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COGNITIVE TECHNOLOGIES FOR WAYFINDING

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Although almost everyone has been temporarily lost at some point, a significant number of people have persistent difficulty in navigating a route and, when they are lost, are unable to find their way without assistance. Many of these individuals have cognitive disabilities, which affect not just their wayfinding ability, but also other important life skills as well (e.g. planning, scheduling). The American Community Survey estimates that 3.9 percent of the civilian non-institutionalized population (over 2 million people) has cognitive difficulties (US Census Bureau, 2014). Unfortunately, prevalence estimates do not exist that would tell us how many of these people experience difficulty with wayfinding. We do know that challenges in wayfinding can negatively affect an individual's ability to work, recreate, and participate in community life. For example, when an individual is unable to wayfind independently, it reduces opportunities for engagement with friends (e.g. it makes it difficult to meet your friends out at the cinema to watch a movie on the spur of the moment), for gainful employment (e.g. it makes it difficult to show up at your place of work on time), and to engage in leisure activities (e.g. it is difficult to run up the street to the soccer field for a quick game).

As we have worked to develop technologies to support wayfinding, we have found that many individuals who have difficulty with wayfinding report that they feel isolated and unable to leave home because they, or their parents and caregivers, fear the consequences of being lost. As a result, challenges in wayfinding result in a significant loss in independence and social contact because people with cognitive disabilities require support (usually from other people – parents, siblings, caregivers, para-transit) in order to travel accurately and safely.

Although supports for getting from one place to another may exist in a community, they come with significant costs in terms of flexibility and expediency. Relying on a caregiver or parent to provide transportation means that an individual is restricted to the days and times that that individual is available. Relying on a community service, such as adapted public transportation, increases one's ability to travel independently, but still comes with costs in time and flexibility since one must schedule the service in advance and often wait during a 1–2 hour window of time for the transport to arrive. Because of these challenges, many research groups have explored ways to provide technological support to people with cognitive disabilities so they may travel independently, but safely, without the need for ongoing human support.

As a component of a support system for individuals with cognitive disabilities, cognitive support technologies for wayfinding have great potential to increase independence and reduce the need for personal assistance. Like other assistive technology systems, they consist of "someone (person with a disability) doing something (an activity) somewhere (within a context)" (Cook and Polgar, 2007: 35). Thus, cognitive support technologies comprise a complex interaction between the human user, the activities in which she or he wants to engage, the context in which the activity occurs, and the assistive technology available to support the activity. Planning for the development, selection, implementation, continued use, and evaluation of cognitive support technologies requires an understanding of each variable (Scherer and Craddock, 2002).

In this chapter, we discuss the activity of wayfinding and the issues it poses for people with cognitive disabilities and then overview the technological innovations that are in development to support their independence in wayfinding. We conclude with suggestions for both clinicians and developers.

What is wayfinding?

Wayfinding refers to the ability to find one's way from a base location to another location (or locations) of interest and back again. Wayfinding can be simple (a child finding his way home from the elementary school down the block) or complex (a taxi cab driver finding her way through the streets of London to a new address). Most people use their wayfinding skills on a daily basis – to navigate to familiar places (e.g. work, school, shopping) and to novel locations (e.g. a new doctor's appointment).

Wayfinding is a foundational life skill that most humans begin to develop at a very early age. Research suggests that wayfinding develops gradually over time from an egocentric (person-based stimulus-response) approach to an allocentric (world-based place learning) approach. Children as young as nine months begin to show some use of allocentric strategies, which may be related to the development of mobility through crawling (Bremmer, 1978). Interestingly, Wiedenbauer and Jansen-Osmann (2006) have demonstrated that the age at which a child with spina bifida learns to walk strongly correlates with how many learning trials it took to acquire a route, suggesting again that mobility may be a covariate in the development of wayfinding capabilities. Development of allocentric representations appears to continue until about the age of 10 (Lehnung *et al.*, 1998; Overman *et al.*, 1996; Piajet and Inhelder, 1948). The work of Bohbot *et al.* (2012) suggests that, over the course of the lifespan, older adults (e.g. mid-60s) may revert to a more response-based wayfinding style as they automatize frequently repeated behavior.

Conceptually, wayfinding is complex, and a complete taxonomy of all the cognitive underpinnings that support successful wayfinding has yet to be developed. Researchers have classified wayfinding in different ways, including by the types of navigational knowledge that a person could possess (i.e. landmark, route, survey) and the types of wayfinding tasks in which they might engage (e.g. familiar versus unfamiliar). In the following sections, we briefly describe these classifications.

Types of knowledge

Siegel and White (1975) postulated a framework that included three types of knowledge used for navigation: landmark, route, and survey. In landmark-based navigation, individuals use recognizable features of the environment as a directional cue. Landmarks can cue an individual to move toward or away from the landmark or to implement an action (e.g. turn right) when arriving at the landmark. Landmark-based navigation does not require an overall understanding of the route, just the ability to identify a landmark and execute an action when the landmark is reached. Obviously, not all landmarks are equal (Chan *et al.*, 2012). We have found that the difficulty of using a landmark in navigation can vary depending upon the type of landmark (e.g. building, school, sculpture, road), the uniqueness of the landmark, the distance between the individual and the landmark, the orientation of the landmark to the individual (e.g. in front, behind, to the left or right), and the alignment of the landmark to the path (e.g. walk toward versus keep to your left) (Liu *et al.*, 2009).

Route knowledge refers to navigation that relies on place–action associations. These place–actions can include landmarks, but may also include other types of information (e.g. distance and cardinal direction – for example, "walk down 4th Street for 4 blocks until you reach the clock tower, then turn left"). Neither landmark nor route knowledge requires an individual to have a cognitive map of the environment.

Survey-level knowledge refers to the type of navigation in which an individual has a higher level understanding of the environment that may include a cognitive map of the area with a sense for how routes fit together and the specific distances and angles between locations. Landmark and route knowledge are considered to be egocentric frames of reference because they require navigation that is from the person-level or ground-level perspective. Survey-level knowledge is considered to be an allocentric frame of reference because it requires the individual to hold a frame of reference or perspective that is independent of his or her current location (Klatzky, 1998).

Recently, Chrastil (2013) discussed the adequacy of this three-part framework. She noted that, although the framework makes conceptual sense, it is not empirically-based, does not map to distinct neural correlates, and each type of knowledge likely involves multiple cognitive processes. She argues that, "a finer-grained breakdown of the cognitive processes and sub-processes involved in spatial knowledge is in order" (2013: 210). As part of this effort, she proposed a fourth type of navigational knowledge that she called graph knowledge. Graph knowledge fits between route and survey levels of knowledge and refers to navigation through an understanding of connected points in space (i.e. topological connections) that could be represented like a network map. This type of knowledge is more sophisticated than route knowledge, in which a navigator only knows one path to a destination, but less sophisticated than survey-level knowledge, in which a navigator has an accurate (metric) representation of all possible routes.

Types of wayfinding tasks

In addition to types of knowledge required, wayfinding tasks can also be categorized by type of task. Wayfinding tasks may be made easier or harder depending upon whether the wayfinding is aided or unaided, whether the route is familiar or unfamiliar, and whether the trip is planned or unplanned (Wiener *et al.*, 2009). Aid can come in many forms, both human and technological, but is often required by individuals with cognitive disabilities, especially if they are going somewhere unfamiliar or the trip is unplanned. When routes are unfamiliar or unplanned, most people engage in exploratory activities (e.g. wandering around a new school campus or exploring a new neighborhood) that allow them to develop an understanding of the environment in which they are traveling; however, for people with cognitive disabilities exploration can be risky and non-productive. In our work, we have found that many people with cognitive disability find themselves limited to traveling to familiar places for planned trips, often with the assistance of a human caregiver.

How does cognitive disability affect wayfinding?

People with cognitive impairments are not a homogeneous group and the disabilities they experience have diverse etiologies. Wayfinding research has been conducted with people with cognitive disabilities as a result of atypical development (i.e. intellectual/developmental disabilities such as Down's syndrome, Williams' syndrome, autistic spectrum disorders, and spina bifida) (Courbois *et al.*, 2013a; Courbois *et al.*, 2013b; Farran *et al.*, 2012; Lind *et al.*, 2013; Mengue-Topio *et al.*, 2011; Wiedenbauer and Jansen-Osmann, 2006), injury (e.g. traumatic brain injury, cerebrovascular accident/stroke) (Lemoncello *et al.*, 2010; van der Ham *et al.*, 2013), degenerative conditions (e.g. multiple sclerosis) (Fong *et al.*, 2006; Uc *et al.*, 2007), and aging (both typical aging and conditions associated with aging such as dementia) (Deipolyi *et al.*, 2007; Head and Isom, 2010; Iaria *et al.*, 2009).

Across disability categories, the evidence tends to suggest that people with cognitive disabilities rely on landmark knowledge over other types of knowledge, but may not identify or remember the best landmarks. With good instruction, they learn to execute routes with fluency, but make more errors during initial learning, take more time, and are more hesitant in execution of the route. Finally, although they may develop survey-level knowledge, their cognitive maps are often less complete and more distorted. Different causes of cognitive disability are linked to different profiles or patterns of functional deficits as a result of the ways those conditions affect the neurological status of the brain. Background knowledge and experience also appear to play a role in wayfinding (Frankenstein *et al.*, 2012; Wiedenbauer and Jansen-Osmann, 2006; Woollett and Maguire, 2010): people with more opportunity to explore and learn about the logic of environments (e.g. common placement of landmarks) perform better.

It is important to note that many people with cognitive disability also have co-morbid disabilities that affect hearing, vision or mobility. This cognitive, sensory, and physical diversity has implications for the development of appropriate technologies for supporting wayfinding that we discuss in more detail in later sections of this chapter.

Cognitive support technologies for wayfinding

Providing an appropriate support system can make a substantial difference in the lives of people with disabilities. Support systems consist of three components: personal assistance services, assistive technology, and adaptive strategies (Litvak and Enders, 2001). All three are necessary and important, and no single component can provide an individual with adequate support alone. In any given situation or environment, an individual may rely more heavily on one type of support than another. Cook and Polgar (2007) describe the shifting use of support systems as functional allocation, and Litvak and Enders describe dynamic support systems, but different approaches (personal assistance, assistive technology, adaptive strategies) are optimal for different people and different tasks.

Cognitive support technologies are devices and services intended to reduce the impact of disability for individuals with functional deficits in cognition. These technologies are often referred to as assistive technology for cognition (ATC). When cognitive support technologies are implemented well, they can benefit individuals with cognitive disabilities by increasing independence and success in life activities. These technologies can also enhance the quality of life of caregivers by reducing the demands of that role.

The evidence base for cognitive support technologies for navigation and wayfinding is currently sparse. In two systematic evidence reviews published since 2010 (de Joode *et al.*, 2010; Gillespie *et al.*, 2011) only seven published studies of technologies met the minimum inclusion criteria for quality and were included in the reviews. Of these, four included participants with cognitive impairments (TBI, ABI, intellectual disabilities, MS) and three included elderly participants and those with dementia.

Gillespie *et al.* (2011) rate the evidence from the four studies of participants with cognitive impairments from 2 (well-conducted case control or cohort with a low risk of bias) to 3 (case control or cohort with a high risk of bias) using the Scottish Intercollegiate Guidelines Network (2008) methodology. De Joode *et al.* (2010) rate the evidence of two of the studies also included in the Gillespie *et al.* review as Class III, using methods described by Cicerone *et al.* (2000). Class III studies were clinical series without concurrent controls (Sohlberg *et al.*, 2007), or studies with results from one or more single cases that used appropriate single-subject methods, such as multiple baselines across interventions with adequate quantification and analysis of results (Kirsch *et al.*, 2004).

In all, the preliminary evidence indicates that user confidence and accuracy in wayfinding improves with the use of customizable cognitive support technologies for navigation. Although most devices are prototypes and not available for the general public, the work in this area has grown from using bulky, external GPS units and hand-held PDAs to customized smartphones and specialized apps.

Existing technologies

Most of the work done in the area of navigation and wayfinding has been in facilitating outdoor navigation. Outdoor navigation is based on GPS and/or cell tower positions. Technologies utilizing these systems, such as car navigation systems and apps for most smartphones, work quite well but are not error free. These systems require regular updating and, at best, location is accurate within 50 feet (Stephenson and Limbrick, 2013).

Representation in existing technologies typically includes text (step-by-step) directions with speech output and a map with directional overlay (e.g. a moving car, an arrow, or a compass) and speech output. Prompting is provided as corrective feedback when the traveler makes an error.

Existing technologies developed specifically for individuals with cognitive impairments are still largely in the pilot stages and none have been widely deployed. These cognitive support technologies specific to navigation rely on sensors in the environment for indoor navigation and GPS/cell tower positioning with human backup for outdoor navigation.

The form factors have evolved in cognitive support technologies as they have with technologies not specifically developed for individuals with disabilities. Hand-held PDAs and pagers (such as NeuroPage) have given way to apps developed for use on mobile phones for outdoor navigation. Using sensors to interpret environmental cues to location indoors, such as differences in fluorescent lighting, has evolved into using sensors embedded in the environment to locate and orient the user, such as AmbienNet (Abascal *et al.*, 2010) and AssistMote (Chang and Wang, 2010b).

Despite advances in both outdoor and indoor navigation technology, issues remain that result in barriers to use of both existing and designated devices for individuals with cognitive impairments, including reliability of location information, provision of information about orientation (i.e. "in which direction am I facing?"), representation, and prompting or cuing. In addition to these technical and user interface challenges, we have also identified barriers related to decisions about privacy, independence, and safety that arise when new technologies are put in place.

Issues in location and orientation

In outdoor navigation systems, we rely on GPS and/or cell tower positions (GSM). As noted above, these are only accurate to within approximately 50 feet. For individuals with impaired executive function resulting in difficulty with problem solving, approximate location is not adequate. Human-backed technology (Bigham *et al.*, 2011) ensures just-in-time reliable assistance when needed. In focus groups with individuals with cognitive impairments and their caregivers (Chu *et al.*, 2013), human-backed technology was highly valued. Participants stated that they thought technology, especially for navigation, could fail and "a real life person backup is always going to be important."

Indoor navigation also poses significant issues in location and orientation. We can determine a person's location indoors by dead reckoning (using sensors such as accelerometers to estimate current location), direct sensing (e.g. use of RFID, bar codes) or triangulation (wireless base stations in the environment) (Fallah *et al.*, 2013). Of these, direct sensing provides the most accurate information, but requires changes in the environment (installation of the sensors) and a way for the individual to receive the information. In early pilot studies of indoor navigation (Fong *et al.*, 2006; Liu *et al.*, 2008; Uc *et al.*, 2007) they determined that the use of multiple sensors for localization was essential. Wi fi, while useful, does not provide orientation and typically does not work in elevators. Combining other sensors (such as an accelerometer for dead reckoning) proves more successful in providing indoor wayfinding assistance to individuals with cognitive impairments.

While technologies, especially smartphones, now have embedded sensors, such as accelerometers, recent research indicates a continued need for reliable, easily deployable, accurate indoor location and orientation technologies (Fallah *et al.*, 2013).

Issues in representation

How information is represented, both in indoor and outdoor navigation systems, is critically important. The most common method of representation is the map. However, map usage has steadily declined in recent years; even geography students report relying on satellite navigation systems over maps to find their way in unfamiliar places (Speake and Axon, 2012). For those with some types of cognitive impairments, maps are too abstract to provide meaningful navigation assistance (Brown *et al.*, 2005).

To address this issue, both off-the-shelf and navigation technologies developed for individuals with cognitive disabilities have trialed alternative methods of representation, including photographed landmarks and photographed landmarks with directional overlays, such as arrows (Chang and Wang, 2010a; Fong *et al.*, 2006). While landmarks selected by the end user were the most effective (Liu, 2010), individuals with intellectual disabilities have some difficulty selecting distinctive, permanent landmarks (Courbois *et al.*, 2013a). The usability of landmarks is influenced by seasonal changes (Kettunen *et al.*, 2013; Liu, 2010) prompting the recommendation in several of these studies to include either audio or text directional cues to supplement landmarks.

Issues in directional prompting

Much of our work in both indoor and outdoor navigation systems for individuals with cognitive impairments focused on effective representation and directional prompting. Lancioni *et al.* (2009) categorize directional prompting into technologies that provide corrective feedback and technologies that provide directional cues. Corrective feedback works best for individuals who are able to initiate a path, but make a mistake and need to be redirected. An early system called Opportunity Knocks (Liao *et al.*, 2007) provided corrective feedback by alerting the user to the mistake (e.g. missing a bus stop) and then providing the user with new directions to their destination.

Later iterations of Opportunity Knocks trialed the use of directional cues based on predicting where the individual is trying to go and providing guidance to the user (Liu, 2010). While we found that proactive directional cues are effective for individuals who may be unable to initiate a path, the functional variability among individuals with cognitive impairments demands a wayfinding system that is both customizable and adaptable to the end user (Liu *et al.*, 2010).

Balancing safety, privacy, and independence

As part of our research, we talked with many individuals with cognitive disabilities and their caregivers (paid and unpaid). Discussing wayfinding technologies often led them to consider the tension between the themes of safety, privacy, and independence. In short, caregivers wanted the most wayfinding independence possible for the people they supported, but worried that independence might increase risk. For example, they worried that, if their son/daughter/client were to get lost, they might end up in a neighborhood where they were at risk of predation or they might injure themselves (e.g. tip over in their wheelchair) and not be able to get assistance. However, they imagined that the technology could provide a link to allow greater independence while still maintaining the ability to monitor and provide assistance if needed.

One element of having this kind of monitoring for safety that most caregivers had not thought about much was the risk to privacy that it brought. They tended to be comfortable (especially parents) with a reduction in privacy for their son/daughter if the privacy loss was kept within the family, but had much greater concerns if the privacy loss was with an outside provider.

Discussion

Using cognitive support technologies for wayfinding in clinical practice

Implementing cognitive support technologies for wayfinding in clinical practice requires that at least two things be in place. First, there must be technologies available that are appropriate, affordable, and reliable. Second, clinicians must themselves be prepared to use, problem solve, and repair technologies as well as train consumers in the use of technologies. Unfortunately, in the field of cognitive support technologies for wayfinding, there is still much work to do before technologies can be implemented in the daily lives of people with disabilities.

Our experience suggests that commercially available devices for supporting wayfinding (GPS, smartphones, apps) are not appropriate for many people with cognitive disabilities because they are complex to operate and provide directions in ways that do not support the strengths of people with cognitive disabilities (e.g. most devices are map-oriented). There have been some improvements in recent years. For example, Garmin has developed a system called Real Directions that uses landmarks to provide directional cues. These systems may eventually be developed to a level that allows for them to be customized to the needs of people with cognitive disabilities. Individuals with cognitive disabilities who are highly motivated and have adequate support may be good candidates for trialing current systems.

Work is being done in research labs and universities to develop new technologies that are not yet commercially available. These devices, however, are not readily available to clinicians, have often only been developed to the point of proof of concept and are not reliable enough to trust with a consumer. We expect that some of the innovations being developed will eventually be built into commercially available systems, whether those systems are targeted toward the general consumer (like Garmin) or are more focused on specific populations (such as the work of companies like AbleLink).

Unfortunately, even if devices were available for use, many clinicians would not be ready to use them. De Joode *et al.* (2012) conducted a survey of professionals who had participated in a symposium on stroke-related cognitive rehabilitation that asked about their experience with assistive technology and opinions about its use in cognitive rehabilitation. Only about 30 percent of professionals reported previous assistive technology use. This finding suggests that not much has changed since the study conducted by Hart *et al.* (2003) where they found that, although clinicians believed that electronic devices could be useful in supporting their clients, especially in the areas of learning, memory, planning, and organization, two-thirds of the clinicians rated themselves as "not at all" or "somewhat" confident in their ability to teach clients how to use the devices.

Developing cognitive technologies for wayfinding for people with cognitive disabilities

Developers who want to create technologies for wayfinding that are appropriate for people with cognitive disabilities need to consider the needs and challenges of this target group. In our work, we have had the opportunity to engage in a number of user interface studies and user interviews to determine technology strategies that may work (Liu *et al.*, 2009; Liu *et al.*, 2006; Liu *et al.*, 2008). A primary recommendation we would make to developers is that they not work in isolation. They must work with consumers in a human-centered, iterative design and development process in order to understand the needs of people with cognitive disabilities and to develop effective devices.

Out of our work, we have conceptualized four design implications that developers should consider when addressing the cognitive support technology needs of people with cognitive disabilities. These four implications may help guide developers' decisions about the functionality needed in cognitive support technologies for wayfinding.

First, as a result of the differing etiologies of cognitive disabilities and varying functional limitations, we assume individuals will possess *different prerequisite skills and knowledge* that might impact the use of cognitive support technologies. For example, individuals with adult onset degenerative conditions or acquired brain injury may have been proficient technology users prior to the onset of their condition and may be able to learn to use new technology with more ease than individuals with intellectual disabilities who might not have previous experience. The design implication of these different prerequisite skill profiles is that, ideally, devices would be able to provide adaptive support for users who may need more or less assistance in learning and using the device. In addition, user interfaces will need to be developed that are intuitive and appropriate for users with diverse cognitive challenges.

Second, we expect that individuals will differ *in terms of the type of deficits with which they present*. For example, individuals with acquired brain injury may have patterns of specific and global deficits based on their specific type of injury and very specific cognitive losses related to the location of trauma, whereas individuals with intellectual disability will commonly have more generalized deficits. It is also important to remember that many individuals will present with concurrent (non-cognitive) disabilities, such as mobility or sensory impairments. The design implication of these different deficits is that devices will, ideally, be customizable (i.e. capable of being set up differently for users with different deficits – e.g. audio only for people with vision impairment, capable of supporting different input approaches for people with limited dexterity in their hands).

Third, we expect that there will be *differences in the flexibility required of the cognitive support technologies* based on an individual's condition. For example, individuals with multiple sclerosis and Alzheimer's Disease will generally have decline of cognitive function, while individuals with acquired brain injury may show improvement, and individuals with intellectual disability will likely be relatively stable in their cognitive function over time. The design implications of these different cognitive trajectories is that, ideally, a device will be adaptable over time (i.e. provide more or less support based on the user needs).

Finally, we expect that *the need for cognitive support will differ based upon the cognitive demand of the task being attempted* and that individuals who function quite well under some conditions will function less well when the demands of the task or environment change. Cognitive load theory (Paas *et al.*, 2003) acknowledges that the "cognitive architecture" of the brain (e.g. working and long-term memory, attention) has limits that can be overloaded. For example, working memory can handle only a small number of interactions at one time. When cognitive limits are reached, an individual becomes overloaded and unable to process more information. Cognitive load theorists also postulate that there are intrinsic and extraneous cognitive loads. Intrinsic loads refer to the inherent demands of the task. For example, traveling to the neighborhood store is easier than traveling to the large mall in another town. Extraneous loads are cognitive loads that serve to increase the difficulty of the task; for example, completing a trip with a time constraint or traveling during rush hour. Intrinsic load serves as the base load of the task. Extraneous load, on the other hand, is modifiable. There are many variables that can be manipulated to modify extraneous load, including novelty of the task, complexity, speed of completion, and stress. These concepts apply to individuals with disabilities using cognitive support technologies. The interrelationship between their cognitive strengths and deficits and the intrinsic and extraneous load of the task help define what an individual can do. The design implication is that cognitive technologies must provide a means for reducing, and not increasing, some of the extraneous load.

Conclusion

People with cognitive disabilities desire autonomy and self-direction as they move through the world, and they have goals and desires related to travel. However, they face challenges to autonomy that can be addressed through a good support system. Technology can serve as one element of a strong support system for wayfinding. However, there is much work to be done before these technologies are ready for "prime time." In particular, researchers need to continue research into the cognitive challenges faced by the diverse population of people with cognitive disabilities; developers need to continue working with and for people with cognitive disabilities to understand and meet their needs with creative low- and high-tech devices; and clinicians need to keep abreast of these developing technologies so they will have the skill to use them with their clients.

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