Use of Haptic Devices to Provide Contextual Cues in a Virtual Environment for Training

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ABSTRACT

The usefulness of incorporating haptic devices into virtual environments (VEs) is becoming an increasingly prevalent area of research in the training arena. The work described in this paper investigates the utility of incorporating haptics in a VE for Military Operations in Urban Terrain (MOUT) training, focusing on two primary research questions: How do haptic cues interact with and compare to auditory cues for the identification of task-relevant VE events, and how does the inclusion of haptic cues impact presence using the Witmer & Singer (1998) Presence Questionnaire? To answer these questions, participants performed a building search task eight successive times in a desktop VE. Using vibrotactile stimulation applied to the torso, arms and legs, participants received either no haptic cues, haptic cues that were approximations of real-world stimuli ("Natural Haptics"), or haptic cues which were metaphoric signals for real-world stimuli ("Metaphoric Haptics"). Across the haptics groups, half of the participants were given auditory cues for the stimuli events (explosions, gunshots, and collisions), and the other half received no auditory stimuli. All participants received identical visual cues. Results from 74 participants showed that participants in the Natural Haptics condition showed better identification of collision and gunshot events compared to participants in the other groups, whereas participants receiving auditory cues showed better identification of explosion events. Regarding presence, the scores for participants in the Natural Haptics group only increased over trials on the Interface Quality subscale, and participants in both haptic groups showed increased scores over trials for the Adaptation and Immersion subscale. However, there was not a general advantage in presence scores that was related to haptics, perhaps due to ceiling effects. Other findings showed that haptics was associated with increased perceived task demands.

ABOUT THE AUTHORS

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INTRODUCTION

As the Army transitions to Objective Force, virtual training environments are becoming increasingly important to the U.S. Army for training warfighters. Overall, training systems are providing more realistic battlefield contexts for the dismounted soldier, increasing soldier immersion and providing a better basis for transfer to operational systems. However, in support of better real-world simulation, the development and incorporation of vibrotactile cues has lagged behind the simulation of visual and auditory cues. Reasons for this include the difficulty simulating tactile information due to technology limitations, restrictions in hardware and software supporting haptic systems (e.g., impeding movement of users), and the lack of research on how best to employ haptics. The research described in this paper examines the utility of incorporating vibrotactile cues into a Virtual Environment (VE) for training using a Military Operations in Urban Terrain (MOUT) scenario.

HAPTICS IN VIRTUAL ENVIRONMENTS

Interactions in the real world often involve a high degree of tactile information, which provides the individual with information regarding the environment, giving the individual situational awareness information. The term "haptics" refers to the incorporation of tactile information into displays provided within both operational systems and training environments (Hale & Stanney, 2004) When used for displays, haptic information can be used to recreate or approximate cues found in the real world, or it can provide metaphoric cues and signals to support additional experiences. The inclusion of haptic feedback in VEs, as either natural cues or metaphors, should support widespread training applications such as enhancing the individual's immersion levels in the VE, or expanding the breadth of skills that can be trained in the VE.

Although evidence has been documented to support any training effects of a variety of haptics, these data are just beginning to accrue. Thus far, research indicates that addition of haptics can add to the sense of presence in a VE (e.g., Basogan et al., 1998; Dinh, Walker, Hodges, Song, & Kobayashi, 1999). Fowlkes, Washburn, Eitelman, Daly, and Cohn (2005) also found that a vibrotactile display facilitated performance of a room searching task requiring that participants maintain back-to-back contact with a simulated team member. Performance effects are also being documented. Lindeman, Sibert, Mendez-Mendez, Patil, and Phifer (2005) found that haptic displays used in another virtual building clearing task could be used to provide spatial information about areas of the building yet to be cleared, and haptic cues could also be used to minimize exposure to unsafe areas.

Ecological Design and Haptics

Vicente & Rasmussen (1992), in defining Ecological Interface Design (EID), propose three different classifications of behavior: Rule-based behavior (RBB), Knowledge-based behavior (KBB), and Skill-based behavior (SBB). Each classification of behavior is based on a different type of knowledge and the behaviors associated with that knowledge – for example, RBB is based on procedural knowledge of instinct and actions. That is to say, RBB encompasses perception of environmental stimuli, and rapid action based upon that perception, with little to no effort on the part of the individual. One given rule of EID is to integrate more contextual cues into the interface in order to allow the user to select from a larger catalogue of known behaviors when searching for the appropriate behavior by providing a "consistent one-to-one mapping" between environmental constraints and cues afforded by the interface (p. 598) – i.e., when designing a system, give the VE user the context that will allow the employ of intuitive skills that have already been developed naturally over the course of a lifetime.

Gross, Stanney and Cohn (2005) also addressed EID and RBB in their paper discussing the need for environmental affordances in VEs. They suggest that since VEs are by their nature not ecologically valid, critical affordances (i.e., "environmental and state stimuli" p.484]) should be presented, but current inadequacies in VE systems are in part due to contextual cues that are invalid and/or lacking in their presentation. In their discussion on how best to use sensory substitution, Gross et al. (2005) also note that some supplemental stimuli, though meant to augment, occasionally distract from the user's experience, but that stimuli substitution schemes should be designed so that the substituted stimuli match the situation spatio-temporally.

In the words of Tan & Pentland (2001):

> *"A good wearable tactual display should minimize training by displaying information that is salient, intuitive, and easy to interpret through the sense of touch" (p. 592).*

Per the foundations that a good interface is intuitive and requires little to no explanation or training, designing haptic devices so that their interface with the user is also intuitive should provide the user with haptic cues which augment the VE experience and yet require little to no training prior to use. The research described in this paper examines the usefulness of incorporating haptics not as a work-around modality for providing contextual cues in a VE, but rather as the contextual cues themselves presented in as much of a naturalistic way as possible given the limits of the technology, therefore hypothetically needing no explanation or instruction in their meanings. Participants in this research performed a building search task eight times consecutively in a desktop VE. Using vibrotactile stimulation applied to the torso, arms and legs, participants then received either no haptic cues, haptic cues that were approximations of real-world stimuli ("Natural Haptics"), or haptic cues which were metaphoric signals for real-world stimuli ("Metaphoric Haptics"). Performance data, questionnaires, and verbal protocols then were analyzed so as to explore the possibility of providing users with haptic cues that fit into the user's mental schema of real-world expectations for a variety of cues, and if providing the user with intuitive, ecologically valid ("natural") cues haptically affects performance in the VE.

METHOD

Participants

Participants were 74 college students from the University of Central Florida and Valencia Community College East campuses, both in Orlando, FL, who responded to fliers and notices posted on the campuses. The participants ranged in age from 18 to 43 (M= 22.47, SD=5.08). Forty six (62.2%) of the participants were male and 27 (36.5 %) were female (one participant declined to respond). According to a demographic survey completed by participants, participants' time per week playing video games ranged from zero to forty hours (M=5.5, SD=7.80). Of the 74 participants, 58 indicated that they previously had experienced some form of VE.

Design

The task required that participants search a building in a VE for fellow troops who had lost radio contact. Specifically, participants were asked to search a building and identify threats (enemies) and teammate hostages as well as give status updates. As participants performed the task, they were told to constantly talk to their "commander" detailing everything occurring in the environment including what they were experiencing, thus providing verbal protocols. The participants were randomly assigned to one of the six conditions shown in the Table 1.

Table 1. Experimental Conditions

Natural Audio Cues	**Haptic Cues**		
	Natural Haptic Cues	**Metaphoric Haptic Cues**	**No Haptic Cues**
Present (On)	Group 1	Group 2	Group 3
Not Present (Off)	Group 4	Group 5	Group 6

All participants were outfitted in a haptic vest and leg and arm bands which provided the haptic cueing via haptic "tactors," devices which have a tiny oscillator that activates the cutaneous system when placed on the skin. These electromechanical tactors, or C2 tactors, developed by EAI, are 1.2" diameter by 0.31" high, and weigh 17 grams. These specific tactors have been used by researchers at Princeton University, Boston University, University of Massachusetts, University of West Florida and the University of Central Florida.

They are being applied to the development of at least two biomedical applications, and have gained considerable interest for use in simulation and training, as well as entertainment industries. The location of the tactors is illustrated in Figure 1.

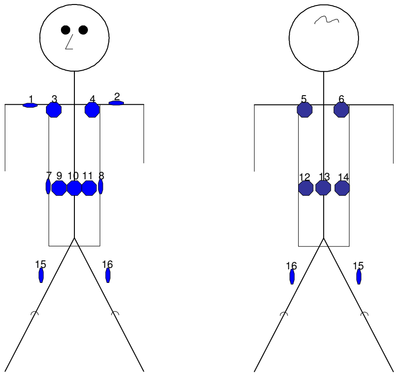

Figure 1. Location of haptic tactors

Haptic cues were used to signal collisions, gunshots, and explosions that occurred within the environment. How the haptic signatures were represented in location, duration, intensity, and pattern varied depending on condition: Individuals in the "Natural" haptic cues groups (Groups 1 & 4) received haptic cueing in ways that would mimic expectations in the real world. For example, if an explosion went off in front of a participant, all the tactors on the front of the participant activated with a "rough" frequency in order to accurately mimic the all-over feeling an explosion would provide, whereas if a participant bumped into a wall on the right side of the body, the tactors on the right arm and/or legs activated with a smooth signature to imply a slight bump only on one side of the body to a hard surface. Individuals in the Metaphoric haptic cues groups (Groups 2 & 5) also received haptic cueing for events in the environment, however their cues acted as "signal cues." For example, if an explosion occurred, individuals received a Morse-code-like stimulus on one tactor on the top of the right thigh, in a distinct and unnatural pattern. Finally, the groups with No Haptic Cues (Groups 3 & 6) received no haptic cues.

In addition, Groups 1, 2, and 3 received additional auditory contextual cueing paired with the haptic cues (e.g., the soft "thud" of a collision of the body with a wall), whereas Groups 4, 5, and 6 did not receive any auditory cueing.

Testbed

The Fully Immersive Tactical Trainer (FITT) system at the Institute for Simulation and Training at the University of Central Florida served as a testbed. This VE simulated a building in which the participants could move about and explore freely, and also included avatars representing both friendly and enemy forces. During the experiment, participants were seated at a desktop workstation. A monitor at the workstation presented the graphical environment and participants used a hand-held game controller to maneuver through the VE.

Questionnaires

The questionnaires delivered in this experiment are described below.

Presence Questionnaire

The Presence Questionnaire (Witmer & Singer, 1998) was used to assess the subjective experience of being in the VE. Participants indicate the extent to which they agree with each item using a seven point scale. The Presence Questionnaire results in subscale scores for Interface Quality, Adaptation and Immersion, Sensory Fidelity, and Involvement. Scores for each subscale are based on the average rating for all the scale items. Higher scores indicate increased perceptions of presence.

Simulator Sickness Questionnaire

Participant simulator sickness was monitored with the Simulator Sickness Questionnaire (SSQ) (Kennedy, Lane, Berbaum, & Lilienthal, 1993). The SSQ consists of sixteen symptoms that are rated as either none, slight, moderate, or severe. The SSQ produces four scores, an overall Total Severity Score, and three subscale scores: Nausea, Disorientation, and Occulomotor. The Total severity score is examined to determine the overall severity of the simulator sickness. The subscales scores are examined to further define the problem. Each of the dimensions is hypothesized to reflect disruption to a different target system of the body. Higher scores indicate more sickness. Simulator sickness was found to be negligible in the present research.

NASA Task Load Index

The NASA Task Load Index (TLX) (Hart & Staveland, 1988) provides workload scores based on ratings on six subscales: Mental Demands (mental and perceptual activity required), Physical Demands (physical activity required), Temporal Demands (pace of the task), Own Performance (success in accomplishing goals of the task), Effort (degree of both mental and physical difficulty), and Frustration (degree to which task was discouraging, annoying, or caused stress). Participants provide ratings on a 100-point scale that characterize the task along each of the dimensions. Higher scores indicate higher perceived workload.

Procedure

Upon arrival, participants were provided with a verbal overview of the project, including its length (up to two hours and a half), the risks associated with participation, expected benefits, and methods for maintaining participant confidentiality. The experimenter then screened participants for those under 18 years of age and those who were not in their normal physical state of health (initial screening had been conducted over the phone). The experimenter also stated the importance of making sure that participants were not experiencing any pre-existing symptoms (e.g., of illness or fatigue) and explained the reason for doing this (they were more likely to develop simulator sickness during the study). Participants read and signed an informed consent form. Following the project overview, participants completed the SSQ and were asked if they were in their usual state of fitness. Participants who had symptoms or otherwise reported that they did not meet these criteria were excused from the study. Participants were then given a PowerPoint briefing indicating the specific instructions for task performance.

Each participant was trained on the VE prior to the first trial. This encompassed learning to perform the simple movement techniques in the VE such as walking forward and backward, turning around, looking up and down, and maneuvering through doorways and hallways. This was conducted without audio or haptic cueing of any kind, regardless of condition. Participants also practiced firing their weapons using the gamepad. Participants then donned the haptic vest, arm bands, and leg bands with the vibrotactile devices. Participants were familiarized with haptic devices and shown what it felt like when the tactors were activated by activating them one at a time (i.e., "This is where all the vibrotactile devices are located in the vest – Can you feel that?"), but they *were not trained* on what each specific haptic cue or signature indicated within the environment.

Participants performed the task eight times. On each trial, the location of the threats and injured friendly avatars changed, however there were an identical number of threat avatars, friendly teammate avatars, and explosions (3 per trial) that the participant could encounter. Participants explored the environment while giving a verbal protocol of their actions and events occurring within the environment. They were asked specifically during the pre-experiment briefing, as well as before each trial, to detail things such as "Turning left" or "Turning right," "Entering Room," and "Impact with a wall," with the intent that through this guided exploration of the environment and verbal protocol, and without prior knowledge of what the specific events would look like or feel like, that participants would either identify correctly, identify incorrectly, or completely ignore the target stimuli. They also were asking to use precise commands to indicate certain task-related events within the environment. Participants indicated when an injured individual was found by saying specifically: "Teammate Located;" when they were engaging in weapons fire with an enemy participants said specifically "Engaging!" during firing commencement, and "Target down!" once the firing had ceased. The trial was over when the participant had found all six teammates and had ensured all enemy avatars were down by saying precisely, "Clear!" The maximum time allowed per trial was eight minutes in order to ensure minimal effects due to simulator sickness. As a result, not all participants completed each trial. Upon completion of each trial, participants were given the Presence Questionnaire and the NASA-TLX.

Once the participant had completed all eight trials (or, in the event that the participant could not complete all eight trials, during the last 20 minutes of the pre-determined experiment time block), participants were asked to complete the Haptic Cue Self-Report Survey and complete a second SSQ so as to ensure no lingering effects of the haptic environment.

Measures

Measures collected included:

- Audio recordings of the participant's verbal protocol which were content-coded for:
    - Accuracy in identification of haptic cues,
    - Accuracy in identifying spatial characteristics in the environment (e.g., dead-ends, doors, etc.),
- Number of gunshots from threats (threat avatars shoot the participant if the participant is within the threat's line of sight for one second, and if the participant has not shot the threat first),
- The number of flash-bang explosions in the environment
- The number of collisions with objects in the environment

- The percentage of accurate identification of target stimuli cues (gunshots, collisions, and explosions),
- The percentage of inaccurate identification of target stimuli cues,
- The number of correctly identified synthetic teammates,
- Scores on the SSQ, Presence Questionnaire, Haptic Cue Self-Report Survey, and NASA TLX,
- And the time to complete each trial.

With regard to the verbal protocol, three coders were used to content code the recordings. Inter-coder reliability was high, and ranged from .97 to 1 (based on correlating coder scores across trials for several of the participants).

RESULTS

Mixed model ANOVAS with haptic (Natural and Metaphoric Haptics versus No Haptics) and audio (Audio On as versus Audio Off) conditions as the between subjects effects and trials (early trial block [trials 1-4] versus late trial block [trials 5-8]) as the within subjects effects.

Recognition of Haptic Events

Recognition of events (gunshots, collisions, and explosions) was scored as the percentage of each event type correctly identified. It was found that Natural Haptics facilitated the identification of gunshot and collision events. Auditory cues were best for signaling the occurrence of explosions.

There was a significant main effect for haptic condition on participants' ability to identify gunshot events (F(2,31) = 5.57, p = .009). No other main effects or interactions were statistically significant. Post-hoc independent t-test comparisons showed that the Natural Haptics condition was superior to the No Haptics condition (t(23) = 2.45, p = .022) and to the Metaphoric Haptics condition (t(20) = 2.43, p = .025). The Metaphoric Haptics condition was not statistically different from the No Haptics condition t(25) = -.027, p = .978).

For collision events (times when the participant bumped into a wall), a three way interaction (haptics by audio by trials) was obtained (F(1, 31) = 6.084, p = .006). Post hoc paired t-test comparisons revealed that significant improvement across the trial blocks occurred only for the Natural Haptics/No Audio condition (t(4) = 2.57, p = .062). Moreover, independent t-tests showed that, within the first trial block, there were no significant differences between groups. Within the last trial block, the Natural Haptics/Audio Off condition was significantly better than the Metaphoric Haptics/Audio Off condition (t(11) = 2.27, p = 0.5) and the No Haptics/Audio Off condition (t(13) = 2.7, p = .02). No other differences were significant.

For the explosions scores, shown in Figure 29, there were main effects for trial (*F*(1, 31) = 14.15, *p* = .001) and audio conditions (*F*(1, 31) = 5.70, *p* = .023) only. None of the interactions were significant. It can be seen in Figure 29 that significant improvements were seen across the trial blocks. In addition, it can be seen that the Audio On groups out performed the Audio Off groups.

Presence

It was found that haptic condition did not produce main effects on any of the Presence subscales although there was evidence that Presence was more likely to increase over trials for both the haptics conditions as compared to the No Haptics conditions on the Interface Quality and Adaptation and Immersion subscales. Audio On conditions were associated with higher Presence ratings on the Sensory Fidelity subscale only. This subscale was based on only one item that was directly related to audio cues. These results are discussed below.

For the Interface Quality subscale, a mixed model ANOVA revealed a haptics by trials interaction (*F*(1, 63) = 4.03, *p* = .022). Post hoc paired t-test comparisons revealed that Presence scores for the Natural Haptics condition only increased from the first to the second trial block (*t*(25) = -4.41, *p* =< .001). None of the independent t-test comparisons at each trial block revealed significant differences between haptics conditions.

Similarly, for the Adaptation and Immersion subscale, a haptics by trials interaction (*F*(1, 63) = 4.0, *p* = .023) was the only significant effect obtained. The locus of this interaction was that the haptics conditions showed greater improvement across trials than the No Haptics conditions.

For the Sensory Fidelity subscale, a mixed model ANOVA revealed a main effect for trials (*F*(1, 54) = 7.87, *p* = .007) and audio conditions only (*F*(1, 54) = 33.44, *p* <.001). It can be seen that the ratings increased from the early to the late trial block. In addition, ratings were higher for the Audio On conditions compared to the Audio Off conditions.

NASA-TLX

The NASA TLX scores indicated that haptics contributed to increased workload on the Effort, Temporal Demand, and Mental Demand subscales. An ANOVA revealed a main effect for haptics (*F*(2,58)=3.7, *p* = .03) but no other main effects or interactions were significant. Independent samples t-tests revealed an advantage for both the Natural and Metaphoric Haptics groups over the No Haptics group (*t*(45)=2.01, *p*=.05) and *t*(37)=3.02, *p*=.005, respectively). There was no difference between the Natural and Metaphoric Haptics groups (*t*(40)=-.79, *p*=.43)

Similarly, for the NASA TLX score for the Temporal Demand subscale, an ANOVA revealed a main effect for haptics (*F*(2,59)=3.2, *p* = .05), but no other main effects or interactions were significant. Independent samples t-tests revealed an advantage for both the Natural and Metaphoric Haptics groups over the No-Haptics group (*t*(46)=2.59, *p*=.01) and *t*(38)=2.4, *p*=.02, respectively). There was no difference between the Natural and Metaphoric Haptics groups (*t*(40)=.36, *p*=.72)

The NASA TLX Mental Demand subscale also shows similar results: An ANOVA revealed a main effect for haptics (*F*(2,59)=4.5, *p* = .02), but no other main effects or interactions were significant. Independent samples t-tests revealed an advantage for both the Natural and Metaphoric Haptics groups over the No Haptics group (*t*(46)=2.09, *p*=.04) and *t*(38)=3.35, *p*=.002, respectively). There was no difference between the Natural and Metaphoric Haptics groups (*t*(40)=-.97, *p*=.33)

For the NASA TLX Performance subscale, an ANOVA revealed an interaction between trials and haptic condition (*F*(2,59)=5.03, *p*=.01), but no other significant main effects or interactions. Independent samples t-tests revealed no difference between the Natural and Metaphoric Haptics conditions on the first trial block (*t*(46)=.35, *p*=.73) or on the second trial block (*t*(43)=-1.32, *p*=.19). The No-Haptics group provided higher ratings of performance compared to the Natural Haptics group on both the first trial block (*t*(51)=-2.50, *p*=.02) and second trial block (*t*(48)=-2.03, *p*=.05). In addition, the No-Haptics group provided higher ratings on the first trial block (*t*(41)=-2.84, *p*=.007) compared to Metaphoric Haptics group but not on the second trial block (*t*(41)=-.68, *p*=.5).

On the NASA TLX Frustration subscale, there was a main effect for trials (*F*(1,57)=5.14, *p*=.03) only. The data show an overall slight decrease in ratings of Frustration from the first to the second trial block. Finally, none of the main effects or interactions were significant on the Physical Demand subscale.

Task Performance Data

An ANOVA indicated that for percentage of team members located, there was a trials effect (*F*(1,31)=8.14, *p*=.008) but no other main effects or interactions were significant. These results indicate a small increase over trials.

An ANOVA performed on the percent of correct verbal reports revealed a trials effect (*F*(1,31)=22.86, *p*<.001) and a trials by audio condition interaction (*F*(1,31)=5.69, *p* = .023). A small increase over trials was evident for both audio conditions, with the change being slightly greater for the Audio On condition.

Trial time decreased over trial blocks, which was confirmed by an ANOVA (*F*(1,61)=69.3, *p*<.001). No other main effects or interactions were significant.

DISCUSSION

This research addressed how haptic and auditory cues affected perceived task characteristics, including the ability to recognize important events in the scenario, presence, and task demands. It was found that participants receiving the Natural Haptics cues were best able to identify gunshots and, to some extent, collisions – findings that may be used to increase the usability and realism of VE training systems. Regarding gunshots, in MOUT and other dismounted soldier training scenarios, trainees may be unable to determine whether they have been wounded or killed. If gunshot information is available to trainees, it is likely that they will receive more realistic, task-relevant feedback and be better able to gauge their own performance. One possible confirmation of this in the present research is that trainees in the No Haptics conditions provided higher assessments of their own performance compared to trainees in the other groups, even though there were no actual performance differences between groups (at least those that were statistically detected).

The Natural Haptic cues in the Auditory Off condition improved ability of trainees to recognize collisions; however the effect was evident only in the later trial block. Thus, this cue appeared to require learning. The rate of learning the *meaning* of collision cues may be improved by the refinement of the haptic signature for collisions and by providing a more limited use of haptics. In the present research, participants in haptics conditions were required to respond to three different haptic cues, which at times may have occurred simultaneously. Sklar and Sarter (1999) point out that, in support of system-human interactions, research is needed to understand better the limitations of the haptics channel in supporting complex discriminations. Based on participant comments given at the time of data collection, discerning the meaning of the multiple signatures was challenging, and a factor which may have detracted from the utility of haptics. Therefore, important research questions brought about by this study include investigating the limitations in the haptic discriminations that can be expected on the part of trainees, as well as determining priorities for the use of haptics. Of course, these research questions interact with the sophistication of the technologies involved. As the presentation of haptic signals becomes more veridical, presumably the haptics load can be increased.

The use of haptics to indicate collisions may enhance navigation in VEs. One drawback of VE training systems is the difficulty maintaining spatial orientation, what Stanney, Mollaghasemi, Reeves, Breaux, and Graeber (2003) defined as wayfinding or the "the ability to maintain knowledge of one's location and orientation while moving throughout a designated space" (p. 451). Difficulty in wayfinding has been well documented in VEs and is associated with consequences that include becoming lost and disoriented (Witmer & Kline, 1998).

Side effects such as disorientation reduce the usability of VEs and can interfere with task acquisition. Witmer, Bailey, and Knerr (1996) reported that inadvertent collisions with walls were associated with loss of task focus and disorientation. In other research, Pleban, Eakin, and Salter (2000) obtained feedback from soldiers regarding their ability to perform critical MOUT tasks in VEs. Several component behaviors were rated low by the soldiers. These included: move around obstacles, maneuver around corners, look around corners, move quickly through doorways, and take a tactical position in a room. The problems in performing these tasks were attributed to factors such as inability to feel team members in a stack (lined up before entering a room), limited field of view which reduced spatial awareness, and difficulty scanning. Other research, documenting similar problems, attribute poor spatial awareness to factors such as reduced field of view, impaired depth perception (distances are underestimated, more so than in real world situations), and eye strain (May & Badcock, 2002). Providing information about collisions may reduce the effects of these factors. In light of the present findings, additional research is warranted to investigate how haptics supporting collision detection can be used to mitigate problems with wayfinding in VEs.

The auditory cues were best for supporting the detection of explosions. The explosion event, three of which occurred per trial, was simulated by "whiting out" the screen. In general, this presentation was confusing to participants. Participants indicated that misinterpretations included interpreting explosions as a computer loading problem, temporary computer glitch, or that they had been killed. Whether haptics would contribute to a more realistic presentation of explosions remains to be explored in future research.

Haptics did not contribute to presence in the present research, and the auditory cues, as expected, contributed enhanced ratings of presence on the Sensory Fidelity subscale which was based on one item related to the usefulness of auditory cues in contributing to recognition of events. Other research has found effects of haptics on presence. Durlach et al. (2005), for example, found that tactile feedback enhanced perceptions of presence compared to auditory feedback on a reaching task in a VE. The lack of a relationship between haptics and presence may be related to lack of haptics-related questions on the Presence scale, or due to the design of the experiment. However, it was expected that the quality of haptics presentations would affect scores on the Involvement subscale that includes items relating to how natural the environment appeared; and on the Adaptation and Immersion subscale, which includes items pertaining to the predictability of the environment and how easy it is to adjust to the environment. Durlach et al. found an effect due to haptics on presence on items pertaining to the Adaptation and Immersion scale used in the present research. Still, refinement of the Presence scale for assessment of haptics related contributions to presence can be explored in future research.

Haptics also increased perceived workload while no effect on workload was found for auditory cues. That is, participants in both the Natural and Metaphoric Haptics conditions reported greater effort, mental effort and temporal demand compared to participants in the No Haptics condition. It is not surprising that the addition of haptics contributed to greater task demands. Haptics, especially for collisions and gunshots, provided more task-related information. In this regard, incorporation of haptics may *increase* training transfer because participants must attend to relevant interactions with the environment, whereas without haptics, trainees may be better able to ignore critical events such as collisions and whether or not they are being shot. Based on the Hancock and Warm (1989) model of stress, it might be expected that the addition of Natural Haptics cues would increase resource capacity optimally, while the Metaphoric Haptic cues may increase the resource demands and potentially result in performance decrements. Because no differences were identified between the Natural and Metaphoric Haptics groups on workload, it may indicate that the cues were perceived similarly by the participants in terms of the information they provide (which was the case). Theoretically and practically, further investigation of this finding would be useful to pursue.

Another interpretation of the NASA TLX data is that haptics increased workload by providing distractions. Trainee comments indicated that for some this may have been the case. However, no differences in the haptics groups were obtained on the level of perceived frustration, which argues against this interpretation.

Haptic cues may also contribute to a VE experience by acting as affordances in the environment. Gross et al. (2005) further expand upon affordances in relation to EID and direct perception, stating that though EID relies on information presentation within the VE to stay within a rule-based or skill-based frame so that the user may draw on pattern recognition and basic cognitive abilities to correctly identify and assess the situation, a VE is not always a conducive environment to these types of linkages. Gross et al. note that VEs do not lend themselves well to tasks which rely more heavily on all sensory modalities rather than just visual and auditory, or integrated sensory experiences, which would be expected. In contrast, however, the research described here has found that within the specific haptic parameters and environment, VEs can meld with intuitive sensory modality design, and provide the user with another type of information in a new modality that doesn't frustrate the user or impact task performance negatively. Given the data discussed in this paper, it can be questioned as to whether or not affordances or perceived affordances are being provided to the user via tactile channels, particularly in the case of collisions, and particularly when the haptic modality is coupled with the visual modality, the auditory modality, or both, as Gross et al. articulated. It would be reasonable to hypothesize that a user in a virtual environment using haptic devices for collisions might be able to perceive, for example, if they are wide enough to fit through a virtual doorway, or if they are backed up against a wall all the way – contexts which may be critical to task performance in some domains. This is another avenue for potential future research in the user of haptics.

CONCLUSIONS

Though the incorporation of haptic cues within VEs for training has not been studied to the extent at which visual and auditory cues have been, the research described in this paper strived to contribute to the current research, as well as uncover avenues for further research. As seen by the data, haptics can contribute meaningfully to a VE for training without detracting from the trainee's performance or adding unwanted frustration. Most importantly, however, the data also indicate that training on haptics cues is not necessarily mandatory, and that it is possible to design cues that are intuitively recognized.

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