Alternative Display and Directional Modalities in Support of Soldier Way-finding

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ABSTRACT

The Soldier Information Requirements Technology Demonstration (SIREQ TD) project was a human-factors-focused experimentation program to identify technologies that could significantly enhance the performance of our future soldiers. SIREQ TD identified navigation as an important task, and further cognitive task analysis confirmed that wayfinding via compass and map is difficult and prone to significant cumulative error, particularly at night. SIREQ TD developed the Future Infantry Navigation Device (FIND) as an experimentation test bed to enable detailed studies of the impact of various modes and levels of navigational information on soldier wayfinding performance. The FIND system used a GPS receiver and magnetic compass coupled to a laptop computer carried in a small backpack to track soldier position and movement. Comparison of position information against the stored map and pre-planned routes allowed the computer to provide navigational cues to the soldier via various means. Studies compared visual, auditory, and tactile display modalities as sensory inputs and investigated the effects of providing different amounts or qualities (ie, 1-dimensional (1D) and 2-dimensional (2D)) of information to the soldier. Studies were conducted during both day and night conditions, with soldiers traversing wooded terrain over pre-planned routes of about 1 km in length, each with 4-5 segments. Soldiers never used the same route more than once. Soldiers were required to: detect and simulate engagement of static enemy targets en route; avoid obstacles such as simulated mine fields; and maintain an awareness of distance travelled, distance and direction to next waypoint, and distance and direction to mission-critical objects in the environment. All studies used a standard magnetic compass and map as the baseline condition, and conditions were presented in a repeated measures balanced design to the maximum extent possible. Measures included: waypoint estimation error, collective error, time to traverse ground, average speed of traverse, and number of targets engaged. Results confirmed that the baseline in-service method of compass and pace count is prone to significant error. Not surprisingly, night-time way-finding performance was significantly worse than that of day-time, regardless of display modality. Performance with the FIND system, regardless of display modality, was considerably better than the in-service method for most measures. Comparison of display modality indicated few significant differences, although it is clear that implementation of the modality is critical to user acceptance. These studies confirmed the

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benefits of aided navigation and SIREQ TD performed several further studies, exploring and refining the interface for all three modalities.

1.0 BACKGROUND AND INTRODUCTION

1.1 The Task of Navigation through Way-Finding

Navigation through unfamiliar terrain is a critical and demanding skill for soldiers. Given an objective, soldiers use maps and awareness of mission factors to plan the best route to reach the objective. Often, there are few terrain indicators or landmarks to guide the way, and soldiers need to rely on their way-finding skills. Way-finding involves dead reckoning, from waypoint to waypoint, while, at the same time, maintaining awareness of distance to the next waypoint. It can be described as an individual's ability to find their way to a particular location in an expedient manner, and to recognize the destination when reached. In-service baseline performance of this task is accomplished with pre-defined waypoints, a compass as well as maintaining a pace count. Knowing the bearing (i.e., direction) of the next waypoint, soldiers use their compass to identify a nearby landmark (e.g., large tree) and then walk directly to that object, counting paces en-route. When they reach that landmark, they throw another bearing to another object and continue on their route in this manner. Soldiers practice and know their pace length, and by keeping track of the number of paces taken, are able to maintain awareness of the distance they have travelled and the distance to the next waypoint. Soldiers must also maintain vigilance of their surroundings, being able to detect and deal with threats posed by the terrain (e.g., obstacles) or mission environment (e.g., enemy targets). Because the navigational task can be so demanding, the tasks of way-finding and surveillance are typically divided among soldiers in the team.

Cognitive Task Analysis [1], conducted as part of Canada's Soldier Information REQuirements Technology Demonstration project (SIREQ TD), confirmed that compass way-finding is difficult, particularly at night. Pace counting is an inaccurate and unreliable method for distance measurement as well as demanding in terms of mental workload. Navigation, using the in-service method of compass and pace count is also an idiosyncratic ability, in that some soldiers possess it, and others do not. And those who do not are often unaware of their skill limitations. Navigational planning can suffer dramatically as a result. SIREQ TD cognitive task analysis also revealed the potential for significant improvements to the navigational task. However, many questions were raised with respect to the types and amount of information to provide, the most effective modality in which to display the information, modality conflicts with other infantry tasks, and interface design issues. The project developed an experimentation test-bed, described below, that would enable detailed study of the impact of navigational information on soldier way-finding performance.

1.2 Aims of SIREQ TD Way-Finding Studies

Twelve separate studies were conducted by SIREQ TD with the following aims:

- Determine information requirements for effective way-finding in wooded terrain, day and night;
- Determine the utility of different display modalities (visual, auditory, tactile) for enhanced way-finding capabilities; and
- Identify interface design issues associated with each modality for design optimization and future experimentation.

1.3 Overview of SIREQ TD Way-finding Studies

Several of the initial SIREQ TD way-finding studies explored the utility of providing navigational information via different human perceptual modalities. Visual, auditory and tactile displays were directly compared with the in-service compass and pace count method for their effectiveness in supporting way-finding. These early studies [2,3] also varied the amount of information provided to soldiers (direction, direction plus distance, etc) in an effort to further explore information needs. This paper will describe these initial studies in some detail. Subsequent SIREQ TD studies explored the utility and usability associated with each of the different display modalities and different ways of displaying information within each: visual [4,5,6,7,8]; auditory [9,10]; tactile [11,12]; and mixed visual and auditory [13]. These follow-on studies are described in a separate paper in these proceedings [14](Frim et al, 2007). All of the way-finding and navigation studies described in this and the subsequent paper were conducted at the individual soldier level (i.e., soldiers were required to perform the way-finding task individually, with an experimenter following).

2.0 METHODOLOGY

2.1 Overview of Way-Finding Study Methodology

The experimental approach involved having soldiers perform waypoint to waypoint navigation through pre-planned routes in wooded terrain using each of the applicable way-finding information display conditions, in a repeated measures counterbalanced design. Routes were typically 1-2 kilometres in length, with 4 to 5 legs in each route. Multiple routes were prepared, for each experiment, which were similar in complexity, so that no soldier navigated the same route more than once (also balanced across conditions) and to minimize the development of "beaten paths" as cues for navigation. In addition to the navigational task, soldiers were required to detect and simulate engagement of static enemy targets (see Figure 1b) en-route, as well as avoid obstacles such as simulated minefields. Depending on the study, they might also have been required to maintain awareness of distance travelled, distance to next waypoint, and direction and distance to mission-critical objects in the environment (e.g., known friendly/enemy; minefields; objective, etc).

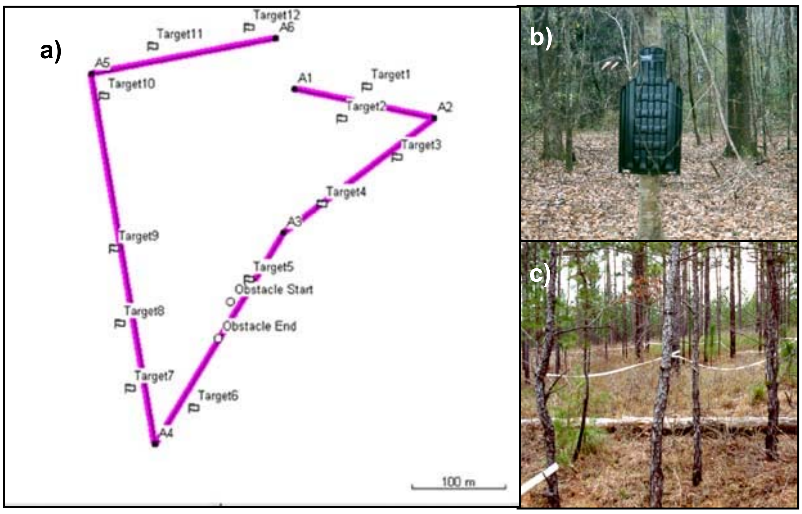

Figure 1: Typical experimental set-up for navigation experiments: a) sample route through wooded terrain showing waypoints, target and obstacle locations; b) example of a static enemy target; c) example of en-route obstacle (taped minefield).

Objective measures typically collected for analysis included: waypoint estimation error; route tracking and obstacle avoidance accuracy; speed of navigation and terrain traverse; target detection and engagement performance; and the frequency and duration of consults of GPS-based navigational aid system (described below). A range of subjective measures were also taken, including standardized tools for measuring subjective workload and situation awareness, as well as customized scales and acceptability ratings for factors such as: ease of use; quality, quantity and type of information; workload demands; ability of the aid to support situation awareness; task-relevant and overall effectiveness, among many other questionnaire items. Questionnaires used in these studies are provided as annexes to the study reports. Other subjective data were collected via Human Factors specialist observation and in-depth focus group discussions with participants.

2.2 Future Infantry Navigation Device (FIND)

The Future Infantry Navigation Device (FIND) was developed as a test-bed for the SIREQ TD navigation and way-finding studies, and is shown at Figure 2. It comprises a ruggedized laptop computer enclosed within a hard-case and carried within a small pack, pack-mounted or shoulder-worn GPS, helmet-mounted digital magnetic compass, an experimenter's remote control (for controlling information presentation and data collection), and a weapon-mounted "display activation" remote control button enabling the user to display the information only when desired. The system provides output options that are compatible with a range of visual, auditory or tactile displays. Pre-planned route waypoints are entered into the FIND software (using a military grid reference system or MGRS). The system continuously samples (at 10 Hz) the wearer's position and direction of regard. The software uses pre-programmed waypoint locations to calculate and then display to the user information about direction and distance to the next waypoint. The type, design and amount of information that can be displayed using the FIND can be set-up in advance of a study, and certain parameters can be controlled by the experimenter during the experiment. Display information can include, but is not limited to: current position and heading, cardinal direction (N, S, E, W), direction/bearing and distance to next waypoint; other waypoint information (number, grid reference), and even position of known friendly and enemy locations or hazards. The SIREQ TD project varied the amount and type of information displayed in order to better understand the information requirements of soldier navigation. The types of displays used were also varied, to better understand the usability aspects of enhanced way-finding information displays.

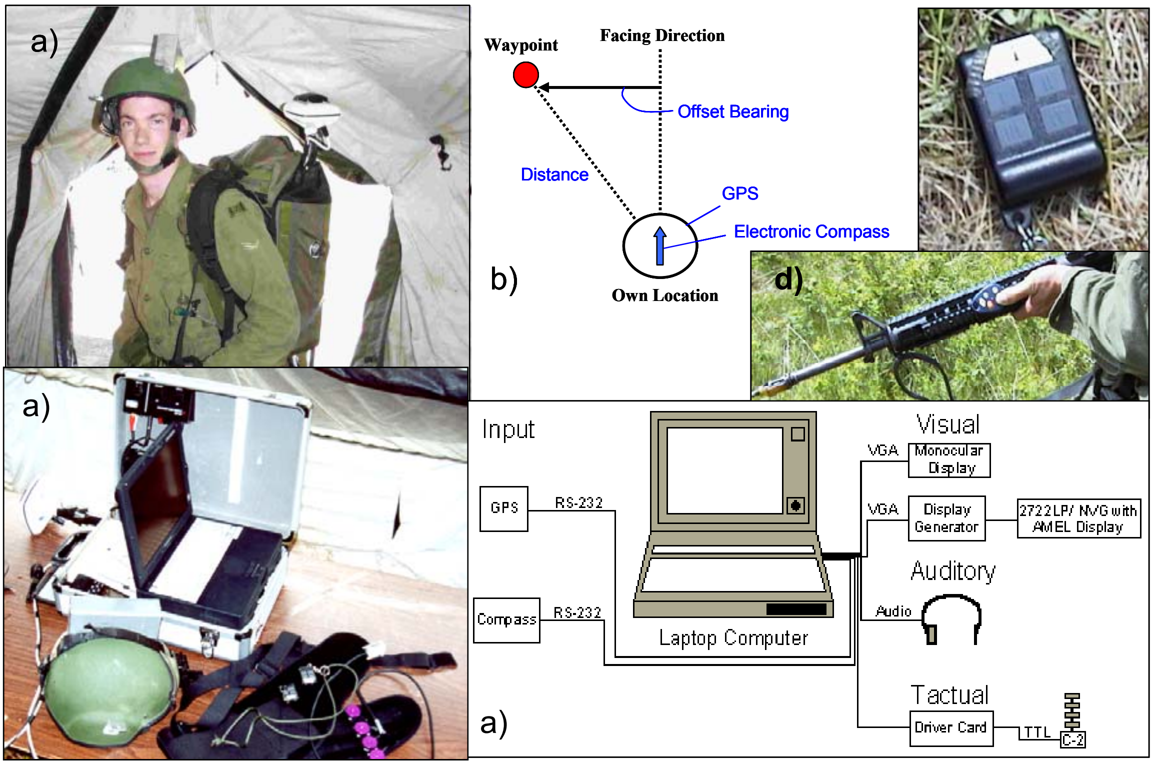

Figure 2: Future Infantry Navigation Device: a) equipment set-up; b) offset bearing measured by FIND; c) experimenter remote control for system operation; d) user display activation remote control

3.0 Direct Comparison of Different Display Modalities

The SIREQ TD project began its foray into the study of enhanced way-finding by conducting two separate studies directly comparing the effectiveness of visual, auditory and tactile displays. The first study [2] was conducted at Fort Benning in March of 2001. The study aimed to provide only the most rudimentary or simplest navigational information to soldiers (one dimensional, 1D, for the purposes of this report); subjects were only given information to advise whether or not they were facing the direction of the next waypoint. The second study [3], conducted at Canadian Forces Training Area Wainwright in June of 2001, built upon lessons learned from the first study. In this follow-on study soldiers were given two-dimensional, or 2D information (both degree of offset as well as direction of next way-point).

3.1 1D study methodology

The first 1D study [2] methodology required twenty soldiers to navigate 1 km routes through wooded terrain using each of the following four conditions in a repeated measures balanced design: in-service map and compass as baseline, and each of three alternative enhanced navigational information display modalities (visual, auditory, and tactile). Routes were comprised of 5 legs of roughly equal length. Ten soldiers were assigned to do the study at night and the remaining 10 were assigned to participate during the day.

Figures 3, 4 and 5 show the display configurations used. For the visual display conditions, subjects used the M1 Tekgear occluded helmet-mounted display (HMD) during the day, and the Special Technical Services low profile night vision goggle with see-through heads-up display capabilities at night. The visual display provided a direction-heading indicator to the next waypoint as shown in Figure 3. The auditory display comprised mono sound speakers mounted to the earcups of the ballistic helmet as shown in Figure 4. Four distinct tones of increasing pitch were provided simultaneously to both ears; the higher the pitch the lower the offset angle between the user's facing direction and direction of the next waypoint (i.e., higher pitch associated with correct direction of next waypoint). This is shown schematically in Figure 4. The tactile display comprised four vibrotactile transducers (frequency 260 Hz) mounted vertically on the front of the user's lower abdomen within a waist belt as shown in Figure 5. The location and amplitude of vibration indicated direction of next waypoint.

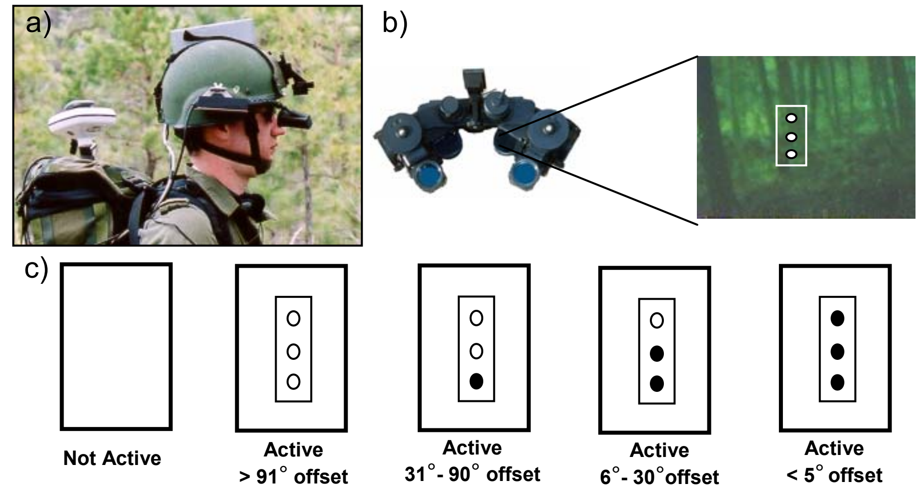

Figure 3: Visual display configuration for study of 1D navigational information displays.: a) M1 Tekgear occluded HMD; b) STS low profile NVG with HUD; and c) simple 1D visual display of offset bearing information.

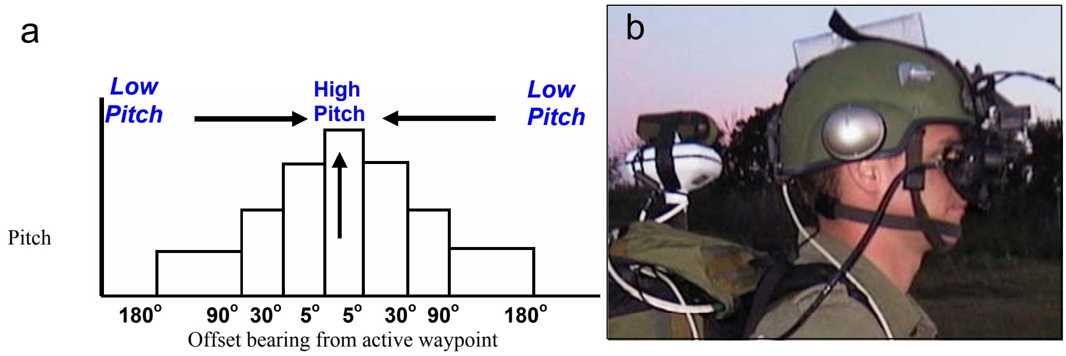

Figure 4: 1D Auditory display configuration schematic: a) helmet-mounted mono sound speakers; and b) schematic indicating audio display of offset angle

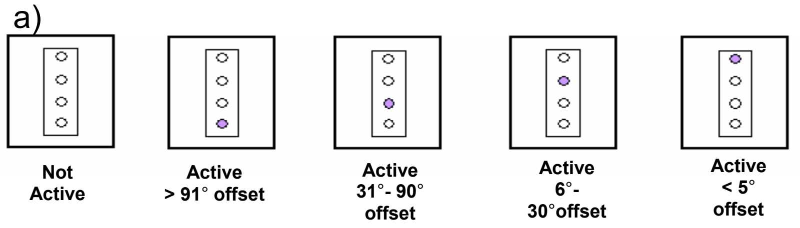

Figure 5: 1D Tactile display configuration using four vibrational tactors: a) schematic of offset angle indication; and b) tactor harness.

3.2 1D Study Main Findings and Lessons Learned

Performance results confirm how difficult the navigational task is at night. Night time performance results (for waypoint estimation error, collective error, time to traverse ground, average speed of traverse, number of targets engaged), were significantly worse than day-time, in spite of significantly more and longer system direction enquiries. Results also confirm that the baseline or in-service method of compass and pace count is prone to significant error. As shown in Figure 6, accuracy of waypoint estimation was significantly better, and there was also significantly less collective error for the routes, when any of the enhanced way-finding systems were used. Interestingly, distance travelled was significantly lower in the compass condition than in any of the enhanced conditions, supporting subjective findings that soldiers were able to make best use of ground when provided with navigational assistance. Comparing the display modalities, there were significantly fewer route deviations using the visual display than with either the tactile or auditory displays. Speed of traverse was significantly faster with the compass and pace count method than with either the auditory or tactile display conditions, highlighting some interface issues experienced by users with the latter systems, particularly the tactile system (e.g., poor tactor placement and design).

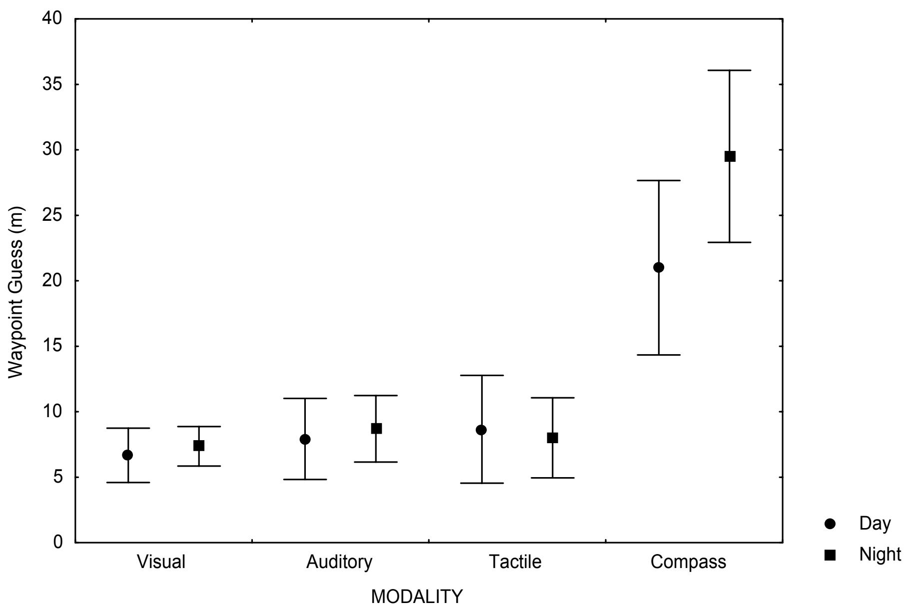

Figure 6: Accuracy of way-point estimation using 1D navigational information (from 9)

These issues were evident in user acceptance ratings and focus group discussions. The visual modality was often rated with the highest acceptance of all the modalities, with the exception of suitability for terrain traverse and target detection tasks. Visual, auditory and compass modalities were rated more acceptable than the tactile modality for the majority of questionnaire criteria. In spite of the reported interface issues, and despite no observable (or measurable) performance benefit, participants felt that there was indeed tactical merit for pursuing design improvements and further study of the auditory and tactile displays. Users also requested that more information be displayed by the navigational aid, such as distance to waypoint, and bearing or directional information. The study suggested a number of improvements for each of the display modalities and well as changes to the study design (e.g., longer routes, uneven legs within each route to reduce predictability of distance to next waypoint, etc). These changes were adopted for the follow-on study that again compared the three display modalities but that provided additional 2D information.

3.3 2D Study Methodology

The following interface design and study protocol improvements were among those made in the second study [3] that directly compared visual, auditory and tactile displays for navigation and way-finding:

- The visual and auditory systems integrated only three levels of magnitude instead of the four levels tested in the first study. Soldiers commented that more than three levels of magnitude are not required to effectively target a waypoint.
- The visual display was moved from the center and placed offset to the right side of the display to improve the soldiers' ability to site (or dead reckon) onto a feature once the correct bearing was achieved.
- The auditory system integrated tones that increased in both frequency (pitch) and rate (time between signals) as the head moved closer to the bearing of the waypoint. The highest (i.e. closest) auditory signal was a continuous tone.
- The spacing between tactors was increased to improve discrimination between vibrations. The tactor system integrated only two levels of magnitude as soldiers had indicated that they required only one distinctive signal to know when they were facing the waypoint. Another signal indicated that the system was activated while not facing the waypoint.
- To improve applicability of the experimental results to actual wayfinding tasks, leg distances were increased and varied in distance. Instead of 200m, distances used in this study ranged from 150 to 450 metres in length. The total route distance was increased from 1 km to 1.35 km.
- Soldiers were instructed to travel to the waypoint as quickly and accurately as possible while using the system to avoid areas difficult to navigate. Strict adherence to a straight line path was eliminated because this path is often blocked by poorly navigable areas that would cause the soldiers to become tangled, or force them to travel off the most direct route. In addition, the straight line may not actually reflect the best approach when tactics or topography are considered.

The method was otherwise similar to the method previously described for the 1D study. Using a balanced repeated measures design, twelve infantry soldiers were required to navigate 1.35 km routes during the day using the FIND system which provided enhanced wayfinding information in three different display modalities (visual, auditory, and tactile). For each modality, however, two systems were tested. The first was a one-dimensional system (1D) that provided information on the location of the waypoint, and how far the soldier had to turn in order to face the waypoint. The second was a two-dimensional system (2D) that provided the same information as the 1D system as well as directional information indicating the quickest way to turn in order to face the waypoint. Display configurations are provided in Figures 7 to 9. Ten subjects completed the study at night using the 2D display configurations only. The current in-service condition of using a compass and pace counting was only trialled at night on a shortened route to remind participants and give more recent experience on the in-service method of completing the way-finding task. As for the original study, soldiers were required to detect and engage enemy targets and navigate around obstacles en-route to simulate the tactical demands of operational wayfinding.

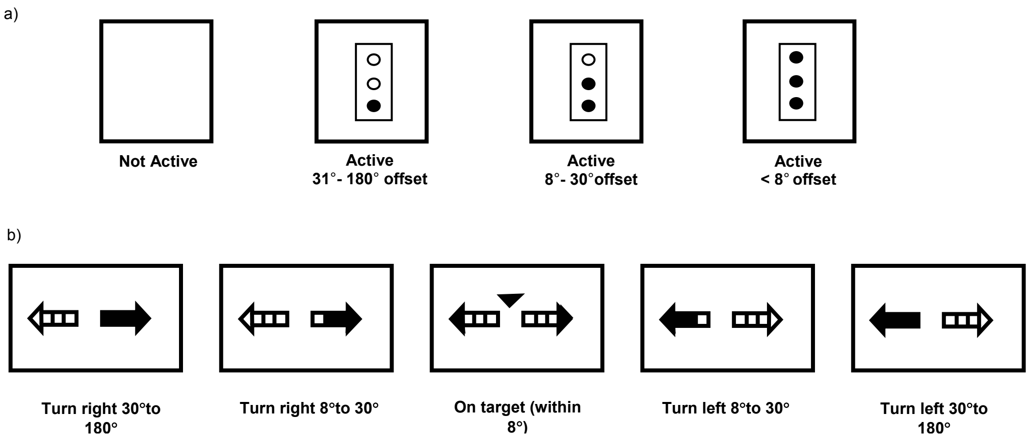

Figure 7: Visual display configurations for 2D study: a) 1D display; and b) 2D display configuration.

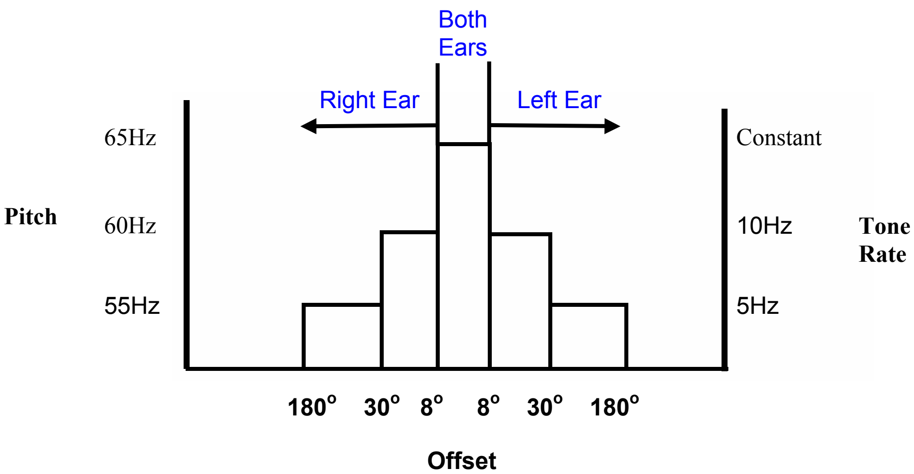

Figure 8: 2D auditory display configuration

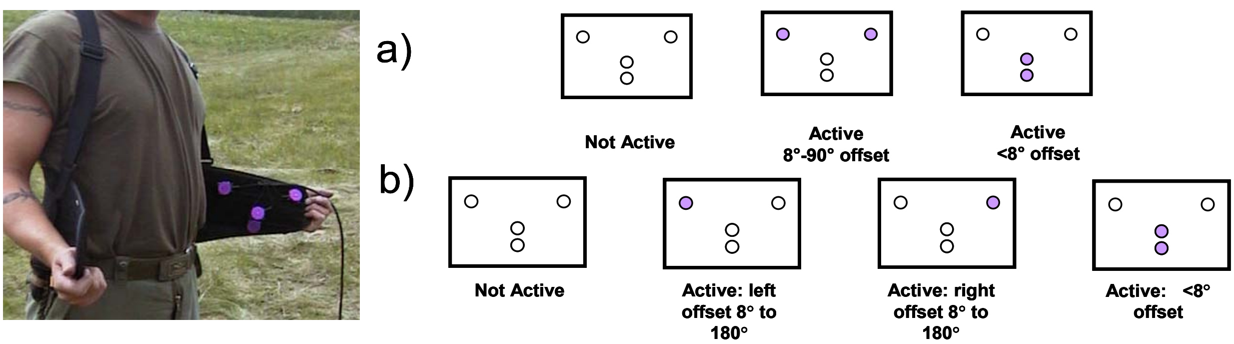

Figure 9. Tactile display configurations: a) 1D; and b) 2D

3.4 2D Study Main Findings and Lessons Learned

As for the original study, performance using any of the FIND-supported conditions was superior to the compass method for locating waypoints accurately, both in bearing and distance. There were no statistical differences between modality, dimension, or time conditions for distance travelled or accuracy of waypoint estimation performance results. Not surprisingly, participants took significantly longer to complete a leg when using a compass compared to the FIND modalities. The FIND system did not adversely affect the ability of the soldiers to perform visual searching, or detection and engagement tasks.

Soldier participants indicated that all of the FIND displays were very easy to learn and were perceived to be very accurate. They felt that while 1D modalities were effective, 2D displays were noticeably better. Unlike the previous experiment, as a whole, participants disliked the visual modality because it frequently required adjustment, obstructed view, and interfered with the rifle sight. Participants liked the auditory modality because it did not restrict their visual field. Many participants liked the tactile modality because it allowed other simultaneous tasks while moving (e.g. visual search for targets, listening for communications and enemy movements). Perhaps the improvements made to the auditory and tactile display interface contributed to their higher degree of acceptance in this second experiment.

4.0 CONCLUSIONS AND RECOMMENDATIONS

These studies clearly demonstrated the benefits, over existing compass-based methods, of providing GPS-based navigational assistance to soldiers. Several areas of future study were suggested by these comparative studies of alternative display modalities, including investigation of additional information for wayfinding, investigation of the utility of 3D auditory displays, as well as the assessment of alternative visual and tactile displays. Further hardware, software, and several methodological improvements were also suggested by the second of these studies. All of these recommendations were implemented in the SIREQ TD project's ensuing modality-specific studies of enhanced way-finding capabilities which are summarized in separately in these proceedings [14].

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