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Vibrotactile 'on Thigh' Alerting System in the Cockpit?

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The objective of this research was to examine the utility of a novel placement for a vibrotactile display in the cockpit. This objective was pursued in stages through a number of research phases, here we report on the final phase concerning the benefit of the vibrotactile display in a visually loaded environment. Results support placing a directional alerting vibrotactile display on the thigh of a seated operator.

Since the visual and to a lesser extent, the auditory modalities have been exhausted in the cockpit, the tactile modality has become a relevant candidate to counteract information overload. It is assumed that the tactile modality does not entirely compete with the visual and auditory modalities and generally requires little to no cognitive effort to analyze spatial directionality (Brill et al., 2004; Eriksson et al., 2006; Jennings et al., 2004). As such, tactile displays may introduce solutions to impending limitations in visual perception and processing in the cockpit (Eriksson et al. 2006; van Erp et al. 2002; 2006). Specifically, Salzer, Oron-Gilad and Ronen (2010) proposed the thigh as a potential platform for orienting in the vertical plane (see Figure 1), demonstrating the ability to localize locations on the vertical plane stimulated by vibrotactors mounted on the thigh of a seated operator.

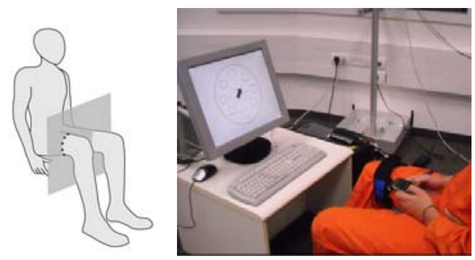

Figure 1. Orientation in vertical plane created by vibrotactors mounted on the thigh (illustration and in-practice).

In today's cockpit's collision-alert system the visual and auditory cues orient the pilot which way to take to avoid collision (i.e., move away from the hazard). Thus, when considering how to implement tactile cue two contradicting display approaches emerge; to have the tactile cue compatible with the direction of the visual and auditory alerting cues, or to simulate the source of hazard (i.e., the direction of the object to avoid). Salzer, Oron-Gilad, Ronen, and Parmet, (in press) evaluated their on-thigh vibrotactile display when added to existing audio and visual alerting cues utilizing two tactile display modes: a) compatible; where the location of the tactile cue was compatible with the visual direction of response, (i.e., aiming away from the source of hazard). b) inverse; the location of the tactile cue was directed toward the direction to be avoided (i.e. generating a tendency to move away from the source of hazard). Their results revealed that directing the way to escape from hazardous situations, compatible with the visual alerting cues, was preferred. Nevertheless, advantages for adding tactile alerting cues over the visual alerting cues alone were not found, probably because these alerts were examined in a quiet environment with no additional cues or noise.

The current experiment aimed to examine the utility of the vibrotactile cues in a loaded environment. It introduced a more demanding environment where both visual load and working memory load were added over collision alerts alone. Overall, it was expected that the general benefit of the compatible mode versus the inverse mode will remain. Yet, it was expected that once the visual modality was more loaded, advantages for the tactile alert display will emerge.

Method

Participants

Five female and 5 male undergraduate students (age 24 to 29, mean 25 years) participated for course credit.

Apparatus

Experimental system. Tactile stimuli were displayed via a prototype developed by IAI-LAHAV (patent 11/968,405 pending), consisting of a tactor controller Eval2.0 (by Engineering Acoustics Inc. (EAI)) regulating eight EAI-C2 vibrotactors. The vibrotactors were stitched to an elastic fiber strip, 6 cm apart from each other, worn on the right thigh over a pilot suit. A designated program in E-prime2.0 running on a PC computer with Windows XP activated the experimental procedure and displayed the visual alerts on a 19" LCD screen. An additional PC computer was used for playing the simulated flight path on a dome projection screen allowing a field of view of 60 degrees. The 19" screen was placed on a table in front of the sitting participant, behind it was the dome projection screen. Response was collected by a standard keyboard.

Visual directional alert stimulus A compass rose was displayed on the 19" screen. The visual cue was a black arrow in the center of the compass rose pointing towards one of the eight directions (up, down, left, right and four diagonals) as shown in Figure 1.

Tactile directional alert stimulus Each of the vibrotactors represented one of the eight directions. The vibrotactile stimulus was a continuous 800ms pulse at 250Hz.

Flight movies and flying objects. Five movies of a flight path accompanied by the sound of a helicopter were allotted randomly to each block. Occasionally, throughout the flight simulation, red and yellow objects appeared flying toward the viewer (i.e. the flying aircraft) (see Figure 2). The participant was required to count the number of red objects observed. At unexpected intervals within the block, a question interrupted the visual cue on the 19" screen, asking the participant to enter the number of red objects counted up to that moment. Once a response was provided, the participant was instructed to restart counting.

SWAT (Subjective Workload Assessment Technique). The SWAT (Reid and Nygren, 1988) questionnaire was submitted upon completion of each experimental block.

Design and Procedure

The design consisted of two within-participant variables; visual stimulus (2; present or not), and tactile display mode (2; compatible or inverse). Each condition was displayed in a separate experimental block. An additional fifth block consisted of visual stimuli only (i.e. without vibrotactile stimuli). The order of the five blocks was counterbalanced among participants. Participants arrived at the lab, one at a time, changed to standard pilot suit, filed an informed consent and were debriefed. The participant was asked to perform two simultaneous tasks; the first task was to count and remember until asked the number of red objects in the video. The requirement to report the number of counted objects appeared three times throughout an experimental block, at random occasions. The second task was to respond accordingly to the spatial stimuli. The numeric keypad was used for collecting participants' directional response; each key 1-9 (except 5) corresponded to a directional visual and/or tactile stimuli according to their relative location. In the compatible tactile display mode, the direction of stimulus was corresponding with the location of the response key (e.g. left most tactor corresponds with key no. 4). In the inverse tactile display mode, the direction of stimulus was opposite to the location of the response key (e.g. left most vibrotactor corresponds with key no. 6). The direction of the visual stimulus always corresponded with direction of response. The participant was familiarized with the tasks by completing a practice blocks of 24 trials prior to each experimental block, of 32 trials. Ten practice trials preceded the 32 experimental trials for the visual-only display block. The participant was instructed to respond as fast and accurate as possible. Feedback was provided only in the practice trials. Upon completion of each block the participant completed a SWAT questionnaire.

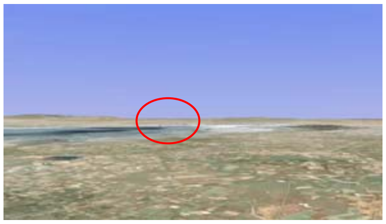

Figure 2. The projected environment of the flight path. The red object is marked for emphasis.

Results

Performance on the Spatial Alerts

Response Time. A two way repeated measures ANOVA with visual stimulus (2; present or not), and tactile display mode (2; compatible or inverse) was analyzed over data from the compatible and inverse display blocks for response times (RT) was conducted. Mean estimates are specified in Table 1. Extreme values of RT, shorter than 150ms and longer than 2500ms, were excluded from analysis. A significant main effect for visual ($F(1, 9)=17.231$, $p=.00248$) was found. At the presence of the visual stimulus, RT was lower (visual present M=978 ms SD=322, visual not present M=1367 ms, SD=158). There was no significant difference between the compatible and the inverse ($F<1$). To evaluate the affect of the addition of vibrotactile stimulus, a repeated measure ANOVA compared the visual display block (V) with the tactile compatible display with visual condition (CTV), which had the shorter RT of the two tactile and visual combined display conditions. There was no significant difference between V and CTV.

Accuracy. A logistic regression model within the framework of generalized linear mixed model (GLMM) over visual stimulus (2; present or not), tactile display mode (2; compatible or inverse) for correct recognition was conducted. The full model included the two-way interaction and main effects. The main effects tactile display mode and visual stimuli presence were significant (Wald Chi-$Square_1$= 5.1, $p<.024$, and Wald Chi-Square= 53.7, $p<.001$, respectively). The interaction was not significant. Correct recognition rate (CRR) for compatible tactile display mode was higher than inverse tactile display mode (CRR=.93, SE=.02, CRR=.87, SE=.03) and the presence of visual stimulus improved CRR (CRR=.97, SE=.01, CRR=.71, SE=.05). Mean estimates are specified in Table 1. A Logistic regression on tactile display mode (3; compatible, inverse, none) for success rate in the unchanged presence of the accompanying visual signals did not reach significance, indicating that recognition was equally good with and without tactile stimulus when the visual stimulus was present.

Table 1
Response Time (RT) and Accuracy (ACC) by Modality and Tactile configuration.

		Tactile Blocks				**Visual Block**
N=10		**CT**	**CTV**	**IT**	**ITV**	**V**
RT(ms)	Mean	1367	872	1368	1085	864
	SD	158	61	122	134	197
ACC	CRR	.98	.76	.96	.66	.98
	SE	.008	.027	.020	.080	.009

*CT=compatible tactile, CTV=compatible tactile+visual, IT=inverse tactile, ITV=Inverse tactile +visual, CRR=correct recognition rate

Visual Loading Task

Participants were asked to count the number of red items that appeared in the environment and to specify this number when asked within the experimental interface. At the end, the total number of items registered by each participant was calculated. Zero was given if a participant failed to reach the appropriate number of items and 1 if the participant specified the correct number of items. The number of participants (out of 10) who correctly identified the total number of items in each experimental block was 8, 7, 10, 7 and 5 respectively for the CT, CTV, IT, ITV and V blocks. Thus, performance was worse in the visual-only condition where half (5 out of 10) of the participants failed to identify the correct number of objects. Performance was perfect in the tactile-only condition (IT) when no visual alerts were present, implying perhaps on the toll of visual load to task performance when visual alerts were present.

Workload (SWAT)

A GEE regression analysis was conducted with participant as the random effect and experimental block (5) as the main effect. The main effect for experimental block was only significant for the SWAT time dimension (Wald Chi-square (4) = 15.17, p<.004). CTV and ITV conditions were perceived as more temporally demanding (mean ratings were 1.5, 1.7, 1.4, 1.7, 1.5, respectively for the CT, CTV, IT, ITV and V blocks).

Discussion and Conclusions

The current experiment revealed benefits for tactile signaling in a loaded visual environment. With regard to the directional alerts, response time and CRR were both facilitated by the presence of visual cues. Comparing to the low-demanding environment where only the directional alerts existed (Salzer et al., in press), the loaded environment generated longer response times, as expected. Nevertheless, accuracy ranges remained unchanged.

The advantages of adding tactile cues became apparent in the loading task where the worse performance was found in the visual only condition, indicating that participants had difficulties in attending to two visually displayed tasks simultaneously. The CTV condition generated the best performance on the alerts, but was not better than the CT and IT conditions in the loading task, indicating perhaps that the presence of visual alerting cues may have disrupted performance on the loading task, or vice versa, that the presence of tactile cues enabled higher performance in the loading task. The benefits of the tactile stimulus with regard to the two tasks were most notable when compared with the visual only mode (V). The SWAT temporal demand scores confirmed that while the presence of visual and tactile cues combined was beneficial in the loaded environment in terms of overall mission performance, the combined CTV and ITV conditions generated higher perceived temporal workload. To conclude, the presence of tactile stimulus helped to maintain balance between the two tasks. Namely, the tactile stimulus contributed to improve situation awareness in the visually loaded environment.

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