Establishing and Maintaining Orientation: Tools, Techniques, and Technologies

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INTRODUCTION

Most people give little thought to spatial orientation as they navigate, including the information they use to plan and execute routes or how they reestablish orientation when disoriented. When a person with typically developed visual abilities is asked how they perform these tasks, which has been informally asked of hundreds of individuals over the years, the majority of people indicate a reliance on visual information to guide their behavior; however, they frequently have difficulty identifying the specific cues and strategies they use. Indeed, for most travelers without visual impairment, the prospect of walking from home to a nearby destination without vision is incredibly daunting. However, many people who are blind or visually impaired accomplish these tasks routinely, traveling independently and efficiently in both familiar and unfamiliar places. The information, strategies, research, and technologies used to support these spatial abilities are the focus of this chapter.

DEFINITIONS AND BASIC CONCEPTS

In the field of O&M for persons who are blind or have low vision, the term mobility refers to the process of detecting and avoiding obstacles in the path of travel, awareness of changes in elevation and terrain, and safe and efficient movement through the environment (Foulke, 1971; Strelow, 1985). The term *orientation* in the field of O&M refers to one's knowledge of the distance and direction of places, objects, or environmental attributes in their surroundings (directly perceived or remembered) and keeping track of these changing spatial relationships as one moves through space (Hill & Ponder, 1976; Long & Giudice, 2010). The meaning of orientation is sometimes used differently depending on the discipline and application, but a common notion is to know where places and objects are in relation to each other and to one's own location and heading (facing direction) in the environment (Pick, 1980).

The terms *navigation* and *wayfinding* incorporate both mobility and orientation components and are frequently used in the field of spatial cognition, which is an area of study in psychology, computer science, geography, neuroscience, and other disciplines interested in how humans learn, mentally represent, and behave in space (Hart & Moore, 1973; Montello & Raubal, 2012). However, these terms are not synonymous. While navigation can occur without conscious effort, wayfinding is more deliberate, usually discussed as including mental planning and other strategic components that guide action, specific movement, and the ability to reach a goal (Golledge, 1999). A substantial body of basic and applied research

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has evolved during the past century regarding various aspects of spatial orientation, wayfinding, and navigation in both humans and animals. This chapter concentrates on a small subset of this research that focuses on studies of people who are blind or visually impaired and the way these individuals perceive, learn, and remember spatial information, and how they use it to guide their travel in everyday life.

FUNDAMENTAL CONCEPTS OF ORIENTATION

Spatial updating and frames of reference represent two fundamental concepts that are important in understanding spatial learning and orientation related to O&M training.

Spatial Updating

Spatial updating refers to the process of keeping track of the changing distances and directions to objects or places that result from self-movement (Klatzky et al., 1998). Since spatial updating is so important to support accurate orientation, it has been studied in many contexts by both basic researchers and practitioners in the field (Kitchin et al., 1997; Klatzky et al., 1995; Rieser et al., 1992; see also Chapter 10). Consider two examples: (a) an object that is directly in front of someone is no longer directly in front after they turn in place; (b) an object that is directly to a person's left and a few steps away before they begin walking is behind them and to their left after they walk forward several yards. The task of keeping track of where various locations are in the neighborhood or community while walking is a more challenging version of these relatively simple tasks.

Teaching people spatial updating techniques to relate self-movement to the locations of objects or places in the environment without vision and using this information to support accurate route navigation and wayfinding are fundamental aspects of O&M instruction. It is particularly important to teach these skills to young children who are blind or visually impaired, as fully grasping spatial concepts using nonvisual sensing is difficult without training. Similarly, focusing on use of nonvisual cues is important for training with people who have lost their vision later in life since these individuals are accustomed to using visual cues for spatial updating and navigation and must learn how to rely on other sources of environmental information as their vision degrades and becomes less reliable. No matter one's age, successful spatial updating involves learning to be aware of and use various sources of nonvisual information in the environment, including unique auditory and tactile cues, the presence of a distinct smell, recognition of a change in terrain, and so forth.

Frames of Reference

A second fundamental concept in spatial learning and orientation is frames of reference. There are two general frames of reference involved in spatial thinking and acting: egocentric and allocentric.

Egocentric Frame of Reference

In an *egocentric frame of reference,* objects and locations in the environment are perceived, remembered, and acted on in relation to the perceiver's perspective (i.e., based on their current location). Egocentric frames of reference are used by people every day as they travel familiar routes to and from school, work, and other locations in the community. Using an egocentric frame of reference, an individual may describe the location of the bank relative to where they stand: "The bank is straight ahead and to the right." Both the terms "ahead" and "right" are egocentric; they indicate self-to-object orientation in space relative to the individual's body and facing direction.

Allocentric Frame of Reference

With an allocentric frame of reference, the relation of objects or places in the environment are represented relative to each other and are independent of the perceiver's perspective and current location in space. It uses an external object-to-object frame of reference rather than the self-based relations of an egocentric frame. Inherent in an allocentric frame of reference is the understanding that the spatial relationships among places are invariant (unchanging) and unaffected by self-movement. For example, the relation of one landmark to another is fixed and independent of a person's perspective or viewpoint as they travel through space. Allocentric frames of reference are important in practical O&M terms because travelers often must recall the locations of various places relative to one another to plan and execute efficient, flexible routes.

Consider Bethan, a traveler who is blind and planning a route that she can walk from her home to the bakery and then to the drugstore before returning home. This route can be entirely planned from her house before starting her trip as she has a mental map of the neighborhood and can locate her house and the two destinations on that map. How does Bethan plan her route? She first considers how to get from her home to the bakery. She then imagines herself at the bakery and recalls the straight-line distance and direction to the drugstore. She also plans the route she must walk, which may or may not be the same as the straight line between these locations, based on her knowledge of walkable paths in the area.

Bethan's ability to perform this task requires her to not only think about the environment based on where she currently is *(egocentric knowledge)* but also to imagine the relation of two other locations that are independent of her current location *(allocentric knowledge).* The ability to think about the global configuration and connectivity of the environment, and to plan the best routes to connect her desired destinations requires what is called *survey-level spatial knowledge* (Noordzij et al., 2006; Siegel & White, 1975). Survey knowledge relates to an understanding of the orientation and distance between known places and locations in the environment and is characterized by learning of layout configuration. This contrasts with *route knowledge,* which refers to the learning of one or more specific paths within the environment but without an understanding of how they relate to each other or the global layout. Survey knowledge is allocentric, as it is independent of a given perspective and is related to a *cognitive map,* which is the term given to how survey knowledge is represented in the brain. Cognitive maps, which are synonymous with the informal term "mental map," are discussed in more detail later in the chapter.

Being able to think in allocentric terms about space and to use survey knowledge for planning a trip or during wayfinding is conceptually more challenging than relying on egocentric information and route-based knowledge, which only requires remembering a fixed set of distance and turn information. However, the ability to use survey knowledge, and the associated viewer-independent terminology, has many benefits.

For instance, imagine that someone plans to meet their friend RJ at a coffee shop that they have never visited, which is located at one corner of a four-way (plus) intersection. RJ gives them the following directions: "When you reach the intersection, cross the street and the coffee shop is on the far side on the left." This description is egocentric, as it assumes that RJ's friend will approach the intersection from a specific direction and the instructions are only accurate if they travel a route that puts them at that exact location. However, what happens if they take a different route and arrive at the intersection from a different direction than their friend expected? The directions RJ gave would then be completely wrong. By contrast, if RJ gives his friend a description based on allocentric terminology, such as "The coffee shop is on the northwest corner of the intersection," then there is no ambiguity; his description is valid no matter what route the friend walks or how they approach the intersection. The use of allocentric survey knowledge is also important when a traveler must determine a detour from a known route, wants to figure out a shortcut, or must plan and travel multiple routes among various places, as was the case for Bethan in the earlier example.

Because of the importance of an allocentric spatial perspective to O&M, it can be extremely valuable for O&M specialists to work with their learners to help them conceptualize space in terms of object-to-object relationships and to use maps, cardinal directions, and other externally referenced geographic systems such as street grids. These tasks are important as they challenge learners who are blind or have low vision to think beyond specific routes and conceptualize space from an allocentric viewpoint. For example, O&M specialists may ask learners to imagine themselves in front of the bank, facing the street, and then ask them to turn so they are facing the post office (or other known destinations), or facing the direction they would walk to move toward these destinations. In addition to these active tasks for reinforcing allocentric knowledge, tactile maps represent an excellent spatial support to teach learners how to think using a global allocentric framework. Since maps convey spatial relations between locations that are independent of a given route and provide access to environmental structure and configuration, information that is particularly difficult to perceive from nonvisual sensing, they are a useful tool for teaching learners about allocentric relations and survey knowledge. Learners may be asked to find locations and routes, connecting them on the map, and then to test their survey knowledge (developed cognitive map), by walking the routes, or finding shortcuts between them, in the actual environment.

KEY THEORIES AND HYPOTHESES

This chapter discusses the use of different sensory information to support spatial learning and behavior by people who are blind or visually impaired, which is called multimodal (or multisensory) perception. This section briefly examines how scientific theories about multimodal perception relate to O&M practice. People explicitly interested in instruction and training may reasonably ask, "Why care?" The short answer is that understanding how multisensory information is learned and represented in the brain helps explain why employing a variety of information sources in O&M instruction is so important. This understanding also provides the rationale for how spatial behaviors done with and without vision can be equally accurate (assuming use of effective training techniques as described in this chapter and throughout this volume) and why technology plays such an important role in providing access to multimodal spatial information. In sum, by considering a few key theories, learners will have a stronger conceptual framework for scaffolding many of the empirically-validated concepts and approaches discussed in this chapter for use in the O&M training toolkit.

Although O&M specialists understand the value of using multiple nonvisual cues in the environment to support safe and independent travel for people without vision, this concept is far less appreciated by many fundamental researchers studying blindness and spatial abilities in the lab. In many instances, these researchers are biased by the "visuocentric trap," which can be thought of as an exaggerated emphasis on visual perception versus an understanding of vision loss and its consequences. In other words, basic researchers often try to understand aspects of visual perception by studying what happens in its absence, rather than being motivated by an explicit interest in understanding how spatial perception, learning, and behaviors are best supported using nonvisual information. One unintended (but significant) consequence of the visuocentric trap is that many potentially relevant concepts and findings from the research literature do not reach the practitioners or technology developers who could use the results in new O&M training protocols or technology design that directly benefit people who are blind. To bridge this gap, the next sections provide a brief discussion of several hypotheses that provide a theoretical underpinning to connect some of the relevant basic research with the O&M-related applications discussed throughout this chapter.

THE INFORMATION-ACCESS HYPOTHESIS OF BLIND SPATIAL COGNITION

The information-access hypothesis of blind spatial cognition postulates that to best understand spatial abilities and behaviors carried out by people without (or with low) vision, it is more useful to conceptualize blindness as being about a change in information access than about the loss of vision or visual experience (see Giudice, 2018, for review). From this perspective, the majority of challenges experienced by travelers who are blind, as discussed in this chapter around orientation and navigation, are not about visual impairment, as is the common conception. Rather, these challenges are actually about insufficient access to (or effective use of) key environmental information that is traditionally mediated through vision.

If true, this hypothesis would predict that when navigation-critical information is available from (and effectively utilized by) nonvisual sensing, such as hearing, touch, and language, these spatial challenges would be reduced or eliminated. A growing body of evidence from the spatial cognition literature supports this prediction; results across a range of spatial behaviors demonstrate that when sufficient information is available during learning, test performance by individuals who are blind or visually impaired is on par with their sighted peers. For instance, studies where both blind and sighted participants learn using the same information and are then tested using an identical task have shown highly similar behavioral performance between participant groups on route completion (Loomis, Klatzky, et al., 1993), spatial updating after learning targets from spatialized audio (where objects/locations are heard as coming from their 3-D position in space) and spatial language (Loomis et al., 2002), updating after haptic map learning (Giudice et al., 2011), haptic map reading and recreation (Palani & Giudice, 2017), discrimination of haptic patterns (Giudice et al., 2012), and route navigation using spatial language descriptions (Giudice et al., 2019). Such findings argue against the long-held theories, discussed later in the chapter, which argue that visual experience plays a critical role in accurate spatial development and that there are inevitable deficits, deficiencies, and differences in spatial abilities and behaviors when performed without vision (for review, see Schinazi et al., 2016). The information-access hypothesis of blind spatial cognition speaks directly to the critical role of O&M training in terms of (a) the importance of using nonvisual and multimodal sensory information from the environment, (b) the value of teaching spatial thinking on the basis of this information, and (c) the significance of utilizing different technologies that provide access to spatial information that may assist, augment, and complement these activities.

THE FUNCTIONAL EQUIVALENCE HYPOTHESIS OF SPATIAL INFORMATION

Another important concept for understanding why similar spatial abilities are possible between use of visual and nonvisual information, and between people with and without visual impairment, requires an appreciation that there are far more similarities than differences between the senses, especially as it relates to how people perceive, represent, and act on spatial information. This notion of the common nature of spatial information between the senses and experimental evidence showing similar information processing in the brain provided the theoretical underpinnings for the functional equivalence hypothesis of spatial information (Loomis et al., 2002). This hypothesis postulates that when appropriate spatial information is available from each input, learning the same stimuli from different modalities (whether auditory, touch, spatial language, or visual information) will lead to functionally equivalent (i.e., statistically indistinguishable) behavior, irrespective of the modality used during the learning process. To better understand this theory, it is necessary to revisit the visuo-centric bias that underlies much of the spatial cognition and navigation literature. In short, while most of the information used to support spatial behavior is traditionally considered visual, it is in fact spatial. While attributes such as color and fine texture are uniquely visual, as they are not readily conveyed through other senses, most of the information used to support navigation and environmental awareness is not specific to visual perception.

Consider the 3D structure of a bedroom: the angle formed by two walls in the corners, the edge of a nightstand and its relation (distance and direction) to the bed, the height of a bureau and its relation to the door, and so forth. These things are spatial properties not visual properties and can be specified and conveyed through other spatial inputs, such as touch and haptics, auditory cues, spatial language, and even smell to a lesser degree. Indeed, all senses encode and process spatial information, with different inputs providing information about a common physical space (e.g., the world). Thus, while the eyes provide an excellent lens for apprehending spatial information and the visual system is highly efficient at processing this information, vision does not have a monopoly on space.

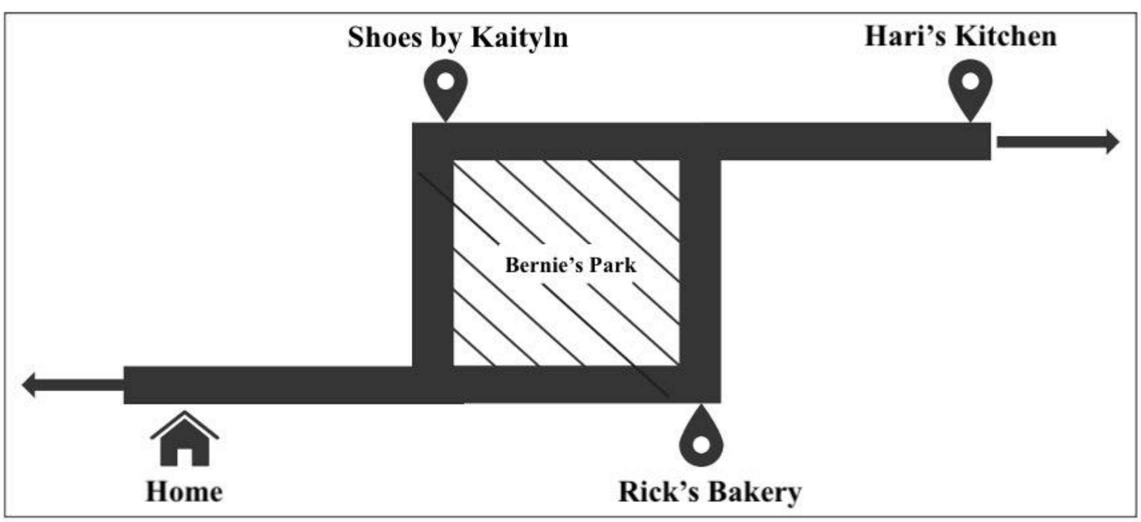
The functional equivalence hypothesis of spatial information, and the notion of space as the common denominator of the senses, is important as it suggests that performance on spatial tasks, such as maintaining orientation and accurate navigation, can be supported equally well by visual and nonvisual sensing alike. There is a growing body of interdisciplinary research supporting this perspective. In aggregate, this research demonstrates that multisensory spatial information can be processed and represented similarly in the brain and that when the appropriate spatial information is available during learning, there is no difference in spatial behaviors supported by use of visual or nonvisual information.

Thought Experiment

As an illustrative thought experiment, imagine that you are tasked with learning this simple sketch map of a city block by either seeing it or by feeling a tactile rendering of the same map. See Figure 2.1.

After learning, you are then asked (a) to close your eyes and imagine standing in front of your house and to point to the restaurant and (b) to "walk" the route between the shoe store and the bakery by tracing your finger along the lines of the map, but now with the landmarks removed, meaning that you must determine the route and indicate these locations from memory. As the spatial information conveyed by this map is available to both vision and touch, the functional equivalence hypothesis predicts that accurate learning is possible from both inputs, resulting in highly similar pointing and route-finding performance on this task. In scientific terms, there would be no statistically reliable difference in accuracy of performance irrespective of whether a person learned the map from vision or touch.

Support for this prediction comes from both behavioral and neuroscientific research across a range of spatial tasks and behaviors. For instance, functionally equivalent performance has been found for spatial updating after learning visually and haptically rendered maps (Giudice et al., 2011) or target configurations (Giudice et al., 2009, 2013). Functional equivalence was also found with spatial updating performance after learning multiple target locations perceived via spatialized audio or spatial language (Avraamides et al., 2004; Loomis et al., 2002), and after learning from visual, spatialized audio, and spatial language (Klatzky et al., 2003).



<u>FIGURE 2.1</u>: A map that can be explored by vision and touch.

Corroborating neuroscientific evidence was shown in a neuroimaging study, using fMRI, demonstrating that a brain region known for processing visual scenes, called the Parahippocampal place area, was found to be similarly recruited for scenes apprehended through haptic and visual perception (Wolbers et al., 2011). This study also found no difference in the spatial performance or patterns of neural activation between participants who were blind and did not have visual impairment on the haptic scene recognition tasks. This outcome is important as it suggests that both groups used the same neural networks for spatial processing and computation, irrespective of visual experience. In aggregate, these studies support the notion of space being the "common denominator" of the senses. Importantly, they also suggest that performance by people who are blind and those who do not have visual impairment can be similarly accurate and that both groups use the same underlying brain mechanisms to support spatial behaviors. These theoretical outcomes speak directly to the value and practical importance of teaching how to effectively use nonvisual information to facilitate accurate spatial thinking and behavior in O&M training.

The Amodality Hypothesis

As Loomis and colleagues discuss, there are several possibilities that could explain why learning from different inputs leads to similar (i.e., functionally equivalent) spatial behaviors (Loomis et al., 2007, 2013). An argument could be made that the spatial information from each sensory input develops into separate but equal mental representations. Another argument is that people are recoding different sensory inputs into a single modality (generally considered to be a visually based representation). A third explanation argues that the individual sensory inputs are built up into an amodal (sensory-independent) spatial representation in memory that is not tied to the original input source. As described in detail in Loomis et al. (2013), the evidence from the extant literature is best explained by the third amodal hypothesis. Several theorists have discussed this notion of a sensory-independent, amodal "spatial" representation in the brain, including the spatial representation system (Bryant, 1997), the metamodal brain (Pascual-Leone & Hamilton, 2001), and the spatial image (Loomis et al., 2013). While the specific name and mechanism of action in the nervous system may be debated, the important outcome of this growing body of research is that visual and nonvisual spatial information can be accurately learned and stored in a common spatial representation in memory that supports functionally equivalent spatial behaviors. In aggregate, these theories and the broad-based evidence in their support have clear relevance to the study of spatial cognition and navigation by people who are blind or visually impaired, to the field of O&M, and to the design of information access technologies.

THE RELATION OF TECHNOLOGY TO O&M INSTRUCTION

Before going deeper into the discussion of specific orientation techniques, it is important to consider the role of technology in O&M instruction. The use of technology supports how travelers who are blind or visually impaired learn about and interact with their surroundings. This topic is increasingly relevant as electronic devices and software apps providing access to environmental information get smaller, cheaper, and more powerful. In the past, a person who is blind and interested in using such technology, sometimes called electronic travel aids (ETAs), may have needed to use multiple pieces of equipment (e.g., a GPS receiver connected to a laptop for assisting with orientation and navigation, a dedicated camera phone to perform real-time optical character recognition and text-to-speech reading of printed signs, a sonar device to augment the long cane or dog guide for detecting head-level obstructions, etc.).

(For a review of traditional ETAs, see Giudice & Legge, 2008; Real & Araujo, 2019; Tapu et al., 2018; as well as Chapter 8.) However, the trend in the last decade is for all these separate devices to be collapsed into a single form factor based on a dedicated computational platform, such as software apps running on a user's smartphone or tablet. While this consolidation is not possible for all types of technologies, as some require specialized sensors or hardware specifications that cannot be implemented on smart devices, the move in this direction is positive for travelers who are blind. Not only is it now possible to carry multiple devices in a single, portable "package," but the cost is also much lower since purchasing software apps is much less expensive than the significant (and often prohibitive) costs associated with purchasing individual, specialized hardware.

It is important to clarify that while there is great value to assistive technology, sometimes called access technology, for spatial learning, navigation, and O&M instruction more generally, technological solutions are not a replacement for traditional mobility tools and O&M training. However, when used correctly, technology affords significant promise in augmenting and complementing these tools and skills. When assistive technology is designed with the user in mind, based on sound research and practical needs, it can make a huge difference for a traveler who is blind to detect spatial information in the environment and to then use this information, in conjunction with their existing spatial skills, to improve the safety, efficiency, and confidence of wayfinding behavior.

This chapter will argue that many spatial challenges experienced by travelers who are blind can be overcome when sufficient information access is available from nonvisual modalities (see the earlier section on Key Theories and Hypotheses for more detail). However, there are limitations to the breadth and depth of information conveyed through nonvisual sensing. Technology is important as it can increase the "perceptual reach" of these senses. In other words, technology often conveys information that is not possible to perceive from our senses alone, allowing a traveler who is blind or visually impaired to access significantly more information than would otherwise be available to them. The result is to further level the perceptual playing field of environmental awareness and spatial information access without vision, which directly benefits spatial behavior.

Although the chapter will discuss how technology aimed to increase spatial information access can improve spatial behavior, this does not necessarily mean that the value added by use of these devices (a) is worth their cost, (b) is offset by the cognitive effort needed to achieve mastery, or (c) provides information that is useful or meaningful.

To be both beneficial and effective, developers of information access technology must carefully consider what information is being provided to the end user and how it is being delivered. For instance, simply producing a one-to-one conversion of a complex visual map into a tactile map is not likely to be meaningful (or accessible) as the information capacity (spatial bandwidth) of the visual channel is estimated to be 500 times greater than that of touch (Loomis et al., 2012). Thus, to create an accessible tactile map that is both intuitive and usable (whether rendered as hardcopy or electronically via a digital display), it is important to carefully consider what information to preserve and what is likely to lead to confusion, clutter, or "perceptual noise" upon conversion. Since the sense of touch relies on a much smaller information "pipe" to the brain, haptic (touch-based) representations (whether diagrams, figures, maps, etc.) must maximize the information that is most obvious (perceptually salient) to touch and eliminate the content that is not. In most cases, this means that much of the information conveyed in the visual rendering must be simplified and schematized in the haptic rendering, a reduction process called *information down-sampling.* When this sensory-specific optimization is considered as part of the design process of access technology, using careful content selection and information down-sampling, nonvisual interfaces have the potential to be used as effectively as visually-mediated interactions in supporting many spatial behaviors (for reviews, see Loomis et al., 2012, and Sidebar 10.1 in Chapter 10).

Access Technology Guidelines

A few simple high-level guidelines are useful for designers to consider when they develop new access technologies. These same guidelines are also beneficial for O&M specialists or users who are blind to evaluate the efficacy and utility of these technologies. These suggestions and design guidelines are neither exhaustive nor specific to individual technologies, they simply reflect best practices that have been cataloged over the years for helping to make access technology more affordable, meaningful, and usable to travelers who are blind and visually impaired.

1) Access technology should avoid the engineering trap. This is a term that refers to technology development based on uninformed intuitions of the developer or that provides a solution to a nonexistent problem (Giudice & Legge, 2008). To avoid the engineering trap, designers should make sure that their technology development is based on a thorough understanding of perceptual and cognitive principles, not intuition, and that the product (whether it be a physical device or software / app) provides meaningful information to address known problems described in the research literature (Loomis et al., 2012). The value added of any product should be carefully weighed against its expense, learning curve, and functional utility compared to existing solutions. For instance, although electronic mobility devices to replace long canes and dog guides for obstacle detection have been developed for decades (see Chapter 11), they have not been widely accepted or adopted. While these devices address a real problem, their cost and information access value are largely offset by what is already possible using the tried-and-true mobility aids of canes and dogs. To avoid the engineering trap, such devices should aim to complement rather than replace traditional mobility tools by providing information that is otherwise difficult to obtain (e.g., alerting a traveler of chest or head-level obstructions that are not readily detectable by a long cane or dog guide).
2) When possible, assistive technology should be multimodal. Multimodal (or multisensory) perception refers to the use of more than one sense (or input) to perceive and interpret the world. This most commonly includes the use of hearing (or audition), touch (called haptics when involving active exploration with the hands), smell (olfaction), vision (from perfect vision to only light perception), and spatial language (terminology used to describe space). Although more is not always better, in most cases, technology that employs multiple types of sensory information will support the broadest base of users (called universal or inclusive design) and will maximize the brain's ability to interpret, process, and represent information.

3) When practical, assistive technology should be built on commercial components. Products that are built on off-the-shelf multipurpose platforms and that can be used for multiple situations will reduce cost and increase usage scenarios and user adoption compared to expensive, purpose-built, and specialized equipment. One reason the smartphone has become such a critical piece of technology for users who are blind or visually impaired is that it is based on a commercial platform with multimodal input and output in the native interface (supporting universal design) and allows for many previously expensive, standalone technologies to be collapsed into a single form-factor.
4) If appropriate, assistive technology should use perceptual versus cognitively-mediated interfaces. A perceptual interface, where the information is directly provided to the user, is faster, more intuitive, and generally more accurate than cognitively-mediated interfaces where the user must interpret the information provided (e.g., as through language) (Klatzky et al., 2008). For instance, it is far easier to feel a map, where the spatial information is conveyed directly through tactile perception, than to verbally describe the map, as words are symbolic, not spatial, and thus involve cognitive interpretation, which is slower and more error prone than direct perception. Spatial information can be used in perceptual interfaces based on vision, touch, or spatialized audio (where the sound of objects and locations are heard from their 3-D location in space). Perceptually-driven spatialized audio displays have been shown to improve navigation performance compared to spatial language (Loomis et al., 1998) and also to require less cognitive load (mental effort) when navigating (Klatzky et al., 2006).

Tactile Maps

As discussed throughout this chapter, the use of spatial technologies represents an important part of the instructional tool kit for many O&M specialists (see also Chapter 9 and Volume 2, Chapter 10). Although there are a growing number of devices to aid O&M (for reviews, see Elmannai & Elleithy, 2017, and Tapu et al., 2018), the discussion here focuses on tactile maps and navigation systems. These technologies represent particularly relevant tools to assist with establishing and maintaining orientation and to support spatial learning and environmental awareness beyond what is possible from traditional mobility aids or the information provided by other types of access technologies.

Tactile maps represent useful tools for O&M specialists to employ when encouraging learners to think about many of the spatial concepts discussed in this chapter that are difficult to directly perceive using nonvisual sensing. For instance, maps are particularly beneficial for teaching learners about the distances and directions between landmarks or locations, encouraging them to think about allocentric relations, and promoting the development of accurate cognitive maps (topics revisited later in the chapter). During the past 50 years, researchers have demonstrated the efficacy of tactile maps by children and adults who are blind, both before and during travel, in supporting spatial learning, orientation, decision making, and cognitive mapping (Andrews, 1983; Bentzen, 1977; Blades et al., 1999; Ungar et al., 1997; see also Chapter 9 and Volume 2, Chapter 10).

Traditional tactile maps are composed of embossed and raised elements that convey spatial properties of the environment through points, lines, and regions; specify symbolic properties and features (such as a lake, road, or stairs) through combinations of dots and dashes, texture variation, and line height and thickness; and often present landmark and feature names and other semantic information using braille labels (for a review of design techniques, see Edman, 1992; Rowell & Ungar, 2003). Despite their potential for teaching spatial concepts and improving environmental learning and navigation performance, tactile maps have several serious limitations that have constrained their broad availability and usage by both O&M specialists and people who are blind or visually impaired. One issue is that the process to effectively create and convert visual maps into tactile maps, or to author and develop tactile maps from scratch, requires specialized human expertise involving careful content selection, information down-sampling, and knowledge of the perceptual and cognitive strengths and limitations of touch. As discussed earlier, these skills are neither trivial nor intuitive and there is a dearth of sufficient guidelines from the research literature and training protocols for practitioners to use in their development. Without this expertise, people are often forced to revert to best guesses and intuition for what works when creating tactile maps; this limits their efficacy as training tools and reduces consistency, which is an important aspect of map making.

Creating tactile maps can also be costly when it requires the use of expensive, specialized equipment, as when using tactile embossing technology. Beyond these map creation and production challenges, the use of traditional tactile maps has several limitations. Since they are generally produced on hardcopy media (e.g., embossed on paper or plastic sheets), the output is static, meaning the content cannot be changed or updated in real-time; is frequently large and bulky, meaning they are difficult to carry and use when navigating; and is limited to only rendering tactile information.

In recent years, a variety of technologies have been developed that provide an alternative to the traditional, static tactile map. These solutions provide the same benefits while addressing many of the limitations of fixed, hard-copy maps. These new types of accessible maps also rely on touch and haptics but are based on digital displays that convey interactive map information. In other words, these maps provide context-relevant information about the location that the user is touching on the map, generally using a combination of tactile and auditory feedback. Some benefits of interactive haptic map interfaces include the following:

1) They provide dynamic versus static information.
2) They usually employ multimodal information to depict and describe the environment versus tactile-only information.
3) Some incarnations utilize portable display technology versus requiring use of large format displays and map booklets.
4) Some solutions are based on commercial hardware versus expensive, specialized hardware.
5) They often support spatial behaviors and interactive user queries that are not possible using physical tactile maps (e.g., zooming and panning operations, "where-am-I" queries, and search facilities).

Digital maps have been around since the 1980s. The early incarnations, called hybrid interactive maps (HIMs), were based on a hardcopy tactile map overlaid on a digital tablet that provides auditory information about street names and landmarks for the location touched (Holmes et al., 1996;

Jacobson, 1998; Parkes, 1988). Other purely digital solutions developed in recent years, called digital interactive maps (DIMs), have also proven useful for supporting nonvisual learning of spatial relations, routes, and global configuration. This DIM approach is beneficial as it does not necessitate a physical map overlay, as is required for HIMs (see Ducasse et al., 2018, for review). Accessible DIMs have utilized a variety of technologies, including haptic force-feedback devices that use pressure and friction to specify spatial attributes (Kaklanis et al., 2013; Rice et al., 2005; Simonnet et al., 2011) and dynamic pin-arrays similar to the refreshable elements used in a braille display (Rastogi et al., 2013; Zeng & Weber, 2016).

While all these digital map solutions have benefits, they also still rely on specialized hardware that is both expensive and not easily accessed in a portable, real-time context. An exception is the newest type of haptic DIM interfaces, called vibro-audio maps, which are built on mobile smartphone and tablet devices and use audio and vibrotactile (vibration information) that is felt as the user moves their finger around the touchscreen. The key advantage of these vibro-audio maps is that unlike the other interactive mapping technologies, this solution is truly portable and satisfies many of the assistive technology design guidelines discussed earlier, such as being multiuse, multisensory, and based on commercial hardware and incorporating many universal design features in the native interface (e.g., text-to speech, speech-to-text, haptic interactions, magnification, and gesture interactions). Use of vibro-audio maps, explored from the device's touchscreen have proven beneficial for map learning and cognitive map development (Giudice, Guenther, Jensen, & Haase, 2020; Grussenmeyer et al., 2016; Palani & Giudice, 2017; Poppinga et al., 2011). While there are pros and cons to all these technologies (for a review, see O'Modhrain et al., 2015), their efficacy as a learning support and their value in the O&M toolkit is without question.

Despite these benefits, map use and map instruction are probably not as widespread as they should be in O&M training. This is mostly because of the issues related to the time and effort required for their creation, lack of guidelines specifying how they should be authored, and expense of the specialized technology needed to render most types of high-quality tactile maps. However, new technologies for making accessible maps are starting to remediate these problems (e.g., the vibro-audio maps that only require a touchscreen-based smart device with a vibration motor to work). Another positive trend is that researchers are beginning to provide empirically motivated design guidelines for these displays, which provide developers with clear parameters to use and ensure that the maps are consistent, intuitive, and meaningful to the end user (Gorlewicz et al., 2020; Palani et al., 2020).

For people wanting to produce traditional tactile maps, new graphic embossers that allow a visual map to be edited and converted into high-resolution output are making it easier to create high-quality hardcopy maps, with some embossers also supporting combined visual-tactile output on the same page. ViewPlus (www .viewplus.com) is one source for such embossers. Likewise, initiatives such as the Tactile Maps Automated Production (TMAP) project, which allows a person to download a map file **about a** specified environmental region such as **around** their home or a place they plan to travel, **and then** to emboss it on their own equipment is very promising (Miele et al., 2006). Regardless of the specific technology used, instruction in map usage needs to be expanded. Since the information provided by these spatial supports is not available from other orientation techniques and technologies, their systematic and creative use is an important tool to teach travelers who are blind how to develop higher order spatial knowledge and support more accurate and flexible navigation behaviors.

Navigation Systems for Orientation

Some of the most promising recent assistive technology development relates to the orientation information that is increasingly available from accessible navigation systems to improve the safety and accuracy of traveling without vision. The advent of this technology has been a great step forward in orientation and wayfinding for all travelers, including those who are blind and visually impaired and those who do not have visual impairment, and has made the exploration of and efficient movement through **both** familiar and unfamiliar places easier and more accurate for travelers who are blind or visually impaired (Ponchillia et al., 2007) (see also Chapter 9 and Volume 2, Chapters 10 and 13).

Navigation systems supporting outdoor travel generally use GPS-based positioning, a digital map of the environment, and an accessible user interface, based on speech descriptions or 3-D spatialized audio. These systems have been studied and refined in research settings for many years (e.g., the personal guidance system; Loomis, Golledge, & Klatzky, 1993, 2001; Loomis et al., 2005). A growing number of accessible commercial products have also been available since the early 2000s, including modern navigation apps such as the Seeing Eye GPS (Sendero Group, 2019), BlindSquare (MIPsoft, 2019), GoodMaps (GoodMaps, 2022), and Soundscape (Microsoft, 2018). While these systems can be extremely useful in assisting with route planning and navigation, for learning about nearby landmarks and POIs, and for receiving useful orientation information about current location and direction of movement, they also have their shortcomings. The primary limitation of these systems is spatial imprecision; they are subject to error from the GPS signal and inaccuracies from the underlying maps. As such, navigation systems should be considered as a secondary tool to augment and complement traditional O&M skills or to validate other cues directly perceived from the environment.

Another limitation of these systems is that the GPS signal cannot penetrate buildings, and so the use of GPS-based positioning technology is not accurate for supporting indoor navigation. There is a growing push to develop indoor navigation systems, analogous to GPS-based systems used outdoors, with this interest driven by commercial initiatives such as OpenStreetMap and indoor maps from Google as well as Apple (for review, see Coleman et al., 2016). The technologies developed as part of these initiatives will benefit travelers who are blind. Indeed, there is a growing body of research and development of systems supporting accessible indoor navigation. As with the outdoor systems, these projects have proven useful for supporting route guidance and spatial learning for travelers who are blind (Ahmetovic et al., 2016; Cheraghi et al., 2017; Giudice et al., 2019; Legge et al., 2013). Some of these systems are available as smartphone apps that provide combined indoor and outdoor navigation assistance, such as ClickAndGo Wayfinding, BlindSquare, NavCog, GoodMaps, and Clew (ClickAndGo Wayfinding Maps, 2019; Kitani, 2015; MIPsoft, 2019; Goodmaps, 2022; Yoon et al., 2019). Some of these systems augment GPS positioning outdoors with Blue-tooth low-energy beacons that are installed at fixed locations around the building to support indoor positioning (e.g., ClickAndGo, Blind-Square, and NavCog), whereas others require no infrastructure modifications by using different camera-based indoor positioning techniques; GoodMaps uses LiDAR scanning of the building and subsequent image recognition to determine location, and Clew uses augmented reality techniques that fuse the phone's camera with inertial sensing to determine position. Whether used indoors or during outdoor travel, the growing prevalence of navigation systems has significant potential to improve navigation efficiency in new places, to complement many of the spatial skills travelers who are blind already use, and to reduce the anxiety sometimes associated with concerns around disorientation with travel in unfamiliar areas.

O&M and Future Technology

The role of information access technology will become increasingly important in O&M training as these products become less expensive and more powerful, intuitive, and "intelligent." The growing prevalence of artificial intelligence (AI), computer vision (CV), and machine learning (ML) algorithms will allow assistive technology design to provide targeted information for specific situations, needs, or applications. Smart processing will increasingly replace general purpose sensory substitution, so that products of the future will be more than simple input sensors and output displays; the technology will increasingly interact with the user and provide information when and where they want it, in a multimodal format that makes the most intuitive sense to the user.

Another exciting advancement in assistive technology design is the growing appreciation for using perceptual interfaces, as discussed earlier. Some products incorporate spatialized audio in their interface. For instance, the commercially available Soundscape navigation app (Microsoft, 2018) allows the user to hear points of interest as coming from their actual location in the surrounding environment or to hear the direction of streets at an intersection (e.g., a street on the left is heard from the left ear and on the right from the right ear). This approach of directly conveying spatial information is beneficial as it is easier to interpret and reduces the cognitive load during learning compared to only using spatial language (Klatzky et al., 2006). Tactile maps are another perceptual display, and the development of new tactile mapping technology using commercially available smart devices, as previously discussed, represents a promising new era for tactile map use in O&M instruction.

Finally, the increasing use of games to teach spatial skills has significant potential for new types of O&M instruction. The advantage of learning spatial skills in a game context is that it uses competition and a sense of fun as the motivator to learn skills. Research with young adults who are blind or visually impaired has shown that game play improves spatial learning, as evaluated by both traditional O&M tasks and via neuroimaging (fMRI) procedures (Connors et al., 2014; Merabet et al., 2012). This work not only demonstrated that game play in a simulated environment based on haptic and spatialized audio cues led to accurate spatial learning, but also that knowledge learned in the game transferred to accurate navigation in the corresponding real-world environment. Importantly, participants who learned spatial skills as part of game play showed the same level of cognitive map development and subsequent wayfinding accuracy as participants who learned in the physical space using traditional O&M training techniques. Given that O&M instruction often requires repeated exposure and multiple training sessions to master a skill, learn a route, or develop a cognitive map of an environment, formal instruction is often especially onerous for youth who are blind or visually impaired. As such, the potential of complementing traditional O&M techniques through gamification and game-based learning, which many learners will find engaging, represents an important new tool to consider in the design and implementation of future O&M training curricula.

The above studies not only demonstrate the important role of game play for teaching O&M skills, but also provide compelling evidence that interactive technologies like virtual reality (VR) and augmented reality (AR) can be rendered using accessible, multisensory interfaces. Further evidence showing the efficacy of this technology was found in a study with individuals who are blind or visually impaired by Lahav and colleagues (2018), who had participants learn simulated indoor environments using interactive VR systems based on multisensory inputs and interactions employing haptic, natural language, and 3-D audio feedback. Results showed that people exposed to exploration and "look-around" in the virtual environments were twice as accurate on navigation tasks in the real space as those who did not have this interactive experience, corroborating the value of VR training for supporting pre-journey environmental learning and cognitive map development. Such findings are important as they demonstrate that this technology can be designed as an effective research and learning tool for people who are blind or visually impaired. This is a significant technological step forward, as VR has traditionally been limited to visual interfaces and interactions. While there are differences in the multisensory cues, amount of realism, and level of detail rendered in non-visual virtual simulations, a growing body of research suggests that use of accessible interactive technologies employing virtual reality (Guerreiro et al., 2020; Lahav et al., 2015; Picinali et al., 2014) and augmented reality, which superimposes virtual information on the real world (Ruvolo, 2021), represent exciting new training tools for use by individuals who are blind or visually impaired in O&M instruction, pre-journey exploration, and cognitive map development.

ESTABLISHING AND MAINTAINING ORIENTATION

Whether one uses information perceived from the environment, assistive technologies, or both, there are many techniques available to assist travelers who are blind or visually impaired in establishing and maintaining their orientation. This section describes common concepts and basic approaches used to support these activities.

Perception: The Impact of Information Access on Spatial Orientation

Given that the visual system can detect and process far more information over a larger field of view than any of our other senses, it is not surprising that visual cues are the most efficient and reliable sources of information for accomplishing spatial tasks. One of the biggest challenges of vision loss on people's spatial abilities is the increased difficulty of processing spatial data from senses other than vision in an integrative manner (Golledge et al., 1996). A traveler without visual impairment readily perceives the distances and directions of many nearby and distant features, simultaneously grasps spatial relationships, focuses on and recognizes objects over a large field of view, and gathers precise information about changes in self-to-object relations that occur with movement. Sighted pedestrians simply see a destination in the distance and maintain visual contact with it and intermediate landmarks as they move toward the destination. Imagine a sighted person walking from their house to the end of the driveway to retrieve their trash bin. From the front door, they simultaneously perceive the distant trash bin and path from the house to the destination and determine the relationship of these features to one another. Avoiding the flowerpot on the front steps, the car in the driveway, and other features between the two locations is easy because these features can be perceived more or less simultaneously.

In the same scenario, individuals who are blind use auditory and tactile information to avoid the flowerpot, car in the driveway, and other potential hazards. Those with low vision may use visual information in addition to auditory and tactile information. People who are blind or have low vision may also use their memory of the environment (cognitive map) for the approximate distance and direction from the door to the trash bin to turn and move in the desired direction and estimate when they are getting close to their destination. As they near the bin, they may directly perceive it using reflected sounds. They may probe with the long cane to identify features they know should be present along the route and trail or follow surfaces with the cane, such as the boundary between the driveway and the yard.

The challenge for blind individuals is that hearing and touch, while effective for guiding travel, convey far less information than vision about self-motion, the relationship of objects to one another, the self-to-object distances and directions to features in the environment, and the global environmental structure. For example, compared to vision, tactile perception affords access only to proximal (nearby) objects, has a relatively small field of view (i.e., what can be felt within the reach of the arm or long cane), and has limited resolution and information capacity. As a result, many potentially useful landmarks and information sources that may be used by a sighted traveler along a route are too small or too far away from the path to be easily detected using tactile sensing. Auditory perception is more distal (able to be perceived at a distance) and is omnidirectional, which makes it useful as an "alerting" sense. However, since auditory perception is not accurate for judging absolute distance or the direction of non-head level sounds, and given that most auditory cues are transient and do not persist over time, compared to vision, auditory information provides far less spatial precision in localizing the distance and direction of objects in the surrounding environment.

One important (and often highly effective) auditory technique used by travelers who are blind is *echolocation.* This involves using echoes from self-generated sound cues (e.g., clicks made with the mouth), or using those produced from footsteps or cane tapping, to gain information about objects in the surrounding environment that facilitate mobility and navigation behavior. Research on echolocation has shown that larger objects, such as poles and walls, are easiest to detect during locomotion (Strelow & Brabyn, 1982) and that detection and localization can be done accurately solely based on reflected sound from cane tapping (Schenkman & Jansson, 1986). Some travelers who are blind, Daniel Kish being a famous example, have developed highly accurate and robust echolocation techniques (Thaler et al., 2017). Indeed, when done effectively, a broad range of variables can be detected solely based on reflected sound, including the location, distance, size, shape, orientation, and even material properties (fabric, wood, brick, etc.) of objects (for review, see Kolarik et al., 2014). This literature demonstrates that while echolocation can be a powerful tool, and strategies for its use can be taught, there is significant variability in its use and effectiveness. In addition, although many factors influence the operable range of echolocation, it is most accurate within the immediate environment around the traveler where reflected sound can be directly perceived. As such, the functional effectiveness of this technique is limited to mobility along the travel path but is not well served for learning global environmental structure or for supporting cognitive map development.

The aggregate result of nonvisual sensing is that navigators who are blind or visually impaired often rely on cues that are more ambiguous and less reliable than the visual information used by their sighted peers; this means that the same tasks done without vision generally require far more conscious moment-to-moment problem solving and hypothesis testing (which is discussed in more detail later in the chapter). Despite these limitations, many individuals who are blind or have low vision travel safely and efficiently in both familiar and unfamiliar environments, using nonvisual information to effectively maintain their orientation relative to a travel goal.

In cases where visual, auditory, or tactile information is unavailable to guide travel, individuals sometimes use a strategy called dead reckoning (or *path integration),* in which internal proprioceptive and kinesthetic cues (i.e., feedback from the movement of joints and muscles) and inertial information from the vestibular organs permits them to keep track of distances walked and turns made (Loomis et al., 1999). For example, when walking a path in a large room where external cues are unavailable or unreliable, such as a hotel lobby, a visually impaired traveler likely uses a dead-reckoning strategy. The ability to accurately estimate the degree of turning and distance walked is important when travel is guided only by internal cues, but this path integration process is challenging as such navigation accumulates error over time and distance. Furthermore, as with all modes of nonvisual navigation, it is susceptible to unintended veer, which can be hard to detect and correct without a clear environmental reference (Kallie et al., 2007).

While the practical techniques taught by O&M specialists and spatial problem-solving approaches adopted by travelers who are blind or visually impaired can offset many of the challenges introduced by differences in information availability between visual and nonvisual sensing, this gap can be further narrowed through the use of technologies for augmenting, complementing, and providing redundant environmental cues to support blind navigators.

Cognitive Strategies and Cognitive Maps in Spatial Orientation

Perceiving information relevant to establishing and maintaining orientation is important, but it is also important to be able to recall and use information about routes and about the spatial arrangement of places in the environment. The term cognitive map is used to describe the spatial representation in the brain that people create about the distances, directions, and relations of landmarks and places that are out of range of their direct perceptual awareness or are recalled from memory. The term is widely used, although with varying meanings. In general, it has been defined as an abstract, viewpoint-independent (i.e., allocentric) mental representation of space that preserves spatial properties such as landmarks, paths, and directions, as well as the general relations between these elements (Golledge, 1999). The use of the word "map" in this context is more metaphoric than literal. Internal mental representations are not analogous to a precise "map in the head" (Kuipers, 1982) and are more appropriately thought of as a mental representation of space characterized by many "distortions, holes, and exaggerations of the real world" (Golledge, 1987). Although they differ from physical maps, cognitive maps represent real spatial mental structures that people build and refine as they navigate and have a well-known neural correlate in the brain. These mental maps are stored in an area of the brain called the hippocampus, which contains specialized neurons (called place cells) that selectively fire based on one's location in the environment (O'Keefe & Nadel, 1978).

Cognitive maps are functionally important as they provide quick and flexible access to a representation of space as a traveler moves throughout the environment. As noted earlier, this representation, based on allocentric survey knowledge, guides route planning and complex spatial problem solving, such as determining detours, shortcuts, or new routes; and it can facilitate the task of communicating spatial information to others (Golledge, 1999; Peruch et al., 2000). An individual's ability to access their cognitive map during navigation allows the map to serve as a memory aid while the individual is traveling. This is considered a higher, more flexible level of spatial ability than simply remembering a sequence of landmarks and associated actions, as is done for route navigation. Many of the suggestions and learning activities discussed in this chapter are useful to O&M specialists as they encourage their learners to think of the environments they are learning and navigating as more than a series of landmarks and routes. That is, the learners practice building cognitive maps by thinking about allocentric object-to-object relations, considering new connections and shortcuts between known routes, and creating a mental "image" of the global layout of the space being learned.

SPATIAL ABILITIES AND AGE AT ONSET OF VISUAL IMPAIRMENT

The Impact of Early-Onset Visual Impairment on Spatial Behavior

The relation of age to when a person experiences visual impairment is one factor that has been considered extensively in the spatial cognition research. Most studied is the role of visual experience on spatial abilities, especially early in life. This age-at-onset variable has been hypothesized to account for variations observed among individuals who are blind in the performance of spatial tasks, and particularly complex spatial tasks such as the development of cognitive maps (Millar, 1994; Rieser et al., 1992). As summarized by Thinus-Blanc and Gaunet (1997), this research reveals that the age at onset of visual impairment has little or no effect on spatial tasks that are fundamentally egocentric in nature, but when tasks require a more allocentric frame of reference, differences sometimes are found between groups of individuals who lost vision early in life and those who lost vision late in life.

These differences in performance may reflect an underlying fundamental difference in the "neurological organization" of spatial information between individuals who experienced early-onset blindness and those who experienced late-onset blindness (Millar, 1994). Alternatively, the differences may reflect the fact that individuals who experienced blindness early in life simply have not learned the key strategies needed to perform higher order spatial tasks at the level of individuals who experienced visual impairment later in life. The logic of this research is that the construction and use of an allocentric frame of reference, and the related ability to make higher order spatial inferences, are facilitated by the ability to perceive environmental information at a significant distance over a large field of view, as is the case when using vision. From this perspective, such tasks are difficult for individuals who are blind, especially those with early onset blindness, since, as previously discussed, the absence of vision dramatically reduces the amount of distal information that is available (i.e., what can be perceived at a distance), and this information is difficult to perceive from nonvisual sensing. When coupled with the absence of vision from birth, this means individuals have never experienced spatial information visually. These facts have led researchers such as Millar (1994) to suggest that people who are blind from birth tend to base their spatial knowledge more on proximal, body-centered egocentric information (such as proprioceptive and kinesthetic information) rather than distal information.

From this interpretation, the development of spatial learning and behavior based on non-visual and therefore less precise sources of spatial information (e.g., auditory and tactile cues) are inherently limited because visual experience is argued to play a critical role in the development of these skills and activities (for review, see Schinazi et al., 2016). Thinus-Blanc and Gaunet (1997) reflected this idea when they suggested that some people who are blind from birth may predominantly use spatial information organized as routes, and these individuals may be limited in performing spatial tasks requiring more map-like representations, such as planning detours or alternate routes. In contrast, people who became blind late in life and thus had some visual experiences that affected their development of spatial concepts would, as a group, likely imagine spaces mentally using a more map-like framework (e.g., cognitive map).

It is important to realize that these theories, and the evidence garnered in their support, are neither definitive nor consistent. Many studies have found no such spatial limitations with participants who are blind, even those with congenital blindness. This may be partially due to individual differences in spatial abilities and also the result of an outcome of the information-access hypothesis (described in the Key Theories and Hypotheses section), which would predict that individuals who have been exposed to accessible spatial supports and have received significant O&M training would not necessarily demonstrate any differences in spatial behaviors compared to individuals who are blind but have had significant visual experience or people without visual impairment (Giudice, 2018). In corroboration, even in studies that are often discussed as showing differences between participants who are blind as a function of age or visual experience, there is evidence of participants who are congenitally and blind early in life that demonstrate superior spatial behaviors compared to participants who become blind later in life and have thus had visual experience (Hill et al., 1993; Lessard et al., 1998; Rieser et al., 1986; Tinti et al., 2006; Voss et al., 2004). Evidence that training with tactile maps leads to reliable improvements on subsequent spatial behaviors in individuals who are congenitally blind (Blades et al., 1999; Ungar, 2000) further supports the importance of formal O&M training and information access tools as critical factors in promoting accurate spatial behavior, especially for those individuals with early-onset blindness. More research is needed to understand how the combination of visual experience, O&M training, and exposure to spatial supports and technologies that provide access to spatial information otherwise difficult to perceive nonvisually, impacts spatial abilities and behaviors in individuals who are blind across a range of visual conditions **and** age of onset.

Age-Related Visual Impairment and Spatial Abilities

Understanding the spatial cognition of older adults experiencing visual impairment at the other end of the "age continuum" is increasingly important. Although poorly studied, the combined factors of the aging population and that most visual impairment is age related, occurring predominately in people over 65 years of age (Congdon et al., 2004; Silverstone et al., 2000), means that more focus should be given to this demographic. The emphasis on younger people who are blind or visually impaired in the research literature and in assistive technology development and evaluation is troublesome given that the number of individuals experiencing significant uncorrected visual impairment is predicted to double between 2010 and 2030 (World Health Organization, 2011).

Although more research is needed to understand the relation of aging, visual impairment, and spatial abilities, there is a growing body of literature looking at spatial cognition and aging more generally. This work has found that when age-related spatial differences occur, at least when comparing adults without visual impairment below and above 60 years, they generally negatively affect spatial working memory, especially for tasks with high cognitive load (see Moffat, 2009, for review) and allocentric tasks such as cognitive map development, pointing between two landmarks independent of the individual's current position, and map reconstruction tasks (Head & Isom, 2010; Iaria et al., 2009; Moffat, 2009). However, performance by older adults without visual impairment on egocentric spatial tasks (e.g., route navigation or identifying locations on a map) are often unimpaired (Rodgers et al., 2012; Yamamoto & DeGirolamo, 2012).

Given that the incidence of visual impairment is rapidly shifting to an older cohort and that it is as important for these individuals to maintain their independence through safe and efficient navigation and use of effective O&M skills, just as their younger peers, there is an immediate societal need to better understand the problems faced by and best solutions for these individuals. One study that investigated the relationship among navigation, aging, and visual impairment found no interaction of these factors on spatial performance, with older adults with and without visual impairment showing similar behavior (Kalia et al., 2008). This study also demonstrated that the presence of clear landmarks conferred particular benefits to older adults with visual impairment, which may speak to training techniques and information sources to prioritize for individuals learning to navigate with reduced or limited vision. Another recent study evaluating the use of an accessible (speech-based) indoor navigation system found highly similar (functionally equivalent) route-finding performance between groups of older and younger participants who were blind (Giudice, Guenther, Kaplan et al., 2020). These results are important as they not only show similar spatial abilities for individuals who are blind across the lifespan but also that older adults were as accurate and competent using an accessible navigation system as their younger peers. Such findings suggest that healthy older adults who are blind will benefit similarly to younger blind travelers from the development of new information-access technologies that support spatial learning and navigation. Explicitly including older adults with visual impairment in research studies and the development of information-access technology is important in order to better understand how spatial behavior may change as a function of age and to identify what spatial abilities might be most improved through the use of technological assistance.

The Relation of Age, Visual Impairment, and Training of Spatial Skills and O&M Techniques

The investigation of the effect of visual experience on ways that individuals conceptualize space is complicated by the fact that there tends to be relatively large individual differences in spatial abilities within groups of individuals who experienced early-onset and late-onset blindness and for older adults who are experiencing visual impairment. As an example, in one study of spatial learning after exploring new places, 14 of the 15 worst performers had experienced an early onset of visual impairment. However, some of the best performers, six of 15, also had experienced an early onset of visual impairment (Hill et al., 1993). Because of these large individual differences in performance on complex spatial tasks, researchers cannot yet draw definitive conclusions about the relationship of age at onset of visual impairment to the strategies used for spatial thinking and the ability of individuals who experienced an early onset of blindness and those who experienced a late onset of blindness to perform complex spatial tasks. Also, as the research findings on individual differences reflect, many O&M specialists report working with individuals with early-onset blindness who possess excellent spatial abilities, including performance on tasks of higher order spatial thinking. Thus, it appears that the age at onset of visual impairment is not the only factor influencing these abilities, a conclusion reflected in much of the literature on this topic (Klatzky et al., 1995; Loomis, Klatzky et al., 1993; Loomis et al., 2002; Schinazi et al., 2016).

Given the complexity of the age-at-onset issue in relation to spatial abilities, and the variability in the performance on spatial tasks among participants who are blind, it is difficult to identify a single factor (or even a reliable set of factors) that helps or hinders orientation while traveling. The use of small research samples, laboratory tests with little real-world validity, and the lack of interdisciplinary discussion between behavioral scientists and O&M specialists has further hampered the interpretation and generalization of results (Kitchin et al., 1997). Giudice (2018) discusses one other bias that has complicated the generalization of spatial cognition research across the broad demographic of individuals who are blind or visually impaired. Although there is significant heterogeneity of causes leading to blindness and a broad range of visual impairment from mild to total vision loss, most basic research in this domain only incorporates and compares participant groups who have no visual impairment (i.e., sighted individuals)with those who are totally blind (preferably with blindness being congenital). The reason for this highly constrained recruitment practice is that comparing these two samples represents the extremes of the vision continuum, with the data from the participants who are blind uncontaminated by potential confounds introduced from residual vision or prior visual experience.

While this approach may well provide greater experimental control and yield "cleaner" data that is easier to interpret by the researchers, it is neither representative of the underlying population of people who are blind or visually impaired nor meaningful to a broad-based understanding of spatial abilities across the broad spectrum of visual impairments. Given that only 5-10 percent of people who are legally blind are estimated as totally blind (Congdon et al., 2004), it is important to consider the entire range of blindness in our research in order to generalize findings to the entire population, rather than basing much of our knowledge on a small sample of people who are totally blind at the tail of the blindness distribution. A coherent understanding of the spatial abilities of individuals who are blind requires that research starts to consider factors such as the etiology of impairment, degree of impairment, age at onset, and amount and type of O&M instruction that participants have received. Given these limitations, more research is needed to explore these issues to better understand how they influence the ability of individuals to think about space and to perform spatial tasks.

THE SPATIAL ASPECTS OF TRAVELING ROUTES

Landmarks and Information Points

Most travel of both blind and sighted individuals occurs along familiar routes that lead to familiar destinations. According to Thinus-Blanc and Gaunet (1997), routes comprise sequences of instructions that specify changes of direction while one is traveling. Identifying landmarks and recalling one's location relative to a destination is a fundamental aspect of traveling routes. Hill and Ponder (1976) defined landmarks for travelers who are blind or visually impaired as familiar objects, sounds, odors, temperatures, or tactile or visual clues that are easily recognized; are constant; and have discrete, permanent locations in the environment that are known to the traveler.

Primary Landmarks

Although not mentioned in the traditional definition of landmarks, there is an important difference between primary landmarks and secondary landmarks. A primary landmark is always present in the environment and would be difficult to miss as one travels a path. For a traveler who is blind or visually impaired, a change in surface texture underfoot that spans the width of a sidewalk is an example of a primary landmark. Unlike a sound, a surface change is unlikely to be transient, and unlikely to be missed, provided it is distinguishable from the surrounding sidewalk and of adequate size to be readily detected. Also, the particular change in texture must be unique, that is, it must not occur frequently in a specific environment.

Secondary Landmarks

Secondary landmarks are similar to primary landmarks. An after-hours book deposit box at a library in a particular neighborhood, for example, might serve as a secondary landmark. It is easily distinguished from other features in a place, unique in a given environment, and permanent. It is the only box of its type along a route. It is considered a secondary landmark only because it is possible to miss the box since it is to the side of the travel path rather than on it. More formally, its detection probability is lower than a primary landmark. Individuals who use a long cane must explore to the side where the feature is located to find it, and they can walk past it without detection if probing with the cane on the other side, or not exploring to the side at all. Individuals who use dog guides must confirm that they are beside the library box by reaching out to touch it or by using reflected sound to locate it.

Information Points

Like landmarks, information points also are useful to establish orientation. They are features that, while not unique along a path and thus not considered landmarks, can be used in combination with other features to provide information about one's location. A parking meter adjacent to a fire hydrant may be an information point. Both objects are found in several places along a route, but they are located adjacent to each other in only one location. Confirming that both a parking meter and fire hydrant are nearby thus can aid to confirm one's location and facing direction (and to reduce one's spatial uncertainty along the route).

Landmarks and information points also aid in identifying locations along a walk where a change in the direction of travel is needed to continue toward a destination. The value of any environmental feature for establishing or confirming orientation depends on whether or not travelers can easily perceive it, and whether they can accurately associate it spatially with other features and with the desired direction of travel. It is also important that they are taught to identify these key sources of information and practice using them during independent travel. As with learning any complex skill, learning to do effective spatial problem solving involves a form of spatial thinking and hypothesis testing, which is further discussed in the next section. Accuracy and comfortability using these different landmarks and information cues takes time and repeated practice, but once a traveler starts making note of, and consistently using, these sources of information, they can become a critical tool to improve safe and efficient travel. For effective navigation, individuals must keep track of their position relative to the sequence of landmarks and information points they have passed, and they must also anticipate the upcoming landmarks and information points.

PROBLEM SOLVING Reestablishing Orientation

In general, establishing and maintaining orientation as one travels familiar routes involves a cycle of perception and action, with action guided by one's expectations regarding what perceptual information one will encounter at a given point along a route. One's expectations could be recalled from a cognitive map of this specific place or could be based on general familiarity with environments similar to the one being negotiated. When perceptions do not match expectations, information gathering and strategic action usually are necessary to reestablish orientation.

Reestablishing orientation is a problem-solving or hypothesis-testing activity. It can be described in four stages: (a) identify that a problem exists; (b) identify alternative strategies for solving problems; (c) select a strategy from the available alternatives and implement it; and (d) evaluate the effectiveness of the selected strategy. Psychologists and educators have used this four-stage schema to study problem solving for a variety of everyday tasks, and it is applicable to orientation problem solving as well (Brans-ford & Stein, 1984; Hayes, 1989). These four stages are applicable to activities as diverse as finding a room in a building, correcting a veer after a street crossing, and reestablishing orientation after getting off a bus at the wrong stop.

Both for sighted and visually impaired travelers, the realization that an orientation problem exists usually occurs when their perceptions of the surroundings do not fit with their expectations based on experience. A landmark on the left should have been on the right, for example, or is not detected at all. Instead, a traveler unexpectedly confronts an obstacle that is unfamiliar. Each of these events may trigger the traveler's desire to evaluate where they are along a route and which way they are facing. If the traveler perceives that they are not on route or moving in the correct direction, they must decide what problem-solving strategies to use to reorient.

Individuals who are visually impaired have a number of strategies at their disposal when reorienting themselves. These strategies can be effective on both familiar and unfamiliar routes. First, they evaluate the available information and form a hypothesis about where they are, where the travel path is, and which way they are facing. They determine the direction they need to move to get back to the travel path and resume walking toward their destination. To accomplish these tasks, travelers may attend to information such as the slope of ground, the sound of traffic, or an available line or border such as a wall or a grass line. They also may explore systematically to locate a landmark with the cane or hand or may use distant sounds for reorientation. They might solicit information from others about their location, the direction they need to walk to reach their destination, and the landmarks they will encounter as they travel. During O&M instruction, individuals are given guidance on various strategies for soliciting help effectively, including techniques such as pointing the direction indicated by a helpful pedestrian to confirm a location or direction of travel or summarizing the information received to affirm it makes sense. If travelers and information providers can use cardinal directions along with their knowledge of the street grid instead of relying only on egocentric directions (e.g., left or right turns), this may lessen the likelihood of left-right confusion that sometimes occurs when receiving verbal directions from others. The ability to use cardinal directions also may facilitate an individual's ability to follow a route and become reoriented when disoriented. If a person relies only on an egocentric frame of reference, it may be more difficult to become reoriented when they are lost.

Sometimes travelers must follow routes that they have not traveled before. In such instances, they may obtain route directions from a map or from another person, or they may create a best-guess route based on their cognitive map of the street grid and the locations of various places relative to one another and their current location. When traveling an unfamiliar route, one's general knowledge of the environmental regularities that occur in most travel environments can be useful for orientation. For example, curb ramps usually indicate that one has arrived at an intersecting street. The end of a building line often indicates that a driveway or intersection is just ahead. Also, streets often are either parallel or perpendicular to neighboring streets. These and other regularities in built environments are useful to establish and maintain orientation in places where landmarks and information points are unknown.

Consider an example of an orientation-related problem and the application of the four-stage problem-solving schema:

> Emily, a pedestrian who is visually impaired, realizes she is disoriented and no longer knows where she is relative to any landmark in the environment. In addition, she realizes that the perceptual information she is "receiving" does not "fit" with what she expected to find on this particular five-block route. In this situation, Emily must reestablish her orientation and determine which direction to walk to continue traveling toward her destination. She thinks the problem occurred because she walked several blocks past a choice point along her route where she usually turns, although she is not certain of this. To reorient, Emily must evaluate the available information, focusing on what she feels under her feet, what she can locate with the cane, and what she hears. Although initially there is little information available to help her to problem solve, she soon locates a row of parking meters with her cane. She recalls that the

only parking meters in the area are along a street one block south and one block east of the information point that she missed along the initial route. Using the late afternoon sun as a crude compass, she walks back to the north and then to the west toward the intersection where she originally intended to turn. Upon arriving there, she veers into her parallel street as she crosses. Realizing this error because of changes in traffic sounds, she is able to correct her veer and to navigate safely to the desired curb. Once on the curb, she continues in the direction she initially intended to travel. Emily has solved her disorientation problem by first identifying that she is disoriented, then determining what perceptual and cognitive information she has at her disposal, and using this information for successfully selecting, implementing, and evaluating a corrective strategy.

Drop-Off Lessons

To give learners practice in solving disorientation problems, O&M specialists sometimes set up situations in which their learners are dropped off in a familiar area but given no information about where they are in the environment. The learners typically are given a destination at the beginning of these lessons, and they must use various strategies to establish orientation and travel successfully to the destination. Learners in drop-off lessons have learned the location of several landmarks and information points in the environment during previous travel and have practiced traveling efficiently once they have accurately determined their initial location and facing direction, which are the two primary challenges to be solved in a successful drop-off lesson. Drop-off lessons are particularly beneficial near the end of O&M instruction because learners who can solve drop-off problems presumably can identify and solve other less demanding travel problems, such as maintaining orientation while traveling to a destination in a familiar place from a known starting point (e.g., from home to work). Drop-off lessons also are very useful in teaching learners to gather information and test hypotheses about where they are and how to get to a destination efficiently (e.g., the spatial problem solving and spatial hypothesis testing mindset that is so critical for successful O&M). When designed properly, drop-off lessons are great confidence builders for learners developing their orientation strategies and practicing the key tools needed for safe and efficient navigation.

As with Emily's disorientation in the previous example, an individual solving a drop-off problem uses a hypothesis-testing strategy. The traveler gathers information to establish and then test their hypothesis about their location. The position of the sun, the sounds of traffic and its direction of movement, and nearby landmarks all may be useful to establish orientation and facing direction. As they move, the student also must keep track of their location relative to the destination (i.e., spatial updating) so they can travel to it efficiently. To accomplish this, they may remember the number of blocks walked in one direction and recall that they must turn in a certain direction at a certain point along the walk to continue walking toward the destination. They likely use landmarks or information points as they move along to gauge progress and determine where changes in direction are required (e.g., "I feel the gravel under my feet and know my turn is coming soon"). Travelers also may simply recall the approximate length of time they need to walk prior to turning, sometimes called time distance awareness (e.g., "I've walked about as far as I usually walk to reach the next turn"). The absence of an expected landmark or information point can further prompt hypothesis testing about whether a person is moving toward the goal or in some other direction.

LEARNING NEW PLACES

Most people, irrespective of their visual status, have little difficulty maintaining their orientation and traveling efficiently in their house or neighborhood. However, accomplishing this task in new places with or without vision can be challenging, particularly when those places are large or complex (Ungar, 2000). This section focuses on these latter issues: how individuals who are blind learn about and travel efficiently in new places.

As with traveling along familiar routes, learning about and successfully moving through both unfamiliar indoor and outdoor environments are critical components of daily life for most people. As noted earlier, travelers in familiar places have the benefit of matching the flow of perceptual information to their memory of what they should encounter as they move about. They can compare the perceptions at a given location to what they expect to perceive and then implement problem-solving strategies if their perceptions and expectations are incongruent. By contrast, when exploring new places, travelers usually do not have prior knowledge of landmarks and information points and must explicitly endeavor to locate and remember them as they learn and navigate the space. Travelers may sometimes solicit landmark information from others before traveling in new places and may have some knowledge of landmarks prior to walking. Once acquired, landmarks and information points aid an individual's efficient travel on subsequent walks, and they may become features of the traveler's cognitive map. The ability of learners to explore in ways that aid them to remember the features in a place, learn the spatial relationships between these features, and implement orientation-related strategies while traveling are three important skills often taught in O&M instruction.

Although it has not been studied in depth, investigating the strategies people who are blind or visually impaired use to explore and learn new environments is important for both theoretical and practical reasons. As noted earlier in the discussion of traveling routes, the lack of access to distal environmental information in unfamiliar environments means that individuals who are visually impaired often face challenges in accessing information during self-exploration to form a well-defined cognitive map of a new place. Lack of such knowledge does not preclude efficient travel along routes once landmarks and information points are learned because individuals can travel routes by executing a prescribed sequence of actions. However, without access to an accurate spatial representation in the form of a cognitive map, it is much harder to perform tasks such as making a detour, determining shortcuts, and reorienting if lost.

Spatial Strategies for Learning Unfamiliar Places

Evidence for the advantages of teaching an exploration strategy that emphasizes the acquisition of an allocentric frame of reference is found in several studies comparing spatial performance of individuals who were blind and those without visual impairment. In studies by Rieser et al. (1982, 1986), participants were guided from a starting point to multiple targets in a room and were then asked to walk or point directly from the starting position to each target or along novel (not previously traveled) routes between the targets. Although both blind and blindfolded-sighted participants were accurate at walking to target locations from the starting position after a guided walk, performance by blind participants was statistically less accurate for pointing to or walking along routes between locations not directly experienced. These findings were interpreted to indicate that people who are blind can learn routes efficiently but may have difficulty integrating sequentially encountered locations into a common, allocentric frame of reference. Although these experiments did not test this hypothesis, it is likely that changing the learning strategy used by individuals to accomplish spatial tasks would have a positive effect on performance. For example, it may be useful to encourage blind individuals to explore the environment and then imagine how the target positions are related to each other. This could be accomplished by having them create a tactile map of the environment or by imagining themselves at various locations and pointing to other locations. With access to a spatial display, such as a tactile map that accurately depicts the object-to-object relations, blind individuals are likely to significantly improve their understanding of the space and their spatial inference making abilities.

Although most studies and training programs in spatial orientation do not examine spatial learning of unfamiliar places, a few studies have investigated the role of exploratory strategies in learning. Three primary exploration strategies have been identified as used by travelers who are blind or visually impaired for self-familiarization: perimeter, gridline, and reference point (Hill & Ponder, 1976). With a perimeter strategy, the traveler walks the outside border of a space and remembers the various features along the border (e.g., the wall) in order, starting from a home-base location (often the door to a room). With a gridline strategy, a traveler systematically crosses back and forth in the interior of a space to locate landmarks. With a reference-point strategy, a traveler explores a place by walking from a known location (e.g., home base) to various landmarks, and then returning to home base before walking to another landmark.

Tellevik (1992) conducted a study to investigate whether different exploration strategies yield different levels of knowledge, and whether specific strategies are preferable to others in facilitating the learning of object-to-object relationships. To evaluate perimeter, gridline, and reference-point strategies, Tellevik asked the 10 sighted participants, who were blindfolded O&M specialists, to find four objects in a room. Videotapes of the study were analyzed to learn about self-exploration strategies and their relationship to spatial-layout knowledge. The results indicated that people initially used perimeter and gridline strategies, but with additional exploration, they tended to adopt a reference-point strategy to gain knowledge about object-to-object locations (Tellevik, 1992). Hill et al. (1993) extended Tellevik's work on self familiarization strategies during exploration of novel places by testing participants who were blind. The authors videotaped 65 adults with both early onset and late onset blindness as they explored a 15 foot by 15 foot space and learned the location of five objects. Perimeter, gridline, and reference-point strategies were used, although not all participants used all the strategies. The top 25 percent of performers and the bottom 25 percent of performers on spatial-layout knowledge as measured by a distance-estimation task between target locations (an allocentric spatial task) were evaluated for frequency of use of each strategy. The results demonstrated that participants with the best distance-estimation performance used more types of strategies than other participants. In general, they also located the five objects more quickly and tended to use the linking strategies of gridline and reference point rather than perimeter search strategies.

A final study by Gaunet and Thinus-Blanc (1996) investigated the use of exploration strategies in unfamiliar environments by individuals with early-onset and late-onset blindness, as well as blindfolded-sighted participants. Their results showed similar patterns of movement behavior to those observed in the previous two studies. That is, participants adopted two general patterns of exploratory behavior. As they began exploring, participants used a perimeter search strategy similar to that described in Tellevik (1992) and Hill et al. (1993). The participants tended to initially travel between a sequence of landmarks, ending up at the same place they started. As they gained more experience exploring the space, they adopted a second search strategy characterized by a back-and-forth pattern of movement between objects. The finding that route traversals between object locations increased with greater experience with the space is in agreement with the findings of the Tellevik and Hill studies showing the use of strategies linking objects to objects. Also, supporting the earlier findings of Hill et al., performance by participants with early-onset blindness tended to be more error prone than that of participants who experienced blindness later in life and the sighted participants who were blindfolded. Researchers attributed this behavior to reliance on a perimeter search strategy and less use of back-and-forth movement patterns by the participants with early-onset blindness. Corroborating the previous findings, the best performers in the Gaunet and Thinus-Blanc study, independent of age at onset of visual loss, were those who adopted multiple, systematic patterns of exploratory behavior.

These studies are important because O&M specialists and their clients need to know more about how various exploration strategies during self-familiarization with novel environments support spatial learning. The knowledge gained from such research has practical application because the exploration strategies that help people develop accurate cognitive maps will in turn facilitate efficient travel in new places. The previously cited studies highlight the need for greater focus on investigating how people interact with their environment and what movement strategies they adopt to learn unfamiliar places. Further research is also needed to learn more about sources of individual differences in other subpopulations of individuals who are blind or visually impaired. For example, research in this area with children or older adults who are experiencing visual impairment may be particularly important. The previous studies were limited in that they addressed exploration only of room-sized layouts. More research is needed to investigate strategy selection for orientation in larger-scale indoor spaces and outdoor environments.

The Role of Free Exploration

There is some evidence that freely exploring a space, versus following specific routes, may be particularly beneficial to people who are blind or visually impaired when building a cognitive map of large-scale environments. The sensorimotor experiences of moving from place to place without following predetermined routes is thought to help integrate multiple discrete locations into an allocentric spatial framework (Giudice, 2004). This hypothesis is supported by a series of studies investigating free exploration of buildings by individuals without vision (Giudice, 2004, 2006; Giudice et al., 2007). In these studies, both blind and blindfolded-sighted participants were started at a random position in a complex large-scale building and asked to learn the space and find hidden target locations by freely exploring the environment. No information about routes was provided.

Verbal messages conveyed by an experimenter described the explorer's heading and the layout geometry (i.e., intersections and corridor structures) at their location. The verbal messages were given following a strict description logic to maintain consistency. A sample message was "You are facing south, at a three-way intersection. There are hallways ahead, to the left, and behind." An important aspect of these messages is that the information provided was context sensitive and dynamically updated, meaning that each verbal message changed depending on the traveler's position and orientation in the environment as the traveler moved. Thus, if the traveler made a 90-degree left rotation at the T junction just described, the verbal message would update the description and tell the traveler that they now face east, with hallways extending ahead, left, and right.

The premise of these studies was that since the verbal descriptions provided real-time information about the person's position and orientation in the environment and conveyed all necessary information to support efficient travel, performance should not differ between groups as a function of visual status (i.e., the information-access hypothesis discussed earlier). The results of these experiments confirmed this prediction and revealed other important findings. First, dynamically updated verbal descriptions were found to be an effective mode of conveying environmental information. Access to these descriptions promoted efficient search behavior of both real layouts (Giudice et al., 2007) and virtual, computer-based environments (Giudice, 2006). These studies also demonstrated that free exploration led to the development of a cognitive map by people who are blind that supported subsequent wayfinding tasks at an equivalent level to sighted participants and had learned the environments using vision. Taken together, these experiments demonstrated that (a) when an appropriate source of nonvisual information is provided, the spatial performance observed between individuals who were blind and individuals without visual impairment does not differ; and (b) orientation is facilitated when people are allowed to learn new environments by free exploration, a finding that speaks to the importance of teaching search strategies.

SUMMARY

This chapter describes three fundamental aspects of the challenge of establishing and maintaining orientation. The first is access to perceptual information that guides spatial decision making. Sometimes information is readily available, easily perceived, and unambiguous. In familiar situations, travelers also have the advantage of comparing what they perceive with their recollection of what "ought to be." In situations where information is unavailable, difficult to perceive, or ambiguous, travelers must make orientation decisions using the information at hand, or they must seek ways to gather additional information. Examples of useful information gathering include using a GPS-based navigation system, an accessible map (tactile or digital), and employing systematic exploration, as well as asking for assistance. In unfamiliar situations, travelers must shift their focus from acquiring route-specific information to a reliance on more general information. In other words, in areas where a pairing of percepts and specific expectations is not possible, travelers rely on more general cognitive strategies to establish and maintain orientation. Approaches to information gathering in familiar and unfamiliar areas have not been systematically explored. Research in this area may lead to a clearer understanding of the kinds of information that enhance spatial abilities in these two situations.

The second fundamental concept concerns the ability of individuals who are blind or visually impaired to acquire information from their mental maps of places and to make strategic use of this information to guide their travel. The concept of a cognitive map was introduced as a metaphor for recalling, thinking about, and using spatial knowledge. The important distinction between thinking egocentrically and thinking allocentrically was highlighted, and the need to encourage allocentric spatial thinking was noted. The research regarding how the age at onset of visual impairment impacts spatial abilities, and how this may change across the lifespan was briefly described. As discussed, there is a need to consider a range of factors that may operate in concert with age at onset to affect spatial abilities.

The third fundamental aspect of spatial orientation is that of selecting strategies for gathering information and for orientation-related decision making. The examples of relocating the travel path and establishing orientation in a familiar area were used to highlight strategy selection. In selecting and implementing strategies for orientation, travelers who are visually impaired bring their information-gathering and cognitive-mapping skills to bear on the particular orientation challenge at hand. Travelers who are blind or have low vision are also increasingly using a host of technologies to aid these processes.

Orientation and mobility instruction represents one key aspect of learning what strategies might be useful in a particular situation, when evaluating alternative strategies is useful, and when assessing the effectiveness of these strategies is most effective. As with the concepts of information gathering and the use of cognitive maps, more research is needed on strategy selection. How, for example, do novice and expert travelers differ in their ability to select the optimal strategy? The studies cited in this chapter regarding exploration of new places suggest that strategy selection is important for efficient (oriented) travel, but much more research is needed to catalog the various strategies and their situational effectiveness and how technology may be used to improve the safety, efficiency, and confidence in performing these activities. O&M specialists can play an important role in working with researchers as they investigate the complex issues surrounding information gathering, the use of cognitive maps, and the selection of strategies for establishing and maintaining orientation in both familiar and unfamiliar places. Given the increasing importance of access technology in all these endeavors, the role of technology in O&M training and the need to teach learners how different devices can be used to augment and complement formal training is increasingly important. Researchers and O&M specialists alike have a role to play in helping to advance our understanding in this important and practical area of O&M. In addition, connecting basic scientific theories with modern O&M instruction forms a bridge that helps explain why certain strategies and techniques are likely to work and how they can be optimized based on how people learn using multimodal information and how this information is processed and represented in the brain.

IMPLICATIONS FOR PRACTICE

1) There are four fundamental aspects of spatial orientation: information gathering, the use of strategies for following familiar routes, the use of cognitive maps, and the application of strategies to solve problems.
2) When traveling, a person who is blind or visually impaired uses a range of multisensory cues (including auditory, tactile, and smell) to establish and maintain their orientation by spatially updating their position.
3) Egocentric and allocentric are the two fundamental frames of reference for thinking about spatial relations. An allocentric frame of reference allows individuals to be more flexible in their thinking about the locations of objects relative to one another. This frame of reference is the basis of what is referred to as survey knowledge, which is stored in the brain in a cognitive map.
4) In familiar areas, travelers can rely on their anticipation of specific types of information in specific places. In unfamiliar areas, travelers must rely on their more general knowledge of the way places are usually arranged, rather than relying on specific information. These differences may require the selection of different strategies for solving orientation problems.
5) Exploring new places is an important task for a traveler who is blind or who has low vision. The approaches travelers use for exploring new places can be studied to determine whether some strategies are more useful than others.
6) Spatial orientation has been studied extensively, and much is known about the spatial orientation of individuals with typical vision. There is a significant need for additional research about the spatial orientation of individuals with visual impairment. The need is particularly great for research about the kinds of experiences that enable children and older adults who are experiencing visual impairment to become independent travelers and to develop high-level spatial skills that support independent travel in both familiar and unfamiliar places.
7) Orientation aids such as tactile maps and electronic orientation aids (e.g., GPS-based navigation systems and multimodal interactive maps) can be helpful tools for establishing and maintaining orientation but should be used in conjunction with a primary mobility aid such as a long cane or dog guide.

LEARNING ACTIVITIES

1) Practice the skill of updating your position in space by walking without vision along two legs of a triangle and then trying to return to the starting point. Point to several landmarks encountered along a walk while standing at the end of a route or at one of the landmarks. What terms can be used to describe the relationship among landmarks, using both egocentric and allocentric frames of reference?
2) Explore rooms and neighborhoods while blindfolded. Use different strategies to explore and remember the features of a place, and think about how these differences relate to knowledge of a place as measured by an ability to make a map, determine a detour, or create novel routes.
3) Think about the information available in a typical office building, a residential area, and a small-business environment. What strategies could be used in each environment to establish and

maintain orientation? Walk around in a large room, such as a gym, that has three to five objects in it. Walk to each object and describe the relationships of objects to one another. Estimate how far it is from the various objects to other objects. Build a tactile map or model of the objects, preserving the spatial relationships among them. Develop a strategy for teaching these skills to children or people who are newly experiencing visual impairment. Travel a familiar route but stop halfway to the destination to identify an alternate route that leads to the destination, and then follow it.

4) Using an array of objects similar to those in the previous activity, learn the relationships among the objects and then imagine standing at one of them and pointing to the others. Is this a harder task than simply pointing to objects while standing at one object?
5) Use a set of note cards, recorded notes, or other means to reconstruct a sequence of landmarks and turns that are too long to remember. How many landmarks are remembered? Do memory aids help with the memory of them? What spatial language can be used to describe the spaces in travel activities?
6) Explore using one of the commercial accessible navigation systems that are available. How might the information it provides be useful to travelers who are blind? What tasks could be designed to incorporate these wayfinding technologies into existing O&M instruction?
7) Try using tactile maps to support the learning of allocentric knowledge or cognitive maps. Encourage learners to learn the map and work with them on strategies for "reading" the information presented and incorporating it into their practice and spatial skill development.
8) Experiment with mental exercises that tap higher order spatial knowledge. Ask, "If I am at point A, how would I plan a route to point B, and what would I do if I found myself at point C?" Mental exercises such as this may be useful to aid learners in thinking about space and can facilitate the development of spatial problem-solving skills and cognitive maps.

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