Nonvisual Route Following with Guidance from a Simple Haptic or Auditory Display

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Abstract: A path-following experiment, using a global positioning system, was conducted with participants who were legally blind. On- and off-course confirmations were delivered by either a vibrotactile or an audio stimulus. These simple binary cues were sufficient for guidance and point to the need to offer output options for guidance systems for people who are visually impaired.

Personal navigation systems using global positioning systems (GPS) are now commercially available for persons who are visually impaired (that is, those who are blind or have low vision). Some of the more widely used systems are BrailleNote GPS from Sendero Group, StreetTalk from Freedom Scientific, and Trekker from HumanWare (see, for example, product evaluations by Denham, Leventhal, & McComas, 2004; and NFB Access Technology Staff, 2006). All these systems use textual information to communicate with the user, in the form of either synthetic speech or electronic braille.

Loomis (1985) proposed that sounds that are perceived as coming from spatial locations (so-called virtual sounds) could be used to guide people who navigate without sight as an alternative to guidance information provided by synthesized speech. He and his colleagues (Golledge, Klatzky, Loomis, Speigle, & Tietz, 1998; Golledge, Loomis, Klatzky, Flury, & Yang, 1991) later developed a Personal Guidance System (PGS) using virtual sound and subsequently experimented with a range of different display devices, in addition to virtual sound, to determine the effectiveness of using different modes and guidance information cues. Three field experiments have shown that virtual sound and a haptic/auditory interface are well liked by users and effective in guiding them along paths. Some of the experiments compared display modes that had the directional compass mounted on the head, hand, or trunk of users (Loomis, Golledge, & Klatzky, 1998; Loomis, Marston, Golledge, & Klatzky, 2005; Marston, Loomis, Klatzky, Golledge, & Smith, 2006). Most recently, Klatzky, Marston, Giudice, Golledge, and Loomis

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(2006) found that virtual sound imposes considerably less of a cognitive load (the level of effort on working memory associated with thinking and reasoning, which potentially interferes with other thought processes) than does speech in a route-following task. In addition to our group, the SWAN project at the Georgia Institute of Technology has been investigating the potential of virtual sound as part of the user interface of wayfinding devices (Walker & Lindsay, 2003, 2005, 2006).

Because the virtual sound and haptic/auditory interfaces just mentioned all involve auditory signals, often with language, we were interested in whether a minimal haptic display that does not involve audition would be effective in guiding users along a route. Such a display may be useful for people in noisy environments, people who are deaf-blind, and people who are visually impaired who want to keep their auditory channels open only for environmental sounds and for conversing with others. Of course, using haptic information for route guidance does not preclude the use of audition for providing other sorts of information, such as the names and locations of streets or points of interest, but it would still be useful for minimizing the use of the auditory channel of users.

Two studies established the feasibility of using haptic displays for route guidance. Ertan, Lee, Willets, Tan, and Pentland (1998) showed that a 4×4 array of vibrotactile stimulators placed on the backs of users allowed the users to traverse indoor paths successfully. Successive pulsing of vertical columns within the array specified the direction of the turn toward the next waypoint along the route. In a more systematic study using a GPS navigation system outdoors, Van Erp, Van Veen, Jansen, and Dobbins (2005) showed that sighted users could easily walk over routes that were defined by invisible waypoints that were sensed by way of vibratory signals. The display used in their investigation consisted of eight vibrotactile stimulators that were spaced evenly about the waist, with the current direction to the next waypoint specified by the active stimulator at the corresponding direction around the waist. The distance to the next waypoint was specified by the spacing between successive one-second pulses of the active stimulator (which operated using a frequency of 160 Hz). With a little practice, the participants were able to walk over paths at acceptable walking speeds.

The vibrotactile display that was used in our study relies on an electronic compass that is attached to a visor worn on the user's head so that the direction to the next waypoint is relative to the head. Since it is worn on the wrist and uses a single vibrotactile stimulator, the display we used is minimal in comparison to previous vibrotactile displays that were worn on the torso. When the head is facing the next waypoint, the vibrator conveys a signal indicating a correct or incorrect head- facing orientation. Thus, the user makes use of both cutaneous information from the vibrator and kinesthetic information from the head to determine the direction to the next waypoint. Because the direction to the next waypoint is not mapped to body locus, the stimulator can be worn on any part of the body. In our study, we compared the vibrotactile display with an auditory display that provided the same binary corrective information. The auditory display did not use directional virtual sound; rather, it used a chime as the cue for correctness. The minimal vibrotactile and auditory displays were tested in two different modes. The cue was activated either only when the user was headed in the correct direction and deactivated when the user headed in another direction ("on-course cue" mode) or only when the user was off course and deactivated when the user was on course ("off-course cue" mode). In addition to the two displays, we also tested a display that had been evaluated in previous experiments, which is described later.

Method

Participants

The participants were eight adults who were legally blind, lived in the local community, and ranged in age from 25 to 85, with a mean of 47.3 years (*SD* 20.0). The etiology of their blindness varied widely. Approval for research with human subjects was granted by the Office of Research at the University of California at Santa Barbara (UCSB), and each participant signed an informed consent form.

Hardware

The current version of the PGS, which was featured in the study presented here, uses a Toshiba notebook computer, Trimble 12-channel differential GPS receiver (better than 1-meter, or 3-foot, accuracy), Honeywell magnetic sensor, and peripheral interface card and proprietary software, all carried on a backpack-like aluminum frame. The magnetic sensor was used as an electronic compass to update the computer database constantly about the heading direction of the user, which was then used to guide the user toward the next waypoint. The vibrotactile stimulator was an Audiological Engineering VBW32 skin transducer, 2.54 centimeters long × 1.85 centimeters wide × 1.07 centimeters thick (about 1 inch × .7 inch × .4 inch) and weighing 6.5 grams (.23 ounce). The transducer was driven by a 290-Hz-square wave signal, generated by the computer's audio hardware. The vibrotactile signal was perceived as well above the threshold for detection by all the participants.

Spatial displays tested

For both displays, each participant wore a hat with a compass mounted on the underside of its visor. The laptop computer received its bearing information from the participant's head orientation. Route guidance information was delivered either by the vibrotactile stimulator worn inside a wristband or by a small earbud that delivered a pleasant chime sound from a 1.75-second wavefile that was continuously repeated. The participants followed a route with six turning points (waypoints). As in previous experiments, they received a "walk straight ahead" cue if they were facing within 10 degrees of the correct direction to reach the next waypoint.

In this experiment, we tested two modes for conveying the "walk straight ahead" information (see Figure 1). In the on-course cue mode, the vibrotactile or audio cue was activated when the head faced within a 20-degree cone around the target heading; the participant heard or felt nothing when outside the cone. In the off-course cue mode, the participant heard silence or received no vibrotactile stimulation when within the cone, but received a cue when outside the cone. We also tested a fifth condition with the handheld Haptic Pointer Interface (HPI) (Loomis et al., 2005) for a comparison with our previous work. In this condition, we mounted the electronic compass on a

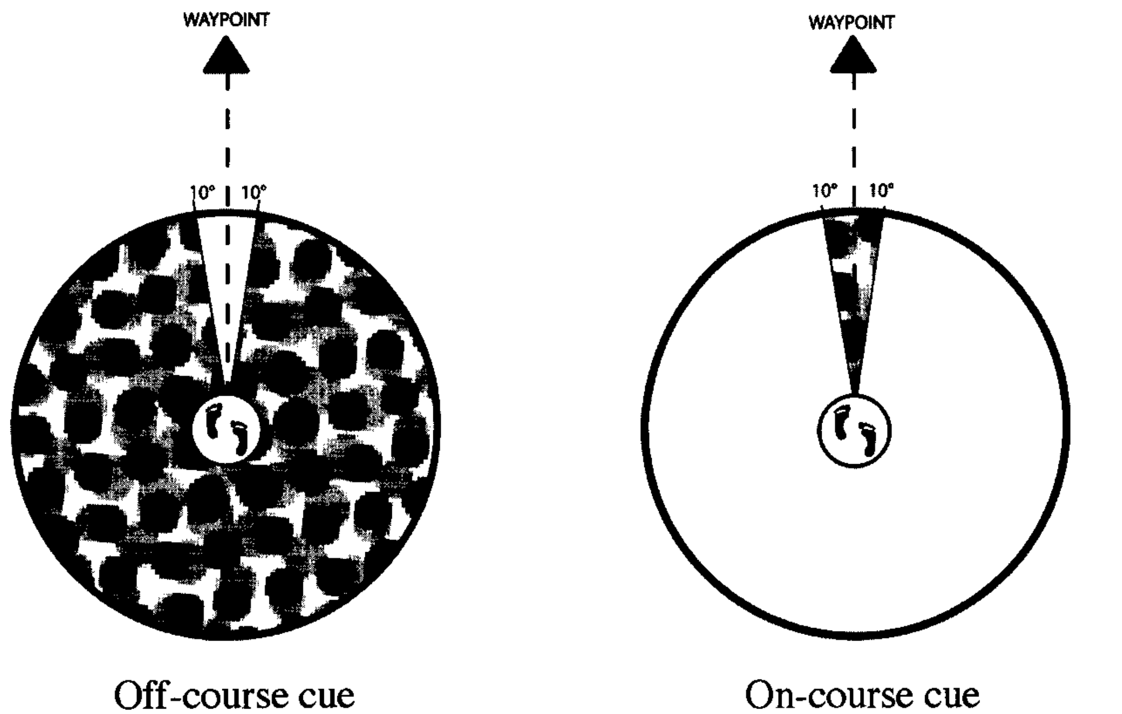

Figure 1. The on-course and off-course cues. The off-course cue gives a signal (indicated by the filled area) when the pointing compass is off course and returns no signal when the pointing compass is within 20 degrees of the correct heading. The on-course cue gives a signal when the pointing compass is within 20 degrees of the correct heading, and no signal when it is off course.

wooden pointer that a participant held in his or her hand, thus providing the computer with the pointing direction of the hand instead of the facing direction of the head. To avoid fatigue, this display was tested only in the on-course cue mode with the audio chime as output. In summary, there were five modes: on-course cue with vibration (on vib), on-course cue with audition (on audio), the corresponding off-course cue conditions (off vib and off audio), and the HPI with an on-course audio cue (on HPI).

Interview and familiarization

After personal information about blindness and orientation and mobility skills was recorded, the participants were familiarized with the procedures and use of the PGS. They were given a raised-line tactile map that they traced with their fingers as an example of a general route-following task. Next, they traced the same route that now included raised circles around each waypoint. They were told that these circles represented the 2.1-meter (6.9-foot) area that they needed to find to trigger the next waypoint signal. A script was read explaining the general tasks to be followed, and before each of the conditions was tested, a specific script was read that gave information about the hardware and how the information would be delivered for that condition.

Route-following test

All the participants were required to use a long cane, and those with any residual vision wore a blindfold. Experiments were scheduled only when GPS reliability was determined to be adequate; we used Trimble Planning Software to determine when the horizontal dilution of precision, an inverse measure of precision, was less than 2.0.

Two paths of 80 meters (262 feet) were designed for a large open plaza at UCSB and logged into the computer database of the campus. Both paths had a right and left 90-degree turn and two left and two right 45-degree turns, yielding seven path segments. The two paths could be started at either end, giving a total of four different paths to walk. In addition, a longer path was created, so the participants could have a practice walk before they tried each of the actual test paths.

The order of the five conditions was different for each participant, and the four paths were assigned to conditions in different orders. Before each trial, the participants had one practice trial on a longer path, where the device was explained and they could ask questions and become accustomed to how it worked.

Results

Travel time and distance traveled

The times it took to walk the various paths were recorded, along with any errors. This version of the PGS, unlike our previous devices, did not provide specific information that a waypoint had been reached or about which way to turn toward the next waypoint. Instead, a waypoint was discovered when the signal suddenly indicated a deviation from the course, at which point the participant had to "scan" around by moving his or her head or hand to find the new direction of the path. The walking speeds were similar to our previous devices that indicated which direction to turn, but there were noticeable delays because the participants had to scan around to find the next waypoint. All the participants were able to use all the displays and modes to navigate the 80-meter (262-foot) paths, make 6 turns, and find the 1.2-meter (about 4-foot) radius endpoint. Although the on-vib condition produced the fastest mean time and the on-HPI condition produced the slowest, there were no significant differences between the five conditions on the basis of an analysis of variance (ANOVA) (see Table 1).

The distance traveled was measured, where 80 meters (262 feet) would be the minimal length of the path. As with the time data, the on-vib condition produced the shortest mean distance and the on-HPI

Table 1.
Path completion times and distance, standard deviations, and range.

Condition	On audio	Off audio	On vib	Off vib	On HPI
Mean time (in seconds)	169.4	163.8	144.6	168.5	173.5
SD	54.0	41.9	31.2	46.4	63.3
Range	110–282	117–238	108–188	115–229	116–287
Mean distance (in meters)	96.8	97.7	90.7	94.5	98.3
SD	14.6	16.7	3.4	5.1	13
Range	84–128	86–138	86–97	84–129	89–110

Note: on audio = on-course cue with audition, off audio = off-course cue with audition, on vib = on-course cue with vibration, off vib = off-course cue with vibration, and on HPI = the HPI with an on-course audio cue.

condition produced the longest, but there were no statistically significant differences among the five conditions.

Posttest evaluation

Persons who are visually impaired are a heterogeneous group with a wide range of abilities, needs, and levels of comfort with assistive devices. They have expressed interest in customizable and more personalized devices (Golledge, Marston, Loomis, & Klatzky, 2004; Marston et al., 2006; Ross & Blasch, 2002). After the experiment, questions were asked to elicit the participants' preferences for the various output devices. Ratings were based on a scale of 1 to 10, from 1 = not at all acceptable to 10 = very acceptable. The first set of questions consisted of five items: precision of the directional information, personal safety while using the device, ease of use, privacy (does not draw attention), and overall opinion. Figure 2 shows the mean ratings for the five conditions and the standard deviations. All the ratings led to significant effects in the ANOVA: $F(4,28) = 2.839, p = .023$ for precision; 3.943, $p = .004$ for safety; 4.026, $p = .004$ for ease of use; 5.221, $p = .001$ for privacy; and 3.177, $p = .013$ for the overall rating. Moreover, variability was the highest for conditions with the lowest mean preference. The ratings for the HPI were the most varied, with some people rating it high and others rating it low. Paired, two-tailed t-tests were calculated to compare each condition against all the others, for each of the five rating questions. The few significant tests consistently showed that the on-HPI condition was rated lower than the other conditions: lower than off vib overall, lower than on vib for precision, and lower than all other conditions for privacy.

Attitudes and preferences

Some participants reported they would not use any kind of device that would draw attention to them, whereas others said they would use a guidance system no matter what its appearance or how much attention was focused on them. This finding was consistent with the finding of an earlier survey (Golledge et al., 2004).

A series of questions, on a scale of 1 = strongly disagree to 10 = strongly agree, was asked to determine if a system like this, with no turn information and a single cue, would be adequate for a PGS to guide travelers who are blind. There was high agreement among the participants that such a system could guide users successfully, even without any information on which way to turn at each waypoint. The participants reported little or no problem finding the new direction (mean rating = 7.6). If only one guidance option was available, they preferred the off-course cue (7.3) to the on-course cue (7.1) but thought that a commercial PGS should offer both as an option (9.3). Some comments indicated that the off-course cue demanded less attention and seemed more natural. The participants strongly agreed (8.6) that sometimes no spoken information would be sufficient and that sometimes spoken information would be beneficial (8.6), and they thought that a commercial PGS should offer both options (9.1).

Constant route-guidance mode

Some GPS devices give spoken instructions about the next waypoint and wait until they are queried again before they give more information. The UCSB PGS gives constant orientation information about the direction to the next waypoint, whether through spatial displays, sound cues, or vibrotactile stimulation. Three questions were asked to see if the participants desired this kind of constant

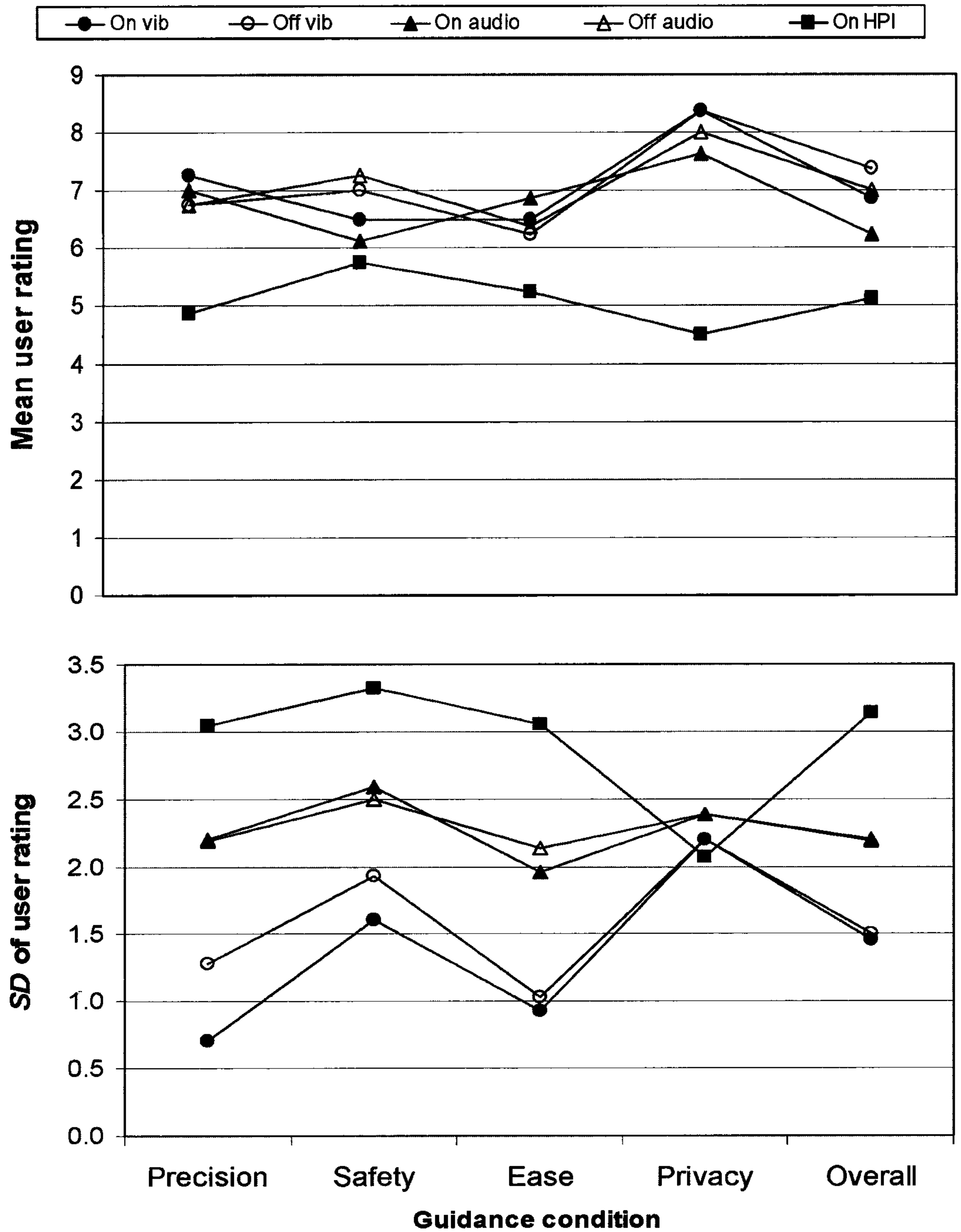

Figure 2. Mean user-preference ratings on a scale of 1–10 (top) and standard deviations (bottom) for the five conditions that were tested.

information about their orientation on a 5-point scale, from 1 = strongly disagree to 5 = strongly agree. The participants agreed that they liked this kind of positive confirmation (4.4) and wanted to have this option in a commercial GPS system (4.9). This finding agreed with the findings of our previous experiment (Marston et al., 2006).

Discussion

This study evaluated simple binary displays on both objective measures of travel time and distance and subjective ratings. The main findings were as follows: (1) a simple binary signal to indicate correct course headings led to accurate route following, (2) tactile (vibration) and auditory signals were equally useful, (3) signals that identified an off-course heading (no active signal when on course) were preferred and rated as more natural, (4) the HPI display produced an essentially equivalent level of performance but was rated as awkward, and (5) the participants preferred having options and flexibility between different displays to accommodate their individual and situational preferences

The performance data indicate that a minimal vibrotactile or auditory display is sufficient for route guidance when GPS information and the signal from an electronic compass are combined to determine the direction to the next waypoint. The use of a single vibrator has obvious advantages over multivibrator displays, such as cost, complexity, and simplicity in attire. A disadvantage is that, upon arriving at a waypoint, the user needs to sweep his or her head or hand to find the direction to the next waypoint, which takes time. Multivibrator displays and virtual sound displays convey this information immediately without the need to search. Because the vibrotactile channel is distinct from the auditory channel, it is likely that a haptic display would permit a user who is blind to travel in a noisy environment or to make use of environmental sounds and carry on a conversation while following a route. In addition, a haptic display may make it possible for a person who is deaf-blind to travel independently. For those with no hearing loss, supplementary auditory information delivered infrequently by a speaker or earphone can be used to confirm destinations, inform the user of his or her progress along the route, and identify points of interest off route.

This experiment and the participants' preferences clearly show that a wide range of output devices work well to guide people who are visually impaired and that a navigation system for people who are visually impaired should offer many options to suit individual needs. If a compass is used to give the heading direction, it should function when it is mounted on various parts of the body. A choice of audio or vibrotactile signals should be offered. If audio output is desired, users should be able to choose the type of signal, instead of having to use a preloaded sound. As commercial GPS systems mature, they should offer more options that will let users design the best output for their individual information needs. In addition, systems like the present one, with appropriately flexible interfaces, may eventually find application among sighted users, such as emergency personnel working in darkness or smoke.

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