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The failure to detect tactile change: A tactile analogue of visual change blindness

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A large body of empirical research now shows that people are surprisingly poor at detecting significant changes in visually presented scenes. This phenomenon is known as *change blindness* in vision. A similar phenomenon occurs in audition, but to date no such effect has been documented in touch. In the present study, we explored the ability of people to detect changes introduced between two consecutively presented vibrotactile patterns presented over the body surface. The patterns consisted of two or three vibrotactile stimuli presented for 200 msec. The position of one of the vibrotactile stimuli composing the display was repeatedly changed (alternating between two different positions) on 50% of the trials, but the same pattern was presented repeatedly on the remaining trials. Three conditions were investigated: No interval between the patterns, an empty interval between the patterns, and a masked interval between the patterns. Change detection was near perfect in the no-interval block. Performance deteriorated somewhat in the empty-interval block, but by far the worst change detection performance occurred in the masked-interval block. These results demonstrate that "change blindness" can also affect tactile perception.

Adaptation theories suggest that the senses evolved to detect salient changes in the environment, thereby facilitating appropriate behavioral responses (see, e.g., Downar, Crawley, Mikulis, & Davis, 2000). However, a large body of research over the last half century has revealed that people appear to be surprisingly inept at detecting changes introduced between one visual scene and the next, both in laboratory settings and under more ecologically valid conditions (e.g., DiVita, Obermayer, Nugent, & Linville, 2004; French, 1953; Hochberg, 1968; Rensink, 2002; Simons & Rensink, 2005; Velichkovsky, Dornhoefer, Kopf, Helmert, & Joos, 2002). Research suggests that the frequent failure by participants to detect changes (known as *change blindness*) is typically caused by the occurrence of some form of disruption (or distraction) that masks the sensory transients that normally draw attention to the location of change (Rensink, O'Regan, & Clark, 1997). Change blindness has been reported within vision and within audition (where the phenomenon has been labeled *change deafness*; Chan & Spence, 2005; Vitevitch, 2003), but never within touch. It is therefore interesting to study whether limitations in information processing such as change blindness/deafness also affect the processing of tactile stimuli. The possible presence of a tactile analogue of visual change blindness might be suggestive of a common mechanism underlying the various manifestations of change detection, perhaps related to a common "spatial" representation of stimuli, or to the multisensory nature of attention (see, e.g., Becker & Pashler, 2002; Franzén, Markowitz, & Swets, 1970; Rensink et al., 1997; Spence & Driver, 2004).

The last few years have seen a rapid growth of interest in the development and utilization of tactile interfaces in various applied settings (e.g., Bach-y-Rita, 2004; Ho, Tan, & Spence, 2005; Sorkin, 1987; van Erp, 2001; van Erp & van Veen, 2003). In part, this interest reflects the growing belief that the visual and auditory modalities may be overloaded in many real-world settings (Sorkin, 1987; van Veen & van Erp, 2001). If this trend toward using the tactile modality to convey information to interface operators continues, it will clearly become increasingly important to understand the limitations of the body surface as a means of transmitting information (Spence & Driver, 1999).

In the present study, we explored the ability of people (without specific experience of tactile interfaces) to

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perceive changes in sequentially presented simple tactile patterns composed of two or three vibrotactile stimuli presented over the body surface. We developed a tactile analogue of the flicker paradigm used in many previous studies of visual change detection, where the changes in successively presented scenes have been shown to be disrupted by the presence of an interleaved mask between the two stimuli (O'Regan, Rensink, & Clark, 1999; Phillips, 1974; Rensink et al., 1997).

METHOD

Participants

Ten right-handed (4 male and 6 female) participants took part in this experiment (mean age, 21 years; range, 18–28 years). All of the participants reported normal tactile perception.

Apparatus and Materials

The experiment was conducted in a normally illuminated room, with participants sitting on a chair. The vibrotactile stimuli were presented by means of seven resonant-type tactors (Part No. VBW32, Audiological Engineering Corp., Somerville, MA), with 1.6 × 2.4 cm vibrating surfaces. The tactors were placed on the participant's body on top of any clothing that they happened to be wearing, by means of Velcro strips. The participants were unable to see any of the tactors directly under the Velcro strips. The seven body sites where stimulation could be delivered were selected on the basis of their relative "salience" in order to minimize localization errors. The sites were (1) the left wrist; (2) just below the left elbow; (3) midway between the wrist and elbow on the right arm; (4) on the waistline, to the right of the body midline; (5) on the back, to the left of the body midline; (6) just above the left ankle; and (7) midway between the ankle and knee on the right leg (cf. Gallace, Tan, & Spence, 2006). The vibrators were driven by means of a custom-built nine-channel amplifier circuit that drove each tactor independently at 290 Hz. The intensity of each tactor was adjusted individually at the beginning of the experiment, so that each vibrotactile stimulus could be perceived clearly, and all of the stimuli were perceived to be of similar intensity. White noise was presented over closed-ear headphones at 70 dB(A) to mask any sounds.

The participants completed three blocks of trials. In each block, the stimuli consisted of two alternating 200-msec vibratory patterns. In one block, the stimuli were presented sequentially, without any gap between them. In a second block, the two patterns were separated by a 110-msec empty interstimulus interval. In a third block, the two patterns were separated by a masked interval consisting of a 50-msec empty interval, followed by a 10-msec vibrotactile mask (consisting of all seven tactors being activated simultaneously), and then a second 50-msec empty interval. The first pattern consisted of two or three tactors presented equally often from each of the different body locations. In the change condition, one of the tactors composing the first pattern moved to a different position. In the no-change condition, the same vibratory pattern was presented repeatedly throughout the trial. The sequence of stimulation was repeated for the duration of the trial, or until the participant responded. Each block of trials was divided into two equal parts, separated by a short break. The order of presentation of the three block types was randomized across participants. The number of tactors activated in any pattern never exceeded three, given that people's ability to detect simultaneously presented stimuli over the body surface shows a marked decrease as the number of tactors activated exceeds this number (Gallace et al., 2006).

Procedure

The participants were instructed to press one of two keys on a computer keyboard as soon as they decided whether or not a change was present in a given display. The trial was terminated if no response was made within 10 sec of stimulus onset. No feedback was given regarding the correctness of the participant's response. For each experimental condition, 120 trials were presented. In 50% of the trials, a change was presented (equiprobably an onset or offset change), and in the remaining trials no change occurred. There were 360 trials for each participant. At the beginning of each experimental block, 20 practice trials with visual error feedback were presented. The participants repeated the practice trials if their performance fell below 75% correct.

RESULTS

Trials in which participants failed to make a response (<5% of trials overall) were not included in the data analyses. The percentages of correct (hits) and incorrect (false alarms) change detection responses was used to calculate a value for the perceptual sensitivity (d') and for the criterion/response bias (β) according to signal detection theory (Macmillan & Creelman, 1991). These measures were then submitted to two repeated measures ANOVAs with the factor of block type (3 levels: no interval, empty interval, and masked interval). The analysis of d' revealed a significant effect of block type [$F(2,18) = 65.58$, $p < .0001$]. A Duncan post hoc test revealed significant differences among all of the experimental conditions (all ps $< .05$). The lowest d' (lowest rate of correct change detection) was observed in the masked-interval condition and the highest in the no-interval condition. The analysis of β revealed a borderline significant main effect of block type [$F(2,18) = 3.32$, $p = .06$]. These results show that the differences in error rates among the three conditions were primarily due to the differences in the discriminability of the vibrotactile stimulus patterns, and not to any changes in the participants' response biases (in fact the response biases were quite small; see Figure 1).

DISCUSSION

Our results demonstrate that under certain conditions, people may fail to detect the presence of positional changes between two sequentially presented vibrotactile patterns delivered over the body surface. The poorest change detection performance was reported when a vibrotactile mask was presented between the two to-be-discriminated vibrotactile patterns, and the best performance when the two patterns alternated without any gap. Under the latter condition, people's ability to discriminate between change and no-change trials was at its highest. By contrast, in the masked-interval condition, participants often failed to discriminate accurately between the presence and the absence of a change. This pattern of results is very similar to that reported in previous studies of visual change detection (Hochberg, 1968; Rensink, 2002; Simons & Rensink, 2005).

It has been suggested that the representation of a visual scene may be limited to the number of items that can be held in visual short-term memory (STM) at any one time. Following on from this, one possible account of our results might be related to the role played by tactile STM in retaining a veridical representation of the two vibrotactile

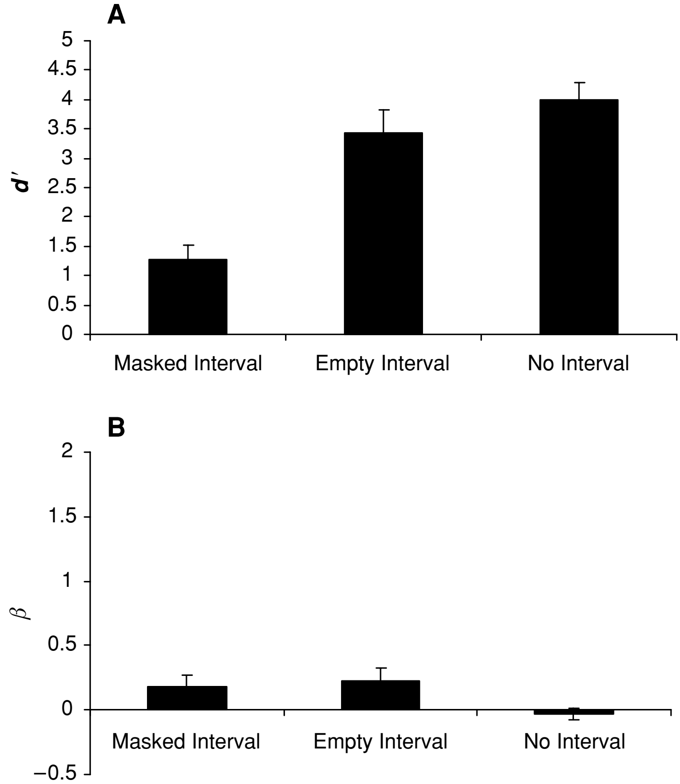

Figure 1. Performance in each experimental block: (A) Mean *d′* values. (B) Mean *β* values. Error bars represent the standard errors of the means.

patterns to be compared in order to successfully detect that change has taken place. However, the "decaying tactile STM" interpretation cannot explain the differences between the masked- and empty-interval conditions, given that the two patterns were separated by the same temporal interval in both cases. Instead, it might be possible that tactile change blindness might be related to the lack of awareness of the spatial location where change took place (Thornton & Fernandez-Duque, 2002). This might be the result of the masking of any sensory transients (such as possibly apparent motion in the present study) normally used to detect the location of a salient event and draw attention to it (Rensink et al., 1997). Our results might also be consistent with the view that change blindness may reflect a more general multisensory/amodal, rather than specifically unimodal, underlying mechanism, related to the nature of the internal representation of space and/or attention (see Driver & Spence, 1998).

We believe that our results may have important implications for the design and implementation of future tactile information displays. The poor performance of participants in detecting the presence of change in sequentially presented vibrotactile patterns (i.e., up to 30% errors in the masked-interval block) highlights an important constraint on the possible transmission of information via tactile interfaces. Future research should address the role of variations in perceptual load (Lavie, 2005) on the tactile perception of participants having both extensive and limited prior experience of tactile interfaces/prostheses.

In conclusion, our results provide the first empirical evidence for the existence of a tactile analogue of visual change blindness. In comparison with the findings from the literature on visual change blindness, the tactile deficit reported here appears of particular note, given the very simple vibrotactile patterns used (consisting of no more than three stimuli at any one time) and the unspeeded nature of the response required.

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