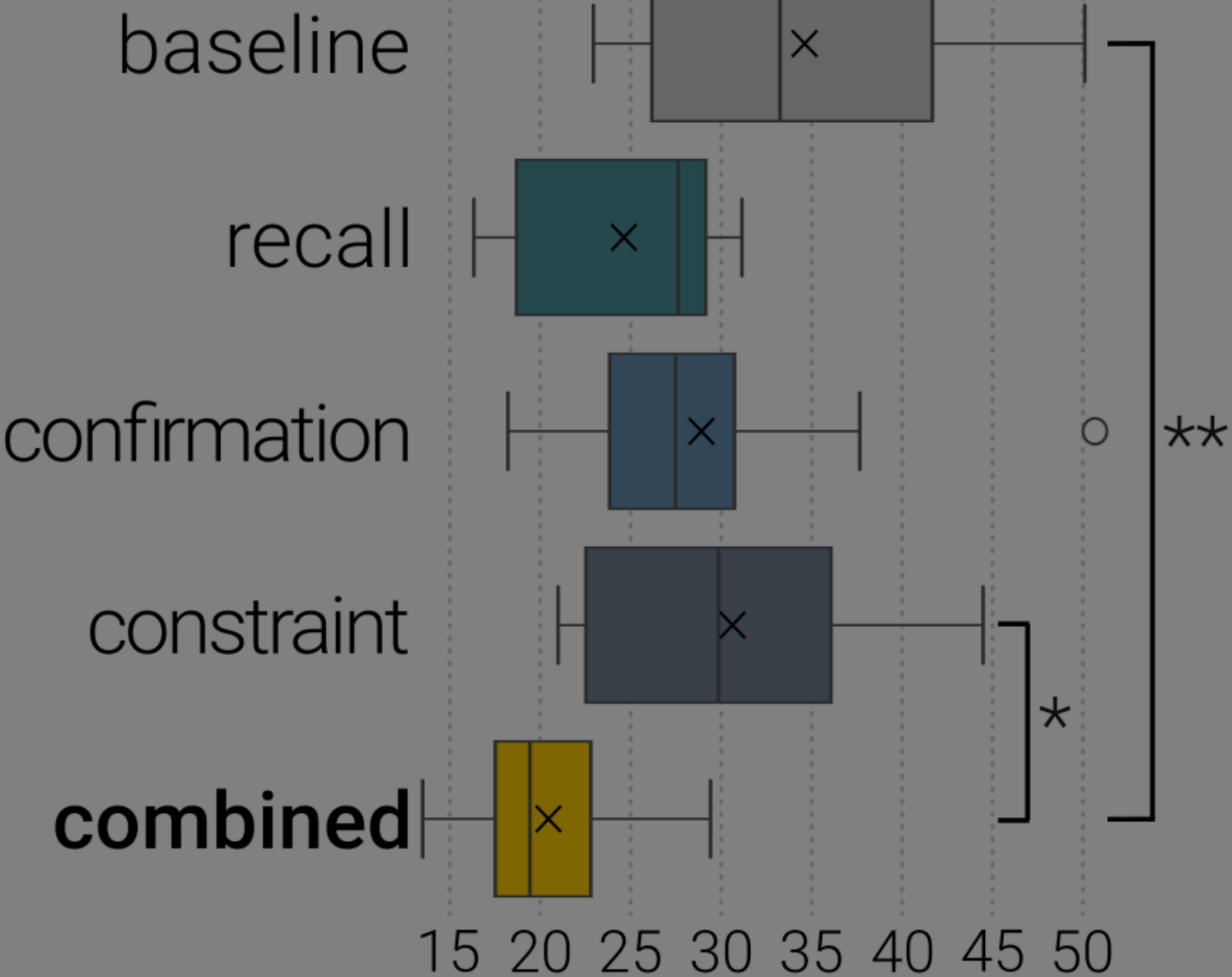
combined



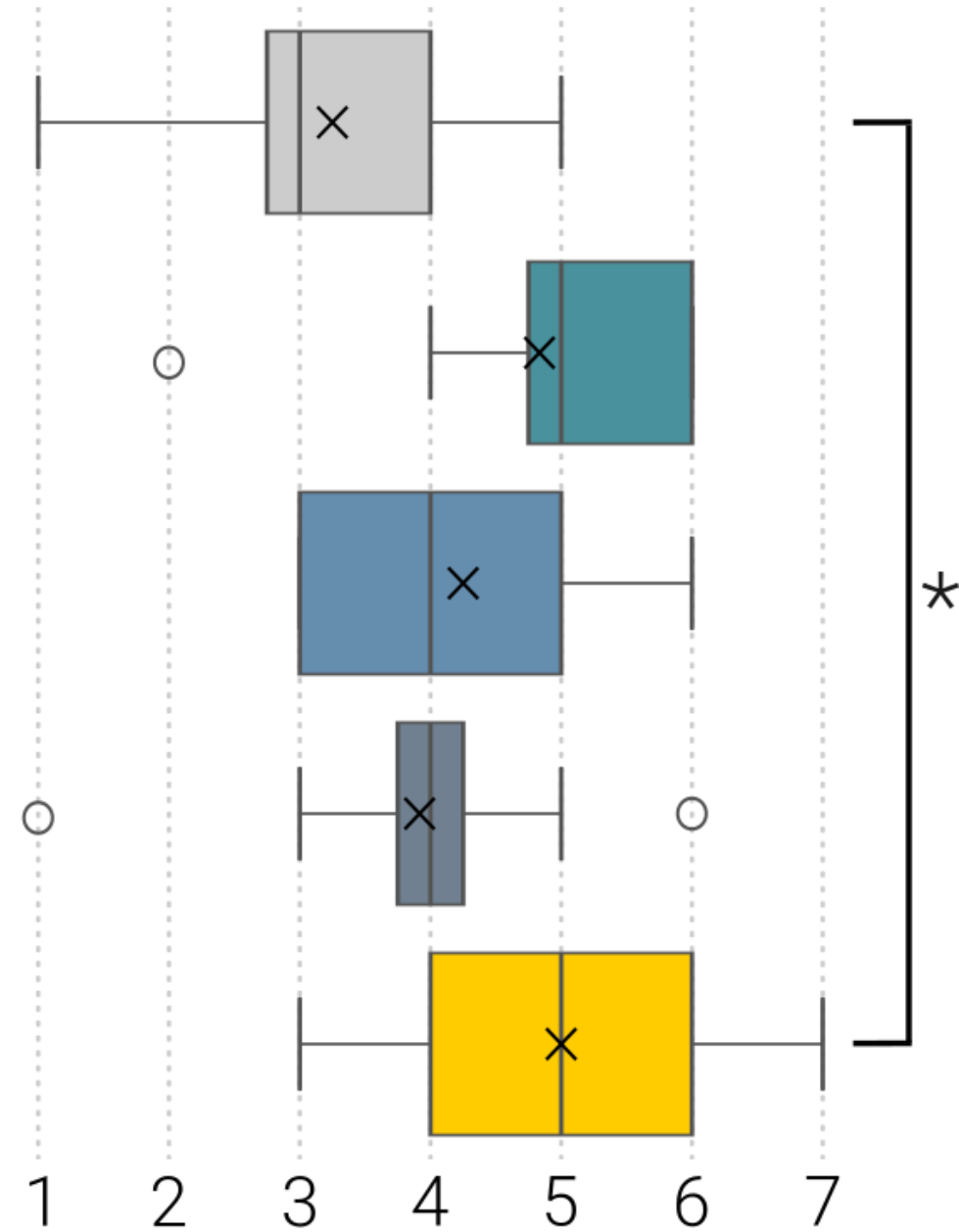
absolute error (deg)

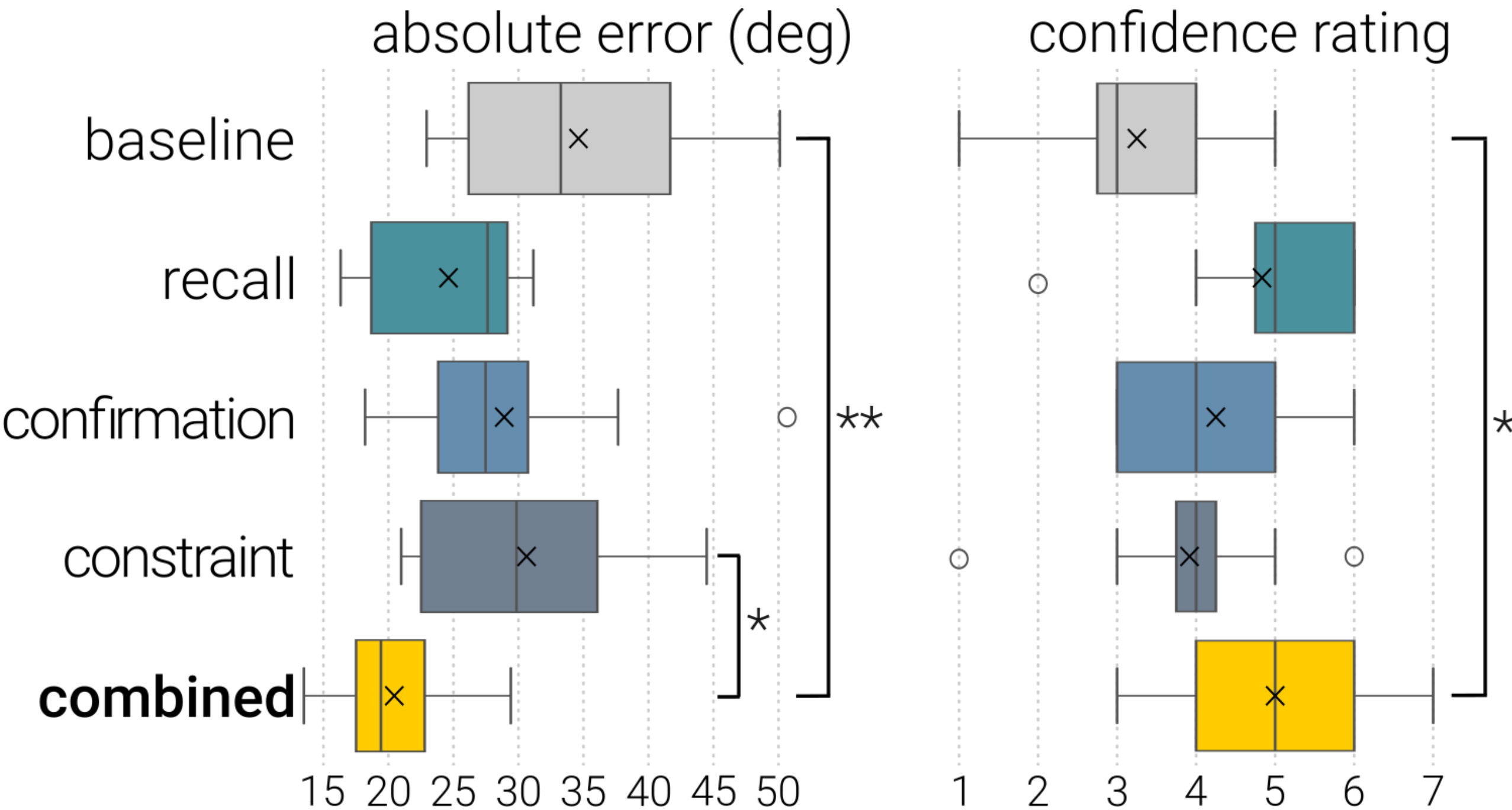


absolute error (deg)



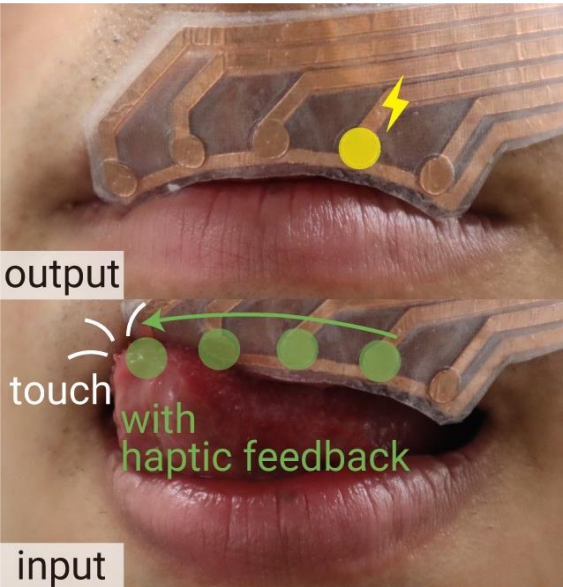
confidence rating





6. conclusions & future work

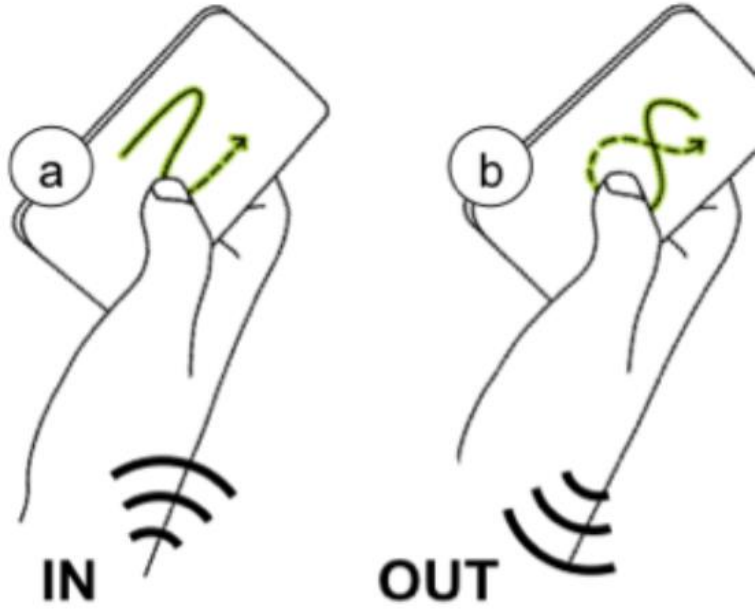
embodied devices offer a new class of devices, that excel at extreme scenarios (e.g., eyes/ear free)



LipIO (CHI '23)

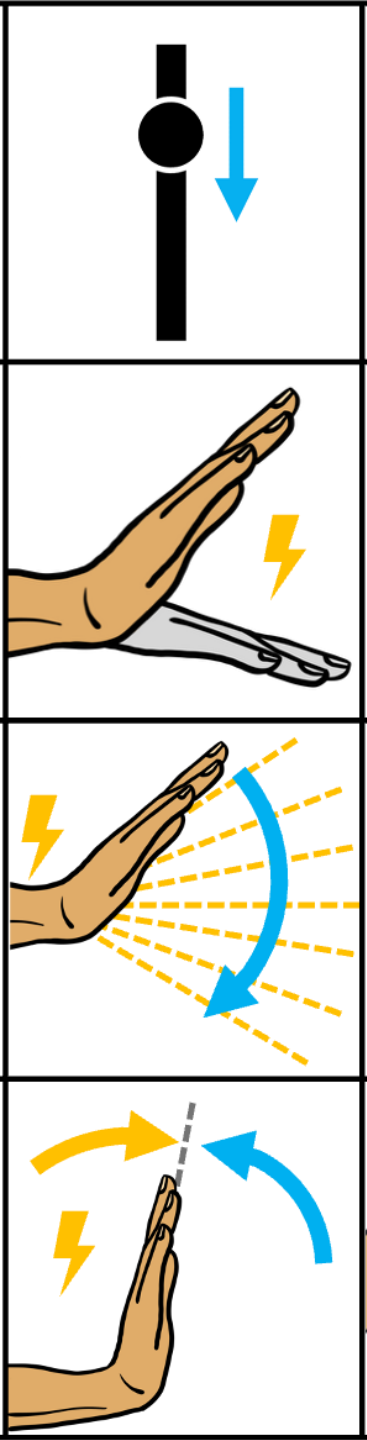





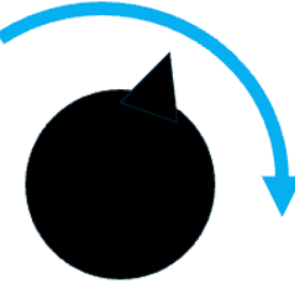







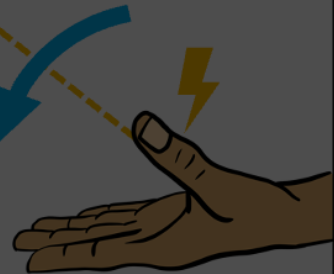

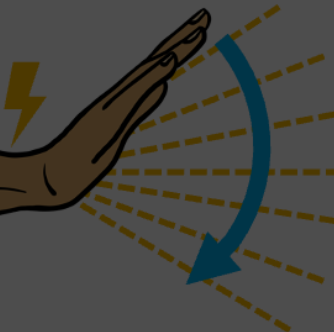

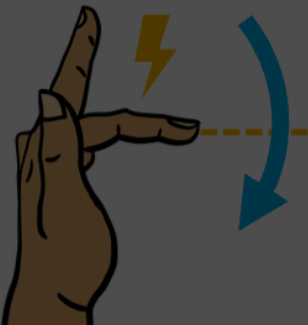
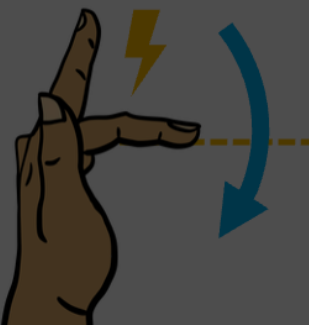
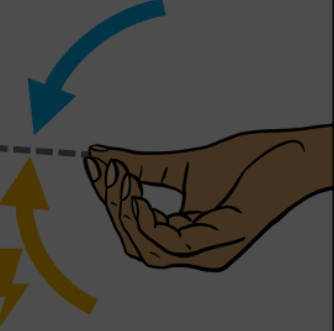
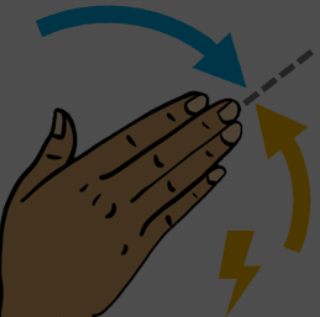
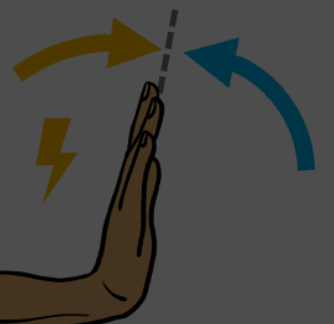
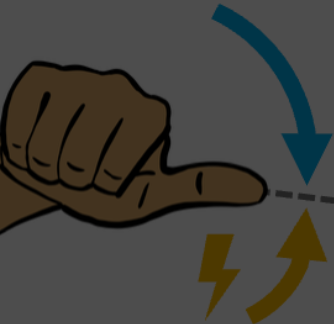


MuscleIO (IMWUT '18)



Gesture Output (CHI '13)

recall, confirmation, and constraint increased **input accuracy** on an embodied slider by 40%



GUI element						
recall	stateless					
confirmation						
constraint						

GUI element						
recall	stateless					
confirmation						
constraint						





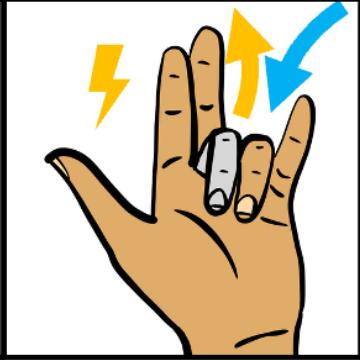
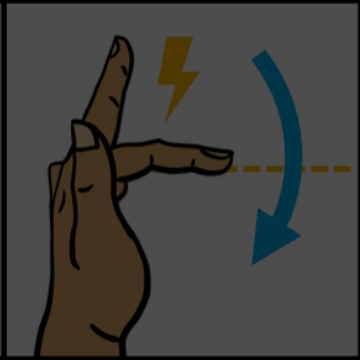
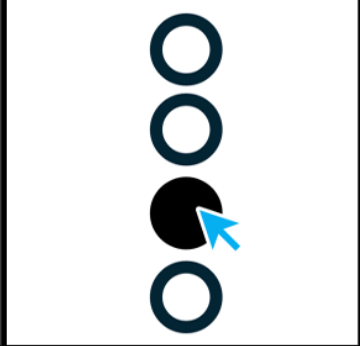
old input released by **muscle stimulation**



only one selection remains




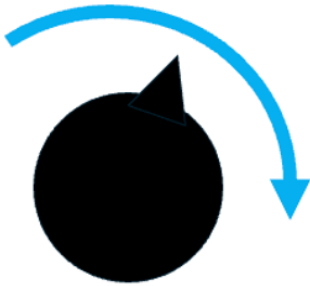



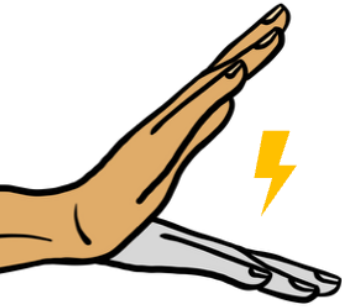



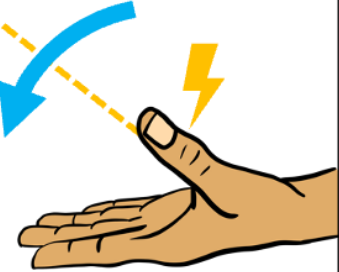

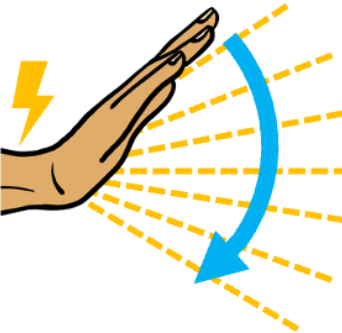

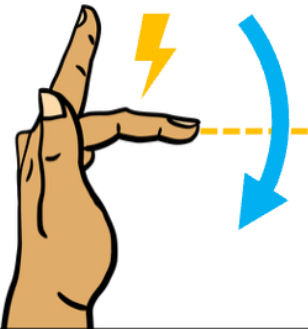
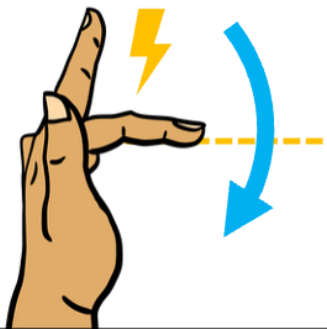
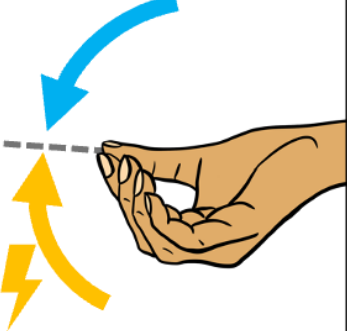

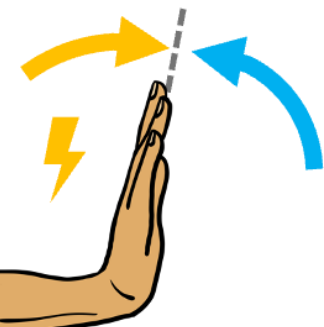
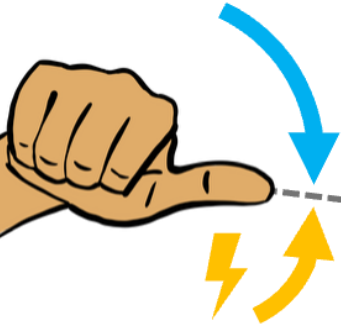
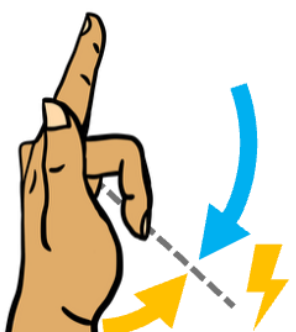

● ● ●
playback speed

- 0.25x
- 0.5x
- 1x
- 2x



constraint



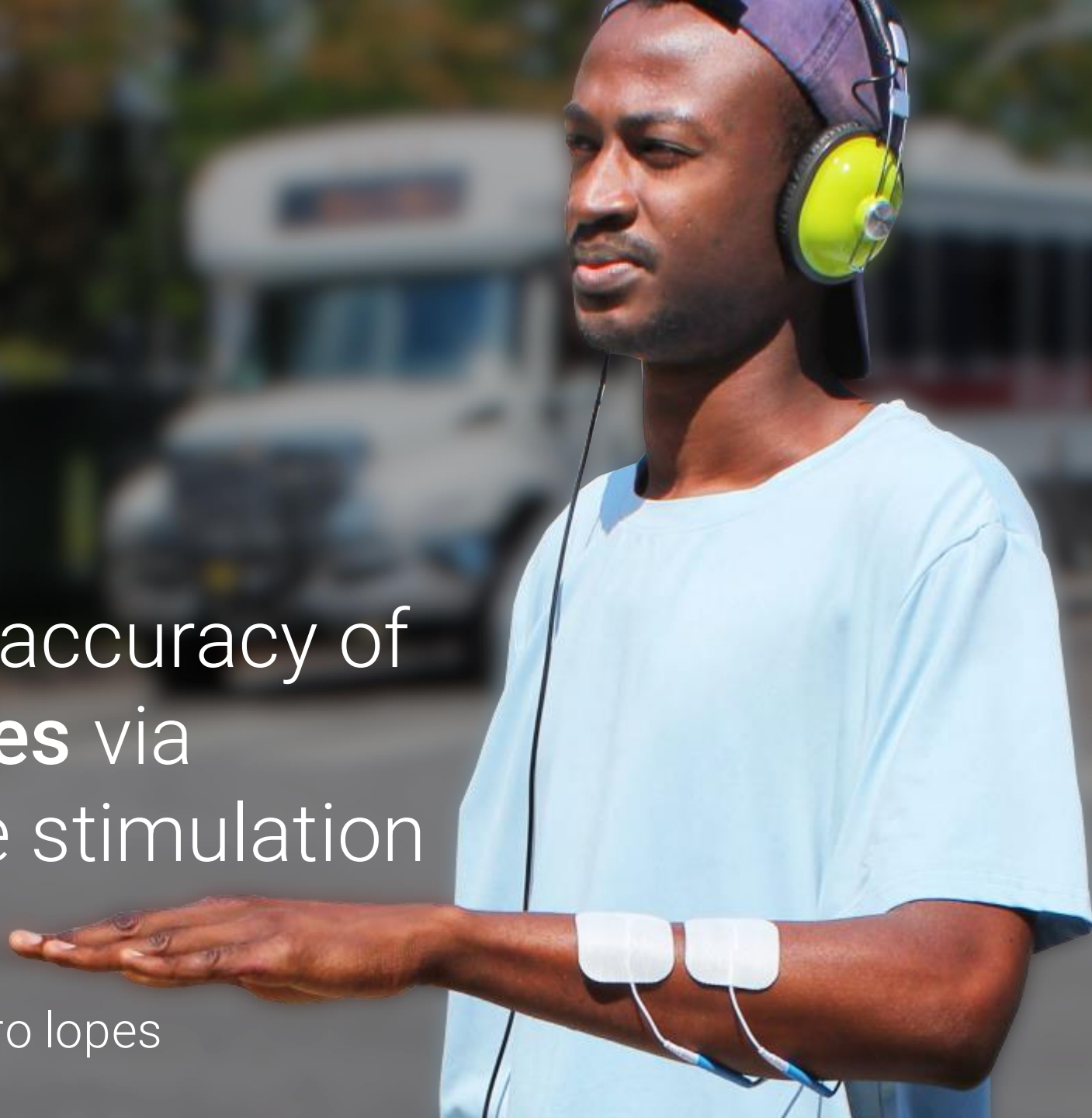
<p>GUI element</p>						
<p>recall</p>	<p>stateless</p>					
<p>confirmation</p>						
<p>constraint</p>						



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increasing input accuracy of
embodied devices via
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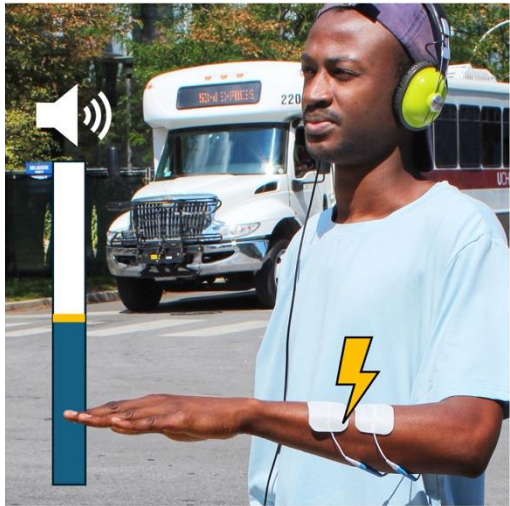
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More on this paper (or others of our lab) at: <https://lab.plopes.org/>



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