Tactile Change Blindness in an Unmanned Aerial Vehicle Control Task

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One promising means of overcoming data overload in complex domains is through the introduction of tactile displays, which can offload the overburdened visual channel. However, the effectiveness of tactile displays depends on taking into consideration attentional systems and the limitations of the human perception. One important question is the extent to which the tactile modality is susceptible to change blindness, i.e. the failure to detect even large and expected changes when these changes coincide with a "transient" stimulus. Recent research has demonstrated an analog of change blindness in the tactile modality for pattern change recognition. The present study examined whether tactile change blindness, as well as crossmodal visual-tactile change blindness, occurs in the context of search and monitoring tasks, and whether it is affected by the addition of a secondary task. The application domain for this experiment was simulated Unmanned Aerial Vehicle control. The findings confirmed the occurrence of tactile change blindness; however, no crossmodal change blindness was observed and change detection was unaffected by the addition of a secondary search task. Overall, this research add to the knowledge base in multimodal and redundant information processing and can inform the design of multimodal displays for complex, data-rich domains.

INTRODUCTION

The introduction of multimodal displays (i.e., displays that distribute information across multiple sensory channels) has been shown to be effective in offloading the overburdened visual channel and thus address data overload to some extent (Sarter, 2006). Combining the above modalities in multimodal displays can serve to support a variety of functions, such as increased bandwidth, spatial orienting and navigation tasks and communication of complex concepts and messages (Oviatt, 2003; Sarter, 2002; Jones & Sarter, 2008). However, the effectiveness of multimodal displays may be compromised if they are not designed to take into consideration attentional systems and the limitations of the human perception. For instance, there is limited empirical evidence already that the tactile modality may also be subject to change blindness (Gallace, Tan, & Spence, 2006). If confirmed, this could pose challenges for the design of effective multimodal displays. The goals of this study was to determine to what extent, and under what circumstances, the sense of touch (the least studied modality to date) is also susceptible to change blindness effects and whether this occurs crossmodally between vision and touch.

Change blindness

Change blindness refers to the failure in detecting even large and expected visual changes within a scene when these changes coincide with a visual "transient" stimulus. Note that the word 'expected' here refers to the general expectation of some change without prior knowledge of the nature, timing, or location of the change. The phenomenon has been studied and demonstrated using various paradigms, such as "flickers" (a complete or partial masking stimulus that obscures the visual scene; e.g. a blank screen between an original and changed image; see Figure 1) and "mudsplashes" (Figure 2).

Both these transients involve repeating between the sequence of the original scene, transient, and the modified scene until the observer detects the change. Both a flicker and mudsplash are examples of masking (O'Regan et al., 1999; Sperling & Speelman, 1965) which refers to a reduction in the visibility of an object (i.e. the target) caused by the presentation of a second object (i.e. the mask) nearby in space or time (Enns & DiLollo, 2000).

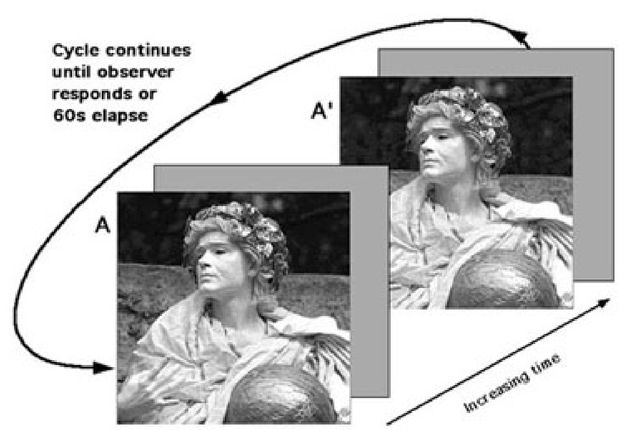

Figure 1: General design of the flicker paradigm where the change is the movement of the background wall level (Rensink, 2002)

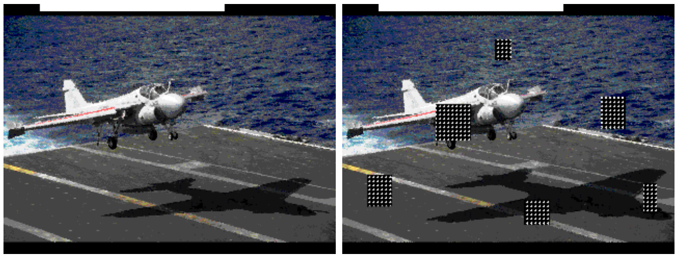

Figure 2: General design of the mudsplash paradigm where the change is the size of the airplane shadow (O'Regan et al., 1999)

Tactile change blindness

To date, change blindness has been documented primarily for vision and very few studies have demonstrated the phenomenon in the tactile modality. For example, a significant performance decrement was observed when subjects had to distinguish between simple vibrotactile patterns from 2-3 tactors (devices that present vibration stimuli to the skin) located across the body in the presence of a vibrotactile mask (vibrotactile stimulation from tactors not related to the pattern of interest; equivalent to a visual mudsplash) (Gallace et al., 2006; Gallace et al., 2007; Ferris et al., 2010). Even when the tactile stimuli were presented to the highly touch sensitive fingertip region, change blindness was still elicited in the presence of a tactile mask (equivalent to visual mudsplash; Malika et al., 2008). Manual control actions, such as pressing a button or turning a steering wheel, have also been shown to elicit tactile change blindness (Gallace et al., 2009). However, these studies have looked at change detection in tactile patterns, which may not be ideal since the tactile modality is better suited for low complexity cues (Lu et al., 2013).

In the present study, participants performed tasks expected of an Unmanned Aerial Vehicle (UAV) controller. One task involved monitoring for visual or tactile radar indications. In some scenarios, participants were also required to engage in a target search task, i.e. actively looking for suspicious objects. At times visual and tactile displays experienced "static," which was used to recreate two change blindness paradigms: flickers and mudsplashes. The static could occur at the same time as a change indication from the radar system. Expectations were that: 1) there would be an intramodal visual and tactile effect, that is visual transients would affect visual change detection and tactile transients would affect tactile change detection, 2) there would be a crossmodal effect, that is visual transients would affect tactile change detection and vice versa, and 3) the presence of a secondary task would not affect change detection based on the findings from Ferris et al., 2010.

METHOD

Participants

Twenty undergraduate and graduate students from the University of Michigan participated in this study (8 males and 12 females; mean age = 22.5, stdev = 3.4). Participants were required to possess normal or corrected-to-normal vision, have no known disorders or injuries that may impair their sense of touch, and have no history of epilepsy. They were compensated $20 for every hour of participation.

UAV control task

The simulation ran on one 20" monitor at a distance of 30" from the participant. Each participant played the role of an Unmanned Aerial Vehicle (UAV) controller and was responsible for detecting radar system indications in a simulated combat scenario. Each radar indication occurred every 11.5 sec and constituted an experimental trial. For each trial, the indications could be presented either on the visual display with the nine UAV feeds or the tactile vest/belt with the 12 tactors.

The tactile display consisted of 12 vibrating "tactor" devices (C-2 tactors developed by Engineering Acoustics, Inc.), divided into a 3x3 display, was secured to the participant's back by a tactor belt and vest. For the purposes of this study, the location of each tactor was spatially mapped to the location of its respective video feeds (*note: the middle column had two tactors to avoid vibrations directly on the spine). White noise was played using disposable earbud headphones to mask the sound of tactor activation and loudness was set on a participant-to-participant basis.

Primary task: Monitoring task (responding to radar indications)

For the purposes of this study, participants were informed that experimental displays, both visual and tactile, were being evaluated in their ability to present information about the presence of long range targets beyond the scope of the video feed. For each trial, participants were instructed to indicate whether they detected changes in the brightness of one video feed or changes in vibration intensity of one tactor during its 8.5 sec presentation, which communicated the presence of a long range target. Sixty-six percent of the trials involved either a visual or tactile change (i.e. "change trials") while the other 33% of the trials presented a constant brightness or intensity (i.e. "no change trials").

The initial brightness of the video feed background was presented at 0.77 fL and the brightness for the change was 14 fL. The initial intensity of the tactile display was presented at 250 Hz with a gain set at 0.3 and the intensity for a change was presented at 250 Hz with a gain set at 0.65. Pilot tests verified that both visual and tactile changes were clearly perceptible in baseline conditions. Presentations of visual and tactile trials were distributed amongst the nine video feeds and tactor sectors for each scenario.

The visual and tactile trials could be categorized as one of the six presentation conditions: visual baseline, tactile baseline, visual flicker, tactile flicker, visual mudsplash, and tactile mudsplash (Figure 3). Similar versions of the visual flicker and mudsplash were developed for the tactile modality. Pilot testing was used to ensure each transient were equally salient in both modalities. In the present study, participants were told that the transient stimuli were “static” from the environment.

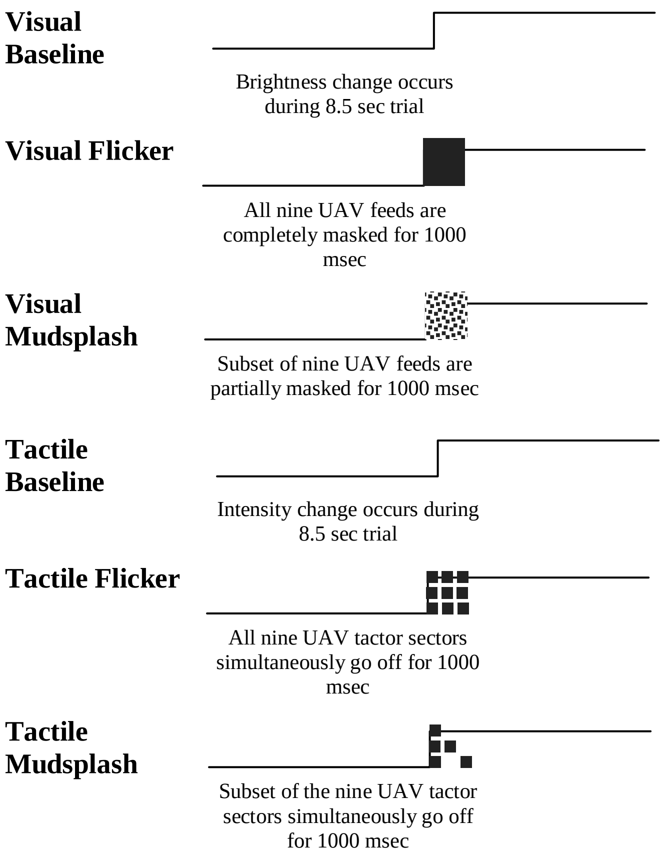

Figure 3: Brightness (visual) and intensity (tactile) in change trials for each of the six conditions

The visual trials involved highlighting the video feed of interest at the initial brightness which could be followed by a visual or tactile transient stimulus either two, four, or five seconds after the start of the trial. These visual transients could coincide with a change, in which case, the remaining duration of the 8.5 sec trial would present the background at the higher brightness.

The tactile trials were presented in a similar fashion, but involved pulsing a tactor sector every 500 msec for 850 msec at the initial intensity. This again could be followed by a visual or tactile transient either two, four, or five seconds after the start of the trial and could coincide with a change, in which case the remaining duration of the 8.5 sec trial would be presented at the higher intensity. For this experiment, visual and tactile transients lasted 500 msec. When changes in brightness or intensity were detected, participants were instructed to press the “Target” button on the top right hand corner of the respective UAV feed to indicate the presence of a long-range target (Figure 4). When there were no changes in brightness or intensity, participants were instructed to press the “No Target” button. If at any time the participant was unsure whether or not there was a change in brightness or intensity, they were instructed to press the “?” button. Participants could make their selection anytime during the 8.5 sec trial and up to 300 msec after, with the final response being used for data analysis.

Figure 4: Screenshot of one UAV feed with response buttons (top to bottom: ‘Target’, ‘No Target’, ‘?’, and ‘Tank’ button)

In each of the four blocks, the six conditions were balanced across 70 experimental trials. Two blocks were dedicated to visual transients, with one single task block and one dual task block, and similarly, two blocks were dedicated to tactile transients. For both modalities, there were four trials for the “no change” conditions, seven trials for the “change” baseline condition, and eight trials for the “change” condition with each transient.

Secondary task: Target search task (responding to suspicious activity in video feeds)

For two of the four scenarios, participants were instructed to actively search for any ‘suspicious activity’ which included armed soldiers and tanks in the highlighted window, which for tactile trials, also corresponded to the tactor sector of interest. If the participants spotted suspicious activity, they pressed the ‘tank’ button on the lower right-hand side of each video feed (Figure 4). Participants were instructed both tasks were of equal importance.

Experimental design

The primary independent variables in this study were presentation condition (six conditions), whether a trial involved a brightness change (change, no change), whether a trial involved an intensity change (change, no change), and number of tasks (single, dual task). Accuracy was recorded for each participant and analyzed under the Signal Detection Theory framework: hits, misses, correct rejections, and false alarms. The measure of interest, response bias (c value), was calculated for each participant under each combination of factor levels.

Procedure

Experimenters first described the overarching goal of the Department of Defense to increase the UAV to operator ratio, the experimental visual and tactile displays, and the required interactions from the participants. Next, participants underwent two 8-minute training sessions which allowed them to practice the visual and tactile baseline condition, i.e. the change detection tasks without the presence of transients. By the end of the second training session, participants were required to achieve at least 90% accuracy before continuing. Upon successful completion of the training sessions, participants were provided a transient demo. The participants then completed the four blocks/scenarios: 70 experimental trials with visual transients in the single and dual task conditions and 70 experimental trials with tactile transients in the single and dual task condition. The order of the blocks were balanced between subjects. After completing the experiment, participants filled out a debriefing questionnaire which included questions regarding the study.

RESULTS

Accuracy

Hit Rates

Tactile change detection was significantly affected by tactile transients (Figure 5, $F(5,15)=13.820$, $p<.001$). Post-hoc tests showed that accuracy was significantly worse with the intramodal tactile conditions, namely tactile change detection in the presence of a tactile flicker (48%) and tactile mudsplash (52%). When comparing the results between single and dual task conditions, there was no significant effect on the number of tasks ($F(1,19)=0.000$). However, tactile change detection alone did significantly improve in the dual task condition compared to the single task one (96% and 85%, respectively). Visual change detection was also unaffected by tactile transients.

Visual and tactile change detection was unaffected by visual transients in the single task conditions ($F(5,15)=0.155$) and the dual task conditions ($F(1,19)=0.033$).

Correct rejections

When there was no change, visual transients and tactile transients did not affect correct rejections ($F(4,16) = 1.634$, $p=.214$; $F(5,15)=0.695$, $p=.635$).

Signal Detection Theory measure: c values

The measure "c" relates to the degree which a participant is biased towards responding with a "change" (negative c values) or "no change" (positive c values). The c values for all conditions were positive (0.04-0.81 across all conditions), suggesting there is a slight overall tendency for participants to respond that a change did not occur.

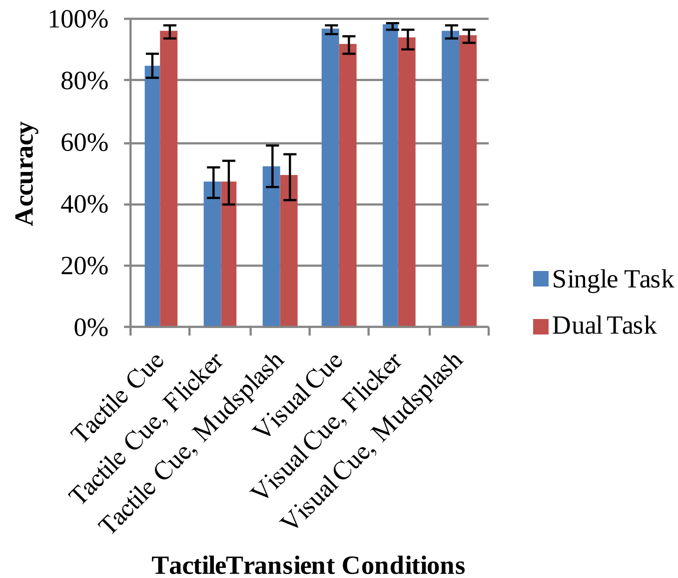

Figure 5: Accuracy for change trials in the presence of tactile transients

DISCUSSION

The introduction of multimodal displays, namely ones that include the tactile modality, can offload from the overburdened visual channel. However, to ensure that multimodal displays are designed appropriately, their design needs to take into consideration perceptual and attentional limitations like change blindness. The goal of this study was to determine whether visual, tactile, and crossmodal change blindness occurs in the context of UAV control.

As predicted, there was a significant intramodal tactile effect. Compared to the baseline condition, tactile change detection is significantly worse when it coincides with a tactile flicker or mudsplash. This study supports previous findings and demonstrates change blindness not only in the tactile modality, but also in the absence of a tactile pattern change recognition task. The findings suggest that tactile change detection is adversely affected by the presence of tactile masking effects. In the context of display design, it is recommended that tactile displays be designed to account for unexpected vibrotactile events (e.g. vibrations from aircraft, vehicles, or movement).

Given that flickers and mudsplashes are common paradigms used to induce change blindness, it was unexpected that visual transients did not affect visual change detection. However, it is important to note the visual changes used in this study differed in change magnitude compared to previous studies. Typically studies employing a flicker and/or mudsplashes required participants to look for a "local" change, that is searching for a change to one aspect of the display. For the present study, the change was "global," since the entire background brightness of the UAV feed changed. Since there was a null effect, global changes may be a means to effectively present visual changes. However, this method needs to be studied more systematically to determine for instance transient duration before there is a detriment to visual change detection.

Contrary to the initial hypothesis, there was no crossmodal effect, that is visual change detection was unaffected by tactile transients and vice versa. This may be due to the "global" changes unique to this study which are easier to detect compared to "local" ones and due to the brevity of the transients in this study (500 msec). Previous work has shown that longer masking effects may inhibit tactile stimuli short-term memory and further work needs to establish whether this affects crossmodal change detection. The findings from this study also showed that change detection was unaffected by the addition of a secondary task, and tactile change detection without any transients even benefited tactile change detection. This finding supports previous findings (Ferris et al., 2010) and also suggests that change blindness may be an inherent perceptual limitation.

In conclusion, the findings from this study provide further evidence demonstrating the existence of tactile change blindness. Since multimodal displays have been found to be beneficial in offloading the visual modality, those incorporating the use of the tactile modality should take into consideration the phenomena of change blindness into their design. To ensure tactile displays are appropriately designed, future work can examine appropriate tactile intensities and presentation methods to counter change blindness. Overall, the findings from this work contribute to a deeper understanding of change blindness and breakdowns in tactile information processing. This knowledge can be applied to the design of future more effective multimodal interfaces for complex data-rich domains, such as military operations, aviation, or the medical domain.

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