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Multi- and unisensory visual flash illusions

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Abstract. The role of stimulus structure in multisensory and unisensory interactions was examined. When a flash (17 ms) was accompanied by multiple tones (each 7 ms, SOA $<$ 100 ms) multiple flashes were reported, and this effect has been suggested to reflect the role of stimulus continuity in multisensory interactions. In experiments 1 and 2 we examined if stimulus continuity would affect concurrently presented stimuli. When a relatively longer flash (317 ms) was accompanied by multiple tones (each 7 ms), observers reported perceiving multiple flashes. In experiment 3 we tested whether a flash presented near fixation would induce an illusory flash further in the periphery. One flash (17 ms) presented 5° below fixation was reported as multiple flashes if presented with two flashes (each 17 ms, SOA $=$ 100 ms) 2° above fixation. The extent to which these data support a phenomenological continuity principle and whether this principle applies to unisensory perception is discussed.

1 Introduction

Perception of a stimulus usually involves several different sensory qualities and modalities. When eating an apple, the red color may be seen, the round shape and smooth texture may be felt, the snap may be heard as a bite is taken, and the pulpy mass may be tasted. Although there are many different stimulus qualities that affect the subjective experience of eating an apple, the multiplicity of stimulus qualities may be nonetheless often perceived as a unitary experience. The question how such stimulus information is integrated into a unitary percept is referred to as the binding problem (eg Bayne and Chalmers 2003; Revonsuo 1999). The focus of the present research was on a narrower aspect of multisensory experience: how the stimulus structure in one modality influences the perception of a stimulus in a second modality, and if such effects are limited to multisensory experience.

Although perceptual experience often involves multisensory processing, vision has often been claimed to be the dominant modality in human perception (see Posner et al 1976). However, several examples in which auditory stimuli induce an illusory perception or memory by modulating visual experiences have been reported (for review, see Shams et al 2004). One example of auditory stimuli modulating visual perception is auditory driving (see Myers et al 1981; Shipley 1964; Welch et al 1986), an effect in which change in the rate of a sequence of brief tones (auditory flutter) causes a change in the perceived rate of a sequence of brief flashes (visual flicker). Another example of auditory stimuli modulating visual perception is the sound-induced illusory flash (SIIF), an effect in which a single visual flash accompanied by multiple brief auditory tones is perceived as a sequence of multiple visual flashes (Shams et al 2000).

Many multisensory interactions have been tied together or studied by examining phenomenal accounts of the stimuli structure in instances where a certain modality seems to dominate, as in the modality appropriateness hypothesis, which states that each modality possesses one or more functions that it specializes in and relies on in circumstances of competing information (Welch and Warren 1980). However, Shams et al (2001) dismiss the modality appropriateness hypothesis in explaining the SIIF.(1) In the SIIF, transient discontinuous auditory stimuli have been said to influence the perception of the continuous visual stimulus and the overall multimodal percept because they are more salient compared to continuous stimuli (Shams et al 2000). This greater salience was said to have resulted in the auditory tones having a 'special status' in the multisensory interaction because of their discontinuous structure, and so the more salient auditory tones influenced the perception of the less salient visual flash. More broadly, we can generalize this idea into a continuity hypothesis in which a transient or discontinuous signal determines the nature of a multisensory interaction. In this series of experiments we examined whether a general continuity principle applies to cases of concurrently presented stimuli (experiments 1 and 2) and if the general pattern of the SIIF is limited to multisensory perception (experiment 3).

2 Experiment 1

If continuity is a general principle, then auditory stimuli such as brief tones should affect the perception of a concurrently presented flash. Although Shimojo and Shams (2001) suggested the continuity hypothesis applied to cases such as Saldana and Rosenblum's (1993) illusion in which a discontinuous stimulus completely overlapped the continuous stimuli, such a notion has not been empirically examined with multiple discontinuous stimuli. Therefore, we designed the current experiment to examine whether observers reported multiple flashes when the auditory tones completely overlapped a single visual flash. In the current experiment, one or two tones (each 7 ms) were accompanied by a brief flash of 17 ms, replicating Shams et al (2000), or accompanied by a longer flash of 317 ms.

2.1 *Method*

2.1.1 *Participants.* Eighteen participants (nine in the 17 ms flash condition and nine in the 317 ms flash condition) naive to the hypothesis were recruited from Texas Christian University and received partial course credit for participation.

2.1.2 *Apparatus.* Programs were written and data were collected with MEL software (Microexperimental Laboratory; Schneider 1988, 1995) and run on a 486/33 MHz PC. Stimuli were presented on a Compaq V50 color monitor (60 Hz). A floor-mounted chin-rest was used to keep the viewing distances constant. Headphones delivered audio stimuli. Participants entered responses via a PST serial response box (model 200A) with the response keys labeled from 1 to 5.

2.1.3 *Stimuli.* Participants viewed the display binocularly from a distance of 60 cm. As in Shams et al (2002), the visual stimulus (ie a flash) was a white circle subtending 2 deg of the visual field. The circle was presented on a black background and appeared at 5° vertical eccentricity below a fixation cross. The circle was presented for 17 ms for half of the participants and for 317 ms for the other half of the participants. The auditory stimuli were 7 ms 3500 Hz 60 dB tones separated by 60 ms or 160 ms SOAs on two-tone trials. The onset of the flash and the onset of the single tone or of the first tone in the two-tone sequence were simultaneous (see figure 1). Each participant received two blocks of 20 trials (2 number of tones $\times$ 2 SOAs $\times$ 5 replications) in a different random order.

(1) It is possible that the modality appropriateness hypothesis could explain the results seen in the SIIF. Shams et al (2002) concluded that the SIIF is not explained by the modality appropriateness hypothesis because of an asymmetry in their data (the reverse modulation of the fusing of two flashes into one by a beep is negligible). However, Andersen et al (2004) reported that when multiple flashes accompany a single beep, fewer flashes are reported.

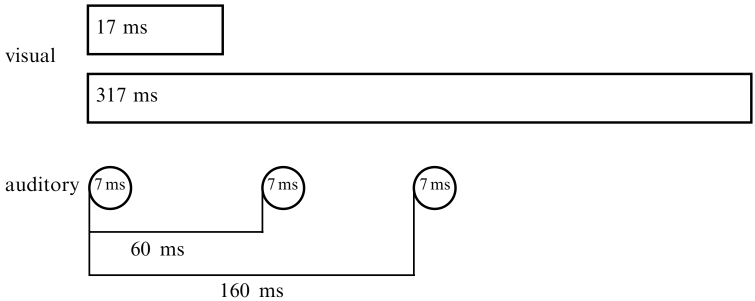

Figure 1. A schematic representation of stimuli used in experiment 1. Either one or two tones were presented with one flash, and with the onset of the first tone simultaneous with the onset of the flash.

2.1.4 *Procedure.* Participants received 5 practice trials that were selected randomly from the experimental trials. Each trial was initiated by pressing a designated key, after which a fixation cross appeared and remained visible for 700 ms. The participants were instructed to fixate on the cross throughout the trials, and to report the number of times the white circle, appearing below the cross, flashed. After the stimuli were presented, a question mark replaced the fixation cross, indicating that participants should enter the perceived number of flashes by using the response box, which had options for 1 to 5 flashes. No performance feedback was given during any of the trials. After the completion of the trials, participants were interviewed and debriefed.

2.2 *Results*

The responses were analyzed with a 2 (flash duration) × 2 (number of tones) × 2 (SOA) analysis of variance with flash duration as a between-subjects variable and number of tones and SOA as within-subject variables (see figure 2). There was a main effect of number of tones ($F_{1,16} = 125.36$, MSE = 0.140, $p < 0.001$), such that more flashes were reported on two-tone trials ($M = 2.03$) than on one-tone trials ($M = 1.04$). In addition, there was a significant effect of flash duration ($F_{1,16} = 6.34$, MSE = 0.211, $p < 0.02$), such that more flashes were reported in the 17 ms condition ($M = 1.67$) than in the 317 ms condition ($M = 1.40$). The number of tones × flash duration interaction was also significant ($F_{1,16} = 9.03$, MSE = 0.140, $p < 0.05$). For the two-tone condition, there was a significant effect of flash duration ($F_{1,16} = 7.56$, $p < 0.01$), whereas in the one-tone condition there was not a significant effect of flash duration ($F_{1,16} = 0.061$, $p < 0.80$). For the two-tone condition, more flashes were reported in the 17 ms two-tone condition ($M = 2.30$) than in the 317 ms two-tone condition ($M = 1.75$). Finally, there was a main effect of SOA ($F_{1,16} = 10.14$, MSE = 0.06, $p < 0.01$), such that more flashes were reported in the 60 ms condition ($M = 1.63$) than in the 160 ms condition ($M = 1.44$).(2)

2.3 *Discussion*

More visual flashes were reported when multiple auditory tones were presented than when a single auditory tone was presented.(3) In the 17 ms flash condition, the data replicated previous SIIF findings (Shams et al 2000) and in the 317 ms flash condition an illusory effect was also evident. The number of tones × flash duration interaction was significant and upon further inspection, the two-tone condition was responsible

(2) This 'flash-break' illusion has been replicated with a within-subjects design; data not reported here.

(3) An attentional-based explanation of such illusory effects as those reported here might be an explanation of mechanisms regarding flash illusions. For example, Watanabe and Shimojo (1998) attribute the perception of bouncing (as opposed to streaming) to the abrupt presentation of a visual distractor. Such salient stimuli may be characterized as discontinuous stimuli, and thus have an effect on the perception of visual flashes.

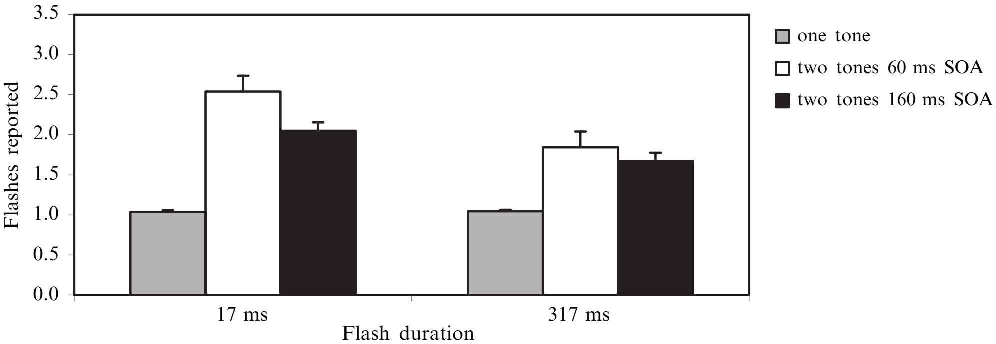

Figure 2. Mean number of flashes reported as a function of flash duration, number of tones, and SOA. Error bars are standard errors of the means.

for this effect in that more flashes were reported in the two-tone 17 ms condition. Indeed the illusory flash effect was stronger in the 17 ms than in the 317 ms condition, and this is consistent with Shams et al's (2002) finding that the strength of the SIIF decreased when the second auditory tone preceded or followed the flash by more than 70 ms. Also, in the 317 ms condition participants reported perceiving a 'break up' of the longer visual flash into two shorter flashes when the longer flash was accompanied by two tones. These differences in effect sizes and in subjective experience may suggest a different perception than the reproduction of the visual flash occurring with SIIF (Shams et al 2001). Regardless, results from experiment 1 provide further evidence supporting a multisensory continuity principle.

3 Experiment 2

It may be no surprise that when one flash is presented with one tone, only one flash is perceived. However, in previous studies of the SIIF, stimuli were not presented concurrently, and in experiment 1 two tones were presented while a 317 ms flash was on the screen. One possible phenomenological explanation for multiple flashes being perceived in this two-tone sequence is that only the second tone in a two-tone sequence (that is presented after the onset of the flash) is responsible for the perception of multiple flashes [as a single discontinuous stimulus in Saldana and Rosenblum (1993) is responsible for affecting the continuous stimulus]. Experiment 2 was designed to answer the question: can a single tone that is presented after the onset of a flash result in the experience of multiple flashes? If the second tone in a two-tone sequence leads to the illusion, then the first tone may not be necessary for affecting an observer's perception of a second. However, if the second tone alone does not affect perception of the flash, then it would provide evidence that multiple tones are necessary for the illusion to occur. Additionally, catch trials were included in experiment 2 in the form of multiple flash trials, which were lacking in experiment 1.

3.1 *Method*

3.1.1 *Participants.* Seven participants naive to the hypothesis were recruited from Texas Christian University and received partial course credit for participation.

3.1.2 *Apparatus.* The apparatus was the same as that used in experiment 1.

3.1.3 *Stimuli.* The stimuli were the same as in experiment 1, with the following exceptions: on half of the trials, 317 ms flashes were broken into two discrete flashes by the insertion of a 17 ms blank interval during 317 ms duration (the onset of the break in the flash coincided with the presentation of the second tone).

3.1.4 *Procedure.* The procedure was the same as in experiment 1, with the following exceptions: one or two flashes were presented with one or two auditory tones. One flash was presented for 317 ms and included a 17 ms break in two-flash catch trials (the onset of the break in the flash coincided with the presentation of the later tone). One or two auditory tones were presented on each trial. A tone was presented 60 ms after the onset of the flash on all trials, and on half of the two-tone trials another tone was presented simultaneously with the onset of the flash.

3.2 *Results*

The responses were analyzed with a 2 (number of flashes) $\times$ 2 (number of tones) within-subjects ANOVA (see figure 3). A main effect of number of flashes was found ($F_{1,6} = 43.86$, $\text{MSE} = 0.121$, $p < 0.001$), such that more flashes were reported in the two-flash condition ($M = 2.4$) than in the one-flash condition ($M = 1.54$). A main effect of tone was found ($F_{1,6} = 12.05$, $\text{MSE} = 7.29$, $p < 0.01$), such that more flashes were reported in the two-tone condition ($M = 2.34$) than in the one-tone condition ($M = 1.62$). The number of flashes $\times$ number of tones interaction was not significant ($F_{1,6} = 0.458$, $\text{MSE} = 0.126$, $p < 0.524$).

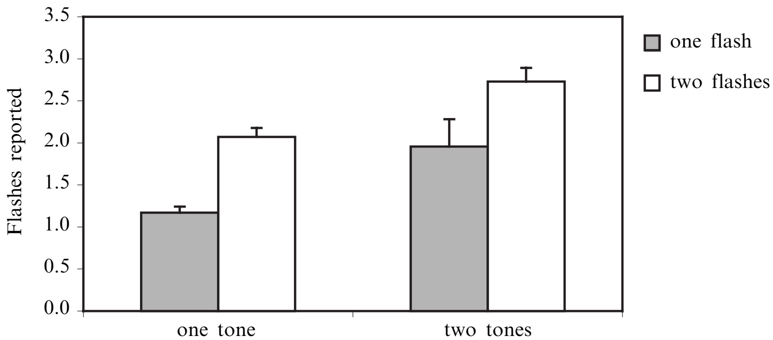

Figure 3. Mean number of flashes reported as a function of number of flashes and number of tones in experiment 2. Error bars are standard errors of the means.

3.3 *Discussion*

The presentation of multiple tones influenced the number of flashes reported. In one-flash two-tone trials, participants reported seeing on average two flashes, and so an illusory effect occurred. In two-flash two-tone trials, more than two flashes were reported ($M = 2.73$). One possible explanation is that this occurred because the visual and auditory systems have different latencies to perception. Studies of temporal order judgment suggest the latency to perception is significantly shorter for auditory than for visual stimuli (Bald et al 1942), and so it may be possible that, although the break in the flash and second tone had nearly synchronous onsets, the tone was perceived as having occurred before the break in the flash. As a result, the subjective occurrence of an additional flash was observed.

Participants accurately reported the number of flashes occurring on one-tone one-flash trials and on two-flash one-tone trials. Performance on one-tone trials is indicative of the importance of number of tones, and established that a single tone presented concurrently with a relatively longer flash did not result in the experience of multiple flashes. It therefore seems that a general principle of continuity can be applied to concurrently presented stimuli. However, is there something special about auditory stimuli in inducing illusions such as those reported in the SIIF? Or is continuity a more general notion that applies within a single modality as well as between auditory and visual modalities?

4 Experiment 3

In experiments 1 and 2, we examined the continuity hypothesis for cases when stimuli from one modality affected the perception of stimuli from another modality. Could such illusory flashes be elicited within a modality? Experiment 3 was designed to determine whether an illusory effect similar to the SIIF could be obtained within a single modality. If a similar effect could be attained, then this would suggest that the principle of continuity applies not only to multisensory illusions, but also to a unisensory illusion.

4.1 *Method*

4.1.1 *Participants.* Nine participants naive to the hypothesis were recruited from Texas Christian University and received partial course credit for participation.

4.1.2 *Apparatus.* The apparatus was the same as that used in experiment 1.

4.1.3 *Stimuli.* No auditory stimuli were presented to the participants. Visual stimuli were white circles on a black background taking up 2 deg of the visual field; one circle was located at 2° of eccentricity above the fixation cross, the other circle was located at 5° of eccentricity below the fixation cross. The two white circles were simultaneously presented to the participants for 17 ms and each circle was flashed once or twice. Circles that were flashed twice had an SOA of 100 ms between flashes (see figure 4). Each participant received 80 total trials, and trials were presented in a different random order across two blocks of 40 trials. In each block, participants received 20 replications of the circle 2° above the fixation cross (one or two flashes presented) and 20 replications of the circle 5° below the fixation cross condition (one or two flashes presented).

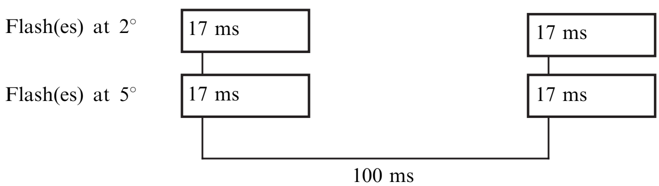

Figure 4. A schematic representation of stimuli used in experiment 3. The circles at 2° and 5° were flashed once or twice depending on trial type, and the onset of the flashes was simultaneous.

4.1.4 *Procedure.* The procedure was the same as that used in experiment 1, with the following exceptions. One or two circles in each position were concurrently presented on each trial, one above the fixation cross and one below. Circles that were flashed twice had an SOA of 100 ms. Participants were given instructions to report the number of times they perceived the circle at 5° below the fixation cross (further in the periphery) to flash.

4.2 *Results*

The responses were analyzed by means of a two-factor [2 (number of flashes presented at 2°) × 2 (number of flashes presented at 5°) repeated-measures ANOVA. One subject was excluded from the analysis owing to a failure to follow instructions. There was a main effect of flashes presented at 5° ($F_{1,7} = 39.34$, MSE $= 0.04$, $p < 0.001$), such that participants reported more flashes occurring at 5° in the two-flash 5° condition ($M = 2.45$) than the one-flash 5° condition ($M = 1.51$). There was a main effect of flashes presented at 2° ($F_{1,7} = 90.53$, MSE $= 0.08$, $p < 0.001$), such that participants reported more flashes occuring at 5° when two flashes were presented at 2° ($M = 2.20$) than when one flash was presented at 2° ($M = 1.76$). As shown in figure 5, there also was a significant interaction of the number of flashes presented at 2° × number of flashes presented at 5° ($F_{1,7} = 37.86$, MSE $= 0.02$, $p < 0.001$), such that in the 5° one-flash

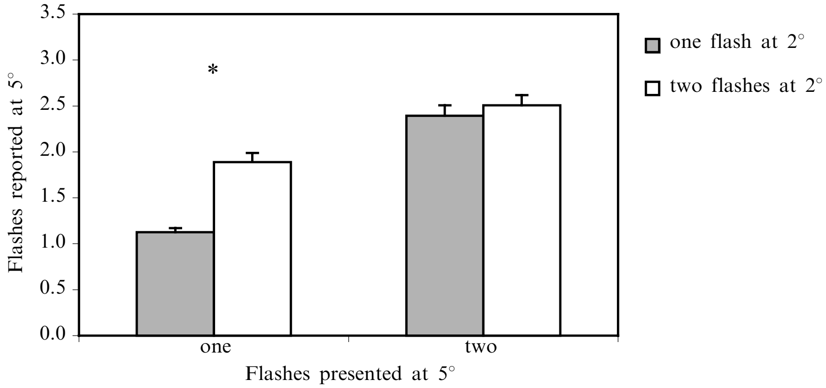

Figure 5. Mean number of flashes reported as a function of the number of flashes presented at 2° and flashes presented at 5°. Error bars are standard errors of the means. The asterisk denotes significant difference by Scheffé a posteriori test ($p < 0.001$).

condition the number of flashes reported changed with the number of flashes presented at 2°. The nature of this interaction was a difference between the means in the 5° one-flash condition which was significantly different by Scheffé a posteriori test ($p < 0.001$), while in the 5° two-flash condition the number of flashes presented at 2° did not affect the number of flashes reported.

4.3 *Discussion*

When multiple flashes were presented at 2°, the number of flashes perceived at 5° was affected, resulting in a visual illusion. It seems that multiple stimuli presented nearer to the fovea effectively influenced the perception of a single flash in the peripheral visual field, as an illusory flash was not reported in the one-flash 5°, one-flash 2° condition. When two flashes were presented at 5°, the number of flashes reported was unaffected by flashes presented at 2°; however, when one flash was presented at 5°, the flashes at 2° had a much bigger effect.[4] An illusory flash similar to that found in the SIIF was attained from multiple visual flashes that were presented near the point of fixation. This suggests that the perception of a single peripheral flash can also be affected by stimuli within a modality. This finding is interesting because it shows that the affecting stimulus can also be within a modality, and suggests that a continuity principle might be valid in presentations of unisensory stimuli.

5 General discussion

Shams et al (2000) presented a case in which a single visual flash is accompanied by brief multiple auditory tones, which resulted in the perception of multiple flashes. In such studies of the SIIF, the auditory stimuli did not completely overlap the visual stimuli [as in other studies cited by Shams et al (2000), as supporting the continuity hypothesis, eg Saldana and Rosenblum (1993)]; therefore, experiments 1 and 2 presented overlapping auditory and visual stimuli to examine the effect on subjective experience. It was found that two tones overlapping a single relatively longer flash affect the perception of a longer flash, resulting in multiple flashes being reported.

Although other researchers have recognized that the SIIF is much like auditory driving (Berger et al 2003), what the participants are subjectively experiencing with concurrently presented flashes and tones has not been specifically addressed. It is possible that the SIIF reported by Shams et al (2000) and the multiple flashes perceived with

[4] Discontinuous stimuli are typically shorter than continuous stimuli with the exception of stimuli in experiment 3. However, it may be possible that the affecting flash nearer to the fovea is subjectively shorter in duration than flashes in the periphery (Gottleib et al 1985).

a relatively longer single flash of 317 ms are different illusions in which the SIIF is a subjective reproduction of a flash, and the longer flash used in experiments 1 and 2 is broken up by the auditory stimuli. Regarding the SIIF being subjectively reproduced, Shams et al (2001) examined visually evoked potentials (VEPs) in an effort to evaluate where in the visual pathway the auditory stimulus exerted its influence. VEPs in SIIF trials were modulated in a very similar fashion to VEPs measured in catch trials in which two physical flashes were presented, which may suggest that the perceived second flash modulates activity in the visual cortex just as an actual second flash would. This suggestion is strengthened by participants' inability to discriminate between the illusory flash and the actual flash conditions. Regarding a 317 ms flash being broken up, in experiment 1 of this paper participants reported a 'breaking up' of the longer 317 ms flash. Additionally, participants reported significantly fewer flashes in the 317 ms condition than in the 17 ms condition, which may indicate a different subjective experience in each. However, more empirical evidence is needed to clearly demonstrate that the illusions in the two cases are indeed different. Nevertheless, it was demonstrated that discontinuous auditory stimuli affected the perception of a relatively longer flash than previously examined in studies on the SIIF.

Experiment 3 was designed to determine whether an illusory effect resulting from discontinuous stimuli, similar to the SIIF, could be obtained within a single modality. Experiment 3 was designed to look for an illusory flash within a modality of vision by presenting one flash (17 ms) 5° below a fixation point. This single flash is reported as multiple flashes if presented in succession with two flashes (each 17 ms) 2° from a fixation point. Additionally, in experiment 3 we found that multiple stimuli of the same duration in the same modality (vision) could affect the number of times a circle further from the fixation cross was reported to flash. As a result of this finding, it should also be noted that discussion and conceptualization of illusions such as those discussed here, along with phenomenological principles applying to these illusions, should not be limited to multisensory perception.

It may be unlikely that, if one presents any discontinuous stimulus for a shorter duration than a second (continuous) stimulus, that perception will be affected and certain caveats such as SOA timing parameters and perhaps modality specificity could prevent illusory effects from occurring [eg modality asymmetry; see Shams et al (2002)]. Therefore, caution should be used in assigning and describing continuity as a general principle. This is not to say that the structure of stimuli is not imperative in describing and determining multisensory (and unisensory) interactions; rather, it is possible that more case-specific stimulus structure could accurately reflect different sensory phenomenology. Nevertheless, it seems that visual perception of flashes is affected by briefly presented stimuli both within and across modalities.

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