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Haptic Cueing of a Visual Change-Detection Task: Implications for Multimodal Interfaces

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ABSTRACT

This study is part of an ongoing program designed to investigate the integration of visual and haptic information in the context of multimodal interfaces. With the current experiments, we study whether haptic cues can be used to redirect spatial attention in a visual task where an observer is asked to detect a change between two scenes. Subjects were asked to look at visual scenes consisting of rectangular horizontal and vertical elements of equal sizes. Their task was to detect an orientation change in one of the elements. Prior to this visual task, the subject was tapped on the back at one of four locations by a vibrotactile stimulator. It was found that reaction time to detect a visual change decreased significantly when the location of the tactor coincided with the quadrant of the visual scene where the changing element occurred. It was also found that reaction time increased when the location of the tactile stimulation did not coincide with the visual quadrant where change occurred. These results have implications for designers of multimodal interfaces where a user can benefit from haptic attentional cues in order to detect and process information in a small area within a large and complex visual display.

1. INTRODUCTION

The growing trend in interface research is towards multimodal human-computer interfaces. This is motivated by the facts that humans naturally employ multimodal information channels for communication, and that multimodal interfaces have been demonstrated to be effective (Oviatt, 1999). Cognitive research has shown that multimodal communication results in increased amount of transmitted information (Miller, 1956). It is well known that a signal with a single varying attribute can at most transmit 2-3 bits to a human observer (for example, we can only identify about 5-7 loudness levels of a fixed-frequency pure tone). However, greater information transmission can be achieved by employing signals with multiple attributes (for example, one can easily identify hundreds of faces at a glance of a person or a photograph, because many facial features contribute to the appearance of a face). This increase in transmitted information can be achieved whether multiple modalities convey different information or encode the same information redundantly (Miller, 1956). Therefore, multimodal interfaces facilitate more natural and efficient human-computer interactions.

One challenge in multimodal interface research is the lack of multimodal interface systems. Robust systems for applications such as speech recognition or gesture interpretation require long-term research and development efforts from a multidisciplinary team of investigators. True multimodal interactions can not take place until problems in each of these application domains are solved. Compared with visual and auditory interfaces, the field of haptic interface research is a less developed yet fast-growing and promising area. For the past several years, we have been developing a tactor-array for the back of a user. We have been studying its effectiveness in conveying directional information for applications such as a haptic navigation guidance system for drivers and blind travelers (Ertan, Lee, Willets, Tan, & Pentland, 1998; Tan, Lim, & Traylor, 2000; Tan, Lu, & Pentland, 1997; Tan & Pentland, 1997, 2001).

Recently, we studied the integration of visual and tactile information about moving objects (Gray & Tan, 2000). In one experiment, we found that tactile pulses simulating motion along the forearm facilitated the speed and accuracy with which subjects discriminated visual targets on the same forearm. In another experiment, we concluded that an approaching visual target's time to contact with the forearm influenced subject's ability to perform tactile discrimination on that forearm. These results demonstrate dynamic links in the spatial mapping between vision and touch. In the current study, we explore this issue further with a paradigm that examined how haptic cueing might affect an observer's visual spatial attention. The long term objective of our research is to investigate the integration of visual and haptic information in the context of cross-modal priming.

In the current study, we investigate whether haptic cues (taps on the back) can be used to redirect spatial attention in a visual task where an observer is asked to detect a change between two scenes. Recent research has shown that attention is required to perceive (even large) changes in a visual scene. This phenomenon, termed "change blindness," occurs in both laboratory (Rensink, O'Regan & Clark; 1997) and real-world (Simons & Levin, 1998) conditions. The proposed explanation for "change blindness" is that we do not form a complete detailed representation of our surroundings. Such a representation occurs only for the small part of the visual field that we are attending. In the typical experimental setup for studying "change blindness", termed the flicker paradigm (Rensink, 2000), two scenes are alternately displayed with a blank inserted between them (to mask motional cues). An observer is asked to respond as soon as a difference between the two scenes is detected. It has been found, using scenes consisting of photographs, that reaction time in such tasks depends on the degree to which the changing element is of interest (i.e., captures the viewer's attention). If attention is the key factor affecting reaction time, then any means of manipulating an observer's attention should affect the reaction time associated with the detection of scene changes. Our experiments are therefore designed to investigate whether such effects can be elicited by drawing an observer's attention to a spatial location via haptic stimulation.

2. METHODOLOGY

2.1 Stimulus

The visual stimuli used in these experiments were based primarily on the flicker paradigm used for the study of "change blindness" (Rensink, 2000). The visual scenes consisted of rectangular elements of equal sizes, but in either horizontal or vertical orientations (Fig. 1). Two scenes, differing only in the orientation of one of the elements, were presented in an alternating order with a blank scene inserted in between. The duration of the two patterned scenes was called the "on time". The duration of the blank scene was called the "off time."

The experimental apparatus for haptic cueing consisted of a 3-by-3 vibrotactile display developed at the Purdue Haptic Interface Research Laboratory. The tactor array is draped over the back of an office chair (Fig. 2). For the experiments reported here, only the four corner tactors (i.e., tactors No. 1, 3, 7, and 9 in Fig. 2) were used. Each tactor could be independently driven by a 60-ms sinusoidal pulse. The frequency of the pulse was between 290-306 Hz (corresponding to the resonant frequencies of the four tactors). The intensity of the vibration was between 26.1-27.9 dB SL (sensation level) under unloaded condition.

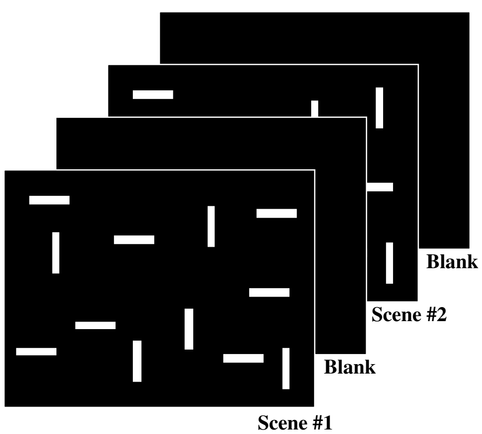

Figure 1. The two visual scenes used in our change-detection experiments (modified from Fig. 2 in Rensink, 2000).

Figure 2. The haptic cueing system. Shown here is a 3-by-3 tactor array draped over the back of a chair.

2.2 Subjects

Ten college students, 5 females and 5 males, participated in the experiment as paid research participants. The average age of the subjects was 21 years. All subjects had normal or corrected vision. They reported no known abnormalities with tactile perception on their back.

2.3 Procedures

Before the experiments began, subjects were informed of the nature of the task. Specifically, they were told that they needed to locate a rectangular element on the computer screen that was changing its orientation. Their job was to *locate* and *identify* this element as quickly as possible.

To ensure that the subjects could clearly feel the vibrations presented by the tactor array on their back, and that the subjects could correctly associate each tactor location with the corresponding quadrant on the computer screen, an absolute identification experiment was conducted with the tactor array before each new session. The subject's task was to click on one of the four quadrants on the monitor (represented by four large rectangles) in response to a vibration on the back (e.g., the correct response to a vibration near the right shoulder would be to click on the upper-right quadrant of the monitor). Each subject had to complete one perfect run (i.e., 100% correct) of 60 trials before starting the visual change-detection task. This test with the tactor array was repeated each time the subject left and returned to the chair.

During the visual change-detection task, the subjects were instructed to click the left mouse button as soon as the changing element was found (without moving the cursor over the element). The screen then froze and the color of all elements turned from white to pink. The subjects were required to make a second mouse click with the cursor centered on the element that they perceived to change orientation. The timing of the first mouse click was recorded as the reaction time. The x-y positions of the second click were used to discard trials where the wrong element was identified.

The independent variables employed were the state of the tactors (OFF or ON) and on time (80, 480, and 800 ms). Three 60-trial runs were conducted for each experimental condition and each subject. The order of the eighteen runs (2 tactor state × 3 on time × 3 runs) were randomized. For all experimental conditions, off time was fixed at 120 ms. The total number of rectangular elements was fixed at 12 (or equivalently, 3 elements per quadrant). The x-y positions of the elements were chosen randomly within each quadrant with the constraint that the elements never overlapped. For the experiments where tactors were ON (i.e., haptic cueing was present), the interstimulus interval (ISI — the interval from the time the tactor was turned off to the time the first scene was shown on the monitor) was fixed at 50 ms. The percentage of trials with *valid* haptic cues (i.e., the location of the vibrating tactor coincided with the quadrant where the changing element occurred) was fixed at 50%. Our subjects were aware of the fact that the location of the haptic cue may or may not be valid on any particular trial. They were left to decide on their own whether and how they would utilize the information provided by the haptic cues.

Throughout the experiments, subjects were instructed to sit upright with their back pressed against the tactor array. They were instructed not to move their body relative to the chair, or to move the chair relative to the monitor. Headphones were used to block any audible noise from the tactor array. Each subject typically finished all the experiments within 2-3 sessions.

2.4 Data Analysis

The dependent variables were mean reaction time and standard error. For each of the six experimental conditions tested (2 tactor state × 3 on time), data from all subjects were pooled. Data from the tactor OFF condition served as a baseline measure for reaction time. Data from the tactor ON condition were separated into two subgroups: those with valid haptic cues and those with invalid cues. Mean reaction times for the two groups of trials were computed separately. All error trials (where the subject selected the wrong rectangle element during the second mouse click) were discarded.

3. RESULTS

In general, our results show that reaction time decreased significantly with valid haptic cues, and increased with invalid haptic cues. For example, results for one subject (S5) are shown in Fig. 3. It can be seen that the average reaction time for each experimental condition increased monotonically with the value of on-time. Compared to baseline measures (i.e., reaction times with no haptic cues, shown as filled diamonds), reaction time decreased with valid haptic cues (filled circles), and increased with invalid haptic cues (filled triangles). This is true for each of the ten subjects tested.

The extent to which valid or invalid haptic cues decreased or increased reaction time varied from subject to subject. For example, shown in Fig. 4 are data from another subject (S9) who has a lower baseline measure than S5 (i.e., faster response without haptic cues). Subject S9 benefited less from valid haptic cues than S5 (i.e., a smaller decrease in reaction time). This subject was also less distracted by invalid haptic cues than S5 (i.e., a smaller increase in reaction time). Subjects S5 and S9 represent the two most extreme observers among the ten subjects tested. We hasten to point out that, despite the obvious differences in the data shown in Fig. 3 and 4, our general

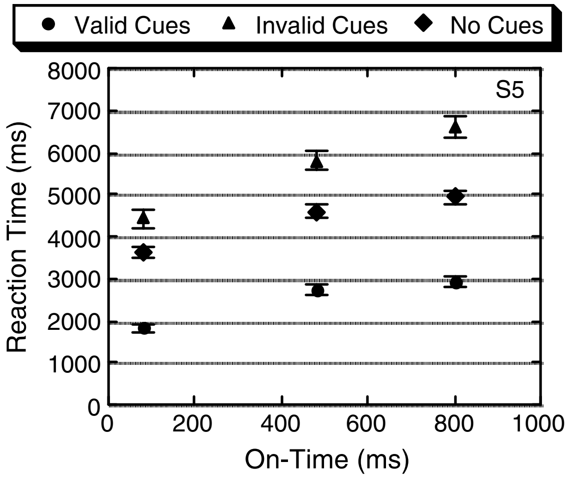

Figure 3. Mean reaction times and standard errors for subject S5.

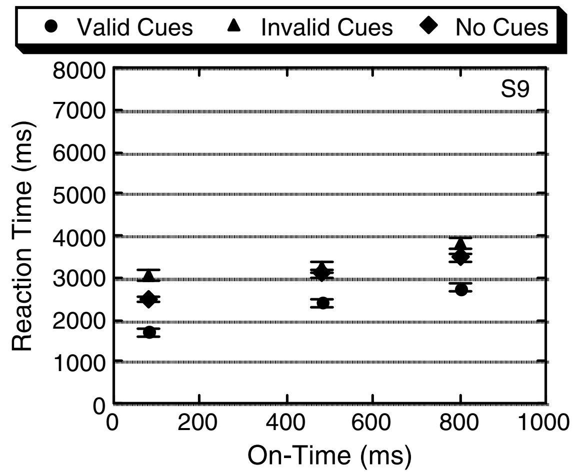

Figure 4. Mean reaction times and standard errors for subject S9.

conclusion regarding the effect of valid and invalid haptic cues on the reaction time of our visual change-detection task is still valid.

Results averaged over all ten subjects are shown in Fig. 5. As found with individual subject's data, mean reaction time increased as on-time increased, for the valid-cue, invalid-cue and no-cue conditions. Overall, compared with baseline measures, reaction time decreased by 1630 ms (40.6%) with valid haptic cues, and increased by 781 ms (18.9%) with invalid haptic cues. All standard errors are relatively small as compared to the values of reaction time.

One interesting observation from Fig. 3 and 4 is that the datum points for the valid-cue condition for subjects S5 and S9 seem to be quite similar, despite the large differences in reaction time for the invalid-cue and no-cue conditions. To investigate this further, standard deviations of reaction time from data pooled from all ten subjects were computed (Fig. 6). Indeed, it seems that the standard deviations for the valid-cue condition are lower than those for the other two conditions across the three on-time values tested. We therefore conclude, based on the limited data we have collected, that valid haptic cueing reduces the inter-subject variability in the response time for the visual change-detection task employed in this study.

Finally, average number of error trials varied among the subjects tested, with a range of 0-9 per experimental run of 60 trials. Averaged across the subjects, there were fewer than 4 error trials per 60-trial run.

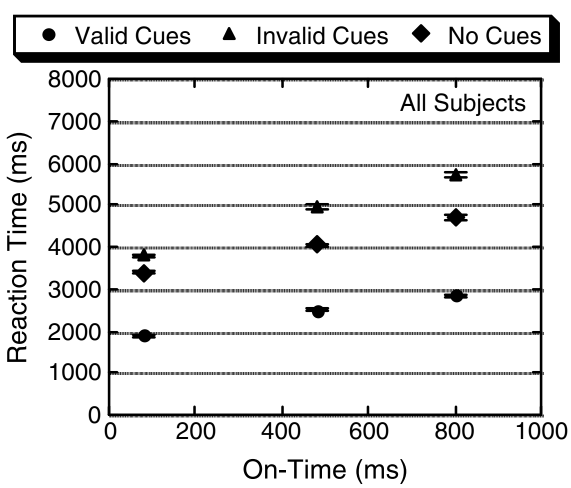

Figure 5. Mean reaction times and standard errors averaged over all ten subjects.

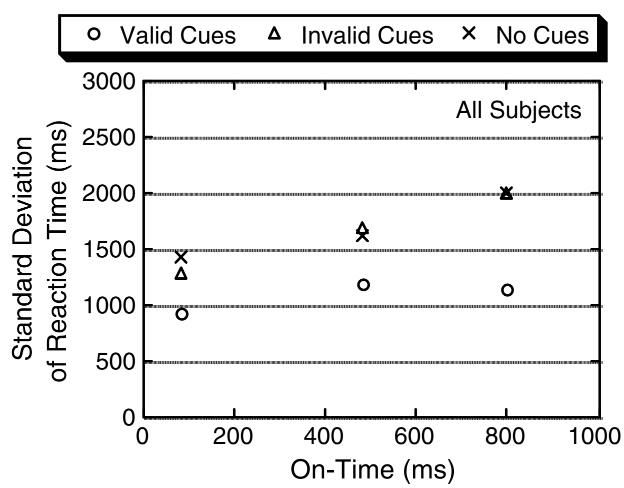

Figure 6. Standard deviations of reaction time from data pooled over all subjects.

4. CONCLUSIONS

In this study, we examined the extent to which haptic spatial cues can speed up or slow down an observer's reaction time to detect a change in a visual scene. Our data suggest that (1) valid haptic cues decrease the reaction time for the detection of a visual change, and (2) invalid haptic cues increase the reaction time (to a lesser degree) for the same task. This general conclusion holds for data from individual subjects as well as for pooled data from all subjects. This conclusion also holds despite the inter-subject differences in their "natural" reaction time (i.e., some subjects tend to react faster than others when no haptic cues are present). Similar results have been reported for visual spatial cueing of a visual change-detection task (Scholl, 2000). Finally, we have some evidence suggesting that valid haptic cues decrease the inter-subject variability in their reaction time.

Our results have implications for designers of multimodal interfaces. In an automobile, for example, a haptic display built into the driver's seat can be useful in alerting the driver of impending collision on one side of the car. In a large and complex visual display for air traffic control, a haptic display used in conjunction with a non-invasive eye-tracking system can remind the operator to look at a neglected area of the visual display, or to pay attention to an area with busy traffic. In general, haptic cueing can provide an effective alternative to visual and auditory cueing for a complex information display.

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