Haptic Directional Awareness in Virtual Reality

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Introduction

Haptic feedback is an essential component of the human sensory system, constituting an important channel that can provide extensive complementary information without significant cognitive interference with other senses (Prewett et al., 2006). As such, haptic technology holds immense potential for virtual reality (VR), which currently mainly combines audiovisual information with limited tactile or haptic information. Advanced haptic feedback can improve immersion and interaction by giving users a sense of touch or offering meaningful information without further cluttering the visual and auditory sensory channels (Monica and Aleotti, 2023; Wang et al., 2024). To explore how users can be provided additional directional information concerning their environment through real-time sensory augmentation and replacement, we devised a VR study employing a wearable vibrotactile vest with minimal tracking effort. The vest's haptic feedback assists users in solving a set of location tasks with varying directional semantics, guiding users toward specific targets or warning of imminent hazards in a virtual environment that otherwise would be difficult to complete due to a lack of salience or visibility.

Study Design

Hardware. The VR hardware employed in this study included an HTC Vive Pro headset and controllers selected for the precise outside-in motion tracking with a set of base stations. We further opted for the bHaptics X40 TactSuit, a commercially available wearable haptic vest with 40 vibrotactile motors (20 on the front and 20 on the back). Each motor can be precisely controlled, enabling the creation of specific tactile sensations on the wearer's upper body.

Environment. We designed a dedicated environment with different zones, as shown in Figure D. 13. One of the environment's central characteristics is its minimalist appearance, with little to no task-related salience, i.e., visual cues. Participants begin in the first zone (X) at the bottom center, where they go through a brief tutorial to familiarize themselves with the controls, general locomotion approach, and the vest's vibrotactile sensation. Following this tutorial, they are asked to complete a series of challenges involving different tasks in subsequent zones A (Floating Orbs), B (Fog Labyrinth), and C (Trapdoor Floor).

- In the *Floating Orbs* zone (A), participants enter a room full of randomly distributed, identical spheres (cf. Figure D. 14a). Participants have no way of visually identifying the two target spheres they are tasked to find, and –in the worst case– would have to try and return each sphere to the designated placers.
- In the *Fog Labyrinth* zone (B), participants navigate a maze to locate a target object and return it to its placer at the entrance. The environment is filled with dense smoke (cf. Figure D. 14b), severely obstructing visibility and further increasing disorientation.
- The *Trapdoor Floor* zone (C) confronts participants with an empty room where they must reach the opposite side without stepping on collapsing floor elements. If they approach one of these trapdoor elements, participants receive a warning to move in a different direction. If they still enter this area, the floor collapses underneath (cf. Figure D. 14c), with participants falling and respawning back where they entered the zone.

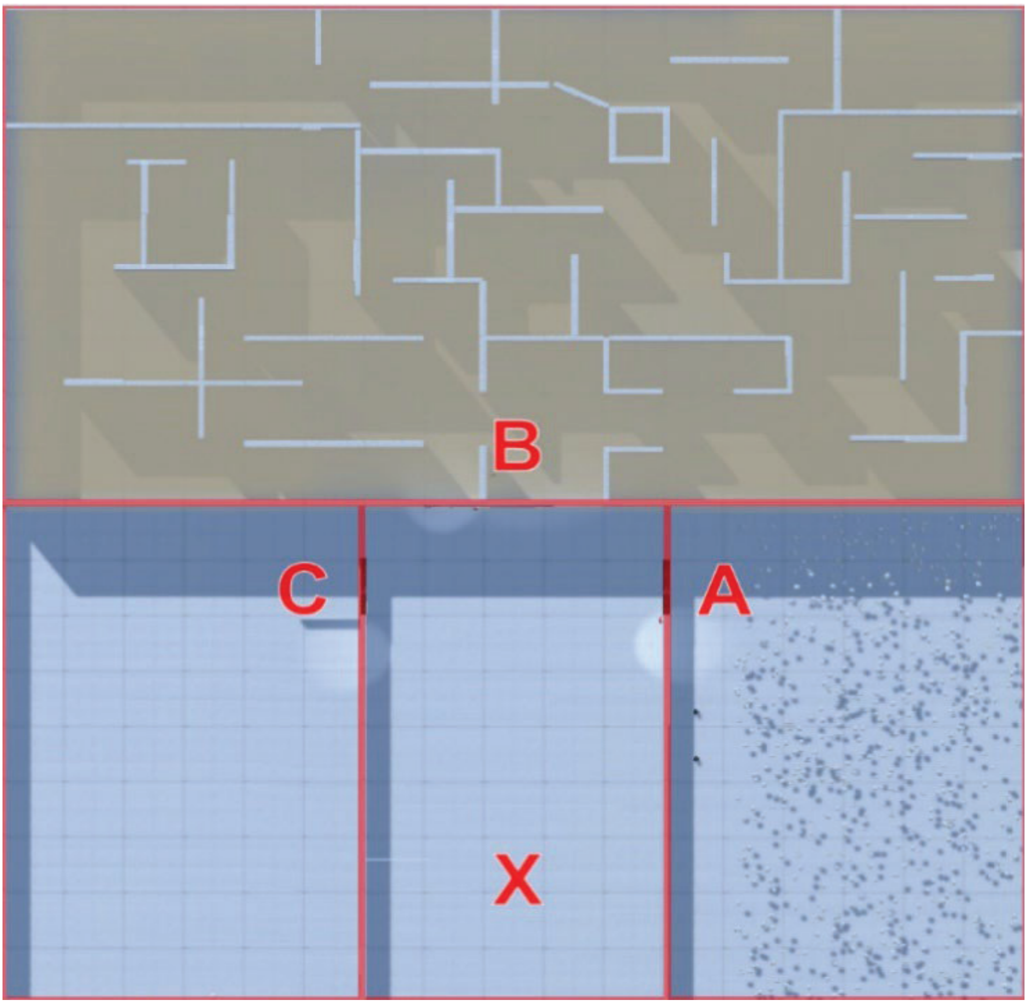


Figure D. 13. Top-down view of the entire virtual environment and different task zones: Start/Tutorial (X), Floating Orbs (A), Fog Labyrinth (B), Trapdoor Floor (C).

(a) Floating Orbs. (b) Fog Labyrinth. (c) Trapdoor Floor.

Figure D. 14. First-person perspective screenshots of each challenge.

Haptic output. As illustrated in Figure D. 15, participants receive haptic feedback on the vest about a target location in relation to their position in the virtual environment. The motors to engage are determined by the intersection of the line connecting the participant's face with the target and a 4×5 matrix of spherical phantom objects placed in front of and behind the user in the virtual world, mapping the vest's motors. A small pilot study indicated that gaze deviating from overall body posture has no perceptible effect on the relative direction information, and the haptic information does not need to be transformed to account for this difference. However, we found that body size is a significant factor in resolving directional information from the motor arrays on the front and back of the vest. Therefore, the user's height is factored into the vibrotactile output, as shown in Figure D. 16. The shorter a person, the more punctual the haptic feedback; the taller a person, the more support motors are used to enlarge the feedback area.

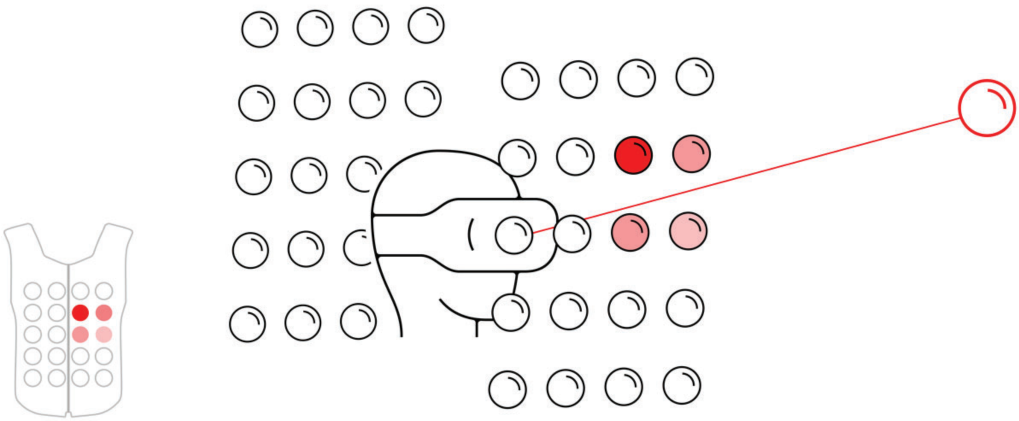


Figure D. 15. Target location mapping on motor array related to virtual position.

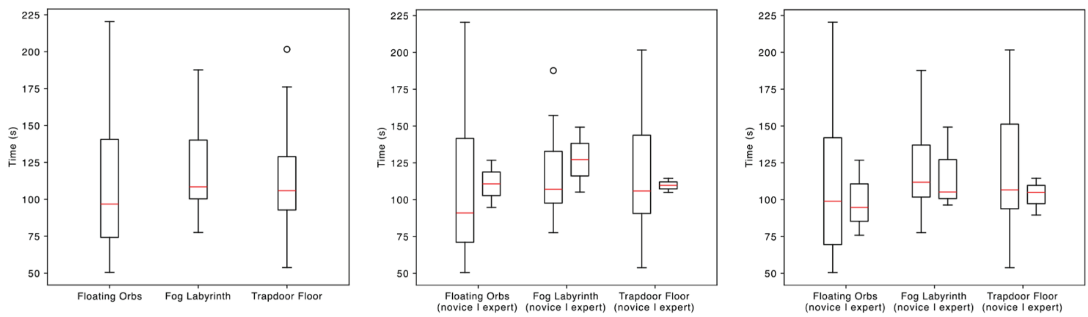
(a) <160cm. (b) 160-170cm. (c) 170-180cm. (d) 180-190cm. (e) >190cm.

Figure D. 16. Example haptic feedback intensities and ranges relative to user height.

Data collection. Various performance-related data were collected for objective evaluation, such as task completion times or the user's distance to the targets during each motor activation. Further quantitative data stem from the continuous tracking of the users' pose, orientation, and movement. In addition to quantitative data, qualitative data were collected before and after the experiment using pre- and post-trial questionnaires, which mainly collect information related to user experience and haptic feedback, including confidence, usability, immersion and presence. The data collected before the experiment included demographic information as well as previous experience with VR, games, controller use, and haptics.

Results

All participants (2 female, 10 male, mean age = 26.7) successfully completed the different challenges. Figure D. 17 shows the completion times also by proficiency levels regarding VR and haptics. Interestingly, VR experts, on average, exhibit slightly higher completion times than VR novices. This may be because users familiar with VR want to explore the virtual environment more, while novice-level users focus more on the task at hand. However, we see only a slight but insignificant advantage for participants familiar with haptics compared to novice-level participants. There were also only minor differences between participants with different gaming or controller use expertise. This similarity in performance indicates that haptic feedback can effectively supply directional cues to users independent of background or expertise.



(a) Aggregate. *(b) VR expertise.* *(c) Haptic expertise.*

Figure D. 17. Mean completion times per challenge.

The questionnaire revealed that participants were confident in completing the tasks. The VR environment was reported to be immersive, and the navigation controls were easy to master. Most participants also subjectively assessed the haptic feedback as clear, intuitive, and useful.

Summary and Outlook

This work presents a novel approach to haptic directional awareness in VR, demonstrating how it can be achieved with minimal tracking effort using a wearable vibrotactile vest. While preliminary due to the limited group size, the results of this study demonstrate the effectiveness and potential of haptic directional feedback to guide users in difficult or otherwise impossible-to-navigate spaces through sensory augmentation or replacement.

The current study opens up many interesting paths to explore. For instance, while our motor activation algorithm works well, different intensities and activation ranges might be even more effective. Physiological measurements might help further assess the user response and explore the parameter space comprehensively to fully understand and validate the generalizability of haptic directional awareness approaches beyond VR applications.

References

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