Dynamic Route Descriptions: Tradeoffs by Usage Goals and User Characteristics

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ABSTRACT
Principles are empirically established for various multi-modal representations of route descriptions that are found to facilitate aspects of user navigation performance on significantly different levels. Some representations clearly minimize navigation completion time, navigation error, and/or distraction to focal view, while others hinder these goals. Furthermore, user characteristics such as brain lateralization and information type preference relate to significant differences in representation effectiveness. "Best Choice" route depictions are presented based on experimental participant performance data from a simulated navigation task. Results may be useful in information design for helmet-mounted displays and other wearable computing devices.

Keywords
dynamic information design, route descriptions, way-finding, secondary displays, notification systems

1. INTRODUCTION
Route descriptions assist people's efforts in getting from one place to another. Certainly, we have all experienced assorted forms of navigational assistance, perhaps most commonly verbal driving directions, road maps or strip maps, and written lists of turns and landmarks required to negotiate a route. While the usability of various forms of way-finding information may be argued by some, there can be no question navigation assistance is often a critical factor for navigation success.

Advances in pervasive computing, display technology, and real-time location tracking, as discussed in [3], enable enormous potential for improving efficacy and usability of route descriptions. These guides appear in automobile dashboards, on wearable displays and handheld devices, and can even be found in some golf carts. While older versions simply allow selection and display of stored data, newer models leverage location tracking features by providing a "you are here" beacon and adaptively updating navigation advice accordingly.

We can do even better. By understanding and capitalizing on variations in route description representations according to types of users and performance expectations, designers can reduce ambiguity and error if they use this knowledge for dynamic, adaptive displays. Just because we *can* render a map with an updating beacon, or just because designers *think* maps are the best route descriptions, lends no solid rationalization to a system design process. However, empirical studies scientifically establishing design principles provide sound arguments for rule formulation required in adaptive systems, as well as evidence for expected success.

Potential usage scenarios best illustrate the need for understanding tradeoffs of way-finding information representation according to user characteristics and their goals. Consider a solitary automobile driver hurrying through an unfamiliar city during busy traffic—although a route description may be critical, minimizing driving-focus distraction is even more imperative. This situation implies some importance in making right navigation choices the first time, but consider a direr instance—soldiers or emergency personnel may depend on route descriptions to negotiate though extremely dangerous conditions (mine fields, chemical or hazardous environments, enemy territory, etc.) that do not tolerate path deviation but mandate navigation speed. In cases like this, a route description must be optimized for accuracy and quick decoding. However, in less demanding situations, such as a leisurely drive on a highway or stroll through the woods, these usage requirements could be relaxed or removed.

Just as usage goals situationally vary; people vary. Certainly, novices and experts alike demand similar system output, yet from an uncommon experience base necessary for output interpretation. People process and understand information differently—yet one-size-fits-all approaches to graphics and interface design seem common. Adaptive presentation of content, based on principles for accommodating user characteristics can potentially reduce these disparities.

2. RELATED WORK
This research effort builds on an ongoing series of related efforts, aimed generally at understanding how to best encode information in a display that is not a user's primary focus. Route description evaluation fits nicely into this

area, because the user's focus can often be presumed to be directed at executing the navigation tasks via some mode of transportation. Consulting a route description requires a transition and context switch from the focal (primary) task to the route guide (secondary) display. Often, this display may only be briefly glanced at, with the expectation that the desired information can be quickly detected, decoded, and processed—requiring little attention shift from the primary task. These are characteristics also typical of multiple view and secondary display systems.

Baldonado and Kuchinsky present eight guidelines for when and how to use multiple, coordinated sets of views for information visualization of a single, conceptual entity [1]. Their work is important because it acknowledges the natural complexity introduced to the user attention system. They claim that though an analysis of impacts to utility this complexity can be managed as cost/benefit tradeoffs. This paradigm, long recognized as a result of attention limitation by cognitive psychology researchers [7], seems to underlie secondary display research and serves as a model for this work as well.

Recent secondary display empirical studies purport to understand how information can be encoded effectively. McCrickard et al. investigated the differences between ticker, blast, and fade methods of information presentation at varied size and speed in a secondary display [10]. Maglio conducted a similar study [9], but conclusions about the effect of distraction the secondary display had on the primary task differ, suggesting fine conditions for cost/benefit tradeoffs. Comparative studies of secondary display attributes also include Somervell's establishment of tradeoffs for use of text or graphic representations at fast and slow speeds [11] and Tessendorf's extension of Cleveland and Mackinlay's attribute ordering to secondary task design [12]. The Tessendorf study is also noteworthy in its finding that identically encoded secondary display images do not convey information as well as focal display images, and even conform to different attribute orderings. Methods used in these research efforts influence the experimental approach and design of this effort.

An important distinction should be made between the studies cited above and this research, which is specific to route descriptions. Secondary displays previously tested encode information not related to the primary task. Although primary task performance level has been found to decrease as a result of user shift in focus to a secondary task and introduction of distraction [9, 11, 12], tasks previously included in experimentation do not require decisions that are guided by secondary display information.

Research specific to route descriptions and way-finding information is certainly focused on effective automated generation, and is well summarized in [3]. Baus et al. recently introduced a mobile display approach for depicting incremental route descriptions resembling 3D-walkthroughs with vector graphics [2]. Additional work investigated how systems could adapt to user cognitive resources, which could be limited by traveling speed, environment familiarity, time pressure, and physical exertion [3]. Darken and Sibert's extension of way-finding strategies and behaviors into virtual worlds provides a good overview of general challenges in spatial knowledge theory and route description evaluation [4]. Using a classification of way-finding objectives based on level of a priori knowledge of environment and target location, they compare effectiveness of map, grid, and map/grid navigation aids to a control condition. However, no efforts have investigated tailoring automated route descriptions to user perceptual and information processing preferences.

In order to understand how to best present information to different categories of users, presumably some data must allow user classification and rule referencing. Certainly, this data could result from system training based on previous user actions. However, if a system could quickly and accurately determine perceptual and processing preferences, cognitive and situational adaptation of route description presentation may be practical.

Many introductory psychology textbooks and commonly available material, such as [6, 8], provide discussion of information processing tendencies associated with dominant brain lateralization (ie., left or right brain hemispheres). Although brain lateralization research has a long way to go before certain principles are established, there appears to be a few well recognized conceptions which would seem to impact effectiveness of route description usability. Left-brain dominance is said to indicate logical, detail-to-detail, linear processing, with little difficulty interpreting symbology or following directions. Characterizations of right-brain processing include being a big-picture, holistic and random approach, with symbolic interpretation relying largely on intuition and contextual cues. Use of brain lateralization assessment to classify users is promising, since it can be quickly ascertained and previous informal studies show that most people can identify their result from five possible result choices, indicating a favorable level of assessment agreement.

3. METHODOLOGY

Upon these related efforts—secondary display studies, route description depiction and evaluation, and brain lateralization application—this research seeks to contribute toward two fundamental questions regarding automated way-finding information and its users:

(1) *do different representations of route descriptions enable significant changes in aspects of navigation task performance?*

(2) *can user characteristics be identified and found to relate to variations in guide representation effectiveness?*

We approach these questions empirically, using a lab-based experiment to isolate independent variables, control internal validity, and collect participant performance data for analysis. Section 4 presents the results of this analysis;

Section 5 summarizes and discusses the results and generalizability; Section 6 concludes this paper with statements about research implications, potential applications and further work required in this area. However, this section prefaces these findings with statements about experiment specifics, to include an explanation of our independent variables and metrics, information about test participants, and a description of the experimental design and platform.

3.1 Independent Variables

We selected six different information representations for guiding a navigation task. A brief description of each route description follows, and examples can be seen in Figure 1.

Graphic route descriptions are a depicted as a simple arrow, pointing in the direction of the next step required to reach the navigation goal .

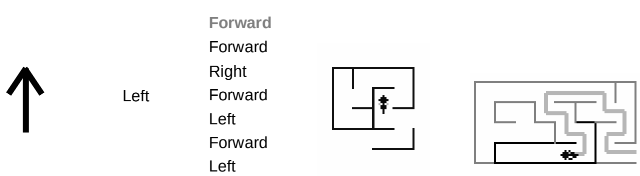
Text is a single word, such as "forward" or "right", which also represents the next step toward the navigation goal.

Audio commands simply read the next text command after any step or change of direction; no visualization is present.

Text List descriptions are a constantly updated series of the next seven required navigation steps, with the immediate step highlighted (yellow) at the top.

Partial Map includes only a current location beacon (red) and scene information immediately visible or already visited; the navigation goal or required steps are not explicitly apparent.

Full Map with Solution Path depicts a current location beacon (red) and the entire navigation environment; a highlighted path (yellow) indicates the route to the navigation goal.



(a) (b) (c) (d) (e)

Fig. 1. *Example of each visual type of route descriptions tested. Images here are displayed in negative for clarity. (a) graphic, (b) text, (c) text list, (d) partial map, (e) full map with solution path.*

Neither map automatically rotated to maintain forward-up orientation, since a target application system does not provide this feature. However, the beacon's point allowed determination of travel direction in relation to the map. These six route descriptions and a control condition (where no route description is provided) are the seven independent variables in this experiment.

3.2 Metrics

In order to measure and communicate the relative effectiveness of the independent variables, we establish three metrics which seem typical to actual navigation task goals:

Navigation Time captures the amount of time passed from the beginning of the navigation task (user presses a "Ready" button in this case) to reaching the navigation objective (which is the maze exit in each round).

Navigation Error describes the number of instances when a user deviates from the solution path before reaching the objective. Even though a user may take multiple steps along an incorrect route, the error is counted as a single instance until stepping off the solution path again.

Distraction to Focal View expresses the relative amount of attention devoted to someplace (presumably the route description) other than the center of the user's field of vision. In the experiment, this is captured by counting user non-responses to various key-press prompts. These prompts intermittently appear and disappear in the center of the screen. So as not to re-attract attention, they are designed not to be easily noticeable with a light-gray color against the cyan maze walls.

3.3 Experimental Platform & Design

Thirteen participants voluntarily completed both parts of the experiment (as discussed below). They ranged in age from 22 to 60 and included males and females. The group represented a wide-variety of computer use comfort and experience levels, although everyone actually used a computer at least occasionally.

The test platform consists of two programs run on a desktop computer. The first program, referred to as Brain Works and developed by Synergistic Learning Incorporated, is comprised of twenty multiple choice questions. Brain Works automatically scores participant answers and provides an assessment in the form of four percentages—a left and right-brain dominance score set

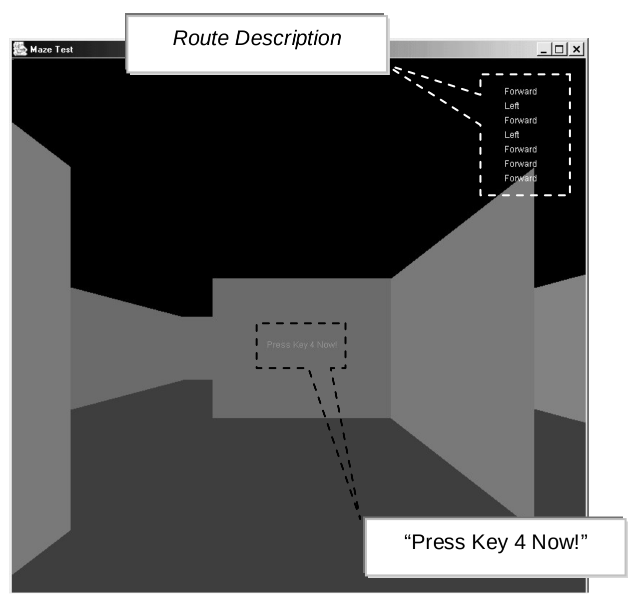


Fig. 2. *Screenshot of the 3D Maze experimental program. The route description appears in the top-right corner of the screen, in the area indicated by the light dotted line. The example shows the text list guide. Barely visible in the center of the screen is an intermittently appearing focal prompt to "Press Key _ Now!"*

and a visual and auditory information preference score set. Both sets total to one-hundred percent. After completing the Brain Works questions, participants begin the Maze Test (see Figure 2)– seven rounds of negotiating a 3D Maze with keyboard arrow keys. During the rounds, the various route descriptions are dynamically updated based on position within the maze and displayed in the top-right corner of the screen. We selected this particular location of the screen to display the route instructions so that results could best apply to helmet-mounted displays and other wearable computing devices typically mounted outside of the main focal area to avoid impacting normal vision. Intermittent key press prompts were used to measure primary task attention by simulating observable events that should invoke some action during a real-world navigation task. For example, a vehicle operator may honk a horn or manipulate the cruise-control in response to observed driving events, and a soldier may react to environmental observations with weapon, radio, or other equipment interactions. The test program automatically computes and records experimental metrics. A single computer was used to test all participants, ensuring comparable program processing overhead.

We used a Latin square implementation to rotate the appearance order of the independent variables among equal portions of the test population. That is, two participants started with the graphic route description, then text, text list, audio, partial map, full map, and finished with the no indicator condition. The next two started with the text route description, continued with the same order, and finished with the graphic route description. The continued pattern ensured that no independent variable was disproportionately presented in the beginning or ending rounds, when participant maze proficiency could be confounding. However, maze structure for each round is constant across experiment versions, regardless of supporting route description. Maze structure does change from one round to the next to prevent solution learning.

4. RESULTS

Findings discussed in this section are based on analysis of data collected in our experiment. The section is organized into two parts—general results, which apply to the test population at large, and results specific to samples filtered according to brain lateralization (left/right) or information type preference (visual/auditory). Inferential statistics rely on Student's *t* distribution, due to the small test population. Nevertheless, conclusive findings ($p < 0.05$) are apparent, demonstrating differences between various route descriptions and the population mean under all three metrics. Discussion and comment on results is withheld until Section 5.

4.1 General Results

Consideration of route description mean scores under all three metrics show some representations allowed better performance than the control condition (no indicator), and others seemed to impair performance. In particular, graphic, audio, text, and text list representations support way-finding best under all three metrics, while the partial and full maps seem to be poor choices. However, analysis must consider performance variance, of which there is plenty. Therefore, the results presented according to each metric are limited to sample difference tests. Comparison of sample means is possible on associated figures.

Navigation completion time is the first metric, capturing the differences in amounts of time the navigation task took when various route descriptions are presented. Figure 3 shows the performance results and confidence intervals for navigation time according to each route representation.

Two types of representations offer significantly better navigation completion times than the overall average: the audio commands ($t(12,2)=3.84$, $p=0.002$) and the arrow graphic ($t(12,2)=3.31$, $p=0.006$). That is, when participant maze navigation was supported by the audio or graphic route descriptions, significantly faster maze completion times resulted, compared to the average completion time for all rounds. Although performance supported by both types of maps was generally poor, the high variance prevents a statistically conclusive result (that the maps cause slower navigation time) at the 95 percent confidence level.

The second metric is navigation error, or the number of instances a participant leaves the solution path in a given round. Figure 4 depicts the differences in maze navigation error. Clearly, three route representations allow fewer navigation errors: graphic ($t(12,2)=7.17$, $p<0.001$), audio ($t(12,2)=4.45$, $p<0.001$), and the text list ($t(12,2)=3.68$, $p<0.001$). Since the confidence intervals also are much narrower for these three types, it can also be said that the amount of navigation error is much more predictable when supported by graphic, audio, or the text list. Furthermore, there is also a significant difference between the numbers of times participants left the solution path when assisted by the graphic representation compared to when there was no route indicator ($t(24,2)=2.09$, $p=0.046$) [graphic vs. full map with solution is marginally significant as well ($t(24,2)=1.95$, $p=0.062$)].

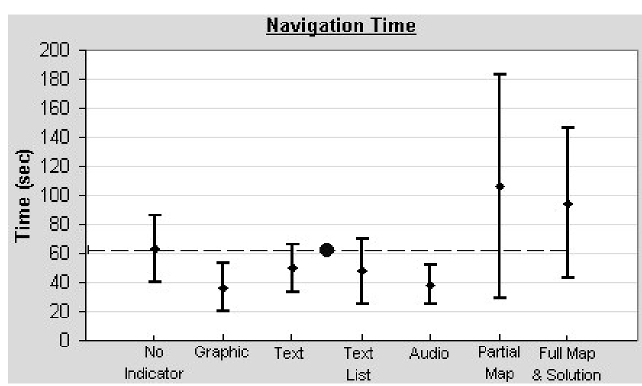


Fig. 3. *Comparison of participant maze round completion times for the control condition (no route description) and the six route descriptions. Means for each condition (small dots) with 95 percent confidence intervals (vertical bars) are compared against population mean (large dot) round completion times.*

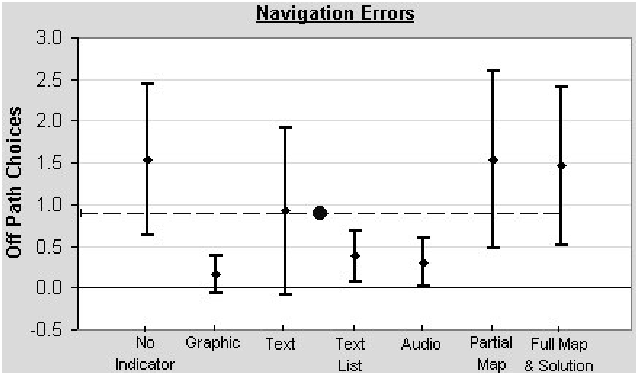


Fig. 4. *Comparison of the number of instances participants left the solution path in rounds testing the control condition and the six route descriptions. 95 percent confidence intervals shown.*

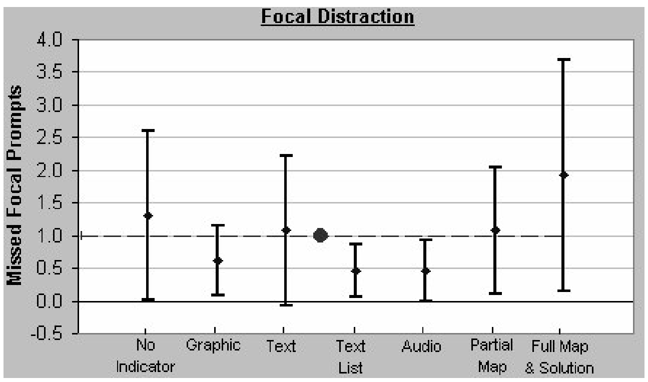


Fig. 5. *Comparison of the number of instances participants failed to properly satisfy key-press prompts in rounds testing the control condition and the six route descriptions. 95 percent confidence intervals shown.*

Focal distraction is measured by the number of times during a round a participant failed to notice and act on a prompt to press a key. It is the third and final metric for comparing the route description representations, perhaps indicating the amount of attention required to use each type. Two representations cause significantly less focal distraction/attention shift: audio commands ($t(12,2)=2.45$, $p=0.031$) and the text list ($t(12,2)=2.88$, $p=0.014$). Figure 5 shows the means and confidence intervals obtained for this metric. Note this is the only metric in which the partial map mean seems different than the full map mean. Inspection of the raw data reveals that each type of route description supported round completions in which all key-prompt responses were acted on.

The results of the Brain Works portion of the testing indicated the participants were fairly well balanced within the group according to brain lateralization and information type preference. No trend was observed linking either assessment result to age, education level, or computer experience. No participant expressed disagreement with his or her assessment. Seven participants were assessed as left-brain dominant, and six were right-brain dominant. For the visual/auditory scores, eight exhibited a visual

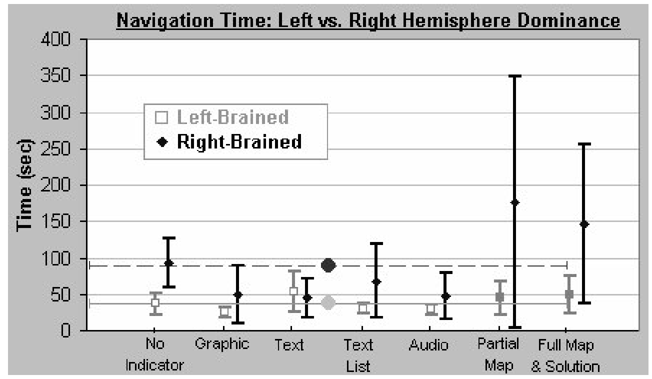


Fig. 6. *Comparison of participant maze round completion times for left-brain group and right-brain group according to each condition and overall (large dots). 95 percent confidence intervals shown.*

information preference and four showed an auditory preference. The remaining participant was evenly visual-auditory, and was included in both groups upon filtering. The following sections repeat analysis under the three metrics, similar to that reported above, only on groups of participants filtered according to their assessed lateralization and information type preference.

4.2 Left & Right Brain Dominance

When grouped together, the seven participants assessed as left-hemisphere dominant exhibited stronger navigation performance in general, especially with the no indicator condition. This can clearly be seen in Figure 6, which shows the left-hemisphere group vs. the right-hemisphere group for maze completion time. Of particular interest is the relative decrease in the amounts of performance variance with the graphic, text list, audio, and map route description representations. For the left-brained group, three types of representations caused a faster completion time than average: graphic ($t(6,2)=4.65$, $p=0.004$), audio ($t(6,2)=3.30$, $p=0.017$), and the text list ($t(6,2)=3.10$, $p=0.021$). The text list difference was not a result seen for the general population.

For navigation error avoidance, left-brained participants found the same types of route representations effective: graphic ($t(6,2)=5.57$, $p=0.001$), audio ($t(6,2)=5.57$, $p=0.001$), and text list ($t(6,2)=2.53$, $p=0.045$). By this metric, the left-brained group was quite indistinguishable from the general population. However, for the prevention of focal distraction, the two representation types which were found to be significantly better for the general population did not produce significantly more key-prompt responses for the left-brain group. In fact, no representation proved effective by this metric for this group. Most surprisingly, the text representation had the greatest amount of variance, causing the confidence interval to be +/- 2.4 missed key-prompts per round.

The six participants forming the right-hemisphere dominant group can be best characterized by the variance in the completion times while assisted by either form of map.

Like the left-brained group and the general population, both the graphic and audio route descriptions supported significantly faster than average round completion times ($t(5,2)=2.61$, $p=0.047$ and $t(5,2)=3.35$, $p=0.020$), however, a single text instruction also proved to be effective ($t(5,2)=4.27$, $p=0.008$). Similarly, for navigation error avoidance, the same three types are seen to be significantly more effective: graphic, audio, and text (all $t(5,2)=4.14$, $p=0.009$). Text was not effective for either the general population or the left-brained group. Although the text list showed marginal significance in difference for preventing focal distraction and missing key-press prompts ($t(5,2)=2.37$, $p=0.064$), no route description representation was distinguishable by this metric.

4.3 Visual & Auditory Information Preference

Neither the visual or auditory group displayed more extreme scores than the groups based on brain hemisphere. In fact, if Figure 6 were to include the visual and auditory groups, the means and lengths of confidence intervals would fall between those of the left and right-brained groups—with a single exception. Largely due to the similarity in left and right group round times when supported by text cues, the visual group performed better than both and the auditory group performed worse (although not significantly).

When the nine visual information preference participants were grouped together, the only significant differences between route descriptions were with the graphic representation. The difference results for navigation time with graphic support is $t(8,2)=5.64$, $p<0.001$; for prevention of navigation errors the difference is $t(8,2)=3.34$, $p=0.010$. No route representation minimized focal distraction any more than the average.

Conversely, participants that formed the auditory information preference group were able to achieve better results with at least one representation under each of the three metrics. To minimize maze navigation time, the audio commands were significantly better ($t(4,2)=3.13$, $p=0.035$). Rounds supported with graphics were navigation error-free, yielding a significant difference (*all perfect scores*, $p=0$) with the average. Likewise, the text lists and audio commands also were effectively better at preventing errors ($t(4,2)=3.03$, $p=0.038$ and $t(4,2)=3.03$, $p=0.038$). For this group, the full map with solution was actually significantly worse for preventing navigation error ($t(4,2)=2.86$, $p=0.046$). The same two route representations that were effective for general population minimization of focal distraction were also effective with the auditory group: text list ($t(4,2)=3.36$, $p=0.028$) and audio ($t(4,2)=3.36$, $p=0.028$).

5. DISCUSSION

This section presents a summary of experimental findings for both the general population and user characteristic groups, a discussion of actual and expected results, and comments about result generalizability.

Table 1. Route Description Representation Differences ($p < 0.05$)

Usage Goal	User Characteristic	Best Choice
Minimal Navigation Time	General Population	1. audio, 2. graphic
	Left Dominance	+ text list
	Right Dominance	+ text
	Visual Preference	– audio
	Auditory Preference	– graphic
Minimal Navigation Errors	General Population	1. graphic, 2. audio, 3. text list
	Left Dominance	(2. text list, 3. audio)
	Right Dominance	– text list, + text
	Visual Preference	– audio, – text list
	Auditory Preference	(No change)
Minimal Distraction to Focal View	General Population	1. text list, 2. audio
	Left Dominance	– audio, – text list
	Right Dominance	– audio, – text list
	Visual Preference	– audio, – text list
	Auditory Preference	(No change)

Recommendations ordered and based on significant differences with population mean. "Best Choice" indicators enabled better performance under metrics corresponding to usage goals, $p<0.05$. For user characteristic groups (left or right brain hemisphere dominance and visual or auditory information preference), Best Choice notations reflect changes ("+" = addition, "–" = subtraction) to the general population findings.

5.1 Summary of Findings

Table 1 summarizes the significant experimental findings, based on consideration of all rounds and route description types for the general population and groups established according to brain lateralization and information preference scores. This table should be used to guide system design decisions, after prioritizing usage goals of a navigation-support display. Recommendations applicable to a general population are likely to be most suitable for an unknown user. However, if information is available that provides insights about user characteristics (such as that obtained with the Brain Works program), the refined design recommendations may be more useful.

5.2 Actual vs. Expected Results

Many of the experiment results and observed behaviors were predicable and even expected. However, many others we expected to see simply were not validated or were sometimes wholly refuted. Alternately, other findings were complete surprises which seem to evade any explanation. This section discusses the various results according to level of expectation. The discussion begins with unpredictable and unexpected findings.

Perhaps the most surprising result was the complete inadequacy of the map representations for all navigational purposes. In fact, rounds played without any route description, even as beginning rounds, almost always were completed faster than map rounds—even though participants were told they could ignore the route description if it was confusing them. Another unexpected user behavior which was observed during testing was the effect the audio commands had on navigation cadence. Even when some participants could see a long, straight hallway ahead of them, they often took only one halting step at a time, waiting until the next audio command told them to go forward. This behavior was not replicated with any other route representation. Most curiously, round completion times with audio cues were often still significantly faster.

We also expected most, if not all, of the rounds with some type of route description to be completed faster and with less error than the control condition rounds. While a simple ordering of means shows this, there was usually too much result variation to find significant differences. Likewise, the rounds without an indicator should have certainly had among the lowest missed focal prompt rates. However, the mean number of missed focal prompts in the general population control condition was only exceeded by the mean for the rounds with the full solution displayed.

Several other counter-intuitive results are apparent. Based on the information that right-brained people should prefer a holistic approach, and left-brained people favor single step directions, the results for the single text command and the text list seem reversed. Clearly, left-brained people used the text list best, and right-brained people made effective use of the single text command.

The most predictable result which was empirically verified is that those with a visual information preference complete maze rounds fastest with graphic route descriptions, and those with an auditory information preference perform best with the audio cues. However, as unimpressive as this conclusion may appear, the startling fact is the auditory preference participants received such classification by the Brain Works program—which was comprised of completely visual questions and contained no audio support at all. The apparent accuracy of the classification itself seems to be the true achievement here, providing a possible basis for adapting display properties to best fit user characteristics.

5.3 Result Generalizability

Generalizability must be a concern prior to any application of these findings. The navigation task, that of negotiating a 3D maze on a desktop computer, may not extend at all to a real environment. If it did, we would expect that the environment layout would have to closely resemble that of the maze—perhaps a building with many halls and rooms, or a dense, urban setting.

Metrics would certainly need to be reassessed to accurately apply to the target environment, since navigation would occur by some type of locomotion rather than keyboard arrow keys. Likewise, in this experiment the route indicator appeared in the corner of the screen, but an actual indicator would probably be positioned differently in relation to the user's field of vision, potentially impacting effectiveness of various representations.

However, this study provides a reusable and extensible evaluation model that can be tailored to any navigation environment or task to gain refinements to route description differences.

6. CONCLUSIONS

The findings of this study are exciting for several reasons. We have certainly established that different representations of route descriptions enable significant changes in aspects of navigation task performance. Like all secondary display design decisions, selection of route representations must not be arbitrary, but should consider the cost/benefit impacts to the user's attention system. To facilitate this, we have also determined that user characteristics can be convincingly identified with the Brain Works program and found to relate to variations in guide representation effectiveness. These findings begin rule collection required for dynamically adapting navigation support systems to user characteristics and usage goals.

Much more further work can be done on this topic to increase its contribution in several directions. Virtual environments can add necessary realism to improve generalizability in a lab-based test setting. Results from Darken's work [4] indicate that way-finding in virtual environments may be very similar to real world tasks, which is very encouraging as virtual environments are considered as research platforms for continued route description evaluations. Using eye tracking for future experiment replications may be a more accurate method of measuring focal distraction, and may provide other insights about perceptual patterns relating to way-finding. Since auditory route descriptions performed so well despite the observed halting tendency they caused in user navigation performance, and research has shown that auditory sensory memory lasts up to four seconds longer than visual sensory memory [5], auditory cues merit further investigation. In particular, perhaps they could be implemented more effectively (and less annoyingly in the long-term) if they were sounded on an on-request basis, forcing the user to decide when he or she actually needed a route indicator. Combinations of the six presentation techniques, particularly pairings of text, graphics, and audio, may also provide better route description options, and are likely conditions for follow-up studies. We would also be interested whether forward-up maps facilitate better performance than the maps this platform used. Larger numbers of users should be tested with the Brain Works program and similarly efficient surveys during other perceptual principle experimentation. Analysis resulting from classification filtering will help establish assessment limitations and viability for service as part of an adaptive graphical system.

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