Touch-induced visual illusion

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Although vision is considered the dominant modality, recent studies demonstrate the influence of other modalities on visual perception. For example, in the sound-induced flash illusion, two auditory stimuli cause one visual flash to be perceived as two. We report an extension of the sound-induced flash illusion to the tactile–visual domain, yielding the touch-induced flash illusion. Observers reported seeing two flashes on the majority of trials when a single flash was presented concurrently with two task-irrelevant brief tactile stimuli. Somatosensory stimulation changed the sensitivity (d') of detecting visual stimuli, which suggests that the observed effect is at least partly due to perceptual interactions. Together with other recent findings, these results challenge the notion that the processing of visual information is independent of activity in other modalities. *NeuroReport* 16:1107–1110 © 2005 Lippincott Williams & Wilkins.

Key words: Crossmodal interaction; Illusion; Multisensory integration; Sensory integration; Somatosensory–visual interaction; Tactile–visual interaction; Visual illusion

INTRODUCTION

Historically, perception has been viewed as a process involving largely independent sense modalities. While this ‘divide and conquer’ approach has yielded numerous insights about the organization and specialization of brain regions, it has led to a gross underestimation of the interactions among sensory modalities. However, several studies have successfully unmasked the strong interaction between the different modalities by artificially creating a situation of conflict between the information conveyed by two modalities. The McGurk [1] and ventriloquism [2] effects, for example, demonstrate the influence of vision on auditory perception. Similarly, visual capture [3,4] demonstrates the strong effect of vision on proprioceptive and somatosensory modalities. Examples of vision being influenced by other modalities are less common and include the ‘bounce illusion’ [5], where the direction of motion is influenced by sound, and the sound-induced flash illusion [6], in which the pairing of a single visual flash with multiple beeps induces the percept of multiple flashes, showing that visual perception can be radically altered by auditory stimuli.

While most multisensory research has focused on interactions between vision and audition, interesting phenomena involving interactions between somatosensory and other modalities have recently been reported as well. Hotting and Roder [7] reported a parallel of the sound-induced flash illusion in the auditory–tactile domain, indicating that auditory stimuli can significantly alter the perception of tactile stimuli. The proximity of somatosensory and auditory cortices makes the finding of the auditory–tactile interactions not entirely surprising. However, evidence of perceptual interactions between visual and somatosensory modalities [4,8] has also been found. The aforementioned visual capture effect is a compelling example of such interactions. Visual spatial attention has also been shown to be modulated by tactile stimulation [9] and vice versa [10], and there are reports of bidirectional attentional blink between vision and touch [11]. Furthermore, a transcranial magnetic stimulation-induced virtual lesion in the extrastriate visual cortex has been shown to interfere with a tactile orientation discrimination task [12]. Finally, visual and tactile features can also be erroneously bound together, leading to crossmodal illusory conjunctions [13].

Recently, Ernst *et al.* [14] showed that visual slant discrimination can be influenced by concurrent tactile stimulation, indicating that vision can also be affected by somatosensory processing. Here, we asked whether vision can be qualitatively altered by tactile stimuli, and, if so, whether such interactions can occur at a perceptual level or only at postperceptual levels. We adopted a tactile–visual version of the sound-induced flash illusion paradigm [6,15] discussed above, to examine this question.

MATERIALS AND METHODS

Nine undergraduate UCLA students participated in the experiment. All participants were right-handed, and reported normal or corrected-to-normal vision, hearing, and somatosensation and no neurological abnormalities. They were all naive to the purpose of the experiment, and were given credit needed to fulfil a class requirement. The experiment was conducted in accordance with UCLA’s Office for the Protection of Research Subjects, and participants gave written consent before taking part in the experiment.

Participants sat in front of a computer monitor at a distance of 52 cm, with their chins placed on a chin rest. They were asked to place the index finger of their left hand on top of a refreshable Braille cell device, which was placed out of sight in a sound-insulated box. Because our previous experiments have shown that sound can modulate visual perception in this task [6,15], the following measures were taken to eliminate any possibility of the observers hearing the very weak clicking sound generated by the tactile device. The device was insulated in a sound-attenuating box, and, additionally, participants wore foam earplugs and closed cup headphones that presented a white noise burst enveloping the time of visual and tactile stimuli presentation. The auditory white noise (75 dB) was presented for a duration of 1200 ms, and visual and/or tactile stimuli were presented approximately in the middle of this period, with a normally randomized jitter of 333 ms. We insured that the sound of the tactile device was not audible by asking a few pilot participants to judge the number of clicks (generated by the Braille device) while it produced none, one or two taps in random order, without any contact to their body. The participants performed at chance level, indicating that the tap-produced sound was not audible.

Each participant was given instructions to fixate on a central cross and report the number of flashes that they saw on the screen, regardless of what was felt under the finger. The visual stimuli consisted of a uniform grey disk subtending 1.4° of visual angle in diameter presented on a black background at 7.0° eccentricity below the fixation point. The disk was presented below fixation because observations from the sound-induced flash illusion suggest that the illusion is substantially weaker when the visual stimulus is presented in the fovea as opposed to the periphery. The disk was presented for less than 10 ms (one frame on a 19″ NEC MultiSync 97F monitor, set to a spatial resolution of 800 × 600 pixels and a refresh rate of 100 Hz). In the double flash condition, the disk was presented twice, with a 60 ms (six frames) separation between the two flashes. The tactile stimulus was a 'tap' of all eight pins of the Braille cell, which were raised simultaneously by 2 mm for a duration of 34 ms; the second tap was presented 60 ms after the onset of the first tap. Stimuli were timed so that the middle of each coincided in time with the middle of the other. The tactile stimulation device was located to the left of the screen, approximately 50 cm away from the visual stimuli. Participants placed their left index finger on the Braille cell throughout the experiment, which lasted about 15 min. On trials in which both visual and tactile stimuli were present, the onset of the tap was 15 ms prior to the onset of the visual stimulus, thus aligning the midpoints of the two stimuli in time. The stimulus presentation was controlled by PsychToolBox [16] for MatLab. A factorial design was used by varying the number of flashes (1 or 2) and number of taps (0, 1 or 2). Thirty trials of each of the six conditions were presented in a pseudorandom order.

Before starting the experiment, each participant was briefly trained on a discrimination task to familiarize them with the visual stimuli and the experimental requirements. The training task involved discrimination between one or two flashes in the absence of any tactile stimuli, in blocks of 10 trials. After each block, the participant was given feedback through a written message on the computer screen. Training was terminated at the end of a block once the participant was able to perform the task with 90% accuracy on both conditions, calculated separately. Most participants needed only two training blocks and found the task relatively easy. At the start of the experiment, it was reemphasized to the participants that they should ignore the tactile taps and concentrate on what they see on the screen.

RESULTS

A 2 (number of flashes: 1 or 2) by 3 (number of taps: 0, 1 or 2) repeated-measures ANOVA, revealed a significant interaction between the number of flashes and number of taps, $F(2,16)=108.09$ $p<0.001$. Both main effects of the number of taps and the number of flashes were also significant, $F(2,16)=38.28$ $p<0.001$ and $F(1,8)=95.31$ $p<0.001$, respectively. Tactile stimuli significantly changed visual perception in the following ways. Most interestingly, observers reported seeing two flashes on 62.6% (SD=21.3%) of trials when a single flash was accompanied by two taps compared with 20.7% (SD=1.5%) of trials when it was presented in the absence of taps or 26.7% (SD=12.8%) when it was presented with one tap (Fig. 1).

We refer to this effect as the 'touch-induced flash illusion.' This effect is highly significant [planned comparison one-tailed pairwise *t*-test, $t(8)=5.90$, $p<0.001$, and $t(8)=5.50$, $p<0.001$ for comparisons of double-tap condition against zero-tap and single-tap conditions, respectively]. A much weaker, yet significant [planned comparison one-tailed pairwise *t*-test, $t(8)=2.54$, $p<0.05$], fusion effect was also observed, in which observers reported seeing one flash when two flashes were paired with one tap in 19.5% (100%–80.5%, Fig. 1) of trials as opposed to 7.3% (100%–92.7%,

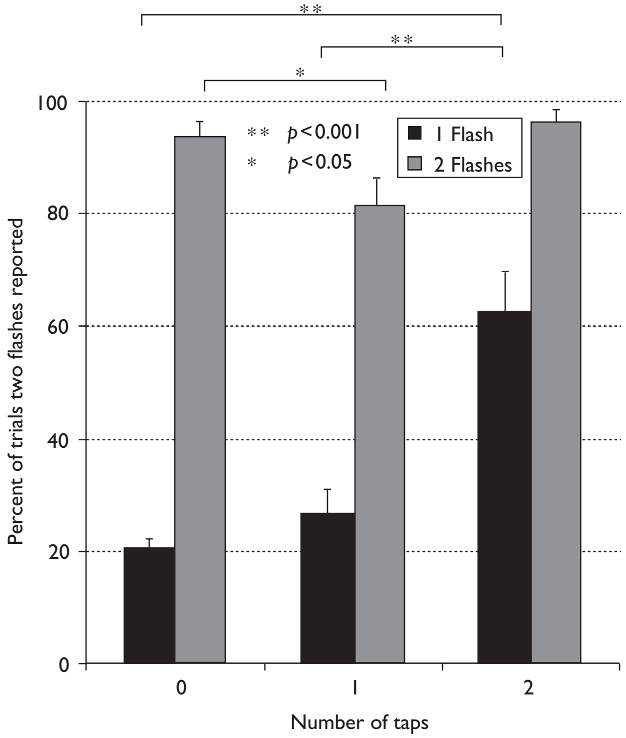

Fig. 1. The effects of task-irrelevant tactile stimuli on visual detection of two brief flashes. The perceived number of flashes in each condition is averaged across all trials and all participants ($n=30 \times 9$). The error bars represent the standard error (SE) across participants.

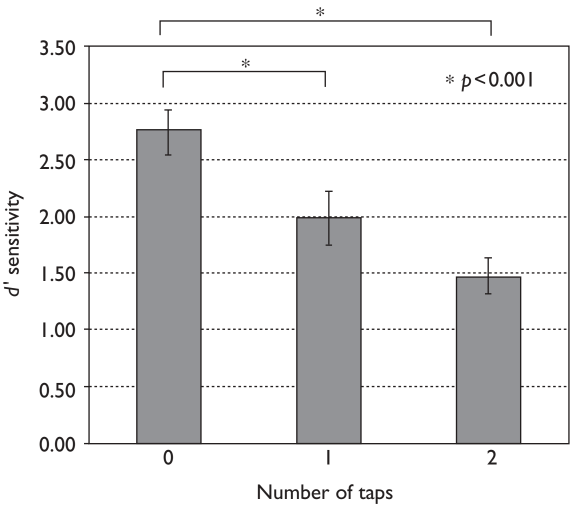

Fig. 2. Sensitivity (d') for detection of two flashes in different conditions, averaged across participants. The error bars represent the standard error (SE). The presence of one tap decreases the sensitivity by making the double-flash stimulus more similar to one flash as can be seen in Fig. 1. The presence of two taps reduces the sensitivity by rendering the single flash similar to double flashes (see Fig. 1). The double-flash illusion (i.e., single flash paired with two taps perceived as two flashes) is stronger, and the corresponding change in d' is also larger.

Fig. 1) of trials when two flashes were presented in the absence of tactile stimulation.

Furthermore, signal detection theory analysis indicated changes in sensitivity d' across tactile conditions for the correct detection of two flashes (Fig. 2). Sensitivity d' was defined as $d'=z(\text{hits})-z(\text{false alarms})$, where z is the inverse cumulative normal [17]. For this analysis, double flashes were treated as the target and a correct identification of that stimulus was counted as a 'hit', while the correct identification of a single flash was counted as a 'correct rejection'. 'False alarm', therefore, corresponded to single-flash trials on which participants reported seeing two flashes.

On average, the presence of two taps ($d'=1.48$, SD=0.49) decreased sensitivity by 46.2% [one-tailed pairwise t-test, $t(8)=5.57$, $p<0.001$] compared with the visual-alone conditions [$d'=2.75$, SD=0.62]. The presence of one tap ($d'=1.99$, SD=0.71) decreased the sensitivity for discriminating visual stimuli by 27.4% [one-tailed pairwise t-test, $t(8)=3.85$, $p<0.001$] compared with the visual-alone conditions. Had the illusion been the result of a change in bias only, we would expect the sensitivity to stay constant; yet we see significant changes in d' due to the introduction of tactile stimuli, suggesting changes in the perceptual processing of the stimulus as opposed to changes in decision bias.

DISCUSSION

The results of this study indicate a strong modulation of visual perception by tactile stimuli. Recently, neuroanatomical pathways have been identified, which can mediate direct modulation of visual processing from the auditory cortex and indirect modulation through superior temporal polysensory regions [18,19]. No such pathways have yet been identified linking the somatosensory cortex to the visual cortex. It is possible that the observed touch-induced flash illusion is the result of convergence of tactile and visual inputs in high-order associative cortical areas. On the other hand, the sound-induced flash illusion has now been shown to be associated with modulation of activity in the early visual cortex [20–23]. The touch-induced and sound-induced flash illusions are perceptually similar, and exhibit similar properties. For example, as in the sound-induced flash illusion, we also found a fission effect (i.e. a single flash paired with two taps perceived as two flashes) to be stronger than the reverse, fusion effect (i.e. two flashes paired with a single tap perceived as a single flash). Therefore, it is probable that they involve similar neural processes. This would suggest that the touch-induced flash illusion may also involve modulation of activity in the early visual cortex.

Previous imaging results are consistent with this hypothesis of early tactile–visual interaction. Macaluso *et al.* [24] showed that tactile stimulation can modulate activity in extrastriate occipital areas in addition to somatosensory (postcentral gyrus) and multimodal (intraparietal sulcus) regions. Sathian *et al.* [25] reported activation of visual regions during tactile orientation and spatial frequency discrimination tasks. Furthermore, this activation seems to be necessary for carrying out some tactile tasks, as inhibition of occipital cortex using focal transcranial magnetic stimulation interferes with the tactile discrimination of grating orientation [12]. All these findings are consistent with the hypothesis that the visual cortex receives somatosensory input. However, further neuroimaging, neurophysiological and neuroanatomical studies are needed to map the circuitry involved in tactile modulation of visual perception.

CONCLUSION

We report an original illusion demonstrating tactile capture of visual structure. One flash accompanied by two taps can be perceived as two flashes. Furthermore, this phenomenon seems to be due to a perceptual mechanism, as opposed to a cognitive or decision-making bias. These findings indicate that visual perception can be qualitatively and radically altered by tactile stimuli. Together with many other cross-modal effects, these results highlight the interconnectivity among modalities and challenge the long-held belief in the exclusive modularity of perception.

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