2022
The Journal on Technology and Persons with Disabilities

Creating Accessible XR Technologies: Rehabilitation for TBI

Jesse D. Flint[1], Jennifer M. Riley[1], Caitlin J. Lang[2]
Design Interactive, Inc.[1], University of Central Florida[2]
jesse.flint@designinteractive.net, jennifer.riley@designinteractive.net,
caitlinjlang@knights.usf.edu

Abstract

Extended reality (XR) technology has the potential to serve as an assistive tool for those with functional limitations- Both as support for those with long-term disabilities, and as a rehabilitation aid for recovery following acute injuries. This paper will explore possibilities for XR in recovery from head trauma, as well as consider how XR can be adapted to support people with functional limitations. Implications for rehabilitation and re-training for individuals with traumatic brain injury (TBI) will be discussed. TBI survivors typically have deficits in spatial cognition that lead to difficulties in navigation tasks. Individuals with TBI experience impairments in navigation skills, specifically in landmark recognition, allocentric location (ability to remember where landmarks are located on a map), and path route knowledge (recall for which direction to turn at intersections). To date there are no guidelines on the implementation of Augmented Reality (AR) specific to the development of tools to assist survivors of TBI in navigation. The first section of this report will document research related to TBI as well as provide specific evidence-based guidelines for designing navigational aids for individuals with TBI. The next section will provide general guidelines for creating augmented reality (AR) and mobile systems targeting the training and support of navigation for individuals with TBI. The final section of the report will provide a use case to demonstrate how the guidelines would appear in a mobile application to support navigation and re-training of navigation skills in users with TBI.

Keywords

Augmented Reality, Virtual Reality, Extended Reality, Traumatic Brain Injury, Navigation, Egocentric Navigation

Introduction

Traumatic Brain Injury (TBI) is a form of acquired brain injury cause by a bump, blow or jolt to the head (CDC 1). The most frequent causes of TBI in civilian populations are falls, motor vehicle crashes, struck by or against events, and assaults (Langlois et al. 375). Within military populations, the major cause of TBI is from blast injuries and can be caused by changes in atmospheric pressure from a blast wave (primary blast injury), by being struck by an object in motion from a blast (secondary blast injury) or by the person hitting something like the ground or inside of a military vehicle (tertiary blast injury) (Warden 398). Disability stemming from TBI can cause immense disruptions to activities of daily living, and occupational therapy is often necessary to re-train some daily tasks. TBI survivors typically have deficits in spatial cognition that lead to difficulties in navigation tasks (Livingstone and Skelton 21). Individuals with TBI experience impairments in navigation skills, specifically in landmark recognition, allocentric location (ability to remember where landmarks are located on a map), and path route knowledge (recall for which direction to turn at intersections) (van der Kuil et al 4).

Fidopiastis et al. (11) provided a user-centered design framework focused on creating virtual environments for rehabilitation of persons with head trauma. The framework extended the ISO 9241-210 guidelines set for interactive systems by requiring technology assessment prior to use for persons with functional limitations. These assessments included human factors testing of system components and the integrated system with a user-in-the-loop protocol. However, to date there are no guidelines on the implementation of Augmented Reality (AR) specific to the development of tools to assist survivors of TBI in navigation.

Discussion

Impacts to Navigation

Individuals with TBI experience difficulties with memory including facial recognition, story recall, semantic information, perspective memory, and autobiographical memory (Skelton et al. 189). These issues with memory result in decreased capability to traverse known routes or to lean new routes, and even the inability to recognize familiar places and landmarks (Skelton et al. 189). Barrash et al. (820) demonstrated that individuals with focal brain lesions to the medial occipital and posterior parahippocampal cortices in either hemisphere, the right hippocampus, and the right inferotemporal region demonstrated reduced capabilities to learn real-world navigation routes. Skelton et al. (13) demonstrated that individuals with TBI navigating in virtual environments in which the end destination was not clearly visible followed indiscriminate paths (vs. control participants that navigated directly to the known location), took longer to reach the destination, and required more distance to search for the destination. Individuals with TBI have particular difficulty with interpreting allocentric navigation instructions and translating from allocentric to egocentric navigation information (Cogné et al. 168). Allocentric navigation refers to navigation that uses cues external to the traveler such as landmarks via a 2D overhead map. Typical navigation platforms such as Google Maps found on most smartphones are examples of allocentric navigation. Egocentric navigation refers to navigation from the perspective of the traveler. First person shooter style video games in which a player explores their surroundings from the first person perspective is an example of egocentric navigation.

Because TBI can impact different areas of the brain, the degree and type of impairments relevant to navigation can vary across individuals. However, a review of 67 case studies across 58 research papers of neurological impairments by Claessen et al. (94) did find a trend for one or more of three different areas of impairments. First, many of the case studies found that individuals experienced difficulty with identifying or remembering familiar or new landmarks. The second type of common impairment was for recalling and/or acquiring information about landmark locations and their interrelationships. Finally, many of the individuals have difficulty acquiring or remembering the paths between locations. They have a tendency to produce distorted maps or were unable to describe routes between landmarks.

Support for Individuals with TBI

Programs designed to assist people with TBI in daily living skills can include training that addresses navigation impairments. However, due to the chronic nature of TBI as a source of cognitive impairment, navigation training does not generalize well and individuals with TBI still wrestle with problems such as forgetting scheduled trips, forgetting the purpose of a trip mid-trip, failing to recognize bus stops even for trained routes, getting irrevocably lost if a bus stop was missed, and experiencing anxiety about traveling alone or the possibility of getting lost (Sohlberg et al. 1253). Livingstone and Skelton (28) demonstrated that focus on the use of proximal landmarks can aid navigation in TBI survivors. Aids for navigation for individuals with TBI need to be in a format that can be used on a regular basis, include capabilities for reminders, and have functionality that can address situation in which users find themselves off course. Aids need to provide information on landmarks.

Assistive mobile devices are commonly used by people with TBI during wayfinding and navigation due to their portability and non-stigmatizing advantages (Schipper et al. 839). Liu et al. (1) evaluated the effectiveness of a mobile navigation device in an outdoor environment with two separate display modalities. For the first study, the device was capable of embedding plain photographs, directional symbols, photographs with highlighted areas, and photographs with overlaid arrows. In addition, the device provided just-in-time directions to the user via redundant audio and text communications. Unsurprisingly, results for the first study found that when audio, text, and image assets were unsynchronized or misaligned with the users' perspective, navigation errors increased. The second study sought to measure how different landmark characteristics might influence navigation performance. Specifically, the mobile device portrayed images of landmarks from the users' perspective (i.e., egocentric viewpoint) that were either distinct (i.e., sculpture) or non-distinct (i.e., flagpole). The results concluded that navigation errors decreased when landmark images matched the users' perspective and were unique.

A crucial aspect of treatment for individuals with TBI includes improvements in "participation" which includes the ability to engage in meaningful activities and having a sense of belonging (Schipper et al., 839). Johnson & Davis (520) demonstrated that individuals with TBI who received therapy in which they interacted more with activities in the community demonstrated improved integrated social contacts. The ability to navigate with independence while still having access to support could play a critical role in developing "participation" in individuals with TBI. Aids for navigation for individuals with TBI need to provide the capability to communicate with a caregiver and provide the caregiver with real-time information on the location of the individual that is traveling.

In addition to improvements in the quality of life of individuals with TBI, it has been demonstrated that Virtual Reality (VR) navigation training tasks might also improve long term memory. Caglio et al. (124) provided VR navigation training for 90 minutes per session for three sessions a week across a three month period for a TBI patient who had shown no cognitive improvements across one year of rehabilitations. After the VR navigation training, the participant showed improvement on a number of visual-spatial memory learning assessments and also showed increased activity in the hippocampus based on FMRI scans.

Sorita et al. (1377) demonstrated that individuals with TBI learn routes approximately as well in a virtual environment and a real environment. Participants demonstrated that most learning occurred from the first to the second time through a practice route and that error rates for 2 out of 3 assessments of route learning and wayfinding were the same across virtual and real routes. However, the assessments in which no differences were observed were for allocentric measures such as sketching out the route that was followed. The main difference in performance was for the only egocentric measure in which participants sorted pictures of actual intersections. Aids for navigation for individuals with TBI need to include the ability to rehearse routes (most likely through Virtual Reality) before traveling a new route.

Guidelines for Designing AR Mobile Applications for Individuals with TBI

Based on the research presented in the previous section, the following are guideless for designing AR mobile applications for individuals with TBI:

1. **Support user safety by connecting the user to their caregiver when they are in need of help.** The system should provide a help button for the user to initiate live and direct contact with caregivers when they need assistance. The system should alert the caregiver to potential safety information such as deviations from a route, inactivity.
2. **Provide photo or video-based information regarding landmarks and destinations to assist with recognition.** TBI users have difficulty remembering and often processing landmarks. Only proximal landmark information should be presented at any given time.

3. **Provide the user with an opportunity to practice and familiarize themselves with a route before they depart.** The user should have an option to rehearse the route before they depart, familiarizing them with the route, the navigational cues, and the landmarks.
4. **Provide the user opportunities to train with the device to understand the system.** In addition to rehearsing a route, it is important that the user is able to properly train on using the application before departing.
5. **Allow users to create reminders before, during, and at the conclusion of navigation.** TBI users typically forget that they are scheduled to take a trip, the reason that they are currently traveling, and why they have arrived at a destination. The user should have the option to set pre-trip and on-route reminder such as time to leave for a trip, bus route needs, and what they need to prepare for their trip.
6. **Provide re-routing information quickly and in supportive language.** TBI users experience frustration and confusion when their intended route does not go as planned (e.g., a bus stop is missed). Any re-routing of users must secure user attention quickly and present useful information on how to handle being off route. Possible options for user information are: reminders of the purpose of the trip and direction they should be headed, and suggestions to call a care giver for support.
7. **Present the user with limited options to support decision making and prevent the user from being overwhelmed.** Individuals with TBI can experience information overload when engaging in tasks that might have been relatively easy pre-injury (Fasotti et al. 47). When information overload makes the user aware of their reduced cognitive performance, emotional distress and impulsive behavior may result (Rath et al. 487). Display no more than 2-3 working items per page or nested list.

8. **Limit the complexity of displays of sensory information.** In addition to limiting the number of decision points on any given page, the system should not display irrelevant stimuli. This, in tandem with guideline 7 will further help prevent information overload.
9. **Information should be displayed in a user-centric manner, which matches the user's perspective.** User-centric displays of navigation information reduce ambiguity in which way the user should be headed and eliminates the cognitive load of mentally translating allocentric information to the first person perspective.
10. **Provide redundant cues in multiple modalities.** Redundant cues promote clarity and reduce the chance that a message will be missed or misinterpreted (Wickens et al. 722). Audio directions should also be displayed visually when possible.
11. **Provide instructions in short, concise, and clear messages.** Language decrements can make understanding long and complex messages difficult. Messages should be as concise as possible and not include unnecessarily complex sentence structure or vocabulary.
12. **Slow down audio cues.** For longer sentences, it would be beneficial to slow down the cue so that slowed information processing speed or language decrements are less likely to interfere with the user's ability to understand them.
13. **Allow for repetition of cues.** The user should have the ability to easily replay audio messages or repeat visual or vibrotactile cues as needed, cues should be repeated frequently during long periods of time between new cues.
14. **Provide frequent repetition and assurance that the user is headed in the correct direction.** Individuals with TBI may be easily distracted, and need help focusing their attention. Providing frequent feedback will support them in staying on task.

15. **When giving the user a choice, provide the choice first, and the response selection action second.** Responses should be intuitive and simple. The user should not be required to hold a response in working memory, and the response should be intuitive. For example, rather than telling the user, “Say ‘let’s go’ to begin route to the doctor’s office,” a better prompt would be, “To begin your route to the doctor’s office, say ‘begin route’.”
16. **Support maintaining path while avoiding cognitive overload through just-in-time multimodal directional cues.** Auditory and visual cues should be consistent and simultaneous, but not overwhelming. If a user is approaching an intersection, the system should tell them just in time when they are approaching a turn, rather than reminding them several times as they approach from a distance.
17. **Progressive disclosure of route via a virtual path and waypoints to avoid cognitive overload while supporting navigation.** Facilities like airports and hospitals experience high volumes of users not familiar with the facility that tend to experience cognitive issues. These facilities stress using the concept of progressive disclosure to aid in navigation throughout the facility (Huelat, 17: Liu et al., 25). Users are presented only with information that is necessary to get them to their next waypoint or decision point.

Use Case of AR in Navigation Applications

Based on the literature, certain features of a navigation support and re-training application are highly applicable to AR technologies available on smart phones. One of the key difficulties with navigation for individuals with TBI is with allocentric (top down 2D map projections) navigation. A navigation support and re-training application could use AR to overlay direction of travel on the actual scene in which a traveler is moving. Figure 1 presents a visualization of a visual AR egocentric travel mode overlay. The next issue of highest importance with TBI navigation is with the use of landmarks. Many users have difficulty processing landmarks even for known locations. A possible solution that AR could provide is the replacement of the use of landmarks with the use of "waypoints" which are simple representations of the next area a user will need to arrive at. Use of waypoints coincides well with the use of "proximal landmarks" used in some studies as the users is simply focused on the next (proximal) location they need to achieve. Waypoints could indicate (for example by changing color) that a traveler has successfully navigated to the next stage of their trip. Figure 2 demonstrates the use of a waypoint in which the base of the waypoint has turned green to indicate that the traveler has successfully arrived as well as AR arrows indicating the next direction of travel and a text box indicating the direction of the traveler's "next steps".

Fig. 1. Example of AR Used to Present Egocentric Information for TBI Travelers.

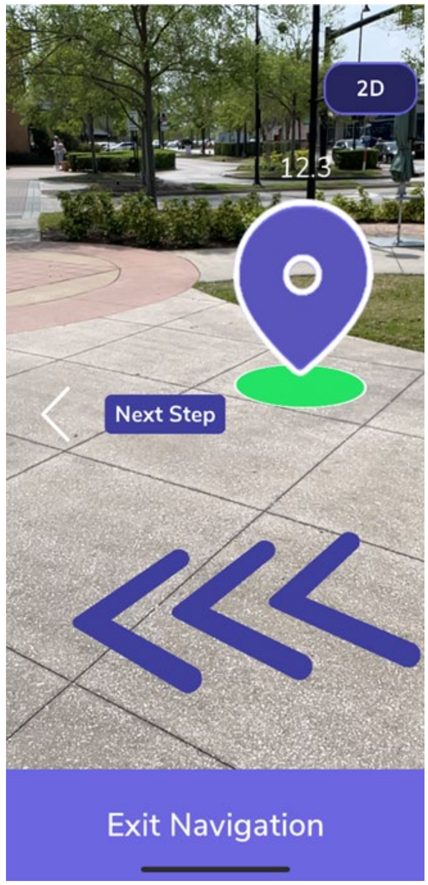

Fig. 2. Example of AR Waypoint Indicating Successful Arrival.

Conclusions

Wickens et al (653) proposed that map-study and practice in augmented or virtual spaces may provide a direct path to acquiring higher-order spatial skills in a representative environment, though to the best of our knowledge, this strategy has not been reviewed thoroughly in TBI-related literature. We propose future research into whether route practice in AR improves environmental mental models in individuals with TBI, and provides a benefit over traditional, 2D map study.

Haptic cues can provide information in an unobtrusive manner and provide redundancy to supplement auditory and visual information. Future research should determine how best to incorporate haptic, tactile, and vibrotactile cues to support individuals with TBI. Research is needed to determine whether vibrotactile cues through a mobile device can effectively support wayfinding in individuals with TBI, or if TBI hinders the ability to use and remember vibration patterns as directional indications.

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