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HapEar: Vibrotactile Array around the Ear for 3D Spatial Cues

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***Abstract*—We present a vibrotactile display integrated into the earcup region of a headset, aiming to deliver 3D spatial cues. In a point localization task using ERM motors, single-point stimuli (8 locations) yielded an information transfer of 2.83 bits and a mean response time of 0.86 s, while a mixed set of 20 stimuli—including both single-point and two-point phantom stimuli—yielded 3.94 bits and 1.67 s. These results suggest that the earcup is a viable site for spatial tactile feedback, and future improvements that reduce high-frequency noise may help minimize auditory interference and enhance overall usability.**

I. Introduction

Spatial awareness is essential in virtual, augmented, and immersive environments, enabling users to interpret, navigate, and interact with the surrounding space. While most systems rely on visual feedback, this can lead to overload, limitations in low-light conditions, or inaccessibility for visually impaired users. Auditory feedback is often used as a complement, but it may be susceptible to environmental noise and less effective for precise spatial mapping.

As an alternative, tactile modality has gained attention as a robust and intuitive feedback channel. Various body locations such as the head, wrist, back, and waist have been explored for delivering vibrotactile cues, depending on the application context and the required level of spatial resolution. In particular, the region around the head [1, 2] is well-suited for vibrotactile feedback due to its high sensitivity, symmetrical structure, and proximity to widely used wearable devices such as headsets and HMDs. These characteristics support precise spatial encoding while minimizing interference with other sensory modalities.

Headsets, already worn in close contact with the ears in devices like HMDs, provide a promising platform for integrating vibrotactile feedback. Their stable mechanical structure and proximity to the skin allow reliable delivery of spatial cues without requiring additional hardware. Despite its potential, the headset earcup area has been largely unexplored as a tactile display, possibly due to concerns that conventional vibration motors may produce high-frequency noise that interferes with auditory perception [1, 2].

This study proposes a vibrotactile display integrated into the earcup region of a headset and investigates its capability to convey 3D spatial cues around the user. Specifically, we aim to:

1. Explore the feasibility of using the skin around the ears, in contact with headset earcups, as a site for delivering 3D spatial tactile cues.
2. Design a headset-integrated vibrotactile display capable of stimulating the ear-adjacent skin to render 3D spatial cues.
3. Evaluate the localization performance of the proposed system in terms of information transfer and response time.

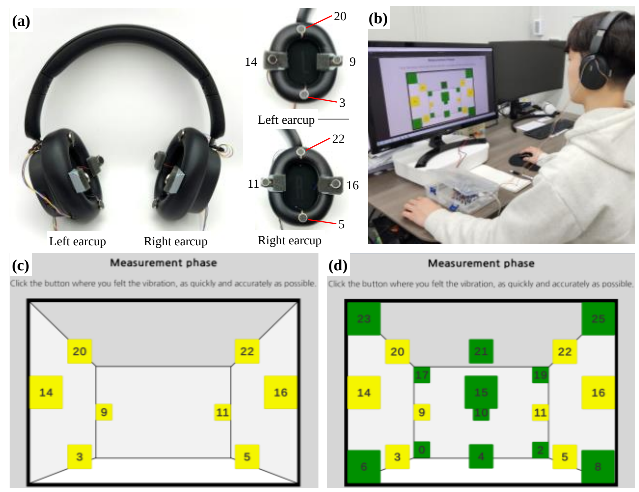

Fig. 1. (a) Experimental prototype with eight coin-type ERM actuators mounted around a pair of earcups. (b) Experimental setup (c) User interface used in the single point localization, (d) two-point localization.

II. Methods

We conducted a single point localization task to evaluate the spatial acuity of vibrotactile stimuli delivered through a headset-mounted actuator array. Eight coin-type ERM vibration motors (PN-VM102; radius: 10 mm, height: 2 mm) were symmetrically attached to the front, back, top, and bottom areas of each earcup, positioned 4 cm from the earcup center (Fig. 1(a)). The motors were driven using PWM control via an Arduino Mega at 3.3 V and 35 mA, generating approximately 100 Hz vibrations for 500 ms per stimulus.

Ten participants (2 female, mean age = 25.9) were recruited for the study. Each participant was seated in front of a monitor and responded using a mouse by clicking on-screen buttons corresponding to the perceived vibration location (Fig. 1(b)). The interface displayed eight labeled buttons, each representing one of the actuator positions (Fig. 1(c)). Stimuli were randomly selected and presented in a randomized order. Each location was tested five times, resulting in 40 trials per participant.

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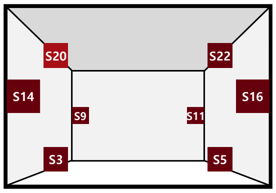
<Single-point localization>

		Response							
		R3	R5	R9	R11	R14	R16	R20	R22
Stimulus	S3	49				1			
	S5		50						
	S9			50					
	S11		1		45				4
	S14					49		1	
	S16						49		1
	S20	1		1		4		44	
	S22		1		3		1		45

	Mean	SD
Accuracy (%)	95.3	3.61
Information Transfer (bits)	2.83	0.12
Response time (s)	0.86	0.25



<Two-point localization>

			Response																			
			single stimuli								double stimuli											
			R3	R5	R9	R11	R14	R16	R20	R22	R0	R2	R4	R6	R8	R10	R15	R17	R19	R21	R23	R25
Stimulus	single stimuli	S3	48								1			1								
		S5		45				1				4										
		S9			49						1											
		S11		1		46				2									1			
		S14					49							1								
		S16						46		1					2							1
		S20					4		43									1			2	
		S22								45									3			2
	double stimuli	S0	5		3						39			1				2				
		S2										42			6				2			
		S4									1		49									
		S6	2				3				9			35							1	
		S8		1				1				5			42							1
		S10														48				2		
		S15											1				49					
		S17									2					1		41			6	
		S19								1									41			8
		S21															6			44		
		S23					1							8				2			39	
		S25						2				2			2				4			40

	Mean	SD
Accuracy (%)	88	5.78
Information Transfer (bits)	3.94	0.17
Response time (s)	1.67	0.42

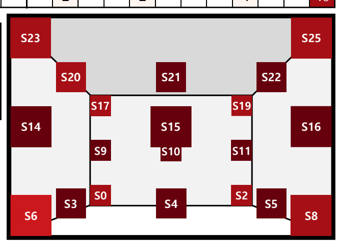


Fig. 2. The stimulus-response confusion matrices, Mean and Standard Deviations (SD) of Accuracy, infromation transfer and response time, and accuracy mapping from the each experiment.

Prior to the main experiment, participants first completed an exploration phase in which they could freely experience each stimulus and familiarize themselves with the response interface. Following this, they underwent a test phase where all stimuli were presented in random order, and only participants who correctly identified over 90% of stimulus were allowed to proceed to the main experiment. All participants successfully met the perceptual criteria during training and no exclusion was necessary.

Following the single-point session, participants were given a 5-minute break. They then completed a second session designed to evaluate the perception of phantom sensations induced by the simultaneous stimulation of two adjacent actuators. In this task, two adjacent actuators were simultaneously activated at a reduced intensity (duty cycle scaled to $1/\sqrt{2}$ of the single-actuator) to induce a phantom sensation, where the stimulus is perceived at the midpoint between the two sources, while matching the overall intensity of a single-point stimulus [3]. The UI was updated to include 12 additional green response buttons corresponding to the midpoints between adjacent actuator pairs, allowing participants to report the perceived direction of the phantom cues (Fig. 1(d)). This session included eight single-actuator and twelve two-actuator stimuli, each repeated five times in random order, totaling 100 trials. All other experimental conditions and procedures remained consistent with the previous session.

III. Results and Conclusion

In the single-point localization task, participants achieved a mean information transfer (IT) of 2.83 bits across 8 locations, with an average response time of 0.86 seconds. In the two-point localization task, which included 8 single and 12 double (phantom) stimuli, the IT increased to 3.94 bits across 20 locations, though the average response time also increased to 1.67 seconds. The stimulus-response confusion matrices for both tasks are shown in Figures 2, illustrating the accuracy of responses across the different stimulus locations.

Compared to existing vibrotactile studies with a similar number of actuators and information in stimulus (IS) range, our system demonstrated higher or comparable information transfer [4]. This was achieved using standard ERM motors on a challenging body site, without relying on temporal illusions or asymmetric stimulation. These results strongly indicate that the ear-adjacent skin can effectively support spatial tactile feedback, providing a promising avenue for future development in wearable haptic technologies.

We propose a refined device that minimizes acoustic output while preserving tactile fidelity. Given the strong baseline performance, we anticipate that such a device can offer superior spatial resolution and usability.

References

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