Psychonomic Bulletin & Review
2006, 13 (2), 304-309

See what you've done! Active touch affects the number of perceived visual objects

WILFRIED KUNDE
Martin Luther University of Halle-Wittenberg, Halle, Germany

and

ANDREA KIESEL
Julius Maximilian's University of Würzburg, Würzburg, Germany

Previous research has shown that visual perception is affected by sensory information from other modalities. For example, sound can alter the visual intensity or the number of visual objects perceived. However, when touch and vision are combined, vision normally dominates—a phenomenon known as *visual capture.* Here we report a cross-modal interaction between active touch and vision: The perceived number of brief visual events (flashes) is affected by the number of concurrently performed finger movements (keypresses). This sensorimotor illusion occurred despite little ambiguity in the visual stimuli themselves and depended on a close temporal proximity between movement execution and vision.

Intuitively, it seems natural that our visual system determines what we see. Of course, this is correct, but it is not the whole story. There is ample evidence showing that the way we see is affected by modalities other than vision. For example, the perceived intensity of a visual stimulus is affected by concurrent auditory stimulation (Stein, London, Wilkinson, & Price, 1996). Likewise, the number of visual events perceived is biased by the number of tones presented concurrently (Shams, Kamitani, & Shimojo, 2000).

Although a wide range of studies have demonstrated the existence of such intermodal cross-talk, only a few studies have investigated the role of touch. For example, the number of tactile stimuli perceived is affected by the number of tones presented concurrently (Hötting & Röder, 2004), and the perceived roughness of a texture is affected by the frequency spectrum of auditory feedback (Guest, Catmur, Lloyd, & Spence, 2002; Jousmäki & Hari, 1998). In these studies, touch is the modality that is subjected to influences from hearing or seeing. Reciprocal influences of touch on other modalities appear to be rare. In most studies, particularly those that have included space judgments, vision has dominated touch when a person creates a multimodal perception—a phenomenon known as visual capture (Klatzky, Lederman, & Matula, 1993; Pavani, Spence, & Driver, 2000; Rock & Victor, 1964). It has been suggested that influences of touch on vision might be hard to obtain, because intermodal discrepancies are usually resolved in favor of the more appropriate or more reliable modality (see, e.g., Welch & Warren, 1986).

Still, some reports of interactions between touch and vision exist. Lederman & Abbott (1981) observed that touch, to an approximately similar extent as vision, contributes to the perception of an object's texture. It might, under certain circumstances, even dominate vision (Lederman, Thorne, & Jones, 1986). Also, visually slant perception is affected more greatly by a visual cue (binocular disparity or texture gradients) that is congruent with haptic feedback from actively touching the slanted surface than it is by an incongruent cue (Ernst, Banks, & Bülthoff, 2000). It seems that both tactile and visual information contribute to a multimodal percept when this information is supposed to originate from a single physical object. This makes sense, intuitively, because exploring a surface's features (e.g., its texture, slant, or length) is the type of occasion in which vision and touch work together most frequently under natural conditions.

In the present article, we report a less intuitive influence of touch on vision that is not concerned with the perception of object surfaces. This influence occurred even though our observers were aware that tactile and visual events were unrelated. Specifically, we show that the perceived number of brief visual events is affected by the number of concurrently specified discrete finger movements. This is an important observation, because it disproves the idea that influences of touch on vision are difficult to obtain or are confined to the evaluation of object surfaces.

Touch can be induced in two different ways, either actively or passively. Active touch bears on cutaneous and kinesthetic feedback from the individual's motor activity. This is distinguished from passive touch, in which

We thank Richard Abrams, Michael Brown, and two anonymous reviewers for helpful comments on an earlier draft. This work was supported by the German Research Foundation (DFG, Grants Ku 1964/1 and Ho 1301/6-3). Correspondence concerning this article should be sent to W. Kunde, Department of Psychology, Martin Luther University of Halle-Wittenberg, 06099 Halle (Saale), Germany (e-mail: w.kunde@psych.uni-halle.de).

stimulation is caused by movement of an external object relative to a stationary tactual receptor surface (Loomis & Lederman, 1986). Active touch does, therefore, benefit from kinesthetic reafferences, and provides more reliable perceptual information than passive touch (Gibson, 1962). Accordingly, we relied on active touch to increase the chance of obtaining an impact of touch on vision. It should be clear from the outset that this choice creates cost, in the form of some ambiguity regarding the involvement of motor processes. We will reconsider this issue in the Discussion section.

Figure 1 (left panel) illustrates the experimental task. Participants were asked to report the number of briefly flashed objects that were presented while they carried out a varying number of keypresses. An influence of active touch on vision would imply that the number of performed keypresses would bias the participants toward perceiving a similar number of flashes. For example, if three keypresses elicited one flash, the number of reported flashes might be higher than if there had been only one keypress. On the contrary, if a single keypress elicited three flashes, the number of reported flashes might be lower than if there had been three keypresses. A control condition, without any keypresses, was also included, to assess the degree of ambiguity of the visual stimuli when no manual action was required.

We report two experiments here. Experiment 1 establishes the basic phenomenon. Experiment 2 rules out possible alternative explanations in terms of postperceptual judgment biases and explores the role of temporal overlap between touch and vision for the reported illusion.

EXPERIMENT 1

Method

Participants. Twelve undergraduate students (6 male, 6 female; mean age = 22 years) from the University of Halle-Wittenberg participated in Experiment 1.

Stimuli and Procedure. The perceptual task resembled that used by Shams et al. (2000). The visual stimuli were white dots (20 mm in diameter) presented on a black background on a VGA monitor. The dots were presented 4 cm below a central fixation cross for 14 msec each, with an interstimulus interval of 42 msec. The manual actions were performed on three custom-made keys (10 × 10 mm, 12-mm interkey distance) connected to the parallel port of the PC. This ensured timing accuracy to the next millisecond. Operating a key depressed it about 1 mm. The keys were pressed with the index, middle, and ring fingers of the right hand, which rested on the keys throughout the experiment.

Each trial started with an instruction to press a certain number of keys. The instruction was the written message "Please press *x* keys afterward" (in German), presented for 1 sec, with *x* being replaced by the number of required keypresses (either 0, 1, 2, or 3). The participants were told to press the keys at any point in time when they felt prepared to do so. The time interval between instruction screen and response onset was not recorded, but, roughly estimated, the participants executed the keypresses, on average, about 2 sec after the offset of the instruction screen. The participants were told to use their index finger when one keypress was requested, their index finger and middle finger when two keys were requested, and their index, middle, and ring fingers when all three keys were requested. If more than one key had to be pressed, the participants were instructed to do this as close to simultaneously as possible. Hence, no specific order of keypresses was prescribed.[1] Trials in which the offset between the first and last keypress exceeded 70 msec were counted as errors and fed back to the participant. These trials were removed from further analysis (6.4% of the data in Experiment 1).

The onset of the first keypress triggered the presentation of either one, two, or three visual stimuli, with a duration of 14 msec and an interstimulus interval of 42 msec. Synchronization with the vertical retrace of the display ensured that the first stimulus was displayed within 14 msec after the onset of the first keypress. The participants reported the number of flashes perceived by pressing the corresponding key of the number keyboard of the PC when they were ready. The participants were informed that there was no relationship between the number of keys pressed and the number of dots flashed. In control trials, no key had to be pressed. In these trials, the dots were flashed 1,500 msec after the offset of the instruction screen.

After 12 practice trials, the participants performed six blocks. Each block consisted of 12 trials, which resulted from the combination of four possible numbers of keypresses (0–3) and three possible numbers of flashes (1–3). The order of trials was random. No error feedback regarding the number of flashes reported was given.

Results and Discussion

Figure 1 shows the mean number of flashes reported as a function of flashes presented and keys pressed. These data were submitted to an ANOVA with the within-subjects factors of number of flashes presented (1–3) and number of keys pressed (0–3). First, and not surprisingly, the number of flashes perceived was affected by the number of flashes presented [$F(2,22) = 134.80$, $p < .001$]. Second, and more importantly, it was also affected by the number of keypresses performed [$F(3,33) = 10.98$, $p < .001$]. No interaction of these factors was present ($F < 1$). Hence, when the number of keypresses was larger than the number of flashes, participants reported an increased number of flashes. This increase was similar to the decrease of reported flashes that was observed in the reverse situation, when the number of keypresses was smaller than the number of flashes.

The control condition, without keypresses (dashed lines in Figure 1), shows that the perceptual task, as such, was relatively easy, although a tendency toward the mean was observed (i.e., on average, more than one flash was reported when one flash was presented, and less than three flashes were reported when three flashes were presented), which is a common observation with this task (Shams et al., 2000). With two flashes, the mean accuracy was almost perfect ($M = 2.00$). Still, the impact of number of actions was reliable for each level of number of flashes, as revealed by separate one-way ANOVAs computed for each level of number of flashes (all ps $< .04$).

Experiment 1 clearly shows that the number of self-stimulated finger touches affects the perceived number of concurrently presented visual stimuli. The size of this illusion is in the range of influences previously reported for audition on touch (Hötting & Röder, 2004). However, there is a tenable alternative interpretation: The actions might not affect the number of "seen" flashes; rather, they might merely bias postperceptual judgment processes. For example, independent of what the participants had seen, they might report the number of keypresses instead of the

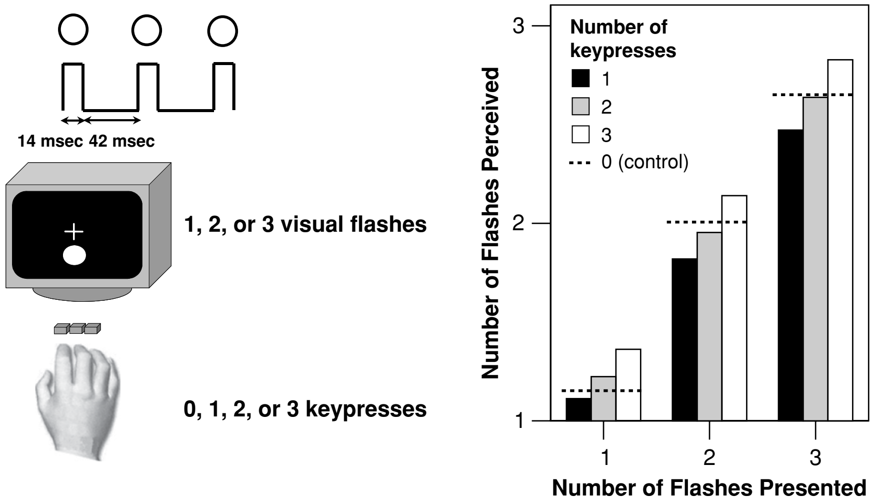

Figure 1. (Left panel) Illustration of the experimental task. Participants had to press either no, one, two, or three response keys. The keypresses triggered an unpredictable number of one, two, or three flashes on a computer screen. The task was to report the number of flashes presented. (Right panel) The mean number of reported flashes, as a function of number of flashes presented and number of keys pressed.

number of flashes. Although participants knew that the number of keypresses and flashes was unrelated, and that trying to relate them was thus useless, they may nevertheless have done this accidentally. To test this objection, and to explore the dependency of the present illusion on temporal factors, we varied the time interval between action execution and flash presentation in Experiment 2. It is not easy to explain why a report bias should depend on the temporal overlap of keypressing and object presentation. Yet such an effect of temporal overlap is quite likely if keypressing actually affects the processing of the presented objects.

EXPERIMENT 2

Conceivably, sensorimotor interactions of the type investigated here are more likely, the larger the temporal overlap is between action and perception. If touch and vision were separated by a long time interval of, say, several seconds, there is little reason to expect that the former would affect the latter. Experiment 2 was conducted as a first step toward exploring the temporal overlap necessary for the present illusion. Furthermore, finding a temporal dependency for the illusion would help to confirm that touch, and not just postperceptual judgment processes, did affect visual perception.

In Experiment 2, participants had to press a cued number of keys on presentation of an auditory go signal. The flashes were presented either 0 msec, 250 msec, 500 msec, or 1,000 msec after the go signal. Given that the mean reaction time to the go signal can be expected to vary between 300 and 400 msec (it was 346 msec in Experiment 2), this created a situation in which flash presentation varied continuously around the onset of movement execution. The flashes now appeared either before, almost simultaneous to, or after the keypresses. This allowed us to explore whether there is a difference between presenting the flashes before, during, or after the keypresses. Previous research suggests that vision is affected by other modalities within a time window of about 150 msec before and after the visual event (Shams, Kamitani, & Shimojo, 2002). We therefore split the data in those trials in which the actions started within a 150-msec interval around presentation of the visual stimuli and compared these with trials outside this time window (Figure 2).

Method

Participants. Twelve new undergraduates (4 male, 8 female; mean age = 23.5 years) from the University of Würzburg participated in Experiment 2.

Stimuli and Procedure. In Experiment 2, the keys had to be pressed after presentation of an auditory go signal (3500 Hz, 50 msec), which was emitted by the PC speaker. As in Experiment 1, each trial started with an instruction message (1,000 msec). 1,500 msec after the offset of this message, the go signal was presented. The go signal was also presented in the event that no keypress was requested. The flashes were presented following a stimulus onset asynchrony (SOA) of either 0 msec, 250 msec, 500 msec, or 1,000 msec after go signal onset. The SOA was blocked, with the order of SOAs counterbalanced across participants. On each SOA level, there were eight blocks of 12 trials, which resulted from the factorial combination of four possible numbers of keypresses and three possible numbers of flashes. 3.5% of the trials were excluded because the asynchrony of the keypresses was considered too large (offsets larger than 70 msec).

Results

We extracted those trials in which the visual stimuli were presented less than 150 msec before or after the onset of the manual action (24% of the trials, mean absolute

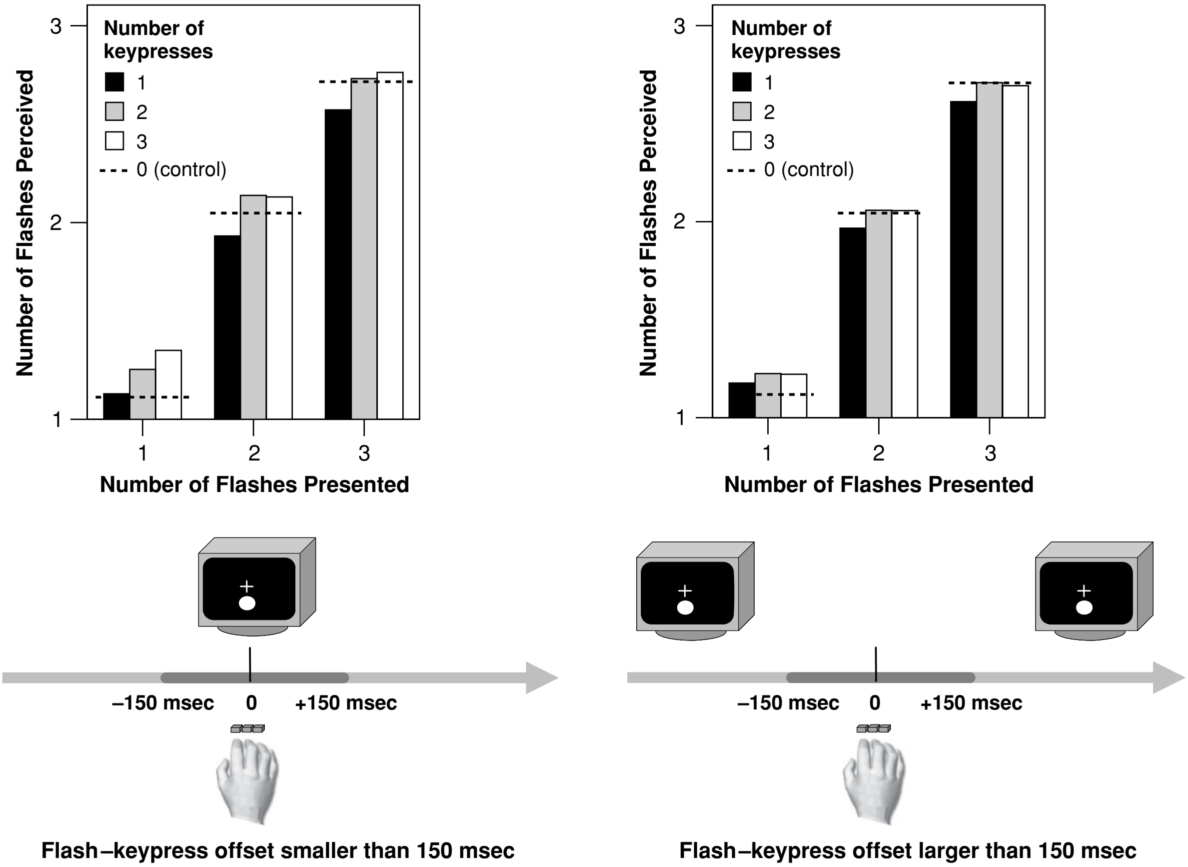

Figure 2. Results of Experiment 2. (Left panel) In trials with high temporal overlap, the flashes were shown within an interval of 150 msec before or after response execution. (Right panel) In trials with low temporal overlap, the flashes were presented more than 150 msec before or more than 150 msec after keypressing. The top half of each panel shows the mean number of reported flashes as a function of flashes presented and keys pressed with either high temporal overlap (left panel) or low temporal overlap (right panel).

keypress–stimulus offset = 68 msec). A preliminary data analysis of the remaining trials (76% of the data) revealed no notable differences between those cases in which the flashes preceded the keypresses more than 150 msec or followed the keypresses more than 150 msec. Therefore, these trials were pooled together and considered to be cases with large temporal keypress–flash proximity (mean absolute keypress–flash offset = 418 msec). An ANOVA with the factors temporal keypress–stimulus proximity (smaller or larger than 150 msec), number of keypresses (1–3), and number of flashes (1–3) confirmed an influence of the number of flashes presented [$F(2,22) = 101.67$, $p < .001$] and the number of keypresses performed [$F(2,22) = 11.76$, $p < .01$]. However, the influence of the number of keypresses was significantly larger when there was a small temporal proximity between keypress and flash presentation (Figure 2, left panel) than when there was a large proximity (right panel) [$F(2,22) = 3.44$, $p < .05$, for the interaction of temporal proximity and number of keypresses]. No other effect or interaction approached significance (all Fs < 1).

Between-Experiments Comparison

The illusion effect in Experiment 2, even with high temporal overlap, appeared to be smaller than the effect observed in Experiment 1 (cf. Figure 2). This was to be expected if temporal overlap is in fact crucial. Note that temporal overlap was perfect in Experiment 1 (tactile–visual offset was essentially zero), whereas it was less than perfect in the majority of trials in the ±150-msec trial sample of Experiment 2 (the average keypress–flash offset amounted to 68 msec). To confirm the impression of a general reduction of the illusion effect due to the reduction of the keypress–flash contiguity from Experiment 1 to Experiment 2, we computed an ANOVA with number of keypresses (0–3) and number of flashes (1–3) as within-subjects variables and experiment as a between-subjects variable. This analysis revealed a significantly larger impact of number of keypresses in Experiment 2 as compared with Experiment 1 [$F(3,66) = 5.29$, $p < .01$, for the interaction of number of keypresses and experiment]. There was no difference between experiments when only control trials (without concurrent keypressing) were considered ($F < 1$), which suggests that there were no general differences in perceptual accuracy or judgment processes between experiments, independent of keypress execution.

GENERAL DISCUSSION

Perceptual systems are subject to mutual cross-talk. However, influences of touch on vision have rarely been found, and when they have been, they have been small in size (see, e.g., Hay, Pick, & Ikeda, 1965). We have reported here a clear influence of this type, which rules out the idea that such interactions cannot occur for principled reason, or might be confined to the perception of a single phenomenal object (see, e.g., Ernst et al., 2000).

Our cross-talk effect differs from previously reported influences of action on vision in several respects. First, our effect was not related to the perception of texture, with which influences of touch on vision have been observed before (Cinel, Humphreys, & Poli, 2002). Second, the effect is specific for the number of actions performed, and does not reflect an unspecific reduction of perceptual accuracy from concurrent response selection (Dell'Acqua & Jolicœur, 2000). Third, the phenomenon does not reflect a reduced perceptual sensitivity for stimuli that share features with concurrent movements (Kunde & Wühr, 2004; Müsseler & Hommel, 1997). Otherwise, performance would be worse (rather than better) when action and perception share the same feature (i.e., number of events) than when they do not. Finally, the present observation goes beyond demonstrating that ambiguous visual percepts can be biased by motor actions (Blake, Sobel, & James, 2004; Wohlschläger, 2000), because the present stimuli were quite accurately perceived without action planning, and can thus barely be classified as ambiguous.

One reason for our finding of an impact of touch on vision might be our use of active touch rather than passive touch. As explained in the introduction, active touch is obligatorily linked to action production, which allows for the (not mutually exclusive) possibilities that either motor-related processes or tactile feedback from motor execution contribute to the present illusion. The purpose of the present study was not to discriminate between active and passive touch, and future research should therefore test whether or not the same illusion effect can be observed with passive stimulation of the palms, as well.[2]

A contribution of efferent processes to the illusion would accord well with recent models of motor control that emphasize the role of anticipated sensory effects for action production. These so-called ideomotor approaches assume that motor actions are stored, accessed, and controlled by the sensory reafferences that these actions produce. For example, to press a key, nothing more is necessary (or in fact possible) than to imagine the proprioceptive, tactile, and visual sensations that occur when the key is pressed (see, e.g., James, 1890/1981). Modern elaborations of this idea have recently received considerable empirical support (Hommel, Müsseler, Aschersleben, & Prinz, 2001; Kunde, 2001; Kunde & Weigelt, 2005). If motor actions are mentally represented and recruited by their sensory consequences, an interaction between action planning (i.e., anticipating sensory events) and perception (i.e., encoding of actual sensory events) can be predicted. Basically, this is what we have shown here. Yet, the dependency of the illusion on a close temporal action–perception overlap (Experiment 2) might indicate a more crucial role of actual rather than anticipated feedback. Unlike anticipated feedback, actual tactile feedback is available only at the point in time of movement execution.

A final comment regarding the functional mediation of the observed illusion is in order. The present experiments leave some room to attribute the effect of keypressing (be it caused by efferent or reafferent codes) to different cognitive processes that intervene between presentation of flashes and verbal report. At present, a "late" effect, such as a response bias or confusion between the instructed number of keypresses and flashes to-be-reported, appears unlikely. As outlined above, it is not obvious why such late processes should depend on the temporal overlap between keypressing and flash presentation on a millisecond scale. In our view, this dependency on a close temporal action–perception contiguity accords better with the idea that keypressing affects processes that start with flash presentation. One such process is encoding of visual objects into short-term memory for later report. Recent evidence suggests that performing an action can favor the encoding of visual stimuli that resemble that action in some way. For example, selecting a left or right response favors the encoding of spatially compatible visual stimuli (Hommel & Schneider, 2002; Müsseler, Wühr, Danielmeier, & Zysset, 2005). Our study furthers this research by suggesting that (1) response execution (or encountering execution-related tactile feedback) rather than response selection might affect stimulus encoding as well, and (2) this impact extends to nonspatial features, such as numbers.

To summarize, we have shown a clear influence of active touch on vision. This shows that vision does not always "win" when vision and touch operate simultaneously, even when touch and vision relate to two nominally independent events. Future research should clarify the role of efferent pathways in this illusion. Finding an involvement of such pathways would imply that influences on vision are not confined to other modalities but that they might cross the border between perception and action as well.

REFERENCES

Blake, R., Sobel, K. V., & James, T. W. (2004). Neural synergy between kinetic vision and touch. *Psychological Science*, **15**, 397-402.

Cinel, C., Humphreys, G. W., & Poli, R. (2002). Cross-modal illusory conjunctions between vision and touch. *Journal of Experimental Psychology: Human Perception & Performance*, **28**, 1243-1266.

Dell'Acqua, R., & Jolicœur, P. (2000). Visual encoding of patterns is subject to dual-task interference. *Memory & Cognition*, **28**, 184-191.

Ernst, M. O., Banks, M. S., & Bülthoff, H. H. (2000). Touch can change visual slant perception. *Nature Neuroscience*, **3**, 69-73.

Gibson, J. J. (1962). Observations on active touch. *Psychological Review*, **69**, 477-491.

Guest, S., Catmur, C., Lloyd, D., & Spence, C. (2002). Audiotactile interactions in roughness perception. *Experimental Brain Research*, **146**, 161-171.

Hay, J. C., Pick, H. L., & Ikeda, K. (1965). Visual capture produced by prism spectacles. *Psychonomic Science*, **2**, 215-216.

Hommel, B., Müsseler, J., Aschersleben, G., & Prinz, W. (2001). The theory of event coding (TEC): A framework for perception and action planning. *Behavioral & Brain Sciences*, **24**, 849-878.

Hommel, B., & Schneider, W. X. (2002). Visual attention and manual response selection: Distinct mechanisms operating on the same codes. *Visual Cognition*, **9**, 392-420.

Hötting, K., & Röder, B. (2004). Hearing cheats touch, but less in congenitally blind than in sighted individuals. *Psychological Science*, **15**, 60-64.

James, W. (1981). *The principles of psychology*. Cambridge, MA: Harvard University Press. (Original edition published 1890)

Jousmäki, V., & Hari, R. (1998). Parchment-skin illusion: Sound-biased touch. *Current Biology*, **8**, R190.

Klatzky, R. L., Lederman, S. J., & Matula, D. (1993). Haptic exploration in the presence of vision. *Journal of Experimental Psychology: Human Perception & Performance*, **19**, 726-743.

Kunde, W. (2001). Response-effect compatibility in manual choice reaction tasks. *Journal of Experimental Psychology: Human Perception & Performance*, **27**, 387-394.

Kunde, W., & Weigelt, M. (2005). Goal congruency in bimanual object manipulation. *Journal of Experimental Psychology: Human Perception & Performance*, **31**, 145-156.

Kunde, W., & Wühr, P. (2004). Actions blind to conceptually overlapping stimuli. *Psychological Research*, **68**, 199-207.

Lederman, S. J., & Abbott, S. G. (1981). Texture perception: Studies of intersensory organization using a discrepancy paradigm and visual versus tactual psychophysics. *Journal of Experimental Psychology: Human Perception & Performance*, **7**, 902-915.

Lederman, S. J., Thorne, G., & Jones, B. (1986). Perception of texture by vision and touch: Multidimensionality and intersensory integration. *Journal of Experimental Psychology: Human Perception & Performance*, **12**, 169-180.

Loomis, J. M., & Lederman, S. J. (1986). Tactual perception. In K. R. Boff, L. Kaufman, & J. P. Thomas (Eds.), *Handbook of perception and human performance: Vol. 2. Cognitive processes and performance* (pp. 31.1-31.41). New York: Wiley.

Müsseler, J., & Hommel, B. (1997). Blindness to response-compatible stimuli. *Journal of Experimental Psychology: Human Perception & Performance*, **23**, 861-872.

Müsseler, J., Wühr, P., Danielmeier, C., & Zysset, S. (2005). Action-induced blindness with lateralized stimuli and responses. *Experimental Brain Research*, **160**, 214-222.

Pavani, F., Spence, C., & Driver, J. (2000). Visual capture of touch: Out-of-the-body experiences with rubber gloves. *Psychological Science*, **11**, 353-359.

Rock, I., & Victor, J. (1964). Vision and touch: An experimentally created conflict between the two senses. *Science*, **143**, 594-596.

Shams, L., Kamitani, Y., & Shimojo, S. (2000). Illusions: What you see is what you hear. *Nature*, **408**, 788.

Shams, L., Kamitani, Y., & Shimojo, S. (2002). A visual illusion induced by sound. *Cognitive Brain Research*, **14**, 147-152.

Stein, B. E., London, N., Wilkinson, L. K., & Price, D. D. (1996). Enhancement of perceived visual intensity by auditory stimuli: A psychophysical analysis. *Journal of Cognitive Neuroscience*, **8**, 497-506.

Violentyev, A., Shimojo, S., & Shams, L. (2005). Touch-induced visual illusion. *NeuroReport*, **16**, 1107-1110.

Welch, R. B., & Warren, D. H. (1986). Intersensory interactions. In K. R. Boff, L. Kaufman, & J. P. Thomas (Eds.), *Handbook of perception and human performance: Vol. 1. Sensory processes and perception* (pp. 25.1-25.36). New York: Wiley.

Wohlschläger, A. (2000). Visual motion priming by invisible actions. *Vision Research*, **40**, 925-930.

NOTES

1. The offset times between the first and last keypresses were not recorded in Experiment 1. However, in Experiment 2, with the same type of responses, these offset times were 11 msec with two keypresses, and 17 msec with three keypresses.

2. Independent of the present research, an illusion effect with passive stimulation has recently been reported by Violentyev, Shimojo, and Shams (2005).

(Manuscript received June 4, 2005;
revision accepted for publication September 14, 2005.)