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# Field evaluation of a wearable multimodal soldier navigation system

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Challenging environments pose difficulties for terrain navigation, and therefore wearable and multimodal navigation systems have been proposed to overcome these difficulties. Few such navigation systems, however, have been evaluated in field conditions. We evaluated how a multimodal system can aid in navigating in a forest in the context of a military exercise. The system included a head-mounted display, headphones, and a tactile vibrating vest. Visual, auditory, and tactile modalities were tested and evaluated using unimodal, bimodal, and trimodal conditions. Questionnaires, interviews and observations were used to evaluate the advantages and disadvantages of each modality and their multimodal use. The guidance was considered easy to interpret and helpful in navigation. Simplicity of the displayed information was required, which was partially conflicting with the request for having both distance and directional information available.



## 1. Introduction

In recent years, navigation systems have been developed for many user groups, such as those driving vehicles (Murata et al., 2013; Reagan and Baldwin, 2006; Szczerba et al., 2015), pedestrians (May et al., 2003; Münzer et al., 2006; Pielot et al., 2009; van Erp et al., 2005), and people with visual (Johnson and Higgins, 2006; Lewis et al., 2015; Wilson et al., 2007) or cognitive (Fickas et al., 2008) impairments. In addition, navigation systems for safety-critical domains have been suggested, for example, for firefighters (Streefkerk et al., 2012), first responders (Smets et al., 2008), and infantry soldiers (Elliott et al., 2010; Eriksson et al., 2008; Kumagai et al., 2005).

Challenging environments pose difficulties for navigation systems. A visual display may be useless in dense smoke or muddy water (van Erp et al., 2005). Similarly, terrain navigation is challenging when the environmental conditions are bad, for instance, when there is poor visibility due to darkness, heavy rain, snow, or thick vegetation, or when it is dangerous to walk there. In these conditions, the use of compass and map, or even a hand-held GPS (Global Positioning System) device, may be slow and cumbersome. Furthermore, the disadvantage of using traditional navigation means is that there is high mental workload required to pace count and detour around obstacles (Kumagai et al., 2005).

To cope with these challenges, the use of wearable systems have been suggested. For example, tactile displays, or vibrating tactors placed around the user's torso, have been studied on their own (Jones et al., 2006; Pielot et al., 2009; Srikulwong and O'Neill, 2010; van Erp et al., 2005), and in combination with electronic maps (Smets et al., 2008), head-mounted displays (HMDs) (Elliott et al., 2010; Kumagai et al., 2005; Streefkerk et al., 2012), and speakers or headphones (Calvo et al., 2014; Eriksson et al., 2008; Garcia et al., 2012; Kumagai et al., 2005). Many benefits of using wearable systems were found, including the selection of shorter routes and lower probability for disorienting (Pielot et al., 2009), faster performance (Srikulwong and O'Neill, 2010), less error in night-time navigation (Kumagai et al., 2005), and short familiarization time with the devices (van Erp et al., 2005). Additionally, in outdoor environments under high cognitive and visual workload, tactile displays were found useful (Elliott et al., 2010). Wearable devices can also improve users' situation awareness, i.e., perception and integration of surrounding information with respect to the situation at hand (Laarni et al., 2009).

### 1.1. Multimodal systems

In a multimodal system, as framed by Möller et al. (2009) and Dumas et al. (2009), human-machine interaction takes place via a number of media and utilizes different sensory and communication channels. Typically, the sensory channels refer to the visual (V), auditory (A) or tactile (T) senses. A common view in cognitive

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psychology is that humans process modalities partially independently, and human performance can be improved by multimodal interaction (see, e.g., Dumas et al., 2009). For example, multisensory integration may make the stimulus more salient, and thus improve performance in selective attention tasks (Van der Burg et al., 2008). Wickens' Multiple Resource Theory (Wickens, 2008) can be used for modelling the mental resources available: information coming from a single stimulus can be processed in parallel, if different sensory resources are required. It has been shown that multimodal cues can shorten response times in complex environments (Ferris and Sarter, 2008). Similarly, tactile and auditory cues can facilitate visual target search (Hancock et al., 2013).

### 1.2. User evaluations in navigation and military contexts

Challenging environments pose difficulties also for user evaluations. In many contexts researchers are unable to go near the activity, for example in firefighting and military tasks. Sometimes, the conditions may be so challenging that the researchers are be forced to take the tests to a laboratory (e.g., Andersson and Lundberg, 2004), where the context of intended use can be only partially simulated.

In order to get an overview of user evaluations of multimodal systems, a table was prepared listing methods used in the evaluation of multimodal systems especially in navigation tasks and in military contexts (Table 1). Most evaluations were performed in applied or laboratory conditions, with the exception of a study by Elliott et al. (2010). In most studies, performance measures (PMs, e.g., elapsed time), or observations and user comments are utilized. Statistical significance tests are often carried out with PMs, but also sometimes with questionnaires. Questionnaires typically cover user-related issues such as usability, suitability for task, acceptability, comfort, workload and situation awareness. Physiological measurements (electrocardiogram, ECG) have also been used (Mynttinen, 2010).

### 1.3. Aim and scope of study

We studied a wearable, multimodal navigation system with users in a controlled outdoors environment and in the context of a military exercise in demanding outdoor conditions. Our demonstrator system is capable of tri-modal output, i.e., feedback to user can be given via three different modalities (visual, auditory, and tactile). In the two studies we carried out, we used unimodal (one), bimodal (two) and trimodal (three modalities) output.

This paper addresses two research questions: Does the demonstrator system help in navigation? What are the advantages and disadvantages of each modality, and also of multimodal use? The research questions are contemplated mainly on the basis of data collected using questionnaires, interviews and observations.

Although the navigation system described in this study can be used for several purposes (e.g., within-group communication and warning signals), in this paper, only the navigation support provided by the system is considered. Participants were encouraged not to use a hand-held device (with GPS capability), which was a part of the navigation system. In the analysis, only the wearable devices of the system are considered. This paper focuses on the evaluation phase of the navigation system; phases such as task analysis and system design are not covered (see e.g., Laarni et al., 2009; Lemmelä et al., 2008).

In this paper, Section 2 reports two studies in which the system was tested in outdoor conditions. Section 3 discusses the study findings regarding unimodal and multimodal use of the navigation system and provides some considerations to support the future design and evaluation of wearable multimodal systems.

## 2. Materials and methods

The multimodal navigation system used in this study has been developed in multiple phases, including scenario specification, cognitive task analysis, requirement specification, and concept design. The two studies described in this section concern the evaluation of a demonstrator, where various functionalities, including the multimodal outputs, have been integrated. In Study 1, the system was tested using unimodal and trimodal outputs in a controlled environment, and in Study 2, two bimodal conditions were used (visual + auditory (VA), tactile + auditory (TA)) in the context of a military exercise. The evaluation design was adapted from earlier work in the field, especially from (Elliott et al., 2010; Mynttinen, 2010).

### 2.1. Navigation system and multimodal outputs

The navigation system was built on Saab 9Land Soldier system. It included a hand-held unit with a 3.7″ display and computer, and terminals for voice and data. The display showed a non-rotating, north-up map with zooming possibility. Waypoints could be set to the route using the hand-held device. The navigation was based on GPS: The user's position was transmitted periodically and automatically, and the heading direction was inferred from preceding GPS readings. The system generated output for the visual and auditory modalities at 10 m intervals (corresponding to 7–12 s at walking speed). When the user stepped outside of the navigation corridor (corridor width 25 m, waypoint diameter 10 m), system output was generated for the auditory and tactile modalities. Table 2 summarizes the information presented for the participants.

Visual information was shown via an HMD (Penny C Wear Interactive Glasses (Fig. 1, left)). The glasses are see-through, and near-retina projection is used to display information to the right eye. The perceived image is hovering in front of the user (Fig. 2, right); the opacity of the image depends on the surrounding lighting conditions and its size and position on the physical facial characteristics of the user. In Study 1, left, right and forward arrows instructed the participant the correct direction to turn (Fig. 2, left). A researcher manually controlled the shown arrows from a remote location, because the system integration had not been completed at the time. In Study 2, the system showed the distance and direction to the waypoint in text format (Fig. 2, centre). When the waypoint was reached, a rectangle (Study 1) or an oval shape (Study 2) was shown.

Auditory instructions were speech-based and transmitted via headphones (Fig. 1, left). In TA condition in Study 2, a more robust set of headphones (Peltor™) with a volume knob was used. Examples of phrases spoken by the system were “Go North-West 120 m”, “You are off track, turn left” (prompted when stepping outside of navigation corridor) and “You have reached the destination”.

Tactile vibrations were transmitted using a vest made of stretch fabric. There were 36 tactors, or tactile vibrators, equally spaced in three rings around the torso (Fig. 1, right). The tactors vibrated at 120 Hz. The vibrations were either to the left or right side of the torso (Fig. 3), which indicated the direction where the user should turn to in order to get back to the navigation corridor, or a round-torso circling vibration when a waypoint was reached. The tactile vest was worn over a thin shirt in both studies.

### 2.2. Study 1: preliminary navigation test

Study 1 was a navigation test in a controlled outdoors environment.