Human Factors Suggestions for the *Advanced Pedestrian Assistant*:

Usability and performance concerns of
Advanced Accessible Pedestrian
Signals for low vision users

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Defining Low Vision

To date there is no common or legal definition of the term low vision. Different industries tend to focus on different aspects of the term and define in accordance with their own domain, and the needs that are prevalent within them. As Corn and Koenig (1996) propose, the etiology of the word starts with the term blind. Up until the 20th century, people tended to refer to blind individuals as those with no vision whatsoever, which of course is not common. The term blind began to evolve during the 20th century to include those with low vision or visual impairment. It is at this point that the concept of legally blind emerged.

The cut-off point, for being considered legally blind for acuity is 20/200 or less, but a person may also be put into this category if their visual field subtends from angular distance of no more that 20 degrees. However, even with a definition this precise we still find that there are individuals with other visual impairments that may not fit into this definition, such as those with low sensitivity to light. However, as of yet the definition of legal blindness has not changed in 60 years.

Now that the brief histories of blind and legally blind are understood, some terms will be explored that professionals use outside of the legal vernacular. Any of the following terms are referred to as Visual Function. Partial Site is a term that describes someone with at least one eye having a corrected acuity between 20/70 - 20/200. Functional Blindness is used to describe children who could benefit from learning Braille. The term low vision has many definitions and is the dominant term being used today. Those with low vision include:

1) Those with vision loss severe enough to interfere with everyday tasks
2) Those having impairment, but also some useable vision
3) Those that have an acquired, congenital, or hereditary condition that has affected some part of the biological make-up visual system that depreciates visual awareness
4) Those severely impaired after correction, but who can benefit from optical aids

The overall goal of these terms is to establish a dichotomy between those whose vision can disrupt their everyday life, and those whose vision does not. The problem with this however, is that two people with the same level of vision can be affected differently depending on the degree in which their blindness impairs them. Individuals who identify themselves as being blind tend not rely on their vision for many tasks, while individuals that do not identify themselves in this way will rely on their vision for many more tasks.

As previously stated, different organizations use these terms contextually. However, most organizations tend to use the word visual impairment. This term refers to people who have no vision at all as well as those with varying levels of low vision. Another term commonly used in industry is visual disabilities. However, disability is defined as “a condition that prevents an individual from performing a specific task because of impairment.” The term visual impairment is typically used.

For our purposes we will use part of a theory of visual impairment that is operated by a person’s
ability to function. The theory involves three dimensions: visual abilities, environmental cues, and available individuality (the psychological component).

1) Visual abilities: acuity, visual field, motility, brain function, and light and color perceptions
2) Environmental cues: color, contrast, space, illumination, and time.
3) Individuality: cognition, sensory development integration, perception, psychological make-up, and physical make-up. (Corn & Koenig, 1996)

All of these components must be developed to some degree for visual functioning to occur. These three dimensions work together to form an overall picture of a person’s visual functionality. For example, an individual with low vision can manipulate his/her environment and use tools to function in the world. However, since this topic is focused on individuals whose vision is impaired physically, we will only be using the visual ability portion of this theory. As such, when the term low vision is used, this report will discuss it in terms of visual acuity. Within this, all of the above terms for Visual Function (partial site, functional blindness, and low vision), as well as individuals with no vision, will be the make-up of our definition.

Human Sensory Information Concerns

This section addresses sensory information concerns for low-vision pedestrians to cross a signalized intersection safely.

- What is desired? What does the low vision population want in order to maintain and/or expand their mobility?

Before addressing human sensory information concerns, some more low vision terms and concepts are set forth (Blasch & Wiener, 1997) that will help in interpreting the rest of this report.

Perception and action are a cycle. We act in order to learn about our environment and we use what we learn to guide our actions. The knowledge we gain and that guides our actions is orientation.

Orientation is the knowledge of one’s distance and direction relative to things observed or remembered in the environment. It is a spatial relationship (self to object) and it changes during locomotion (giving constant feedback is important).
**Mobility** is the level of moving safely, gracefully, and comfortably through an environment. It depends on the perception of the environment.

**Environmental flow** is the changes in the pedestrians’ distance and direction to things in the surroundings that occur while walking.

**Detection errors** occur when the pedestrian misjudges important objects in the environment.

**Localization errors** occur when the location or distance to an environmental feature is misjudged.

**Signal detection** is one method used to test these errors. Signal Detection Theory states that the state of the world can be broken down into its actual condition and the way the signal detector perceives it. Signal detection theory evaluates dichotomous decision-making tasks into the following matrix:
Low vision population desires and needs

The needs and wishes of the visually impaired pedestrian population were well-covered in 2 surveys and a quasi-experiment. One survey, conducted by Carroll & Bentzen (1999), was administered orally to 158 visually-impaired pedestrians. This will be referred to as the ACB survey because it was completed for the American Council of the Blind. The other survey, carried out by Bentzen, Barlow, & Franck (2000), obtained responses from 349 orientation and mobility specialists. This will be referred to as the AER survey because it was performed under the Association for Education and Rehabilitation of the Blind and Visually Impaired. The SKERI study refers to a quasi-experiment performed for the Smith-Kettlewell Eye Research Institute that observed crossings by visually impaired pedestrians with and without Accessible Pedestrian Signals (APS). Accessible pedestrian signals (APS) are enhancements to the traffic signal system which provide signal phase information in audio, tactile, and/or vibrotactile formats for the pedestrian.

Where is the crosswalk?

SKERI research indicated that pedestrians at 19% of the street crossings without APS systems asked for help in locating the crosswalk, and another 34% that didn’t ask for help started crossing during the flashing or steady “do not walk” intervals. This has become worse with large-radius corners that make it harder to get parallel alignment from the curb. Some crosswalks are also mid-block, and are thus hard to find without good tactile cues. Roundabouts and other novel intersections techniques also impart a huge challenge to the visually impaired pedestrian.

When should I start crossing?

91% and 98% of survey participants, on the ACB and AER surveys, respectively, sometimes had difficulty knowing when to begin crossing at an intersection. 79% on the AER survey admitted having trouble knowing when to cross at crossings with exclusive pedestrian phases (due to the lack of audio clues from parallel traffic). SKERI research indicated that pedestrians at 24% of the street crossings without APS systems asked for advice on when to start crossing, and another 34% that didn’t ask for help started crossing during the flashing or steady “do not walk” intervals.

How long do I have to cross?

Visually impaired pedestrians need to know how long they will have to cross the street, and that time needs to be sufficient to do so. The ACB and AER surveys found that one problem many participants had with push buttons was that they did not have enough time to push the button,
return to the corner, and orient themselves properly before the pedestrian interval started, meaning they had less time to cross, when they actually needed more.

Am I headed toward the opposite corner?
79% of ACB respondents admitted sometimes not being sure where the destination corner was, and in 54% of SKERI crossings, participants were not faced directly toward the destination corner; they were aimed at varying degrees toward or away from the intersection.

How long is the crosswalk?
Information about the width of the road can be partially determined from auditory cues, though with quieter electronic cars this is no longer a completely trustworthy source of information. Pedestrians can estimate the width of a street in terms of steps if they are familiar with the area, but otherwise it may be hard to know until the curb is felt.

What is the geometry of this intersection?
85% of respondents on the ACB survey said they were sometimes confused by unexpected features in the crosswalks, such as islands or medians. On 54% of SKERI crossings, participants did not know whether they had just crossed a T-shaped or four-way intersection; this is important information to know, because the intersection shape can determine probabilities for traffic flow, speed, and turning traffic.

What sort of controls are at this intersection?
It is very important for pedestrians to know whether an intersection is controlled by lights or stop signs. On 50% of SKERI trials without APS, participants could not tell from available audio or other cues how the intersection was controlled.

Is there/where is the pushbutton?
90% and 94% on the ACB and AER, respectively, admitted they had problems with pedestrian push buttons, including whether there was a button, where it was, which direction the button controlled, etc.
Is there a free right on red at this intersection?

Waiting through a traffic cycle or two and listening to traffic patterns may answer this question. If right turns are permitted, it can be quite dangerous for a visually impaired pedestrian, even during a pedestrian-only crossing phase.

What street is this?

There are only very few APS-controlled intersections that relay this information, and that is usually by sound, which may interfere with the hearing navigational/situational awareness process. Most visually impaired pedestrians have to keep track of streets by using mental models and counting blocks.

Note: As long as these questions are answered without deteriorating natural orientation cues, the solution will be a success.

- Current assistive technologies: What is used now? How much of the orientation and navigational needs are met by current technology based solutions?

Before delving into current technological aids, Barlow, Bentzen, Bond (2005) provide the following information about low vision pedestrian tasks for encountering intersections.

Blind pedestrians have the following tasks when they are crossing a street: detecting the street, locating the crosswalk, establishing the correct heading to the destination corner, traveling in a straight path, and determining the proper time to cross.

- Techniques in completing these tasks have changed little the past 30 years.

1. Crosswalk buttons need to be pushed in order for the pedestrian to have enough time to walk across the street before the light changes. If the button is not pushed then the light will not register and prolong the cross time.
2. Blind pedestrians determine their walkway direction by waiting through one signal cycle of an intersection. This allows them to listen to the traffic that is traveling parallel to their path. Once the pedestrian hears this traffic they can accurately align their walkway. By pushing the button they do not have time to listen to the cars and align their path accurately. One technique used to help with this problem is to find a tactile cue that will help them find their correct alignment after they have located and pushed the button.
3. It appears that this study shows the difference in a push button actuation and a pedestrian recall phase (this is where the cross light is automatic every time). In general this study
showed that the onset of crossing was late and total cross time was increased with a push button system.

Current Assistive Technologies

Many intersections are controlled by stoplights or stop signs. In these cases, the visually impaired mostly rely on their hearing to infer the directions of traffic, traffic stop patterns, and orientation. Some visually impaired pedestrians make use of aides such as dog guides, human aides, or long white canes, and many use the sounds of the environment for situational awareness and relative orientation.

**Human Aides:** Sighted human aides can solve most of the problems, but are expensive and/or hard to find. Most visually impaired people will use one at one time or another, but it is not practical for everyday use.

**White Cane:** Blind Pedestrians typically use canes to detect the surface of the walkway. Curbs, steps, and holes are detected by the drop-offs of the noise of the cane striking before, later, or not at all what is expected. The white cane is a sort of predictive display, which alerts the visually impaired pedestrian to obstructions and/or divots in the path before he/she actually runs into them. At intersections, these can help locate poles that may or may not have a push button on them, identify curbs that may or may not lead to a crosswalk, and identify the destination curb just before the pedestrian needs to step up to avoid tripping. The cane therefore gives information preemptively to the pedestrian. The cane, however, does not give information on intersection geometry, how the intersection is controlled, or when to cross. (The APA system should then provide preemptive information regarding the surface of the walkway such as when to expect a curb).

**Dog guide:** Dog guides are used by less than 10% of the blind population. Dog guides obey directional commands from their owners (such as “left”, “right”), so do not actively steer the pedestrian unless in the face of danger. Dog guides do not help a pedestrian know when to cross the street or what street it is.

**Curb ramps:** are commonly experienced downward slopes and act as a cue for the entrance of a street. (This is an issue- how to disseminate the information that the pedestrian has approached the corner of the street). Blue tooth technology could be utilized here to inform the pedestrian that he/she is approaching the corner.
**APS systems:** Accessible pedestrian signals (APS) are enhancements to the traffic signal system to provide signal phase information in audio, tactile, and/or vibrotactile formats for the pedestrian. APS devices available today are of four general types: pedhead mounted, pushbutton integrated, vibrotactile only, and receiver-based. APS systems help with some of the needs of visually impaired pedestrians, but not all, and many do so at the expense of obstructing the natural orienting cues of sound. The following bulleted section on APS devices provides details of each of the APS devices available at the time of this report. Information was obtained from phone, e-mail, Internet, and mail contacts with manufacturers and from the draft report, Accessible Pedestrian Signals: Synthesis and Guide to Best Practice by Accessible Design for the Blind [www.accessforblind.org], being prepared as part of NCHRP Project 3-62: Guidelines for Accessible Pedestrians Signals (7).

- **Pedhead-mounted APS** is the only type that has been commonly installed in the U.S. for the past 25 years. This type has a speaker on top of or inside the pedhead with a bell, buzzer, cheep, cuckoo, speech message, or some other tone during the walk phase of the signal only. Some models respond to ambient sound, becoming louder when the traffic noises are louder and quieter when the traffic is quiet. They are usually intended to be heard across the street and act as a beacon, and are relatively loud as a consequence. Manufacturers include Mallory, Novax, US Traffic, and Wilcox. Prisma and Campbell also have an optional additional pedhead mounted speaker that can be used in conjunction with their pushbutton integrated device.

- **Pushbutton-integrated APS** have a speaker and a vibrating surface or arrow at the pedestrian button. The sound comes from the pedestrian pushbutton housing, rather than the pedhead. This type has been common in Europe and Australia for years and can be used at both actuated and fixed-time signal timing locations. A constant quiet locator tone, repeating once per second, provides information to the blind individual about the presence of a pedestrian pushbutton and its location. The locator tone is intended to be audible only 2 to 4 meters (6 to 12 feet) from the pole or from the building line, whichever is less.

  The walk interval may be indicated by the same tone at a faster repetition rate (Panich, Prisma), by a speech message (Polara, Campbell, Novax, Prisma), or by other tones (Campbell, Polara, Novax). All devices of this type respond to ambient sound levels. These signals are intended to be loud enough to be heard only at the beginning of the crosswalk, although volume can be increased by special activation (Polara, Prisma, Campbell). Manufacturers include Campbell, Georgetown Electric (locator tone not ambient sound responsive), Novax (locator tone and vibrotactile arrow combined with pedhead speaker), Panich, Polara, and Prisma.

- **Vibrotactile-only APS** provide only vibration at the pedestrian pushbutton. The arrow or
button vibrates when the WALK signal is on. It must be installed very precisely next to
the crosswalk to be of value, and the pedestrian must know where to look for it.
Manufacturers include Campbell and Georgetown Electric.

- **Receiver-based APS** provide a message transmitted by infrared or LED technology from
the pedhead to a personal receiver. The pedestrian scans the intersection with the receiver
to receive the message emitted on the pedhead. These devices may also give other types
of information, including information about the name of the streets or the shape of the
intersection. Manufacturers include Résumé and Talking Signs.

The following information was taken directly from Corey K. Fallon’s (see references) proposal
investigating two types of navigation systems:

**Learning from Remote Infrared Audible Signage Systems (RIAS).**

RIAS systems consist of transmitters fixed to signs and other important landmarks in the
environment. These transmitters emit beams of infrared light that contain vocal
messages. The message might be the name of the landmark closest to the transmitter
such as a newspaper stand or a ticket booth (Marston & Church, 2005). For emergency
egress situations these messages can be changed to provide directional information to the
nearest exit. In Crandell et al. (1999) several of the RIAS transmitters located on exit
signs transmitted the message “to exit” to ensure pedestrians that they were on the correct
path to safety.

Pedestrians can receive the audible messages by scanning the environment with a hand
held receiver. The receiver receives the messages and presents them through a set of
headphones (Marston & Church, 2005). The messages are presented continuously
through the light source, and they will increase in clarity and intensity as the navigator
approaches the transmitter. After initial processing of the vocal message, RIAS systems
require the navigator to perform only simple loco motor guidance. Locomotors guidance
is the ability to travel successfully to a perceptual beacon (Foo, Warren, Duchon & Tarr,
2005). Pedestrians must follow the increasing gradient of intensity and clarity to a
particular sensory cue. Locomotors guidance has been described as a stimulus response
behavior and is considered the most basic navigational ability (Foo et al., 2005; Trullier,
Wiener, Berthoz & Meyer, 1997).

**Learning from The Push Button Audible Signs**

Push Button Audible Signs generate a list of directional coordinates at a fixed point on
the route. The navigator must locate the device, which is typically mounted to the wall,
and push a button to receive directions. The device will then generate a series directional
coordinates to the nearest exit. The PBAS system requires the pedestrian to navigate
using route knowledge also known as procedural descriptions. Route knowledge refers to
the sequential record of space between the start point and the destination (Thorndyke &
Hayes-Roth, 1982). This information is typically presented verbally and identifies when
the navigator must change direction and the actions to take at those locations.

Both auditory navigational systems can be evaluated according to the demands they place
on working memory. Because the RIAS systems rely on loco motor guidance they do not
require the use of working memory (Foo et al., 2005). The Push Button Audible Sign
systems on the other hand heavily tax working memory. These systems present the
directional coordinates verbally in the auditory modality. Therefore, this information is
likely to be encoded as auditory verbal information and stored in the
articulatory/phonological loop. This refers to Wickens Multiple Resource Model
(overview in Wickens, 2002), depicted below:

Multiple -Resource Theory
(Wickens, 1980, 1984)

Essentially, this model depicts how mental resources operate and interact. It predicts that
concurrent task performance will only degrade if sapping the same resources. Implications of this
model are discussed later on. Researchers have found that the negative effects of noise on
working memory tend to be greater for noise that is constantly changing compared to a steady
stream of noise (Tremblay, Macken & Jones, 2001). This phenomenon is known as the changing
state effect. According to the changing state effect, a fire alarm that is constantly changing
frequency will interfere with working memory performance more than an alarm stimuli held at a constant frequency and amplitude.

- What kind of sensors and capabilities on an APA would provide the necessary information to both the user and the AAPS?

**GPS/GIS information** for knowledge of street/crosswalk placement/navigational information.

**Radio frequency** (or similar) to communicate with APS systems for pedestrian phase requests.

**Tactile display** to impart information to the pedestrian without compromising natural auditory cues. Considering the Nokia’s limitations, vibrations may be used.

Possibly **Sensors** (such as infrared, or cameras with projective geometry) to estimate distances. The Kyoto Institute of Technology has a road-crossing aid for the blind that measures the width of the street crossing and can tell what color the lights are. The system uses a tiny camera that employs projective geometry to measure the width of crossings and that can see the color of the lights and communicate the information to the blind person.

- What kind of “user errors” can be expected with the APA device?

The APA may be characterized as an auditory display for the sake of ergonomic practicality. Sometimes poor auditory display design may invite errors that are more at fault than the user. According to Reason (1991), auditory displays may invoke three types of user errors. Skill based errors consist of slips and lapses; mistakes grounded in mental errors via interface design. Logically, these may be minimized through better human factors applications to the human-machine interface. Consistent, intuitive, and structured presentation of APA information will minimize the possibility of lapses, as protection against erroneous actions at the skill level can be built into the interface. A second type of auditory display-induced error is rule-based; which may be roughly divided into the misapplication of good design rules and the application of bad design rules. A third type of error is knowledge based; originating from bounded rationality or an incomplete/inaccurate model of the problem space. Bounded rationality refers to the limited decision making abilities of all people, considering time, contextual, priority, and mental resource restraints. Rule and knowledge based errors may be reduced through decision and
knowledge support. In other words, proper interface design for auditory displays primarily only combats skill based errors. However, prototype testing in specific goal, task, and context-oriented situations using a design approach coupled with well-organized user participation can serve to mitigate rule and knowledge based errors.

**Sensory Overload and Discrimination**

How to communicate (provide feedback) this information to the user to guide them across the intersection?

1. The blind use their auditory and tactile senses as the primary means of sensing their environment.
   - How much information can the human auditory/tactile system handle before it becomes overloaded? i.e. noise pollution
   - How can they best discriminate the useful navigational aids from their total environment?
   - What other senses should be used to provide the information about the intersection?

As Steyvers and Kooijman (2009) point out, visually impaired people have to rely on different information to generate a cognitive map of their environment than normally sighted people. Bonebright & Nees (2009) state that little research to date has examined whether symbolic auditory cues—non-spatialised sounds that convey meaning via auditory dimensions such as pitch and timbre—or verbal cues can be used to effectively capture or orient visual spatial attention. Furthermore, the different voices (male and female) employed for the information streams should have offered a salient cue for perceptual segregation (see Ericson et al., 2003).

In one study (Bonebright & Nees, 2009), when participants were asked about how distracting the manipulated sounds were, *speech and tones* were found to be less distracting than sweeps. Given that researchers (e.g. Edworthy, 1998; Kramer, 1994) have long speculated that a major disadvantage of auditory displays may be their interference with other concurrent auditory stimuli, continued empirical investigations of this topic will be imperative for the success of auditory displays. The findings from the current study regarding passage comprehension scores, however, are encouraging and speak to the potential for auditory displays to be deployed in scenarios where concurrent speech must be simultaneously attended to along with the auditory display.

**Auditory Overload**

Presenting too much sound information can result in that information being lost or interpreted as noise. This concept is similar to "interference/masking," which is when sound becomes drowned out, also resulting in lost information.

(Excerpted from "Auditory Overload" appearing in Stroke Connection Magazine)
Sound is airwaves or vibrations that cause a sensory stimulation of the auditory (hearing) system. Many skills are needed to translate sounds into meaningful language. Sometimes sounds become overwhelming, and our brains can’t decipher meaningful speech from noise. If noise levels become too loud or last too long, our auditory system can overload. When that happens, it becomes impossible to understand what is being said. There are several symptoms that may indicate auditory overload. These include:

1. Inability to concentrate on a task or speaker
2. Becoming fidgety
3. Becoming impulsive and doing things quickly
4. Persisting on a task, or doing the same action over and over
5. Becoming distracted by any stimulation such as lights, movements of others or objects in a room

A cross-modal dual attention experiment was completed by 198 undergraduates in three blocks that each consisted of an orientation task and a concurrent listening task. Results indicated the orientation task had no effect on comprehension of the passages compared to a passage-only control for four of the five auditory cue types. All auditory cues resulted in high performance for the orientation task, with speech and complex sounds exhibiting the highest performance. Other implications for auditory display design and for assistive technologies for visually impaired persons are discussed.

The finding that passage comprehension scores for the control group were not significantly different from the scores for tones, pitched instruments, instruments or speech clearly indicates that the addition of the auditory orienting task did not impose sufficiently high workload to interfere with the concurrent listening task except in the case of the sweeps. What does this mean? It shouldn’t be much of a problem for APA users to process auditory messages while they maintain situational awareness of environmental cues. Much research suggests that combinations of speech and earcons may contribute to auditory processing overload.

For warnings, consider recommendations from an untitled work (Cornell University): http://ergo.human.cornell.edu/DEA3250notes/auddisplay.html

a. Use frequencies between 200 - 5 KHz. Preferred range is between 500 and 3 KHz the most sensitive range for hearing.
b. Use frequencies below 1000 Hz when the signal has to travel more than 1000 feet.
c. Use frequencies below 500 Hz when the signal has to pass through partitions or "bend around" obstacles.
d. Use modulated signal (1 - 8 beeps/sec, warble 1 - 3/sec)
e. Use signals with frequencies different from background noise to avoid masking.
f. For choice situations, use moderate intensity easily discriminable frequency or amplitude signals (but not too many).
g. Where possible use separate auditory warning system which is different from other auditory signals.
The following information was taken from accessfortheblind.org and their April 2003 report entitled “Interfacing Accessible Pedestrian Signals with Traffic Signal Control.” These recommendations are the product of five years of research for the National Cooperative Highway Research Program (NCHRP) and National Eye Institute.

These suggestions and observations apply specifically to APS devices such as the ones depicted above.

- Locator tone and walk indication volume adjusts in response to ambient noise levels
  - Louder when traffic is loud or there is other noise at the intersection
  - Quiet when traffic or other sounds are quieter (night)
- Relatively quiet unless audible beaconing is called
- Volume only 2-5dB over ambient noise level
- Audible beaconing on “request” (by holding pushbutton for over 1 second)
- 1 tone per second, each tone less than 0.15 seconds in duration
- Different sounds acceptable (click, beep, etc)
- Vibrotactile WALK indication - arrow (or other surface on pushbutton unit) that vibrates during WALK
- Recent research suggests that it might work best to have increased volume only for the locator tone during the flashing don’t walk (broadcast WALK indication can be ambiguous).
- It is recommended that verbal WALK messages following the model “Beechwood; walk sign is on to cross Beechwood” be used. If speech messages are used, it’s essential that the pedestrian know the name of the street being crossed. An additional feature, a
pushbutton information message, is needed on the device to provide street name information to the pedestrian who is unfamiliar with the intersection. This feature provides the name of the street controlled by the pushbutton when pushed and held during the flashing or steady don’t walk interval.

Concerns with traditional APS pushbutton technology

Actuating the APS pushbutton will provide no information until the next signal cycle is started. Pedestrians may assume the pushbutton is not working and attempt to cross without the aid of the APS device. When the pushbutton is pushed, appropriate messaging is recommended as a speech pushbutton information message to indicate that the signal provides a walk interval on the next cycle. When this type of signal phasing is used, appropriate communication between the APS device and the signal system should be evaluated.

Gustafson-Pearce et al. (2007) found that tactile feedback increased navigational performance when compared to audio info. This was due to the natural mapping of direction through the tactile feedback and the decrease in mental processing to process the information. Because the blind rely heavily on their audio sense for detecting their environment using tactile information may be a channel to relay information without using their audio sensory system thereby freeing it up for use in navigating as they typically do. This then gives the pedestrian two sources of information to navigate.

From this study we can also deduce that information can be presented at:

1) higher order (identifying an object, is it a car or a trash can)

2) And lower order (direction, is an object there)

Some other lessons from this study:

-A problem that many participants encountered was that they began crossing when parallel traffic began moving. This traffic starts with the left turn phase, which brings traffic right into the crosswalk. A technique blind pedestrian’s use for this problem is to wait until they hear a surge of parallel traffic. When traffic is moving parallel then it means that they are blocking the vehicles turning left.

-It is important to be on the crosswalk while crossing the street. Many crosswalks are not perfectly aligned from corner to corner. If a pedestrian is poorly aligned it is unlikely that they will correct their alignment during the cross procedure and remain on the crosswalk (31% 25%). However it is likely that blind pedestrians will cross on the cross-walk if they have an initial good alignment (89%).
Design Recommendations

How can the AAPS’s resources best be implemented into the Nokia?

Gustafson, Billett, & Cecelia (2007) found that tactile feedback increased navigational performance when compared to audio info. This was due to the natural mapping of direction through the tactile feedback and the decrease in mental processing to process the information. Because the blind rely heavily on their audio sense for detecting their environment, using tactile information may be a channel to relay information without using their audio sensory system, thereby freeing it up for use in navigating as they typically do. This then gives the pedestrian two sources of information to navigate. Successful navigation requires knowledge of object-to-object and self to object spatial relationships (Riser, Guth, & Hill, 1982). This means that the pedestrians need a conceptual model of the layout of the objects in their surroundings. This will help them to understand the directions they need to walk to get to their destination. Please consider the following:

- Have auditory messages adjust to ambient noise levels, either automatically or through user preference.

- Think about having pedestrians call for different volumes by holding down actuator for longer.

- Allow user to express whether they know what intersection they are at first, in order to help dictate what type of Beechwood commands (higher or lower order, pg. 17) should be communicated.

- Use vibrotactile feedback only to prompt/during walking phase, such as a simple *dash-dash* pattern for angle left and *dot-dash-dot* for angle right, perhaps in addition to auditory directions urging “too far right” or “too far left.” This will aid in keeping the pedestrian within safe crosswalk boundaries. Prototype testing is the best way to obtain maximum performance for this aspect.

- Barlow, J. M., Bentzen, B. L., & Bond, T. (2005) showed that the onset of crossing was often late. Furthermore, they found that *speech and complex sounds exhibited the highest performance*. Therefore we recommend a simple speech message to notify the user of when to cross, but only after the APA has confirmed they are aligned correctly.

- Utilize Beechwood model of auditory instructions (pg. 16) for communicating most information to user. Perhaps it is best to minimize use of speech instructions for the actual crossing portion, because overload/interference/masking may pose a problem. Additionally, it is not as safe for low vision users, relying mostly on hearing to interpret road dangers, to hold the APA to his/her ear while crossing. This is where the vibratory capabilities come into play- testing shall decide whether relying solely on vibrotactile communication shall suffice in keeping the user within the
crosswalk. If auditory assistance is needed, warnings in the form of icons/earcons should be used. Vibratory feedback similar to the concept of rumble strips for vehicles may work well, with separate patterns for indicating left and right. Low vision people are notoriously adept and keen at interpreting tactile feedback.

-The signal to noise ratio for auditory displays should be at least 5:1 and 200-6100 Hz (Woodson, Tillman, & Tillman, 1992).

-Appropriate messaging is recommended as a speech pushbutton information message to indicate that the signal provides a walk interval on the next cycle. When this type of signal phasing is used, appropriate communication between the APS device and the signal system should be evaluated. Speech instructions possibly coupled with vibratory urging may be necessary. Low vision pedestrians that have interacted with vibrotactile APS in other US cities are used to proceeding when it vibrates. Therefore, it may be wise to follow this protocol with the APA in order to avoid violating user expectations.

-The APA could be utilized at curb ramps to inform the pedestrian that he/she is approaching the corner, again; simple auditory speech.

-Incorporate an intuitive command such as “Red Light” or alarm icons or earcons to keep user informed between walk signals.

-If feasible, the APA has to not only assist the pedestrian in crossing safely but also give them the correct course to the desired destination. At each corner the pedestrian has two options for which direction to cross, so depending on whether the pedestrian knows the destination or not the information presented should be different. For example, the APA could say do you know where you are going (yes or no) option yes would then give the pedestrian the choice to cross at section 1 or 2. If the pedestrian does not know where to go then the APA will give more information such as ‘you are at south side of such and such street’.

-Consider informing user to time and/or distance left of walk signal and whether a free right on red is allowed. Standard pedestrian walking rate that is used in signal timing (from 4.0 to 3.5 feet/second) is recommended to improve intersection accessibility for all pedestrians, including those with disabilities (Coffin & Morrall, 2001). However, the Handbook of Transportation Engineering (Kutz, 2004) recommends a predicted walking speed of 2.8 feet/second to allow for geriatric and disabled pedestrians.

-Learn from Remote Infrared Audible Signage Systems. Consider the application of increasing clarity of directions and APA outputs as pedestrian becomes better aligned with route. This can also be used for initial alignment with crosswalk, before departing curbside.

-Researchers have found that the negative effects of noise on working memory tend to be greater for noise that is constantly changing compared to a steady stream of noise (Tremblay, Macken &
Jones, 2001). Use this advantageously to preserve working memory so that users can worry more about their safety in crossing the intersection.

Auditory messages will better be communicated through earphones, but at the expense of sacrificing situational awareness through direct senses (other environmental noises/cues). This will leave the user more vulnerable to his/her surroundings.

Continuous messages have been shown to decrease mental workload, thereby preserving situational awareness in many cases. For warnings, then, it is best to use discontinuous messages (i.e. “beep beep beep” as opposed to “Beeeeeeeeeep”). Warning earcons should be used only for special cases such as when the APA is recognized to be crossing during a no-walk phase. Assuming the technology is capable, if the APA’s precise location were known, it could alert the user to danger with a warning signal.

Make every effort not to harm concurrent task performance of following APA verbal commands and interpreting auditory noises from the environment. This shouldn’t be much of an issue based on the research we found, but keep it in mind. Consider Wickens’ MRT model on page 12 and sensory overload capacities, which are often contextually dependant. Through prototype testing and post-user feedback, this issue can easily be dealt with.

If any other technology were to be implemented in addition to required APA technology that would serve to assist low vision pedestrians that are not totally blind, such as some indication of APA-traffic signal grid compatibility, it may be important to consider this: objects that are at eye level are harder to identify than objects that are at feet level in pedestrians with low vision. This is likely due to the behavior of low vision pedestrians monitoring the walking surface.

Keep in mind how to combat the three types of “user errors” (pg. 13) through human factors-principled design and prototype testing.

Evaluate prototyping in terms of APA reliability and APA-user performance (Signal detection, localization errors, mean square distance from prime crosswalk path, etc) and incorporate environmental flow for the sake of ecological validity.

Essentially, aim at providing the best mental representation of critical objects in the pedestrians’ immediate environment, using judicious allocation of aforementioned suggestions and APA capabilities.

The final and crucial component of the auditory design process is formative evaluation via user testing (Hix and Hartson, 1993). Targeted listening studies with various sounds, contextual mock-ups, or prototypes of the auditory interface, designed to reinforce or refute the efficacy of the design or its fundamental parts, should be performed to inform and refine iterative design properties.
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