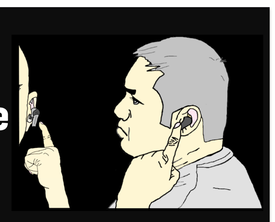
Exploring Above-Neck Unimanual Swipe Gestures for Off-Device Earable Interaction

Shaikh Shawon Arefin Shimon, University of Waterloo, ON, Canada
Ali Neshati, Ontario Tech University, ON, Canada
Junwei Sun, Ningbo Institute of Digital Twin, China
Qiang Xu, Huawei Technologies, ON, Canada
Jian Zhao, University of Waterloo, ON, Canada

Motivation

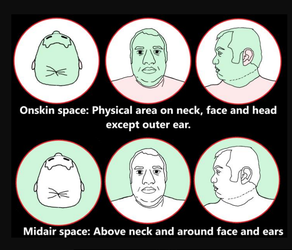


In-Ear Earable Has Limited Space

- ✗ Small size limits on-device input
  - ➢ Tap , Vertical Swipe, Stem pinch
- ✗ Touching earable / outer ear can dislodge device

Expanding Earable Input Beyond The Device

- ⚠ Head motion
- ⚠ Full-body motion
- ⚠ Silent speech commands
- ⚠ Facial expressions
- ✓ Hand-to-face, around-ear gestures above the neck



- ➢ Aligns with natural hand-to-face interaction habits
- ➢ Can be midair / onskin
- ➢ Non-dominant hand-based input = dominant hand free for use

Unistroke **Tap**, **Swipe**, **Pinch**

- ➢ Low shape complexity
- ➢ Easy to learn, recall, perform

Segmenting off-earable space can create bounded interaction regions.

- ✓ Repeating gestures across location
- ✓ More off-device input commands
- ✓ Works well for **Tap** & **Pinch**

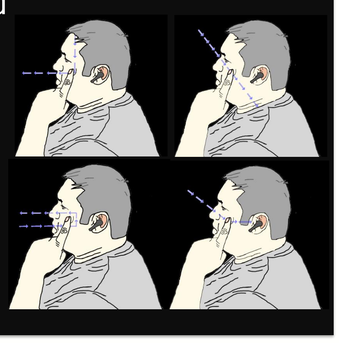
Swipe limited within bounded region

- ✗ Can easily cross boundary
- ✗ Increased chance of wrong input

What about swiping across regions?
= Diverse shape, orientation, contortion

- Unidirectional : Horizontal, Vertical, Non-axial
- Angular : L, U, V-shaped

Unistroke Shapes like ✓ / ^



- ➢ Has Semantic meaning
- ➢ Elicited in prior studies
- ➢ More preferred than multistroke swipes, closer to unidirectional swipe preferences

Research Gap

Prior research has not systematically examined end-user preferences for non-axial and angular off-device swipe gestures for in-ear Earables.

Idea: Swiping Across Regions

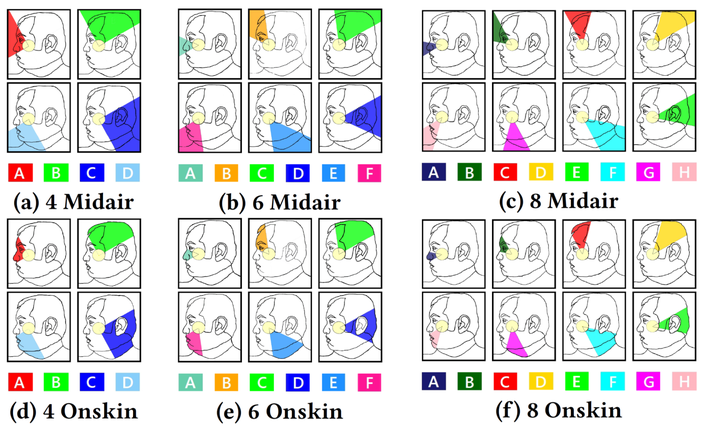
- Start in **Green region**, optionally turn through over cheekbone (**Yellow region**), end in **Blue region**.
- Shape, contortion, and orientation create a rich unistroke swipe vocabulary.
- Complements region-bounded tap and pinch reuse for substantial off-device input expansion.

Research Goal

Explore preferences for unidirectional and angular swipe shape, contortions and orientations in midair and onskin spaces for off-earable interaction.

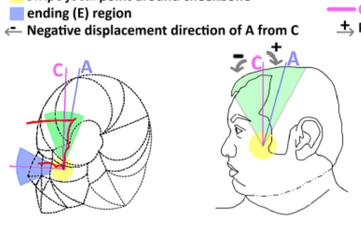
Strategy

Segment Interaction Space to 4, 6 & 8 Regions



- Regions centered around cheekbone
  - ➢ Central location, within peripheral view
  - ➢ Major facial landmarks around it
- Layout aligned with horizontal nose-to-ear axis
  - ➢ Based on prior Horizontal swipe bias
- Segmentation impacts region span and swipe angle

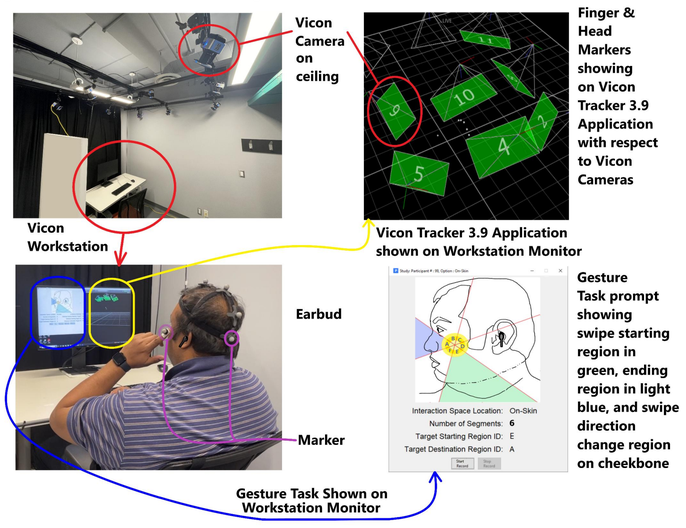
starting (S) region
swipe focal point around cheekbone
ending (E) region
← Negative displacement direction of A from C
Actual swipe path trajectory
Average swipe path trajectory within region S( )
Central plane bisecting region S( )
+ Positive displacement direction of A from C



Regions	Angular Span of Region S	Angular Span of Region E	Central Plane C	Range of angular displacement for A: Anti-clockwise (−)	Range of angular displacement for A: Clockwise (+)
4	90°	90°	0°	−45°	+45°
6	60°	60°	0°	−30°	+30°
8	45°	45°	0°	−22.5°	+22.5°

- Chosen upper & lower limit for region density
  - ➢ Axial swipe – Front, Back, Up, Down = 4 region
  - ➢ Above 8 regions region spans too narrow

Experimental Setup



- **Imaginary interface approach**: Swipe motion capture using Vicon to avoid Earable sensing limitations

Study Design

Independent Variables: Space & Region Density

• Space : Midair / Onskin (**IV1**) • Regions : 4, 6 & 8 /space (**IV2**)

Study Structure (2 IV1 x 3 IV2 = 6 Gesture Blocks)

- 1 session / IV1 each day, counterbalanced **IV1, 2 days total**
- **3** counterbalanced **blocks** / session, breaks between blocks
- (4x4) + (6x6) + (8x8) = **116 condition** / space
- **Randomized** condition / block, 1 sample each condition

Participants (24)

- **15 M, 9F, 21** Righty, **18** Earbud Users, **No** upper-joint issues
- **$50** / Participant for **2x 90 min** session, 5568 total swipes

Evaluation Metrics

Evaluation

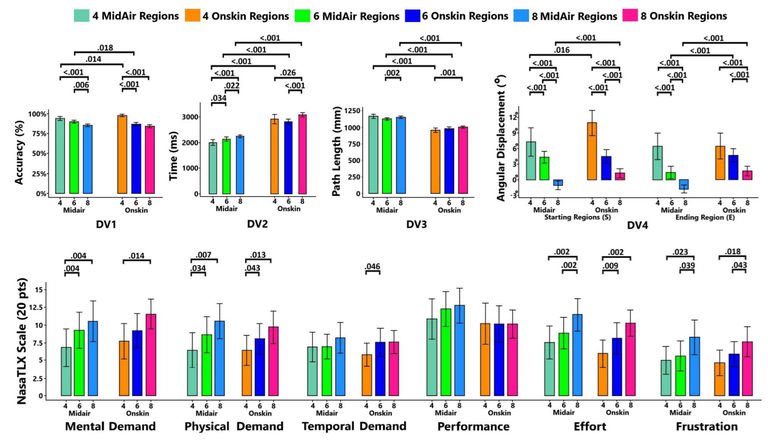
- **Performance**
  - ➢ Accuracy
  - ➢ Path Length
  - ➢ Time
  - ➢ Angular Drift
- **User Experience**
  - ➢ Nasa-TLX Workload
  - ➢ Region Rating

Research Questions

RQ1: Midair Vs. Onskin in comparable gesture blocks
RQ2: Effect of Increasing region density in midair / onskin
RQ3: Swipe starting / ending locations & shapes each block

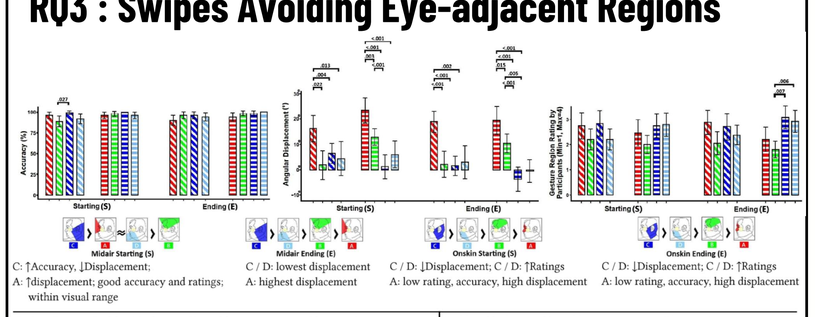
Findings

RQ1 & RQ2 : Onskin in 4 regions, Midair ≥ 6



- In higher (**≥ 6**) region densities, onskin swipes had more constraints and shrinking region span, midair preferred
  - 8 regions not preferred for any space, **max 6 regions**

RQ3 : Swipes Avoiding Eye-adjacent Regions



C: ↑Accuracy, ↓Displacement;
A: ↑displacement; good accuracy and ratings; within visual range

C / D: lowest displacement
A: highest displacement

C / D: ↓Displacement; C / D: ↑Ratings
A: low rating, accuracy, high displacement

C / D: ↓Displacement; C / D: ↑Ratings
A: low rating, accuracy, high displacement

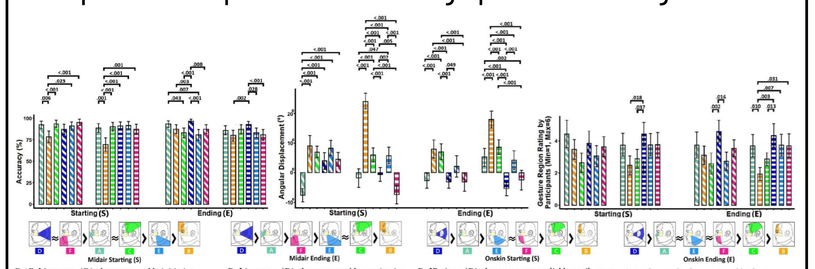
Swipe Group	Stable	Moderate	Unstable	Observation
Axial	AC, BD DB	CA	–	Axial swipes show high stability.
U-shaped (180°)	BB, CC DD	AA	–	Loops reliable near ear, temple and chin.
L-shaped (90°)	CB	BC, DC CD	AB, AD BA, DA	Angular swipes show higher variability; especially when terminating around eye.

(a) Midair

Stable	Moderate	Unstable	Observation
AC, CA BD, DB	–	–	Axial swipes show high stability.
BB, CC DD	AA	–	U-shaped Loops reliable near ear and chin Nose loop shows larger but manageable drift.
–	AD, DC, CD BC, CB	AB, BA DA	Angular swipes involving region **A** showed weakest stability.

(b) Onskin

- **Ear (C)** was the preferred swipe start/end region, followed by **Jawline (D)** in most cases for **4-region layout.**
- **Nose (A)** was preferred only for **midair swipe initiation**.
- Users **avoided eye-adjacent onskin regions** but reported adequate maneuvering space within regions.



D / F: ↑Accuracy, ↓Displacement; stable initiation
A / C: good accuracy within FOV, mild directional bias
E: limited visual feedback
B: ocular avoidance, lowest accuracy

D: ↑Accuracy, ↓Displacement; stable termination
A: strong visual guidance; F: moderate stability
C / E: reduced separability;
B: highest angular skew

D: ↑Ratings, ↓Displacement; most reliable tactile start
A / F: combined visual + haptic feedback
C: moderate stability
B: ocular constraint, highest displacement

D / A: lowest displacement and highest accuracy
E / F: intermediate endpoints
C: reduced separability
B: highest skew and lowest ratings

Swipe Group	Stable	Moderate	Unstable	Observation
Axial	AD DA	–	–	Stable on cheek–chin axis; lowest deviation
Non-axial	CF FC	EB	BE	Stable toward F; B, E weaker
U-shaped (180°)	AA, DD EE, FF	BB CC	–	U-shapes mostly stable; B / C less consistent
V-shaped Medium (30°)	CD, DC FA	AF, FE, EF DE, ED	AB, BA BC, CB	Stable near D; Upper-face angular swipes weaken
V-shaped Large (60°)	CA, DF BD, EA	AC, AE, FD FB, EC	BF, DB CE	Stable on D–F axis; long B/C/E crossings degrade.

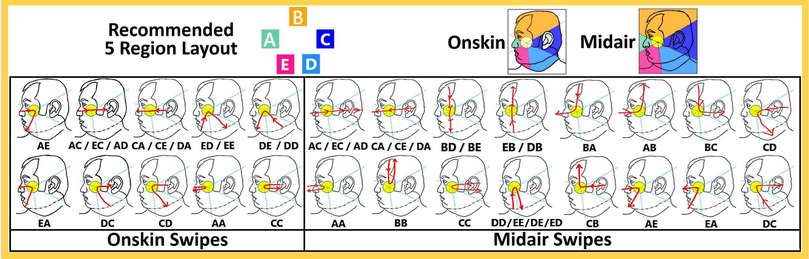
(a) Midair

Stable	Moderate	Unstable	Observation
AD DA	–	–	Stable on cheek–chin axis; lowest deviation
CF FC	EB	EB BE	Stable toward F; swipes intersecting B unstable
AA, CC DD, EE	FF	BB	Stable at A/D/E/F anchors; loops at B unstable
CD, DC, ED EF, FE	FA, AF DE	AB, BA BC, CB	Stable near D; swipes crossing B unstable
DF FD	AC, AE, CA EA, CE, EC	BD, BF DB, FB	Stable on D–F axis; eye-crossing swipes unstable

(b) Onskin

- Eye-adjacent region **avoidance increased** in **6-region** layout, especially for **onskin** swipes.

Proposed Layout



- Merge Eye (**B**) and Temple (**C**) in 6-region Layout
- Consolidate & filter less distinguishable swipes