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Research Report

Visually induced feelings of touch

*Ruth M. Johnson**, *Philip C. Burton*, *Tony Ro**

Rice University, Psychology Department, MS 25, 6100 Main Street, Houston, TX 77005, USA

A R T I C L E I N F O

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Recent studies have reported that vision can enhance tactile perception, even in patients with somatosensory deficits. However, it is unclear in these previous studies whether visual input truly enhances detection of tactile stimuli or induces a higher propensity for reporting touch by changing response criteria. In this study, we demonstrate in neurologically normal subjects that in addition to small increases in tactile sensitivity when a non-informative, suprathreshold visual stimulus is presented, there are highly consistent changes in response criteria for reporting touch with vision, even when no tactile stimulus is delivered. These results suggest that some of the previously reported enhancements of touch from vision may rather be a consequence of strategic sensory encoding processes that rely upon the typical correlations between multisensory events.

1. Introduction

All of our incoming sensations help to build our perception of the world. However, vision appears to be our most important and relied on sensory modality, typically dominating or altering our other senses. For example, several studies have demonstrated that other senses adapt to a distorted visual image (Harris, 1963; Sekiyama et al., 2000; Stratton, 1897). These studies show that the proprioceptive system adapts to the visual environment, especially when vision and proprioception provide conflicting sensory information. When visual and tactile processing provide conflicting information, the visual system not only dominates but can also alter touch perception (Pavani et al., 2000; Rock and Victor, 1964, 1965; Ro et al., 2004). For example, using a mirror to induce a conflict between vision and touch, Ro et al. (2004) enhanced tactile perception for several minutes and established that this visual enhancement of touch induced by the conflict occurs in the posterior parietal cortex.

Other research has also shown that vision can augment tactile perception, even in cases without any influences from proprioceptive orienting (Kennett et al., 2001; Taylor-Clarke et al., 2002; Tipper et al., 1998, 2001). In one study, for example, Tipper et al. (1998) used a video camera to display a participant's hand on a monitor placed directly in front of the subject and demonstrated that tactile perception was facilitated (i.e., response times were faster) with vision of the hand, independent of proprioception of the head. In a follow-up study, vision influenced tactile detection at body sites that could not be directly viewed by the participants, such as the face or the back of the neck (Tipper et al., 2001). The effect of non-informative vision on tactile spatial resolution has also been investigated (Kennett et al., 2001). Participants were significantly better at a two-point discrimination task when their arm was visible, compared to when the arm was not visible or when viewing a neutral object. Tactile perception was further increased with magnification of the participant's arm. Using event-related potentials (ERPs), Taylor-Clarke et al. (2002) suggested that vision of a to-be-touched body part might modulate tactile processing in the somatosensory cortex via back projections from multimodal posterior parietal areas.

Based on the multisensory facilitation depicted in the previous experiments, some patient studies have investigated

* *Corresponding authors*. Fax: +1 713 348 5221.
E-mail addresses: rwallace@rice.edu (R.M. Johnson), tro@rice.edu (T. Ro).

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whether vision can systematically enhance touch perception. In one study, Halligan et al. (1996) reported a right hemisphere stroke patient who detected all contralesional tactile stimuli when he viewed his left hand being touched, but felt nothing when he could not see the touch. When the patient could not see his hands, however, he could still reliably transfer information from his impaired hand (which he did not know was being touched) to his normal hand. Importantly, in relation to the current study, when the patient watched a previously taped video of his hand being touched, he also reported feeling touches even when no tactile stimuli were delivered. Halligan et al. (1996) suggested that correlated visual information decreased the patient's threshold for touch sensations, but it remains unclear why the patient made false reports of touch under some conditions.

Rorden et al. (1999) investigated another patient whose tactile detection of a tap was also improved by the sight of a non-informative flash of light on a rubber hand placed in the same orientation directly above the patient's own concealed hand. When a salient, but non-predictive light, was attached to the rubber hand, the patient's touch perception was enhanced compared to when the light was in the same location but on the hand of an experimenter who was sitting across from the patient. On light-only trials, when the visual but not the tactile stimulus was presented to the patient, his false alarm rates were very low and did not differ between the rubber hand and experimenter hand conditions. Rorden et al. (1999) concluded that the presence of the light on the rubber hand dramatically increased tactile sensitivity because the patient viewed the rubber hand as being his own but did not feel that way towards the experimenter's hand.

Based on the two previously described patient studies, it is unclear whether visual input consistently enhances tactile perception or changes response biases. Since we have lifelong experiences of visual input correlated with touch, perhaps response biases operate to induce feelings of touch even when no tactile stimulus is present, such as when seeing an insect induces a sensation of something crawling on one's skin. Therefore, we tested whether a non-informative[1] simultaneous visual stimulus can increase threshold-level tactile perception in neurologically normal subjects, with or without associated changes in response biases. We hypothesized that a response bias would raise both the reported detection of touch when a simultaneous but non-predictive flash of light is presented with the tactile stimulus and would also increase errors in reporting touch when a light is presented alone. Using analyses based on Signal Detection Theory (Macmillan and Creelman, 1991), we examined whether the presence of a visual stimulus enhances detection and/or changes response criteria.

2. Results

Five experiments determined that non-informative visual information not only modulated near-threshold touch perception but consistently induced shifts in biases for reporting touch with vision. In each experiment, tactile stimulation was delivered to subjects' hands through ring electrodes attached to their middle fingers. A small red LED was also taped to the ring electrodes and was illuminated for 5 ms when serving as the visual stimulus (Fig. 1).

2.1. *Experiment 1 results*

Experiment 1 used a non-informative light simultaneously paired with a near-threshold tactile stimulus in the critical condition to determine whether it would influence touch detection and response biases. The experiment had four conditions that were presented equally often and in a randomized order throughout the experiment: (1) Light trials; (2) Touch trials; (3) Both light and touch trials; and (4) Catch trials on which no sensory stimulation was delivered to the subject. The subjects' task was to state whether they saw a light, felt a touch, perceived both, or detected nothing. Responses were considered correct if the participants accurately reported all stimuli administered on a particular trial or reported 'none' on the Catch trials. Trials on which subjects were given a Catch trial and responded "touch" or were given a Light trial and responded "both" were considered false alarms.

Fig. 1 – The apparatus and stimuli used in Experiments 1, 2, and 3 are shown. Experiment 4 had a second set of ring electrodes and another LED attached to a participant's left index finger, while Experiment 5 had the ring electrodes and LED attached to the participant's right middle finger.

[1] We use the term non-informative to refer to the fact that the presentation of the light did not signal whether a touch would be given. However, when a light was presented on a trial, it was temporally informative so that participants knew that if a corresponding tactile stimulus was also presented, it occurred simultaneously with the visual stimulus. This temporal information was not available when the touch was presented alone. Note, however, that we did give consistent temporal information on every trial by always providing a warning tone 500 ms before the stimuli were delivered during the experiments. Thus, the additional temporal information supplied when vision was provided with touch was likely to be minimal.

The mean percentages of hits and false alarms averaged across light-present and light-absent trials are shown in Table 1. Tactile detection rates increased 6.9% during Both trials compared to Touch trials (Fig. 2a). Participants reported that they felt the tactile pulse significantly more often when it was paired with the light than when presented alone, $t(23) = 2.22$, $P = 0.037$, two-tailed. Although the 2.1% increase in false alarms was in the expected direction, with more false alarms for reporting touch during Light trials than Catch trials, the difference did not achieve significance, $t(23) = 1.44$, $P = 0.162$, two-tailed (Fig. 2b). Other types of incorrect responses occurred on less than 1% of trials and therefore were not included or further analyzed.

We also utilized signal detection procedures to calculate d' and c (Macmillan and Creelman, 1991). Changes in sensitivity were measured using d', [$d' = z(\text{Hits}) - z(\text{False alarms})$], while changes in criterion, a measure of response bias (Macmillan and Creelman, 1991), were measured using c [$c = -(z(\text{Hits}) + z(\text{False alarms})) / 2)$]. Eight out of 24 subjects did not commit a false alarm in either the Light or Catch trials. False alarm rates were estimated for these participants to allow for signal detection analyses by dividing 0.5 by the number of trials in the experiment (Stanislaw and Todorov, 1999). Average d' and c values by condition are shown in Table 1. In Experiment 1, differences in d' were not significantly different between the Both and Touch conditions, $t(23) = 0.859$, $P = 0.399$, two-tailed (Fig. 3). However, their c values significantly decreased in the Both trials compared to the Touch trials, $t(23) = 2.39$, $P = 0.025$, two-tailed (Fig. 3). This decrease in criterion value reflects a more liberal response bias, with subjects more likely to report feeling a tactile pulse when a visual stimulus was presented. This criterion shift when a light was present contributed to the higher percentage of detection rates in the Both vs. Touch trials and in the Light vs. Catch trials. Rather than an increase in tactile sensitivity when a light was simultaneously presented with a pulse, the criterion for reporting a pulse was lowered when the light was present. This criterion shift contributed to at least some of the significant percentage increase in reporting the pulse.

Table 1 – The percentages of mean hits and false alarms are shown for Experiments 1–5, as well as d' and c values for Experiments 1–3

	Light present				Light absent			
	Hits (%)	FA (%)	d'	c	Hits (%)	FA (%)	d'	c
Expt. 1	63.3	6.9	1.97	0.61	56.5	4.8	1.87	0.75
Expt. 2	57.1	7.5	1.76	0.69	46.9	4.0	1.66	0.92
Expt. 3	59.6	8.3	1.91	0.69	49.8	6.0	1.73	0.88
Expt. 4	77.0	10.9	N/A	N/A	61.4	5.3[a]	N/A	N/A
Expt. 5	80.9	34.2[b]	N/A	N/A	74.0	26.0[b]	N/A	N/A

N/A—not applicable; sensitivity and response criteria were not calculated on the discrimination data from Experiments 4 and 5.

[a] Catch trials on which no sensory stimulation was given did not occur in Experiment 4. The reported false alarm rate is an average of Light trials when subjects reported feeling a touch on the opposite finger from the one with the visual stimulus and Touch trials when subjects reported feeling a touch on the opposite finger from the one that was stimulated.

[b] The false alarm rates for Experiment 5 occurred when subjects reported feeling a touch on the hand where a light was presented during trials where the visual and tactile stimuli were delivered to opposite hands or when they report a touch on the opposite finger from the one that was stimulated. The false alarm rates are considerably higher than in the previous four experiments because participants were forced to choose.

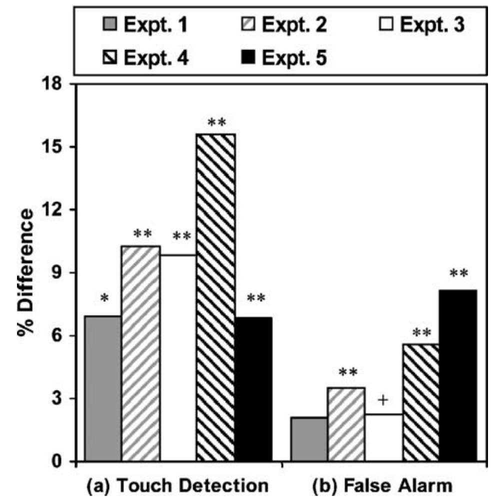

Fig. 2 – (a) The percent increase for each experiment is shown when the light and pulse occurred simultaneously on the same finger in Both trials compared to Touch trials. (b) False alarm differences are also shown for Experiments 1–5. +Indicates $P < 0.1$, *indicates $P < 0.05$, and **indicates $P < 0.01$.

2.2. Experiment 2 results

The second experiment examined whether pairing supra-threshold association trials before the experiment would help

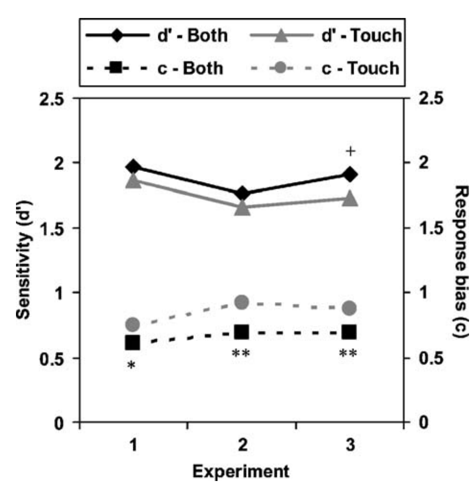

Fig. 3 – Sensitivity and response bias differences are shown for Experiments 1, 2, and 3. Overall, sensitivity (d') measurements were greater during Both trials compared to Touch trials, and criterion (c) values were lower during Both trials compared to Touch trials. +Indicates $P < 0.1$, *indicates $P < 0.05$, and **indicates $P < 0.01$.

to further improve detection beyond any change in response bias during Both trials. Experiment 2 was identical to Experiment 1, except that subjects were given association trials with suprathreshold pairings of light and touch at the beginning of the experiment. After the initial suprathreshold pairing phase, the tactile stimuli were returned to threshold levels by the experimenter, and the experiment followed the same format as Experiment 1.

Mean percentages for hits and false alarms by condition are shown in Table 1. After the association trials, tactile detection rates increased 10.2% during Both trials compared to Touch trials (Fig. 2a). Participants reported that they felt the touch significantly more often when it was paired with the light in Both trials than when the touch was presented alone, $t(23) = 3.04$, $P = 0.006$, two-tailed. Subjects also incorrectly said “both” more often during Light trials than they said “touch” during Catch trials. This 3.5% increase in false alarms was significant, $t(23) = 3.21$, $P = 0.004$, two-tailed (Fig. 2b). Eleven out of 24 subjects did not commit a false alarm in either the Light or Catch trials.

Average d' and c values by condition are shown in Table 1. In Experiment 2, the difference in d' was not significant between the Both and Touch conditions, $t(23) = 1.01$, $P = 0.322$, two-tailed (Fig. 3). However, their c values did significantly decrease in the Both trials compared to the Touch trials, $t(23) = 4.07$, $P < 0.001$, two-tailed (Fig. 3). Again, this decrease in response criterion revealed a response bias, with participants significantly more likely to report feeling a touch when a visual stimulus was presented, regardless of whether the tactile pulse was actually delivered.

2.3. Experiment 3 results

In contrast to the first two experiments, the instructions in Experiment 3 strongly emphasized reporting every tactile sensation subjects felt on their left middle fingers, even when they were not sure it was the pulse. These instructions were intended to induce the same bias for reporting touch across all conditions; thus, false alarms were expected to be higher in this experiment for both reports of “touch” during Catch trials and “both” during Light trials. This manipulation was introduced to determine whether inducing a general bias towards reporting touch might increase sensitivity to touch on the Both compared to the Touch trials.

Table 1 shows the mean percentages of hits and false alarms by condition. Tactile detection rates increased 9.8% during the Both trials compared to the Touch trials (Fig. 2a). As in the previous two experiments, participants reported that they felt the touch significantly more often when it was paired with the light than when presented alone, $t(23) = 3.99$, $P = 0.001$, two-tailed. While false alarm rates were higher overall in Experiment 3, the 2.3% increase in false alarms did not significantly differ between Light trials on which subjects said “both” and Catch trials on which they said “touch”, although it was again in the expected direction, $t(23) = 1.72$, $P = 0.099$, two-tailed (Fig. 2b). Five out of 24 subjects did not commit a false alarm in either condition, despite the emphasis in the instructions.

Average d' and c values by condition are shown in Table 1. In Experiment 3, d' values were higher in the Both compared to the Touch condition, although this difference fell just short of significance, $t(23) = 1.971$, $P = 0.061$, two-tailed (Fig. 3). Consistent with the previous experiments, c values significantly decreased in the Both trials compared to the Touch trials, $t(23) = 3.38$, $P = 0.003$, two-tailed (Fig. 3). This significant decrease in criterion revealed a more liberal response bias for Light trials, with subjects more likely to report feeling a tactile pulse when a visual stimulus was presented.

2.4. Between experiment analyses for the detection experiments

Because these first three experiments were very similar and subjects responded in the same way, we also tested whether any overall differences existed between Experiments 1, 2, and 3. A 2 (condition) × 3 (experiment) ANOVA was conducted on d' measurements of sensitivity with condition (Both and Touch trials) as the within-subject variable and experiment (1, 2, and 3) as the between-subject variable. There was a main effect of condition with significantly higher d' values for the Both trials compared to Touch trials ($F(1,69) = 4.64$, $P = 0.035$). Neither the main effect of experiment ($F(2,69) = 0.558$, $P = 0.575$) nor the condition by experiment interaction ($F(2,69) = 0.234$, $P = 0.792$) was significant. These results demonstrate that participants display a small increase in sensitivity when a light was present during the Both trials compared to the Touch trials (Fig. 3). Another 2 (condition) × 3 (experiment) ANOVA was conducted on c measurements of response bias with condition (Both and Touch trials) as the within-subject variable and experiment (1, 2, and 3) as the between-subject variable. There was a main effect of condition with significantly lower c values for the Both trials compared to Touch trials ($F(1,69) = 32.2$, $P < 0.001$). The main effect of experiment ($F(2,69) = 1.19$, $P = 0.310$) and the condition by experiment interaction ($F(2,69) = 0.719$, $P = 0.491$) were not significant. This analysis confirmed that participants decreased their criterion levels when a visual stimulus was present on a given trial and induced a significant response bias (Fig. 3). Because responses on both trials also reflected a more liberal response criterion level, their hit rates as well as their false alarm rates as measured by percent change significantly increased when a light was present. The signal detection analysis established that the presence of a non-informative light had a small influence on tactile sensitivity overall, but a much greater and consistent effect on participants’ response biases, regardless of whether a tactile pulse was presented simultaneously or not.

The previous three experiments used a detection paradigm to examine the effects of a visual stimulus on tactile sensitivity and found that the presence of a non-informative light increased participants’ reported sensation of touch, independent of tactile stimulation. Furthermore, signal detection analyses showed that this reported difference was due to a significant response bias to report feeling a touch when a light was presented simultaneously, as well as a small and less consistent increase in sensitivity overall when a light was presented. In the next two experiments, we used discrimination tasks to determine if similar effects could be obtained when vision and touch were delivered to different fingers. The discrimination paradigms were designed such that signal detection analyses would not be necessary to determine the differential influences of changes in sensitivity and response criteria for the remaining two experiments.

2.5. *Experiment 4 results*

Experiment 4 examined visual influences on tactile processing across two adjacent fingers and was designed to determine whether a light presented on a different finger from the tactile pulse had the same effect on touch perception as when both the visual and tactile stimuli were presented simultaneously on the same finger. The fourth experiment differed from the previous three experiments in experimental design, instructions, and number of trials. Experiment 4 was similar to Experiments 1–3, except that this experiment used visual and tactile stimuli that were presented to the subjects' left index and middle fingers and required a location discrimination response. Tactile thresholds were set near 60% detection (rather than 50% as in previous experiments) because of the more difficult localization task used in this experiment. Experiment 4 had four conditions that were presented equally often and in randomized order to each finger: (1) Light trials; (2) Touch trials; (3) Both light and touch trials on the same finger; and (4) Both light and touch trials on different fingers. The participant's task was to state the finger (if any) on which the tactile pulse was felt on each trial. Responses were considered correct only if the participant accurately reported the finger on which the tactile stimulus was given or reported 'none' on the Light trials. False alarms occurred when subjects stated they felt a pulse on the opposite finger from the one actually touched or when they reported feeling a touch on a Light trial. Subjects were asked to look at their left hands so they could see the visual stimulus but were not required to report any visual information. In this way, the visual stimulus in this experiment was truly non-informative and unrelated to the participants' task.

The fourth experiment established what effect a light presented on a different finger from the tactile pulse had on touch perception compared to when both the visual and tactile stimuli were presented simultaneously on the same finger. Mean percentages of hits and false alarms by condition are shown in Table 1. Correct tactile response rates increased 15.6% on Both trials presented to the same finger compared to Touch alone trials (Fig. 2a). Participants reported that they felt the tactile pulse significantly more often when it was paired with the light on the same finger than when it was presented alone, $t(23) = 7.30$, $P < 0.001$, two-tailed. Correct tactile response rates also significantly increased by 12.3% during Both trials delivered to the same finger compared to Both trials delivered to different fingers, $t(23) = 4.79$, $P < 0.001$, two-tailed. Furthermore, accuracy rates did not significantly differ between Touch trials (61.4%) and Both trials (64.7%) when the visual and tactile stimuli were delivered to different fingers, $t(23) = 1.17$, $P = 0.256$, two-tailed. Thus, the visual stimulus presented on the opposite finger did not increase reports of tactile sensations above the baseline rates detected in the Touch trials. However, the visual stimulus did influence false alarm rates (Fig. 2b). False alarms occurred when subjects reported feeling a touch on a Light trial or stated they felt a pulse on a different finger than the one that was stimulated for Both and Touch trials. Because Experiment 4 did not have Catch trials where no sensory stimulation was given, the baseline false alarm rate was calculated by averaging Light trials when subjects reported a touch on the finger opposite the visual stimulus (5.1%) and Touch trials when participants felt the pulse on a different finger from the one that was stimulated (5.5%). The two baseline false alarm measures were not significantly different, $t(23) = 0.480$, $P = 0.636$, two-tailed, and were therefore averaged (5.3%) and used for the remaining analyses. Participants incorrectly reported feeling more tactile pulses on the finger where the visual stimulus was present during Light trials compared to the averaged baseline false alarm rate; this 5.6% increase in false alarms was significant, $t(23) = 3.75$, $P = 0.001$, two-tailed (Fig. 2b). In addition, subjects also incorrectly reported feeling more touches (8.5%) on the finger where the light flashed in the Both trials when visual and tactile stimuli were given to different fingers compared to the baseline false alarm rate, $t(23) = 3.95$, $P = 0.001$, two-tailed.

2.6. *Experiment 5 results*

Experiment 5 examined visual influences on tactile processing across participants' hands and was designed to determine whether a light presented on a different hand from the tactile pulse had the same effect on touch perception as when both the visual and tactile stimuli were presented simultaneously to the same hand. Experiment 5 used a discrimination paradigm and was similar to Experiment 4, except that in this experiment, the visual and tactile stimuli were presented to the subjects' middle fingers on the left and right hands. Experiment 5 had three conditions that were presented equally often and in randomized order to both hands throughout each experiment: (1) Touch trials; (2) Both light and touch trials, with both stimuli presented simultaneously to the same finger; and (3) Both light and touch trials, with the stimuli presented on opposite hands. The participants' task was to report the hand on which the tactile pulse was delivered. Responses were considered correct only if participants accurately reported where the tactile stimulus was delivered. False alarms occurred when subjects stated they felt a pulse on the opposite hand from the one actually stimulated. Similar to Experiment 4, subjects did not have to report where they saw the visual stimulus, and therefore, it was truly non-informative and unrelated to the participants' task.

Mean percentages of hits and false alarms by condition are shown in Table 1. Correct reports of tactile stimulation increased 6.9% in Both trials with vision and touch on the same finger compared to Touch alone trials (Fig. 2a). Participants reported that they felt the tactile pulse significantly more often when it was paired with the light on the same hand than when it was presented alone, $t(23) = 3.18$, $P = 0.004$, two-tailed. Furthermore, accuracy rates significantly decreased 8.2% in Both trials when the visual and tactile stimuli were delivered to opposite hands compared to Touch trials, $t(23) = 3.06$, $P = 0.006$, two-tailed. Thus, the visual stimulus presented on the opposite hand from the tactile stimulus increased reports of tactile sensations on the hand where the light was given instead of on the hand where the pulse was delivered. Therefore, the visual stimulus not only increased sensitivity but also induced subjects to commit more false alarms.

3. Discussion

The experiments described in this study demonstrate that a non-informative visual stimulus influences the reported perception of touch in neurologically normal subjects by weakly enhancing sensitivity, as well as creating a strong response bias. In all five experiments, participants were significantly more likely to respond that they felt a touch when both the visual and tactile stimuli were presented simultaneously to the same finger than when the touch was presented alone. Furthermore, in Experiments 1–3, subjects also reported feeling more touches on trials when only a light was presented compared to trials when nothing was presented. Unlike this robust and reliable response bias effect, the effect of the simultaneous presentation of the light on actual sensitivity to tactile pulses was much smaller and was only significant in the between experiment analysis.

The fourth experiment further demonstrated that accurate reports of tactile stimulation increased only when the visual and tactile stimuli occurred simultaneously on the same finger and not when the light was delivered to the other finger, demonstrating the specificity of these effects. In fact, accuracy when the light and touch were on opposite fingers was similar to accuracy on Touch only trials presented to one finger. In addition, the visual stimulus influenced subjects' touch perception and caused them to report false alarms in two different ways. Participants reported feeling the tactile pulse more often on Light trials compared to the baseline trials. Furthermore, when the visual stimulus was presented to the opposite finger from the tactile stimulus, false alarm rates were significantly higher with more reports of feeling the pulse on the finger where the light had flashed compared to the baseline rate. Experiment 5 had similar results as Experiment 4, except that when subjects were forced to choose where they had felt the pulse and a tactile stimulus was delivered on each trial, they were heavily influenced by the light when it was presented to the opposite hand from the touch. Participants incorrectly made more false alarms when visual and tactile stimuli were delivered to opposite hands and reported feeling the touch on the hand where the light had been presented in the fifth experiment.

Response criterion was significantly lower in the Both trials compared to the Touch trials in the first three experiments. This criterion shift contributed to the significant increases in hit rates during the Both trials compared to the Touch trials and in false alarm rates during the Light trials compared to the Catch trials, highlighting the importance of using signal detection measures to compute bias-free changes in sensitivity. Probabilistically, the lower criterion during trials when a light was presented would result in a greater increase in accuracy during Both trials than in false alarms during Light trials (Stanislaw and Todorov, 1999), as was found across the three detection experiments. Thus, although the effects of a response bias may appear small because a substantial proportion of participants never produced any false alarms, it nonetheless clearly influences the report of a touch when visual information is provided.

Several other recent studies have shown how vision can facilitate tactile processing in normal participants (e.g., Kennett et al., 2001; Pavani et al., 2000; Ro et al., 2004; Taylor-Clarke et al., 2002; Tipper et al., 1998, 2001). However, these studies all used body parts as a significant component in their experimental designs. The visual stimulus in our experiment was placed on the finger so that the visual and tactile stimuli would occur in the same location; however, we did not manipulate body part viewing or the visual stimulus. The light in our experiments was non-informative and did not predict if (or where in Experiments 4 and 5) a tactile pulse would occur. In addition, in Experiments 4 and 5, participants were not even required to report anything about the light, yet it still had an effect on their touch perception. These results, therefore, are the first to demonstrate that this increased accuracy in reporting tactile stimulation with vision is largely due to a response bias when the visual stimulus is truly non-informative. Furthermore, none of the previous studies analyzed their results using signal detection procedures (Kennett et al., 2001; Pavani et al., 2000; Ro et al., 2004; Taylor-Clarke et al., 2002; Tipper et al., 1998, 2001) and therefore could plausibly have reflected shifts in criterion in addition to (or rather than) changes in sensitivity.

In a similar experiment studying visual and auditory multisensory processing, Lovelace et al. (2003) showed that a simultaneous non-informative light enhanced the report of a sound. In the first experiment, they found that the hit rate of low-intensity sounds, as well as the false alarm rates, significantly increased with the presence of a light. When signal detection analysis was performed, it was further shown that participants displayed a large decrease in criterion with only a small increase in detection, similar to our results. Further illustrating the subtle nature of the detection increase, the Lovelace et al. (2003) experiment had more trials than the experiments in the current study, which is likely why the detection difference was found to be significant in their study, but only significant in our between experiments analysis and only marginally significant in the independent experiment analyses in one of our detection experiments (Experiment 3). In a second experiment, Lovelace and colleagues eliminated this response bias by blocking light-present and light-absent trials, but still found a small increase in auditory detection. Thus, while it may be that blocking the light-present and light-absent trials may have also resulted in a small increase in touch perception in our experiments, what is clear from these experiments is that there is a robust response bias for reporting an additional sensory event along with vision. This bias may be a consequence of our multisensory experiences in the real world: different sensory information when available is perfectly correlated in space and time when coming from the same object.

Our results also help to extend the findings of two patient studies demonstrating increased tactile perception with vision (Halligan et al., 1996; Rorden et al., 1999). The patient in the Rorden et al. (1999) study only reported feeling tactile sensations when he saw his arm being touched; however, his touch detection improved (from no detection) with simultaneous presentation of a non-predictive light when it was on a rubber hand positioned over his concealed real hand. Interestingly, the patient still reported feeling some of the touches when the light was on the experimenter's hand (32% detection), albeit to a lesser extent than when the light was on the rubber hand (51% detection). The patient also had very few false alarms during light-only trials and hardly ever reported that he felt a touch during these catch trials (4% in both conditions). Therefore, even though the visual stimulus was non-informative and flashed on every trial, the patient in the Rorden et al. study, in addition to exhibiting a change in sensitivity, may have also been revealing a response bias to report feeling more tactile stimuli when a light was present, regardless of whether the light was on the rubber hand or the experimenter's hand.

In our study, subjects also had an increase in reported touch detection when a simultaneous, non-informative visual stimulus was presented and had very few false alarms across all experiments. Nevertheless, we found that even in experiments in which the hit rates differed significantly while the false alarm data did not, signal detection measures revealed that participants were shifting their response criteria in the presence of a visual stimulus, which at least in part accounted for the changes in reported tactile detection rates. Thus, our results highlight the need for signal detection analysis methods to be used more often in these kinds of studies.

The current results further clarify the Halligan et al. (1996) findings because we show that participants rely on the incoming visual information more than tactile information, especially when touch perception is degraded. Even though their patient claimed he could not feel any tactile stimulation unless he could see himself being touched, Halligan and colleagues demonstrated that their patient had some residual tactile sensations that were consciously unavailable but could be heightened into awareness with vision. The patient also stated that he felt his hand being touched during a video replay because he saw his impaired hand being touched and not only believed what he saw but also thought he felt a concomitant touch on his hand. Thus, in addition to any increases in touch perception, this patient also demonstrated a bias to report touch with vision of a touch-associated stimulus. In a similar way, when participants in our study reported a pulse on a Light trial, they likely believed they had felt a real touch. Ecologically, this makes sense because vision and touch are frequently associated: seeing something on one's skin is typically accompanied by a tactile sensation.

In this study, a threshold-level tactile pulse and a flash of light were used to determine whether concurrent visual information could be used to alter touch detection. We found that a simultaneous visual event increased reports of touch in normal participants largely because of a response bias whereby participants lowered their criterion for reporting touch. A small sensitivity change was also demonstrated across the experiments. However, the change in criterion was more robust and likely contributed to an increase in reported tactile perception during both vision and touch trials as subjects were more likely to say they felt a tactile pulse when they saw a visual stimulus. Furthermore, participants also made more false alarms by reporting a touch during trials when a light was presented without a tactile pulse. These results suggest that some experimental procedures using visual cues to enhance touch perception might instead create a response bias to report tactile stimulation when a concomitant light is presented simultaneously.

4. Experimental procedures

Twenty-four undergraduate students at Rice University participated in each experiment (total of 120 subjects). All experiments were approved by the Institutional Review Board, and all participants gave their consent to be in the study. The materials and experimental design were very similar across all five experiments in this study. The participants sat in a chair with their left arms at a comfortable viewing distance on the table in front of them. Each subject's left middle finger was prepared for the study by cleaning the finger with an electrode preparation pad (70% isopropyl alcohol and pumice) and then taping ring electrodes to the finger (Fig. 1). Participants placed their left hands on a wooden block fitted with a Velcro strap to minimize movement. A sponge was positioned underneath the participant's forearm for comfort. Subjects had their right hands resting on their laps. Wooden planks measuring 30 cm tall and 87 cm long were erected at either end of the table to minimize visual distractions during the experiment.

Opposite the subject was a Grass-Astromed (West Warwick, Rhode Island) SD9 electrical stimulator, which delivered tactile stimulation to a subject's finger through the ring electrodes. The electrical pulses were 0.3 ms in duration with the intensity determined by the experimenter as follows. At the beginning of the experiment, each subject's threshold was approximated by applying electric stimulation of varying intensities to the finger, while participants reported whether or not they felt a pulse. After the experimenter determined the intensity at which approximately 50% of the stimuli were felt by each participant, a block of 10 trials was administered at this given intensity. If a subject detected between 4 and 6 stimuli out of 10, this intensity was used for the remainder of the experiment (except in Experiment 4, where an approximately 60% detection rate was used; see below). Otherwise, intensity calibrations were made, and this procedure repeated until an intensity was identified at which the subject detected between 4 and 6 stimuli out of 10. A small red LED was also taped to the ring electrodes on the participant's left middle finger and flashed on for 5 ms when serving as the visual stimulus (Fig. 1). Tactile stimulation did not result in any movement or illumination of the LED or the participant's finger. The computer generated a 1000-Hz tone for 200 ms to notify the subject when each trial was beginning and 500 ms after the tone had finished the visual and/or tactile stimulus was delivered. Each experiment was conducted using an Intel PC and lasted approximately 30 min.

Experiment 1 used a non-informative light simultaneously paired with a near-threshold tactile stimulus in the critical condition to determine whether it would influence touch detection. Eight practice trials followed by 80 randomly presented trials were administered (20 trials in each condition). The second experiment examined whether pairing suprathreshold association trials before the experiment would further improve detection beyond any shifts in response criteria. Experiment 2 was identical to Experiment 1, except that subjects were given 20 association trials with suprathreshold pairings of light and touch at the beginning of the experiment. Suprathreshold tactile stimulation at the beginning of Experiment 2 was about 20% greater than threshold stimulation. In this suprathreshold pairing phase, participants were asked to report whether they saw a light, felt a touch, simultaneously saw a light and felt a touch, or saw and felt nothing. All subjects reported “both light and touch” on all of the association trials prior to commencement of Experiment 2. After the initial suprathreshold pairing phase, the tactile stimuli were returned to threshold levels by the experimenter, and the experiment followed the same format as Experiment 1 with 8 practice trials followed by 80 experimental trials. Compared to the first two experiments, the instructions in Experiment 3 strongly emphasized reporting every tactile sensation subjects felt on their left middle fingers. These instructions were intended to induce the same bias for reporting touch across all conditions. In addition, the third experiment had 8 practice trials followed by 200 trials (50 trials in each condition). This larger number of trials was used to increase the power to detect a visual enhancement of touch.

Experiment 4 was similar to Experiments 1–3, except that this experiment used a discrimination paradigm in which the visual and tactile stimuli were presented to the left index and middle fingers of each participant. Both the left middle and left index fingers were cleaned with an electrode preparation pad, and then ring electrodes were taped to both fingers. Two small red LEDs were then attached to the ring electrodes on each finger, and the electrodes were attached to separate electrical stimulators. Tactile thresholds were determined the same way as described earlier for both the index and middle fingers, except that the initial intensity was set near 60% detection. After the thresholds for both fingers were set, the experimenter then administered 20 trials (10 trials to each finger in a randomly determined order), while subjects indicated whether they felt the pulse on their index or middle finger. If a participant was correct on 5 to 7 trials out of 10 on each finger, this intensity was used for the remainder of the experiment. Otherwise, intensity calibrations were made for each finger, and this procedure was repeated until an intensity was found at which the participant was correct on 5 to 7 trials out of 10. This slightly higher intensity was used because of the more difficult localization task used in this experiment. The participant’s task was to state the finger (if any) on which the tactile pulse was felt during each trial. On each trial, participants were instructed to respond “left” if they felt the pulse on their middle finger, “right” if they felt the pulse on their index finger, or “none” if they did not feel a tactile pulse on either finger. Responses were considered correct only if they accurately reported the finger to which the tactile stimulus was given or reported ‘none’ on the Light trials. False alarms occurred when subjects stated they felt a pulse on the opposite finger from the one actually touched or when they reported feeling a touch on a Light trial. Subjects were asked to look at their left hands so they could see the visual stimulus but were not required to report any visual information. The instructions again emphasized reporting every tactile sensation subjects felt on their fingers while also stressing that a pulse was never presented to both fingers at the same time. Experiment 4 had 16 practice trials followed by 240 randomly presented trials (60 trials in each condition).

Experiment 5 used a discrimination paradigm and was similar to Experiment 4, except that in this experiment, the visual and tactile stimuli were presented to subjects’ left and right middle fingers. Tactile thresholds were determined the same way as described in Experiment 4 for both middle fingers with the initial intensity set near 50% detection. After the thresholds for both fingers were set, the experimenter administered 20 trials (10 trials to each finger in a randomly determined order), while subjects indicated whether they felt the pulse on their left or right middle finger. If a participant was correct on 4 to 6 trials out of 10 on each finger, this intensity was used for the remainder of the experiment. Otherwise, intensity calibrations were made for each finger, and this procedure was repeated until an intensity was found at which the subject was correct on 4 to 6 trials out of 10. On each trial, participants were instructed to respond “left” if they felt the pulse on their left middle fingers and “right” if they felt the pulse on their right middle fingers. If subjects did not feel a pulse on a given trial or were unsure where they felt the touch, they were instructed to make a guess regarding which hand had been stimulated. Responses were considered correct only if participants accurately reported where the tactile stimulus was delivered. False alarms occurred when subjects stated they felt a pulse on the opposite finger from the one actually stimulated. A subject’s hands were placed in blocks (Fig. 1) 20 cm apart and equidistant from the midline axis of the subject. Participants were asked to look at a fixation point placed in between their hands so they could see the visual stimuli presented to their hands, but they were not required to report any visual information. The instructions again emphasized reporting every tactile sensation subjects felt on their fingers while also stressing that a pulse was never presented to both fingers at the same time. Experiment 5 had 12 practice trials followed by 180 randomly presented trials (60 trials in each condition).

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REFERENCES

Halligan, P., Hunt, M., Marshall, J., Wade, D., 1996. When seeing is feeling: acquired synaesthesia or phantom touch? Neurocase 2, 21–29.

Harris, C., 1963. Adaptation to displaced vision: visual, motor, or proprioceptive change? Science 140, 812–813.

Kennett, S., Taylor-Clarke, M., Haggard, P., 2001. Noninformative vision improves the spatial resolution of touch in humans. Curr. Biol. 11, 1188–1191.

Lovelace, C., Stein, B., Wallace, M., 2003. An irrelevant light enhances auditory detection in humans: a psychophysical analysis of multisensory integration in stimulus detection. Cogn. Brain Res. 17, 447–453.

Macmillan, N., Creelman, C., 1991. Detection Theory: A User’s Guide. Cambridge Univ. Press, Cambridge.

Pavani, F., Spence, C., Driver, J., 2000. Visual capture of touch: out-of-the-body experiences with rubber gloves. Psychol. Sci. 11, 353–359.

Ro, T., Wallace, R., Hagedorn, J., Farnè, A., Pienkos, E., 2004. Visual enhancement of tactile processing in posterior parietal cortex. J. Cogn. Neurosci. 16, 24–30.

Rock, I., Victor, J., 1964. Vision and touch: an experimentally created conflict between two senses. Science 143, 594–596.

Rock, I., Mack, A., Adams, L., Hill, A., 1965. Adaptation to contradictory information from vision and touch. Psychon. Sci. 3, 435–436.

Rorden, C., Heutink, J., Greenfield, E., Robertson, I., 1999. When a rubber hand ‘feels’ what the real hand cannot. NeuroReport 10, 135–138.

Sekiyama, K., Miyauchi, S., Imaruoka, T., Egusa, H., Tashiro, T., 2000. Body image as a visuomotor transformation device revealed in adaptation to reversed vision. Nature 407, 374–377.

Stanislaw, H., Todorov, N., 1999. Calculation of signal detection theory measures. Behav. Res. Methods Instrum. Comput. 31, 137–149.

Stratton, G., 1897. Vision without inversion of the retinal image. Psychol. Rev. 4, 463–481.

Taylor-Clarke, M., Kennett, S., Haggard, P., 2002. Vision modulates somatosensory cortical processing. Curr. Biol. 12, 233–236.

Tipper, S., Lloyd, D., Shorland, B., Dancer, C., Howard, L., McGlone, F., 1998. Vision influences tactile perception without proprioceptive orienting. NeuroReport 9, 1741–1744.

Tipper, S., Phillips, N., Dancer, C., Lloyd, D., Howard, L., McGlone, F., 2001. Vision influences tactile perception at body sites that cannot be viewed directly. Exp. Brain Res. 139, 160–167.