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THE IMPACT OF TACTILE FEEDBACK ON THE VALIDATION OF A SYNTHETIC TASK ENVIRONMENT

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ABSTRACT

A synthetic task environment (STE) has the potential to be a suitable platform on which to evaluate mobile support tools before they are adopted in the field. In this paper, a cost-effective game-based STE developed at TNO Soesterberg in the Netherlands is described. To determine its validity, the use of a mobile tactile belt for first responders is tested both in the field and in the STE to find matching patterns between the two environments on navigation performance and situation awareness measures. After the experiment was conducted, one significant pattern was found on navigation performance. Participants in the STE who had the tactile belt navigated significantly faster than those without the belt, whereas in the field the use of the belt did not significantly improve navigation speed. Although this speaks against the validity of the STE, it is premature to confirm this as the navigation task used in this experiment produced a ceiling effect in the field environment. As the primary visual cues used during navigation were found to be similar in the field and the STE, it is concluded that with improvements particularly to the navigation task, the STE is worthy of further study.

1. INTRODUCTION

Synthetic tasks are "research tasks constructed by systematic abstraction from a corresponding real-world task" (Martin, Lyon & Schreiber, 1998, p. 123). When performing a synthetic task, behavioral and cognitive skills associated with the real-world task are elicited. A Synthetic Task Environment (STE) provides the context for a suit of synthetic tasks, offering a research platform that bridges the gap between controlled studies using artificial laboratory tasks and uncontrolled field studies on real tasks (Cooke & Shope, 2004). STEs are becoming increasingly popular to evaluate information technology for a range of professions, including first responders: emergency workers that are first on the scene when a man-made or natural crisis occurs. There is a wide range of modeling and simulation tools available for emergency response (Jain & McLean, 2003a). For the training of first responders, they may utilize tools that provide physical feedback to the trainee, or communicate with them using visual cues on a display (Jain & McLean, 2003b).

Often, evaluations in field settings are expensive, potentially dangerous, and may sometimes be impossible to execute (Jenvald & Morin, 2004). Evaluation in a synthetic task environment can provide an appropriate alternative for field testing. The question is whether an STE is an adequate replacement for the field as an evaluation setting. When an STE is not representative for the field conditions that are critical for the evaluation of a support tool, performance of participants will not be comparable to actual use in the field. In the worst case, this leads to the investment in a tool that has little or no use in the field. This paper studies the validity of a cost-effective game-based STE as an evaluation environment for mobile information technology. To establish validity, patterns found in performance measures in the STE must match with patterns found in the same performance measures in the field. This is done in the context of evaluating a tactile belt for first responders, a support tool that gives directional information through eight vibrating tactors around the waist. This type of tactile feedback was chosen as the test case to put emphasis on the impact of spatial orientation on navigation performance and situation awareness.

The STE used in this paper is based on version 2.5 of the Unreal Engine, which has been the subject of previous research at TNO Soesterberg in the Netherlands (Smets, te Brake, Lindenberg & Neerincx, 2008). Smets et al. (2008) examined the effect of heading-up maps (orientation determines map rotation) and north-up maps (no rotation) on search and rescue performance of first responders, and whether adding tactile feedback support improved performance. Navigation performance and situation awareness were identified as important skills of first responders, and it was found that when there was no tactile feedback, participants rescued the victims significantly faster with a heading-up map than with a north-up map. There were no significant differences found on situation awareness, although a trend suggested that tactile feedback support might lower situation awareness. Tactile displays have also been used for soldier navigation in forested areas by both day and night (van Erp & Duistermaat, 2005). The experiment by day showed that participants had a higher walking speed and reached more targets using tactile feedback than with a GPS compass system. As the context of our research in this paper, the use of tactile feedback support is further investigated.

The STE used by Smets et al. (2008) is adapted for this paper to be able to determine its validity. To allow comparison with the field, the environment depicted in the STE was changed from a portion of fictive city to a portion of the Dutch town of Soesterberg. The search and rescue task used by Smets et al. (2008) was also slightly changed to create a navigation task that could be performed in both environments. Additionally, a tactile belt was constructed to replace the tactile suit for the STE environment used by Smets et al. (2008) to better match the form of tactile feedback used in the field. Together with the influence of the type of environment, the effect of tactile feedback support is tested on measures of navigation performance and situation awareness.

We distinguish 3 main research questions:

1. *What is the effect of tactile feedback on navigation performance and situation awareness in the field?*
2. *What is the effect of tactile feedback on navigation performance and situation awareness in the STE?*
3. *Is the STE valid through a match in tactile feedback patterns found in the field and in the STE?*

Due to the more limited spatial orientation, field of view and amount of visual cues in the STE, it is expected that navigation performance and situation awareness is better in the field than in the STE. It is also expected that having tactile feedback support increases navigation performance particularly in the STE, because it provides spatial orientation that is otherwise lacking. As indicated by Smets et al. (2008), tactile feedback may have a negative influence on situation awareness however. This is because participants can rely on it too much and reduce the amount of attention they are paying to the environment. Due to the increased field of view, fidelity and orientation possibilities of the field environment, it is expected that tactile feedback will be more beneficial in the STE.

Apart from navigation performance and situation awareness, we will also look at the strategies participants develop to complete the task. Furthermore, general and mental effort during task performance is examined, as well as satisfaction with the tactile belt. Finally, the presence participants experience in the STE is measured to get an insight into acceptance of the STE by end users.

In this paper we will first give an insight into relevant related literature. Then, we describe the experiment and present its results. Finally, the results are discussed and conclusions are drawn.

2. RELATED WORK

2.1 Cognitive engineering method

Figure 1 shows a cognitive engineering method that incorporates development in both a synthetic world and a real world to adopt new user interfaces (te Brake, de Greef, Lindenberg, Rypkema & Smets, 2006). Two phases can be distinguished in the development process: iterations in a synthetic environment, followed by development iterations in a real-world setting. During specification, both the human factors expertise and the operational requirements are addressed concurrently. In the assessment activity it is checked whether the specifications agree with the human factors guidelines and the operational requirements. The assessment provides results in terms of effectiveness, accuracy, and satisfaction, which are used to refine the specification. Eventually, the process of iteration stops when the adaptive user interface satisfies all requirements and is ready for evaluation in real-world settings in a similar iterative loop. When in the real-world assessment sub-optimal designs are found due to lack of fidelity of the synthetic environment, this information must be used to make the synthetic environment more realistic.

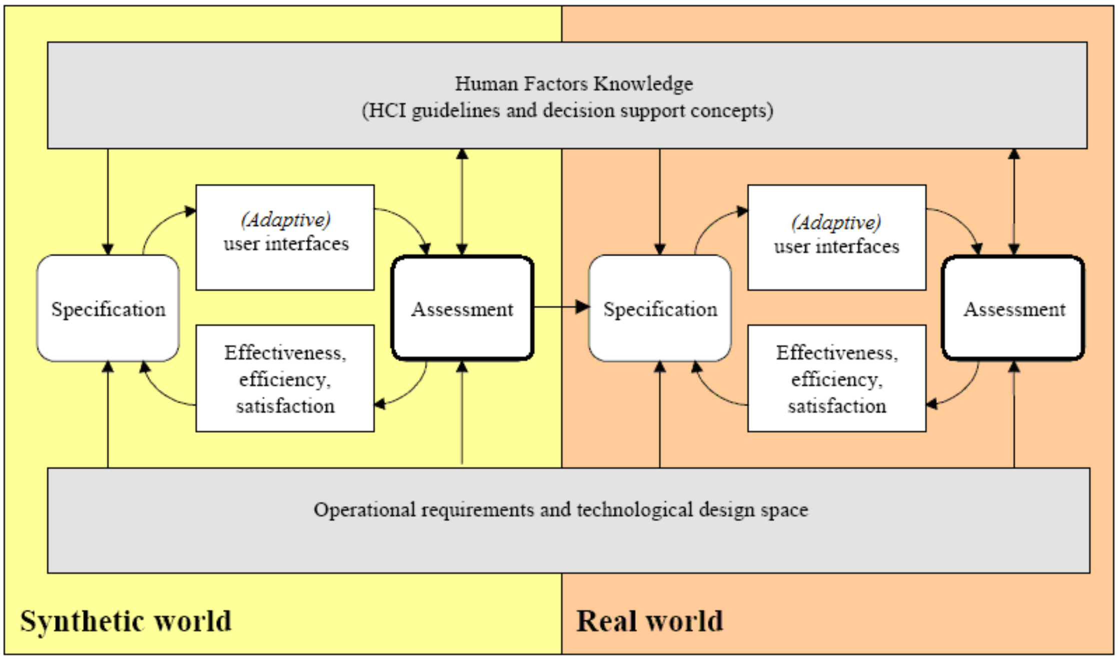


Figure 1: Cognitive engineering method (te Brake, de Greef, Lindenberg, Rypkema & Smets, 2006)

The research in this paper can be seen in the context of the model above. This paper combines the assessment phases in both environments (boxes marked by emphasized borders). The cognitive engineering method was originally designed for adaptive user interfaces. Because the support of tactile feedback used in our experiment is not adaptive, the words ‘adaptive’ (marked by italics) have been put between brackets. In order to validate our STE, the tactile belt is first assessed in the real world to find patterns in the results. Then, the assessment is performed in the synthetic world to see whether these patterns are also occurring. If these patterns match, the human factor and operational requirements that are important to the user interface in the field have been met in the STE, and the STE can considered to be valid.

2.2 Tactile feedback

Tactile interfaces can provide additional information to people, usually through vibrotactile means or by raised interfaces like Braille. A common example is the vibration mode in cell phones and pagers. More complex tactile interfaces use patterns of vibratory feedback through placement of vibrating tactors.

Van Erp and colleagues researched the use of spatially distributed vibrotactile feedback to provide non-visual information to users while they executed other tasks (van Erp, van Veen, Jansen & Dobbins, 2005). One of the goals of this research was to evaluate tactile feedback for use in providing private, low-cognitive load information to military and civilian first responders. Subjects used information presented on a vibrotactile belt to navigate a series of waypoints. Localized vibration on the belt could easily and accurately be interpreted as a direction in the horizontal plane. Employing this principle allowed the presentation of navigational information with a higher resolution than “turn left” or “turn right”. Subjectively, the results indicate that touch is a highly effective secondary communication channel that leaves the visual sense able to better attend to other control issues.

Lindeman, Yanagida, Sibert and Lavine (2003) asked subjects to locate a specific letter from a dynamically updated jumble of letters. Subjects were assisted by various visual and vibrotactile cues. Results indicate that visual cueing is dominant, providing a 30% average performance increase. However vibrotactile cueing also provided a 12% performance increase, making it a viable option if visual cueing is not feasible, such as when the user is visually occupied. This finding is consistent with the work of Van Erp et al. (2005), and demonstrates the value of tactile feedback as a useful means to refocus the user's attention.

Poupyrev and Shigeaki (2003) proposed that tactile feedback can provide sensory stimulation on a subconscious or peripheral level, which leaves the user's primary focus on another task. It was shown that, in mobile contexts, users are often preoccupied with tasks such as walking, driving, or even participating in a business meeting, and that these scenarios provide the perfect context for non-visual tactile communication. The authors investigated the advantage of this tactile feedback for a scrolling task on a PDA, a typical task performed by mobile users. Quantitatively, subjects performed on average 22% faster with tactile feedback. Users' subjective responses indicated that they preferred the tactile feedback device, not because of performance improvement, but because it was perceived to supply a better user experience.

The key to successful implementation of tactile displays lies in the ability to convey a strong vibrotactile sensation to the body with compact, lightweight devices that can be comfortably incorporated in the user's workspace or clothing without impairing movement (van Erp & Duistermaat, 2005).

2.3 Real-world vs. virtual settings

Navigating and developing spatial knowledge in a virtual environment is often more difficult than in a similar real environment simply because the real environment is richer. This richness, known as fidelity, consists of dimensions such as the content of the visual scene and the mechanism used for movement (Waller, Hunt & Knapp, 1998). It was also shown that if the amount of visual content is high and the field of view is large, people can navigate a room-sized virtual environment with similar navigation behavior as in a real environment (Lessels & Ruddle, 2004). Actual navigation performance was still substantially worse in the virtual environment however, indicating the importance of an intuitive control mechanism to move through the environment.

A head-mounted display (HMD) is considered a more immersive way to present virtual environments than the traditional desktop set-up because of the natural way to look around and orientate. However, navigation performance is often similar if not worse (Santos, Dias, Santos, Silva & Ferreira, 2009). The HMD does have another advantage over the desktop (even over a spatially immersive display like CAVE), which is spatial orientation (Bowman, Datey, Ryu, Farooq & Vasnaik, 2002). Being able to use natural rotationas in real settings makes navigation more efficient in a virtual environment. Also, having full physical movement is more important than having a highly detailed environment to navigate in (Ruddle & Lessels, 2006).

Another aspect of virtual environments is presence. It is defined as the subjective experience of being in one place or environment, even when one is physically situated in another (Witmer & Singer, 1998). For first responders, feeling present in a disaster scenario is important because it elicits the typical stress of emergency situations (Pausch, Proffitt & Williams, 1997). Adding audio to a virtual environment is a way to significantly increase presence, while it can also compensate for low-quality visuals (Davis, Scott, Pair, Hodges & Oliverio, 1999).

2.4 Situation awareness

Situation awareness consists of three levels (Endsley & Garland, 2000):

- Perception (level 1). Perception of cues in the environment is fundamental to situation awareness. Humans perceive the environment through one or more of their five senses (visual, auditory, tactile, taste or olfactory senses). Without good perception, situation awareness is incomplete and errors will arise.

- Comprehension (level 2). Comprehension of the perceived information is the second level of situation awareness. It encompasses how people combine, interpret, store, retain, and retrieve information, how they integrate different pieces of information, and how they relate the information to their goals.

- Projection (level 3). The ability to project from the current situation into the (near) future allows for timely decision-making.

The situation awareness measures used in this experiment were based on the research done by Smets et al. (2008). All three levels of situation awareness were included in their study. It was measured objectively through time to return to the starting point and the number of starting points found. For this experiment, two measures were added to expand situation awareness measurement: return path accuracy (the number of wrong turns made at junctions on the way back) and visual cues used during the navigation task.

3. METHODOLOGY

3.1 Participants

Forty participants were used in the experiment as paid volunteers, twenty male and twenty female. All participants were college students with an average age of 23.2 (range 18-28). None of the participants were familiar with the Soesterberg location used in the experiment. For the STE condition, every participant had sufficient computer experience to perform the task.

3.2 Task

In both the field and the STE, participants had to navigate to a number of different waypoints from a single starting point (Figure 2). The locations of the waypoints were the same in both the field and the STE, and were marked by orange cones. The objective was to reach the waypoints as quickly as possible, using a north-up map on which they were indicated. North-up maps were chosen due to technical limitations with the use of heading-up maps in both environments. In conditions with tactile feedback, the tactile belt indicated the location of the waypoint in a straight line (“as the crow flies”) through the tactor that was closest to the direction of the waypoint. After reaching a waypoint the participant had to return to the starting point, without any form of navigation support. This task was repeated eight times using the same starting position and different waypoints. When the participant took longer than 3 minutes to reach the starting point, the trial was ended and the participant was returned to the starting point to continue the task.

The experimenter was present in the vicinity of the participants at all times during the experiment, either walking behind the participant in the field condition, or sitting at the side of the participant in the STE condition. Also, participants were given ear protectors to reduce the differences in sound between both environments. The field condition required participants to move through the environment on foot, while in the STE, the participants moved through the environment using a game controller. They could move forward, backward, sideways, and turn around their axis.

In both the field and the STE, the location of the participant was not visible on the map, only his starting point and the location of the current waypoint. Waypoints were reached by walking up to them. When the participant was sufficiently close, the map was removed from view and the tactile belt (if present in the condition) turned off.

Figure 2: Participants performing the navigation task in the field (left) and in the STE (right).

3.3 Design

In the experiment two independent variables were examined: environment and tactile feedback. The environment could be either the actual location in Soesterberg, or its virtual representation in the STE. Tactile feedback was given by means of the tactile belt, which participants wore on top of their clothing. Each participant conducted the task in only one of the four conditions, making the experiment a between subjects design as displayed in Table 1.

	Environment	Tactile feedback
1	Field	Without tactile waypoint feedback
2	Field	With tactile waypoint feedback
3	STE	Without tactile waypoint feedback
4	STE	With tactile waypoint feedback

Table 1: **Conditions of the experiment**

The following dependent variables were studied:

- Performance data. Navigation performance consisted of (a) time required to find waypoints and (b) start to target path accuracy, consisting of the number of wrong turns made on the way. This accuracy was established by counting at each junction whether the participant made a wrong turn in relation to the optimal turn towards the target.

- Situation awareness. Situation awareness consisted of (a) time required to return to the starting point, (b) return path accuracy (the number of wrong turns made on the way back), (c) the total number of starting points found within the time limit and (d.) the visual cues that were used during the task.

- Strategy. Subjectively, participants were asked about which support tools they used primarily during the task through a post-test questionnaire.

- Effort. General effort and mental effort were gathered subjectively after the experiment through a general questionnaire and the Rating Scale Mental Effort (RSME) (Zijlstra & van Doorn, 1985) respectively.

- Satisfaction (tactile feedback conditions only). The satisfaction with the tactile belt was gathered subjectively using a post-test questionnaire.

- Presence (STE conditions only). The sense of the presence in the STE was measured using the Igroup Presence Questionnaire (IPQ). The IPQ measures general presence, spatial presence, involvement and experienced realism (Schubert, Friedmann & Regenbrecht, 2001).

3.4 Material

3.3.1 Tactile feedback

During field testing, TNO's Personal Tactile Navigator system (PTN) was used (Duistermaat, Elliot, van Erp & Redden, 2007). The PTN system gave directional information through localized vibrations on the body of the participant. The location of one of the eight vibrating tactors corresponded with the location of one of the targets. The tactors were activated by the sensor unit through the microprocessor of the system (486 DX Tiqit matchbox PC). The sensor unit consisted of a GPS processor (Garmin GPS 35-HVS) and an electronic compass (Honeywell HRM 2300). It provided data on the current location (GPS) and heading (compass) of the participant.

The tactile feedback used in the STE is an indoor version of the PTN system, designed to work with the STE. It is a belt with 8 tactors, which vibrate around the waist using data from the Unreal engine in the directions of the targets.

3.3.2 Map support

In the field condition, a Dell Axim X50 PDA was used as the map support tool (Figure 3, left). For each of the eight targets, an image was displayed of the map (grey roads on an orange background) on which the starting point was marked (blue dot with a white ‘S’) as well as the current target location (black dot).

The STE provided the map support through a separate monitor displaying the same map images as the PDA in the field condition. The map support software, which controls the tactile belt, had to be used on a separate PC and monitor because of technical limitations of the PDA.

3.3.3 STE

The field location was recreated for the STE condition using UnrealEd 3.0, the level editor of Unreal Tournament 2004 which is based on version 2.5 of the Unreal engine. Using an adapted version of the Gamebots script, the simulated environment communicated through TCP/IP with the map support tool, which was programmed in C#.

The set-up of the STE consisted of two computers, both with 17 inch computer screens (Figure 3, right). The map support screen lay down in front of the user, while the screen showing the STE from a first-person view was positioned upright behind the map screen. Using a Saitek game controller, the player navigated through the world.

Figure 3: The PDA displaying the map in the field (left) and the map display in the STE (right).

3.3.4 Spatial ability test

In all four conditions, participants were subjected to a spatial ability test (Neerincx, Pemberton & Lindenberg, 1999) on a PC prior to the navigation task.

Repeatedly, participants were shown an image of a 3D shape in the center of the screen. Around this test shape, four similar shapes were displayed. The objective was to recognize which of the four surrounding shapes was a rotated duplicate of the center shape (Shephard & Metzler, 1971), using the mouse to click the correct shape. Either one of the four surrounding shapes was correct, or none of them. At the bottom of the screen there was a fifth option to indicate ‘none’. Participants were given 15 seconds to click the correct answer, but were allowed to change their answer within that time. When no answer was clicked after 12 seconds, the computer produced a beep (audible through a headset) to indicate that the 15 seconds were almost up. The next shape was displayed regardless of an answer after 15 seconds.

The test started with 5 trial shapes, and then proceeded with 40 test shapes. Scores on the test were measured solely by adding up the correct answers.

3.5 Procedure

First, participants were given a written instruction about the experiment. Then they had to fill in a general questionnaire about their background, and (in the STE condition) about their gaming experience and sensitivity to motion sickness. The participants then conducted the spatial ability test.

To allow the participants to get acquainted with their environment and available feedback, they were given the time to practice first. As a test trial in the STE condition, participants had to locate a single waypoint in a fictive virtual environment different from Soesterberg. In the field condition, the route to the starting point in Soesterberg was used as a test trial, using partially blinded spectacles to avoid premature knowledge of the environment. After the test trial, the participants were positioned on the starting location in (virtual) Soesterberg facing north, and began the task. When a waypoint was reached in the STE, the navigation feedback was shutdown automatically, whereas in the field condition, the experimenter took away the PDA and shut down the tactile belt manually.

When the eight trials were completed, the participants left the environment and were asked to fill in a questionnaire on their perceived effort, used strategy and satisfaction with the STE and/or tactile feedback if present in the condition. Only in the STE condition, the IPQ was included to gather the sense of presence.

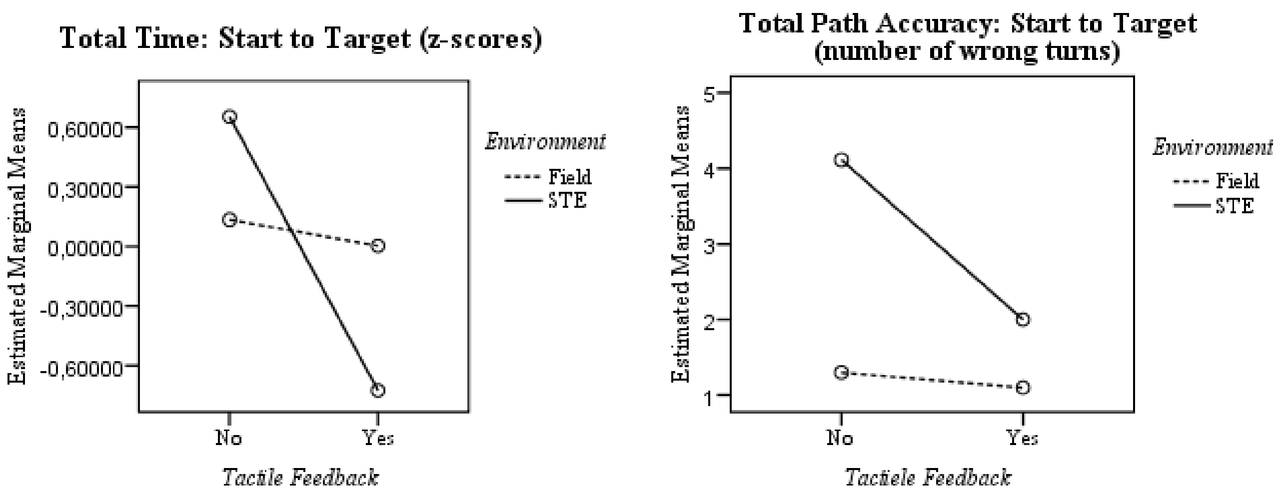
4. RESULTS

During the experiment, it became clear that navigating in the field took more time in general compared to the STE, resulting in a difference in scale between the navigation times in the field and the STE. For this reason, z-scores were used for the analysis of the navigation performance measures (start to target time and return time).

On another note, the covariates gender and spatial ability were taken into account during analysis. Due to their lack of significance however, these covariates are not mentioned in the following sections.

4.3. Field vs. STE: Navigation performance

Two-way ANOVAs were performed to find significant main effects of tactile feedback in the field and in the STE on navigation performance. The measures used for performance are start to target time and start to target path accuracy (the number of wrong turns made). The resulting interactions are shown in Figure 4.



	No tactile fb.	*With tactile fb.*
Field	M = 0.13 SD = 1.07	M = 0.003 SD = 0.49
STE	M = 0.65 SD = 1.11	M = -0.73 SD = 0.85

	No tactile fb.	*With tactile fb.*
Field	M = 1.30 SD = 1.70	M = 1.10 SD = 1.44
STE	M = 4.11 SD = 2.47	M = 2.00 SD = 1.89

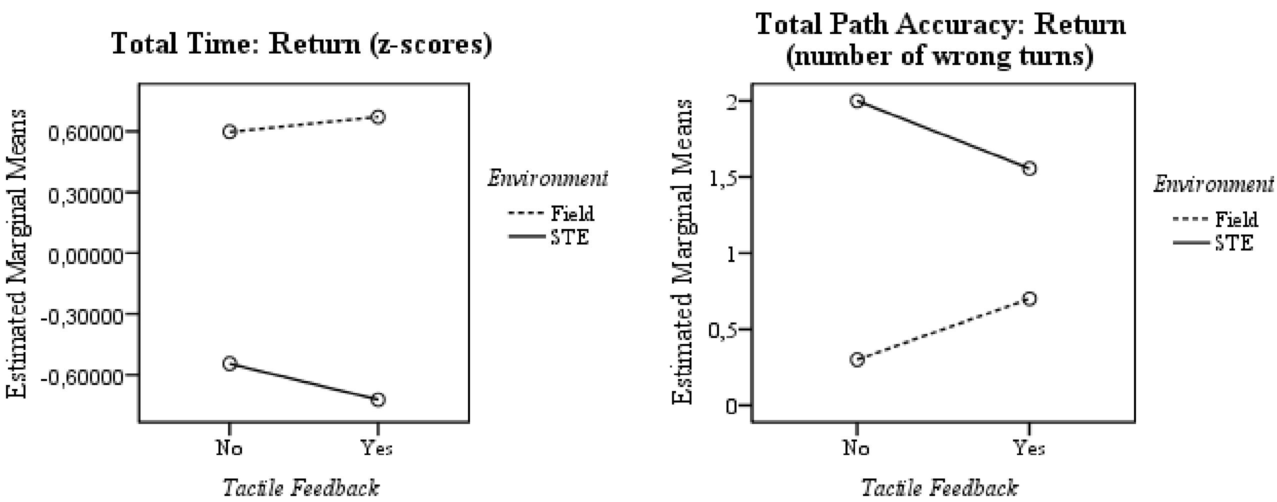
Figure 4: Interactions for start to target time (left) and start to target path accuracy (right), with the means and standard deviations

For start to target time, the main effect of environment was not significant: F (1, 35) = .13, p > .05. The main effect of tactile feedback was significant: F = (1, 35) = 6.749, p < .05, with a medium effect size (ω^2 = .12) (Kirk, 1996). Participants moved faster through both environments with tactile feedback than without. The interaction effect was also significant: F = (1, 35) 4.605, p < .05, with a medium effect size (ω^2 = .08) (Kirk, 1996). Post-hoc analysis using the Scheffé test showed that participants in the STE were significantly faster with tactile feedback than without (p < .05). In the field, there was no significant difference between the participants with and without tactile feedback (p > .05). The left graph in Figure 4 shows that the interaction effect was formed by the large difference in the STE condition. Apparently, the use of a tactile belt had more benefit for participants in the STE than for participants in the field.

For start to target path accuracy, the main effect of environment was significant: *F* (1, 35) = 9.314, $p < .05$, with a large effect size ($\omega^2 = .16$) (Kirk, 1996). Regardless of tactile feedback, participants made less wrong turns on the way towards the targets in the field condition compared to the STE condition. The main effect of tactile feedback indicated a trend: *F* (1, 35) = 3.612, *p* = .06, indicating that participants made less wrong turns towards the targets with tactile feedback than without tactile feedback, but not enough to confirm the result. The interaction effect was not significant ($p > .05$).

4.4 Field vs. STE: Situation awareness

Figure 5 shows the results for return time and return path accuracy:



	No tactile fb.	*With tactile fb.*
Field	M = 0.60 SD = 0.87	M = 0.67 SD = 0.48
STE	M = -0.55 SD = 0.88	M = -0.72 SD = 0.87

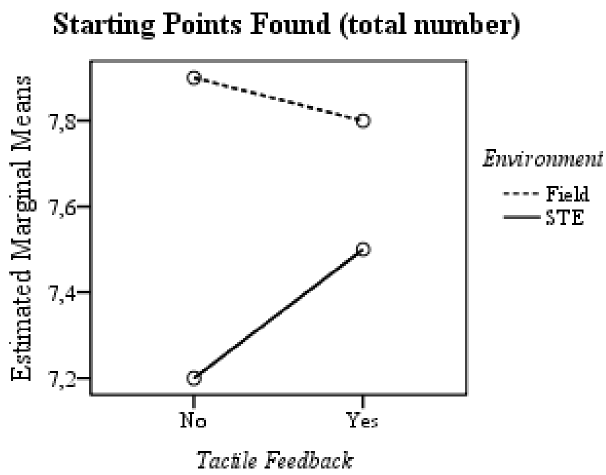
	No tactile fb.	*With tactile fb.*
Field	M = 0.30 SD = 0.95	M = 0.70 SD = 1.06
STE	M = 2.00 SD = 1.63	M = 1.56 SD = 1.59

Figure 5: Interactions for return time (left) and return path accuracy (right), with the means and standard deviations

The main effect of environment was significant *F* (1, 36) = 25.459, $p < .05$, with a large effect size ($\omega^2 = .38$) (Kirk, 1996). Participants both with and without tactile feedback returned faster to the starting point in the STE condition compared to the field condition. The main effect of tactile feedback and the interaction effect were both not significant ($p > .05$).

For return path accuracy, only the main effect of environment was significant: F (1, 35) = 8.907, $p < .05$, with a large effect size ($\omega^2 = .17$) (Kirk, 1996). Participants both with and without tactile feedback made less wrong turns on the way back to the starting point in the field condition compared to the STE condition. The main effect of tactile feedback and the interaction effect were both not significant ($p > .05$).

Figure 6 shows the results for the third measure of situation awareness, the total number of starting points found within the time limit:



	No tactile fb.	*With tactile fb.*
Field	M = 7.90 SD = 0.32	M = 7.80 SD = 0.42
STE	M = 7.20 SD = 0.79	M = 7.50 SD = 0.97

Figure 6: Interaction for the total number of starting points found (maximum = 8), with the means and standard deviations

For the number of starting points found, only the main effect of environment was significant: F (1, 36) = 5.422, $p < .05$, with a medium effect size ($\omega^2 = .10$) (Kirk, 1996). The participants found more starting points in the field condition compared to the STE condition. The main effect of tactile feedback and the interaction effect were both not significant ($p > .05$).

Furthermore, subjects were asked about the visual cues they used during navigation in the field and the STE. These are listed in Table 4:

Visual cues used in the field	*%*	*Visual cues used in the STE*	*%*
Playgrounds	26.9 %	Playgrounds	26.1 %
Road type	23.1 %	Road type	30.4 %
Squares	15.4 %	Squares	17.5 %
Cars / Parking lots	7.8 %	Cars / Parking lots	10.9 %
Road signs	5.7 %	Street lights	6.5 %
Statues	3.8 %	Environment border	4.3 %
House numbers	3.8 %		
Other (cues mentioned once)	13.5 %	Other (cues mentioned once)	4.3 %

Table 4: Visual cues used in the field and the STE as mentioned by the participants

The visual cues can be divided in three categories, which are separated by the rows in the table. The first and top category consists of four visual cues that were mentioned more than once by participants in both the field and the STE. As can be observed in the table, these four cues were mentioned in relatively equal amounts in both environments. The second category consists of the visual cues that were mentioned more than once in either the field or the STE. The table shows more detailed cues in the field than in the STE, where an STE limitation was used as a cue: the edge of the environment. Finally, the third category consists of all the other cues that were mentioned only once in either the field or the STE. The field shows more uniquely mentioned cues than the STE. Figure 7 gives an impression of these differences between both environments.

Figure 7: Differences in visual cues between the field (left) and the STE (right)

Overall, the prominent visual cues used were largely the same for both the field and the STE. More (detailed) cues were mentioned in the field than in the STE because of its higher fidelity.

4.5. Field vs. STE: Strategy

After the experiment, participants were asked about their strategy. The first question inquired which of the following three items were used primarily to orientate and form navigation strategies: (1) the map support, (2) the tactile belt (if available), or (3) the environment itself. A χ^2 test showed no significant differences ($p > .05$). The second question inquired whether the participants had changed this primary orientation item and if so, to which other item. Again no significant differences were found ($p > .05$).

4.6. Field vs. STE: Effort

Concerning perceived effort, participants first had to answer two general questions consisting of five point Likert scales. The first question was about the level of difficulty participants experienced during the task. The second question was about whether they thought they had performed well. A two-way ANOVA using type of environment and presence of tactile feedback as the fixed factors yielded no significant results ($p > .05$).

Participants were also subjected to the RSME, which rated the mental effort for both navigating to the targets and the effort it took to return. A two-way ANOVA was performed, showing only a trend for the main effect of the type of environment: F (1, 36) = 3.421, p = .073. This indicated that participants invested somewhat more mental effort returning in the STE than in the field.

4.7. Field vs. STE: Satisfaction

For the participants who had tactile feedback, the following questions on satisfaction were posed, using a five point Likert scale (1 = very negative, 5 = very positive):

1. Did you find the tactile belt easy to use?
2. Did you find the tactile belt comfortable to use?
3. Did you find the tactile belt useful?

Figure 8 displays the mean scores for both conditions:

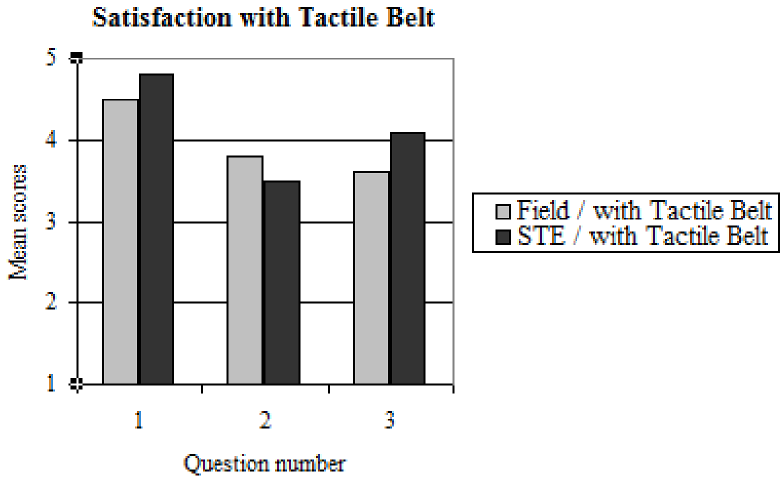


Figure 8: Mean scores of satisfaction questions for both conditions with tactile feedback

In general, the participants reacted positively to the tactile feedback. There were no significant differences when satisfaction was related to environment using a one-way ANOVA ($p > .05$).

4.8. STE: Presence

Presence was measured, but not for finding additional patterns between the field and the STE as it was only measured in the STE. It was included to gain an insight into how the STE is experienced and the acceptance by potential end-users. Figure 9 shows the results of the IPQ:

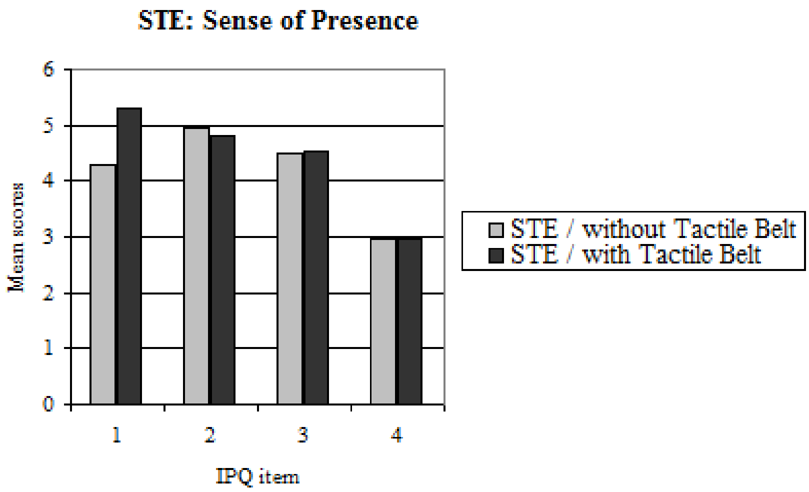


Figure 9: Mean scores of IPQ questions grouped per item for both STE conditions

For the first three items of the IPQ (general presence, spatial presence and involvement), the means indicated presence scores between 4 and 5 (neutral – a little), while on the fourth item (experienced realism) the mean was just below 3 (not a little). There were no significant differences when the IPQ scores were related to the availability of tactile feedback using a one-way ANOVA ($p > .05$).

5. DISCUSSION and CONCLUSION

Returning to the research questions, we will first discuss the effects of tactile feedback on navigation performance and situation awareness in (RQ1) the field and (RQ2) the STE. Then we will discuss the comparisons betweens these effects to answer RQ3.

RQ1: What is the effect of tactile feedback on navigation performance and situation awareness in the field?

When the participants without tactile feedback in the field were compared with the participants who did have tactile feedback in the field, no significant differences were found on navigation performance and situation awareness. We can conclude that in the field, tactile feedback has no effect on both navigation performance and situation awareness.

RQ2: What is the effect of tactile feedback on navigation performance and situation awareness in the STE?

When the participants without tactile feedback in the STE were compared with the participants who did have tactile feedback in the STE, a significant difference and a trend were found on navigation performance. The difference in start to target time was significant: participants navigated faster with tactile feedback than without tactile feedback in the STE. The trend was found on start to target path accuracy: participants tended to make fewer mistakes on their way towards the targets with tactile feedback than without. On situation awareness, no significant differences were found. We can conclude that in the STE, tactile feedback does have an effect on navigation performance (primarily on navigation time), but not on situation awareness.

We now know the effect of tactile feedback within each environment and answered the first two research questions. Next, we discuss the third research question.

RQ3: Is the STE valid through a match in tactile feedback patterns found in the field and in the STE?

To answer this question, we will first discuss the comparisons made between the effects of tactile feedback in the field and the STE on navigation performance, situation awareness, strategy, effort and satisfaction. The results on presence are not discussed as it was only measured in the STE.

When comparing the effect of tactile feedback on navigation performance in the field and in the STE, results showed different patterns. Tactile feedback significantly improved start to target time in the STE, whereas in the field the effect was minimal. So there was an important difference in the effect of tactile feedback between both environments, which was expected as the STE is less rich. It should be noted however that there was a ceiling effect in the field condition. In general, participants in the field had little or no difficulty performing the task, possibly limiting a bigger effect of tactile feedback. For instance, this ceiling effect is apparent in the interaction graph for start to target path accuracy (Figure 4, right graph), where it's shown that on average, participants in the field took only wrong one path over all 8 navigation trials. In the future, the navigation task should be designed carefully to optimally suit both the STE and the field.

For situation awareness, no differences in the effect of tactile feedback between the field and the STE were found. Only the main effects of the type of environment were significant for all three situation awareness measures. Disregarding the availability of tactile feedback, these main effects showed that while it took more time to return in the field compared to the STE, return path accuracy and the number of starting points found were significantly better in the field compared to the STE. This was expected, as in the field participants had the benefits of a large field of view, natural orientation and increased fidelity. It should be noted though that the improved situation awareness on the latter two measures could partly be the result of the longer time that participants spent in the field. Comparison of used visual cues showed that the most important visual cues used in the field and the STE were shown to be largely similar. The STE seems to be sufficient in providing the prominent cues of the field environment that people use to navigate by, allowing for levels 1 (perception) and 2 (comprehension) of situation awareness (Endsley & Garland, 2000).

When comparing the elements used by participants to base their navigation strategy on (the tactile belt, the mobile map, or the environment itself), no significant differences were found.

Concerning effort, comparison of the results on perceived effort questionnaires yielded no significance. However, the RSME which assesses mental effort did show a trend. Participants with and without tactile feedback appeared to invest more mental effort in the STE than in the field. Increased mental effort appeared to be needed to cope with the lack of fidelity, natural orientation and decreased field of view, but further research is needed to confirm this.

Regarding satisfaction with the tactile belt, no significant results were found between the field and the STE. Generally, participants appeared to appreciate the tactile feedback in both environments. The significant difference that was found on navigation performance between the field and the STE appeared not to have an effect on the satisfaction scores for the usefulness of the tactile belt, because the STE scored only slightly higher than the field (Figure 7, satisfaction question 3). Allowing participants the opportunity to experience both the presence and the absence of tactile feedback in a future mixed factorial experiment could give some more insight into this.

Now that we know that tactile feedback has a significantly more positive effect on navigation performance (time from start to target) in the STE compared to the field, and that tactile feedback has no significant effect on situation awareness, strategy, effort and satisfaction, we can answer the third research question: is the STE valid through a match in patterns found in the field and the STE?

Although only one significantly different pattern in the effect of tactile feedback between the field and the STE was found, this mismatch on the measure of navigation performance indicates that the validity of the STE must be questioned. However, to conclude that the STE is not valid is premature at this time, due to the ceiling effects that were encountered during this first experiment. Judging by the significant difference in navigation performance, the participants in the field had a large advantage over the participants in the STE. Apart from the sub-optimal navigation task, the spatial orientation and field of view requirements are obstacles for the STE. Even though situation awareness in general, disregarding the use of the tactile belt, was found to be better in the field compared to the STE, environment fidelity seemed to be less of an issue, as analysis of visual cues showed that the prominent cues that people used to navigate by in the field were present in the STE and were adopted in similar amounts.

Future work should focus on improving the STE and the navigation task to try to better support evaluation of tactile feedback. This way, more insight can be gained into the suitability of evaluating tactile feedback in STEs. For instance, the task can be made harder in the field by increasing the distance to the waypoints. To keep a more difficult field task like this comparable with the STE task, the STE should be changed as well to increase its fidelity (more unique cues).

The use of a HMD in the STE in future experiments could improve upon both the spatial orientation and field of view requirements. A stereo monitor set-up or a wide projection screen are alternatives to improve the field of view, as DiZio & Lackner (2000) have indicated that motion sickness is a serious potential side effect and aftereffect of using a HMD.

Support tools other than tactile feedback should also be evaluated in the STE. As in Smets et al. (2008), the effects of heading-up map support and north-up map support could be analyzed to further study the consequences of orientation in the field and the STE. By experimenting with only one tool at a time, instead of both tactile feedback and map support as in this experiment, it may be easier to isolate and analyze the parameters that are influenced and to devise a task that is optimally suited for both the support tool as well as the two environments.

Although the navigation task that was used in this experiment was not optimal for both the field and the STE, the use of a cost-effective STE such as the one used in this experiment gave interesting insights into the differences between requirements in STEs and real environments. With modifications particularly to the navigation task, it is worthwhile to further investigate the STE for first responders as well as other professions.

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