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# Audition influences color processing in the sound-induced visual flash illusion

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ABSTRACT

Multisensory interactions can lead to illusory percepts, as exemplified by the sound-induced extra flash illusion (SIFI: Shams, Kamitani, & Shimojo, 2000, 2002). In this illusion, an audio–visual stimulus sequence consisting of two pulsed sounds and a light flash presented within a 100 ms time window generates the visual percept of two flashes. Here, we used colored visual stimuli to investigate whether concurrent auditory stimuli can affect the perceived features of the illusory flash. Zero, one or two pulsed sounds were presented concurrently with either a red or green flash or with two flashes of different colors (red followed by green) in rapid sequence. By querying both the number and color of the participants' visual percepts, we found that the double flash illusion is stimulus specific: i.e., two sounds paired with one red or one green flash generated the percept of two red or two green flashes, respectively. This implies that the illusory second flash is induced at a level of visual processing after perceived color has been encoded. In addition, we found that the presence of two sounds influenced the integration of color information from two successive flashes. In the absence of any sounds, a red and a green flash presented in rapid succession fused to form a single orange percept, but when accompanied by two sounds, this integrated orange percept was perceived to flash twice on a significant proportion of trials. In addition, the number of concurrent auditory stimuli modified the degree to which the successive flashes were integrated to an orange percept vs. maintained as separate red–green percepts. Overall, these findings show that concurrent auditory input can affect both the temporal and featural properties of visual percepts.



## 1. Introduction

When a single flash of light is presented interposed between two brief auditory stimuli separated by 60–100 ms, individuals typically report perception of two flashes (Shams, Kamitani, & Shimojo, 2000, 2002). The neural basis of this multisensory sound-induced flash illusion (SIFI) has been investigated in several electrophysiological and neuroimaging studies (Arden, Wolf, & Messiter, 2003; Bhattacharya, Shams, & Shimojo, 2002; Mishra et al., 2007; Shams et al., 2001, 2005; Watkins et al., 2006, 2007). In a detailed investigation of the phenomenon using event related potential recordings (ERPs), Mishra et al. (2007) found that the illusion is based on a rapid interplay between auditory, visual and polysensory cortical areas. Notably, however, the neural activity pattern underlying the illusory flash was found to be very different from the activity elicited by a real flash. These neurophysiological differences raise questions regarding the properties of the illusory flash, in particular whether it can possess distinctive visual features like those of a real flash such as color, shape, contrast and size. In the present study we extend the Shams paradigm by probing additional information about the final visual percept (its color specificity) as modified by concurrent sounds. By doing this, the current experiment provides a more detailed understanding of the featural attributes of multisensory percepts that may occur in real-life situations; for example, the integration of sounds and lights at a music concert or on a busy highway.

Researchers who first described the SIFI have shown that the phenomenon can be elicited under a wide range of stimulus parameters of shape, size, texture and duration (Shams, Kamitani, & Shimojo, 2000; Shams et al., 2005; Watkins et al., 2006), and this was recently expanded to flashed visual objects such as faces and buildings (Setti & Chan, 2011). McCormick and Mamassian (2008) further showed that the illusory flash can have a measurable contrast. In this case, the presence of two sounds lowered the threshold contrast of the second flash in a sequence of two flashes. An unresolved question, however, is whether the SIFI is stimulus specific; i.e., does the illusory flash have the same or similar features as the inducing real flash.

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The present study investigated the stimulus-specificity of the SIFI in terms of its color features. A variable number of sounds (0, 1 or 2) were paired with either a red or a green colored flash, and participants were asked to report the number as well as the color of their final visual percept. If the color of the illusory flash matched the color of the real flash, this would be taken as evidence for feature-specificity of the illusion. In a recent study Setti and Chan (2011) demonstrated the SIFI with face and scene stimuli, but they did not query the feature content of the illusory flash. Hence, their study did not directly test the feature-specificity of the SIFI, which we aim to investigate here by asking individuals to report the featural content of their visual percepts as well as the number of visual stimuli perceived. In addition, we investigated whether concurrent sounds would influence color integration by presenting a variable number of sounds (0, 1 or 2) paired with a rapid visual sequence of a red followed by a green flash. A rapid red–green sequence by itself usually results in a fused orange percept. Again, by asking individuals to report the number and color of their visual percepts, we examined whether auditory input could influence this red–green to orange color integration.

## 2. Materials and methods

Seventeen right-handed healthy adults (8 males and 9 females, age mean ± standard deviation 23.4 ± 3.3 years) participated in the study after giving informed consent as approved by the University of California San Diego Human Research Protections Program. Each participant had normal or corrected-to-normal vision and normal hearing. Participants in the study were pre-selected as individuals who perceived the SIFI on at least 40% of the trials in a short 2-min screen prior to the main experiment. The screening block consisted of identical visual and audio–visual stimuli as previously used in Mishra et al. (2007) to study the illusion. Approximately 34% of individuals screened met this criterion for participation in the study.

The experiment was conducted in a sound-attenuated chamber having a background sound level of 32 dB SPL and a background luminance of 2 cd/m$^2$. Visual stimuli were presented on the horizontal meridian at 8° of visual angle (va) in the left visual field on an LCD monitor, as in our prior investigations of the SIFI (Mishra, Martinez, & Hillyard, 2008, 2010; Mishra et al., 2007). Visual stimuli were annuli (3.7° va outer diameter and 0.8° va thickness) flashed for 32 ms at a luminance level (measured by photometer) of 75 cd/m$^2$. Participants maintained fixation on a cross positioned at the center of the mid-level gray screen at a viewing distance of 83 cm. Auditory stimuli were presented in free field simultaneously from speakers attached to the right and left sides of the monitor display, thereby resulting in centrally localized sounds. Auditory stimuli were 76 dB SPL noise bursts with 10 ms durations.

During the experimental runs, participants were presented with the following 17 different visual (V) and audio–visual (AV) stimulus combinations (see Fig. 1): 8 of the stimuli contained either red (r) or green (g) colored stimuli ($V_{1r}$, $V_{1g}$, $V_{2r}$, $V_{2g}$, $A_1V_{1r}$, $A_1V_{1g}$, $A_2V_{1r}$, $A_2V_{1g}$), while 9 of the stimuli contained a first red and a second green visual stimulus ($V_{2rg}$, $A_1V_{2rg}$, $A_2V_{2rg}$) that were presented at three different red–green SOAs of 50 ms, 84 ms and 100 ms. Suffixes 1 or 2 denote presence of one or two auditory or visual components within each stimulus combination. For audiovisual stimuli, the first sound was always temporally aligned with the first visual stimulus at onset. For audiovisual stimuli containing two sounds, the SOA between the two auditory stimuli was set at a constant 67 ms as this SOA reliably produced the SIFI in our previous studies (Mishra et al., 2007). The 17 experimental stimuli were presented equiprobably and in random order on each experimental run. Each run included 12 trials each of the 17 stimulus types. Inter-trial intervals were set at 800 ms with a ±300 ms jitter. Each experimental run of 204 stimuli lasted roughly 3 min. A total of four runs were conducted in the experiment.

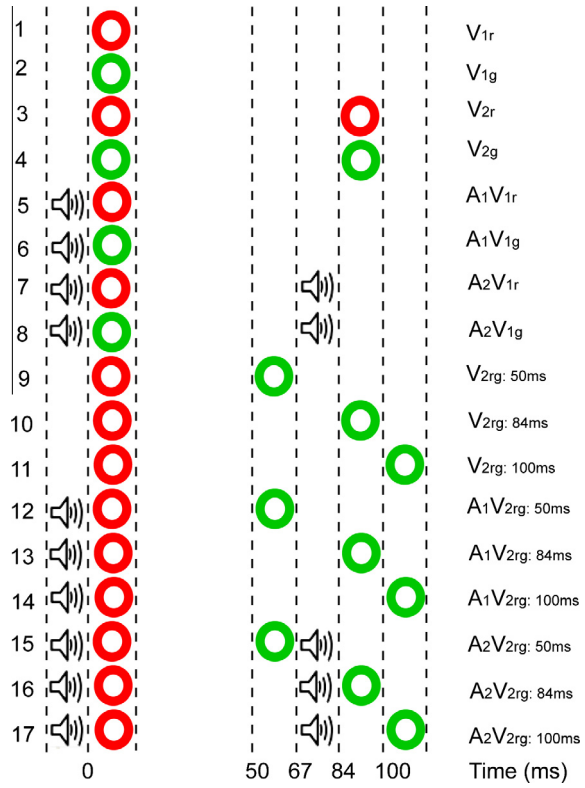


**Fig. 1.** Overview of the experimental design. The stimulus presentation timeline is shown at the bottom, each labeled time point below the dotted lines corresponds to stimulus onset.

Participants used a joystick to report the color and number of visual percepts on each trial. Perceived color was reported as one of four choices (i) red, (ii) green, (iii) orange or (iv) both red and green annuli. Choice (iii) was reported on trials on which the sequential red and green annuli fused to form an orange percept. Color choice (iv) was reported when both red and green colors were perceived on any given trial. The number of perceived flashes (two vs. one) was reported with a separate button. For color choice (iv), subjects were instructed to make the two-flash numerical response if either one or both of the red and green colors was perceived to flash twice. At the end of the experiment participants were asked if they perceived any other color (e.g., white) not provided as one of the red/green/orange color response choices; all participants consistently replied "no".

Percentages of the different types of responses across conditions were analyzed by repeated measures ANOVAs. Post hoc analyses consisted of two-tailed dependent sample *t*-tests. For each comparison, effect sizes were reported as the Cohen's *d* measure (Cohen, 1988).

## 3. Results

The percentages of one-flash and two-flash responses to the visual and audio–visual stimuli that contained a single color component, either red ($V_{1r}$, $V_{2r}$, $A_1V_{1r}$, $A_2V_{1r}$) or green ($V_{1g}$, $V_{2g}$, $A_1V_{1g}$, $A_2V_{1g}$), are shown in Fig. 2A and Table 1. A 2 × 4 repeated measures ANOVA on the percentage of two-flash responses with stimulus color (red/green) and stimulus type ($V_1$, $V_2$, $A_1V_1$, $A_2V_1$) as factors showed a main effect of color with more two-flash reports