Illusory flashes and perception

Péter Csibri Department of Physiology, Faculty of Medicine, University of Szeged, Szeged, Hungary

Péter Kaposvári Department of Physiology, Faculty of Medicine, University of Szeged, Szeged, Hungary

Gyula Sáry Department of Physiology, Faculty of Medicine, University of Szeged, Szeged, Hungary

Information from the environment can be based on a single or several modalities. The simultaneous processing of information separated in space and/or time depends on multiple factors. Visual illusions serve as a good tool with which to investigate the parallel processing of information and their interactions. This study was designed to gain information about a unimodal illusion: a target that flashes once seems to flash more as a result of a simultaneously presented inducer flashing several times nearby. The first aim of this work was to understand whether the number of perceived flashes is merely a result of a bias in the criterion level or whether it is based on a real percept. We then clarified how the illusion finds its way into the percept. The final step was designed to establish the logic of the processing in the background by determining whether the modality appropriateness hypothesis, the information reliability hypothesis, or the discontinuity theory best explains the predominant role of the inducer.

Introduction

Information reaching the different sensory systems is processed by the various sensory cortical areas as though they are specialized to deal with a parallel flow of information. As knowledge accumulated concerning the structure and function of these regions, it became clear that the sensory regions previously regarded as uniform in fact involve subdivisions that process different features in that particular sensory domain.

The visual percept is constructed through two parallel cortical systems. For fine details and colors the ventral (What?) pathway is used, while for spatial attention, speed, and direction of movement, the dorsal pathway (Where?) is relevant (Ungerleider & Mishkin, 1982). We are aware that the cortical streams are functionally not separated, but this oversimplified picture might serve as a good framework facilitating an understanding of the cortical network of visually active areas. Data from monkey electrophysiology experiments have revealed that the different areas within the above-mentioned pathways react with different selectivities (preferences) to different features (Felleman & Van Essen, 1991). Hierarchically higher regions, such as the inferotemporal cortex contain cortical modules that prefer stimuli that are similar to each other (Tanaka, 1996). These observations are consistent with clinical findings of an isolated loss of a certain sensory feature (achromatopsy, etc.; Behrmann, 2001).

One of the greatest challenges is to understand the way in which individual features are integrated into one coherent percept (Livingstone & Hubel, 1988). An approach may be made through the understanding of binding different features relating to the same object and segregating the object and the background (Damasio, 1989). The principles responsible for the association of features that belong together are well known (Koffka, 1935; Köhler, 1975; Kanizsa, 1979). As an example, we tend to perceive stimuli that arrive simultaneously as coming from the same source (Meredith, Nemitz, & Stein, 1987; Watanabe & Shimojo, 2001). Some studies question the physiological relevance of the binding problem (Shadlen & Movshon, 1999) but an increasing number of clinical studies and psychophysical tests on healthy individuals indicate that the binding problem does exist, even in everyday clinical practice (Singer, 1993; Friedman-Hill, Robertson, & Treisman, 1995; Robertson, 2003).

Another way of dealing with the binding problem is to study contextual effects; that is, how the perception of a particular object varies with the context it appears in (Levitt & Lund, 1997; Sengpiel, Sen, & Blakemore, 1997; Somers et al., 1998). The spatial features of such

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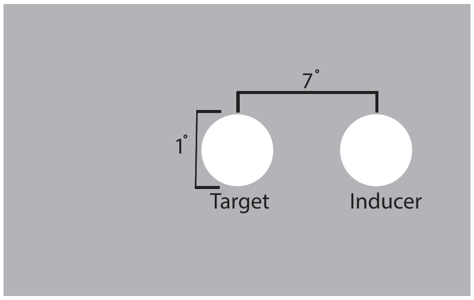

Figure 1. Stimulus arrangement. The target stimulus on the left, located in the middle on the screen, also serves as a fixation point. The inducer (on the right) is situated 7° away, in the periphery. The diameter of both stimuli is 1°. The background is a 25% gray. Please note, that for clarity the stimulus size is largely exaggerated.

interacting phenomena have been well studied, but there have been relatively few studies concerning the temporal aspects of the contextual effect. A high-frequency visual flicker, for instance, may change the subjectively perceived pitch of a sound (it seems higher; Gebhard & Mowbray, 1959; Welch, DuttonHurt, & Warren, 1986). A simple flash presented simultaneously with several beeps leads to the illusion of several flashes (Shams, Kamitani, & Shimojo, 2000). This multimodal flicker illusion or double flash illusion has triggered several studies. It has been demonstrated that the mechanism behind this illusion is not merely a bias in the criterion level (McCormick & Mamassian, 2008), and this finding has been supported by electrophysiological studies indicating that at least some of these illusions give rise to a percept of a real second flash. Electroencephalogram (EEG) studies have revealed significantly higher oscillatory activity, induced gamma band responses, and supra-additive audiovisual interactions during such illusions (Bhattacharya, Shams, & Shimojo, 2002). EEG and evoked potential experiments have led to the findings that the perception activity is strongly modulated during the illusory flash as is the latency in trials in which the illusory flash was perceived (Shams, Kamitani, Thompson, & Shimojo, 2001).

A similar phenomenon can be observed during the processing of unimodal information. In the unimodal illusory flash effect, the perceived number of flashes of a target stimulus can be increased by an inducer flashing nearby (Chatterjee, Wu, & Sheth, 2011). Such illusions are especially suited for the investigation of the temporal binding of information. The previously mentioned, so-called unimodal flicker illusion, has been less researched than the illusion in which two different modalities interact (double flash illusion; Shams et al., 2001). During the flicker illusion, the inducer triggers the illusory percept. The psychophysical and neurological background is not yet clear and raises the question whether it is caused merely by the more liberal criterion answering "yes" in the presence of more than one inducer. This itself might result in more correct hits (Green & Swets, 1966). The key novelty in our paper is that we calculated the individual criterion level for each subject and determined whether and if so how the illusion appears in perception subsequently.

We set out to investigate the possible mechanisms and principles subserving the flicker illusion. We first clarify whether a sound is the source of a simple disturbing signal, or whether it really triggers a perceived flash similar to a real flash. We then attempt to shed light on the mechanisms subserving the illusory flashes.

Experiment I

The first experiment was designed to confirm that our method could elicit an illusion; we then checked whether the triggered illusion was more than a change in the criterion level.

Methods

Participants

Eleven volunteer university students (mean age: 23.7 years, six males) with normal or corrected to normal vision participated in the experiment. All data originating from every person in every experiment was evaluated.

Setup

In all experiments stimuli were generated on an Apple MacBook Pro laptop computer (Apple, Cupertino, CA) in a dark room and were presented using a ViewSonic CRT monitor (21-inch, 800 × 600 pixel resolution, 60-Hz refresh rate; ViewSonic, Walnut, CA). Subjects were seated with their eyes 57 cm away from the screen to cover 1° area on the retina with the stimuli; their heads were supported by a chin rest. The experiments were run in MATLAB (MathWorks, Natick, MA) using the Psychophysics Toolbox extensions (Brainard, 1997; Pelli, 1997; Kleiner, Brainard, & Pelli, 2007).

Stimuli

Stimuli were high-contrast light spots of circles (diameter 1°) on a 33 cd/m^2 gray background. The subjects were asked to fixate the stimulus in the middle of the screen (target stimulus); the inducer was the other spot of circle, placed at 7° horizontally, on the periphery, to the right (Figure 1). Fixation mark was not displayed on the screen (Shams et al., 2000; Chatterjee et al., 2011). The target stimulus was first presented once for the duration of one frame (16 ms); the first flash of the inducer was timed simultaneously with the target onset, but a further second, third, or fourth inducer flash could be presented to induce the illusory flashes of the target stimulus. Between two flashes, only the gray background was visible for four frames (interstimulus interval, 64 ms). Depending on the number of inducer flashes (one to four), four stimulus types were used, which were presented 30 times each giving a total of 120 trials, presented in a pseudorandom order.

Thus, in Experiment I the following stimuli were presented: type 1, both the target and the inducer flashed once; type 2, the target flashed once, while the inducer flashed twice; type 3, the target flashed once, while the inducer flashed three times, and so forth. The task of the participants was to indicate by pressing the keyboard keys the number of perceived flashes, which could vary between one and four. The session continued, and a new trial started only once a response was given (i.e., a keyboard press was detected by the program). There was no feedback given about the correctness of the response.

Depending on the aim, the stimuli were modified in Experiments II and III, forming further conditions (see the corresponding Method sections).

In this study, the illusion presented a situation in which the subjects indicated the presence of a nonexistent stimulus (a false-positive response). In terms of signal detection theory, this corresponds to a false alarm (FA). We calculated the mean numbers of FAs in the categories for every stimulus type across subjects (FA1–4). FAs may originate from a dysfunction or "noise" in the perceptual system or from perceiving the illusory flashes of the targets. We therefore classified the FAs into two main groups. The first group contained trials in which both the target and the inducer flashed only once; there was no illusion (FA1). The second group contained trials in which the target flashed once and the inducer two, three, or four times. There were illusions in this group (FA2, FA3, and FA4). The first group was used to set a baseline for subtraction from the data on illusory groups; in this way the estimated number of illusions, phantom delta, was determined; for example, $\Delta 2 = \mathrm{FA2} - \mathrm{FA1}$.

Due to interindividual differences an experimental subject might be more or less *susceptible* to seeing an illusory flash (d'). The name d', however, comes from signal detection theory and is used to describe the *sensitivity* (Green & Swets, 1966). In order to follow the logic of signal detection theory, we used the term sensitivity in our study, although the term *susceptibility* would have perhaps been a more appropriate expression.

Signal detection analysis was applied to calculate the sensitivity (d') and the criterion level (c). Criterion level (c) calculation was based on the ration of correct hits and false alarms as described in the literature (Green & Swets, 1966; Gardner et al., 1984) and d' was calculated from the hit rate (H) and the distribution of the FAs via the formula $d' = z(\mathrm{FA}) - z(H)$ where z stands for the z-score. The more sensitive the system is to a signal, the higher the absolute value of d'. This allowed us to figure out what appears in the percept. The extent to which the subject tended to give a false-positive response to a nonexisting stimulus was defined by the value of c, determined from the distribution of the false-positive responses.

Throughout the study, one-way repeated measurement ANOVA with the Greenhouse–Geisser correction (Geisser & Greenhouse, 1958) and Dunnett's multiple comparisons tests were used (Dunnett, 1955), in which the flashes of the inducers served as the main factor and the mean number of perceived flashes as the dependent variable.

Results and discussion

The method proved to be a suitable means for eliciting an illusion and in cases when an illusion was present, both c and d' seemed to decrease. A higher number of FAs was detected when the inducer flashed only once as compared to when it flashed several times; flashing the inducer twice resulted in a relatively low number of phantom flashes ($\Delta 2 = 0.187$), while three inducer flashes resulted in a considerable increase ($\Delta 3 = 0.627$; Figure 2). ANOVA indicated $F(1.549, 13.94) = 40.44$ ($p < 0.0001$) that whereas two flashes did not evoke an illusion, three and four flashes did so in about 62% of the trials. Considerable changes were detected in both d' and c if the number of inducer flashes was varied (for type 1, d' was 0.93; for type 2, d' was –0.03, and for type 3, d' was -1.55), while the corresponding values of c were 0.47, 0, and -3.18, respectively, demonstrating that change in c played a substantial role in the number of reported flashes. Accordingly, our method was capable of inducing illusory flashes. The fact that several flashes of the inducer resulted in changes in both c and d' suggested that the perception of several flashes of the target stimulus cannot be explained solely by the more "liberal" tendency to report more than one flash.

Experiment II

In Experiment I we checked whether the target and the flicker illusion produced the same perceptual

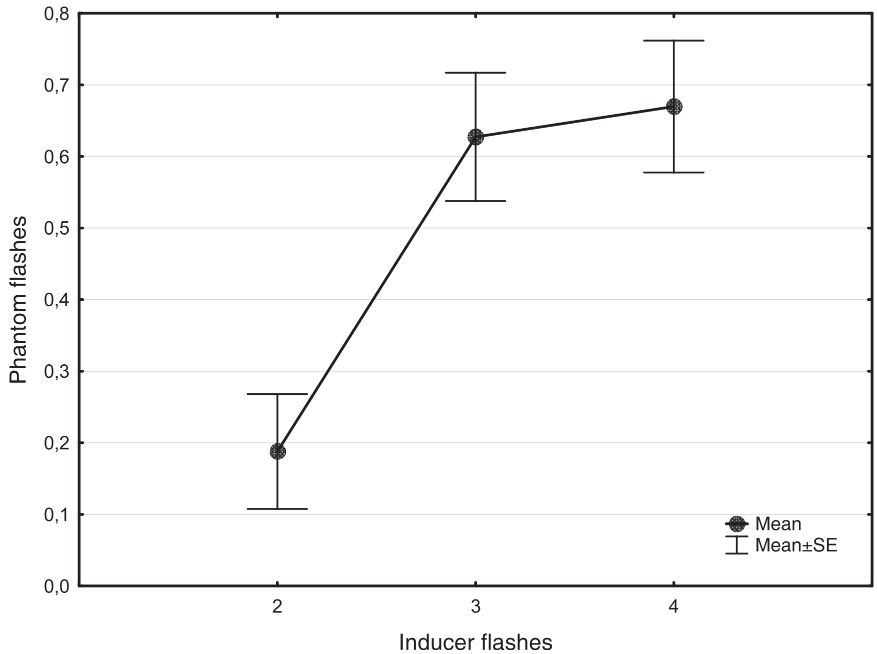

Figure 2. The mean number of phantom flashes as a function of the number of inducer flashes. Ordinate: mean number of phantom flashes (Δ). Abscissa: number of inducer flashes. Data points are means ± SEM.

experience. Next we investigated whether the illusory flashes had the same or opposite polarity as the preceding (target) stimulus. Polarity in this case meant a difference in brightness relative to the background (Figure 3).

In sensory integration one stimulus frequently predominates over the other one; this predominance is probably also present in the case of congruent stimuli, but the phenomenon is usually investigated for incongruent stimuli (Stein & Stanford, 2008; Shams & Kim, 2010; Gori, Sandini, & Burr, 2012). Stimuli can be modified in such a way that, after the first flash of the target, the target continues to flash simultaneously with the inducers. If illusory flashes have the same polarity as the target stimuli, then a second, (low-contrast) target stimulus that matches the polarity of the first, high-contrast stimulus may be supported by the illusory flash, while a second, (low-contrast) target stimulus with the opposite polarity might be attenuated by the illusory flash.

Experiment II was designed so that the first high-contrast target stimulus was followed by low-contrast flashes of the same target stimulus that had either the same (same-polarity subcondition) or the opposite polarity (opposite-polarity subcondition), while the inducer was used to trigger the illusion as described previously (Figure 3). It is important to note that in this experiment Δ depended not only on the phantom flashes but additionally on the existing, low-contrast flashes as well. Thus, similar to the previous experiment, significant differences between the stimulus types proved that the low-contrast value of the target flashes had been successfully set around the perceptual threshold. According to our hypothesis, the perception induction of the illusion would differ under the same-polarity and opposite-polarity subconditions.

Methods

Participants

Ten new volunteer subjects, university students (mean age: 23.9 years, four males) with normal or corrected to normal vision participated in the study. All subjects and all results were included in the statistics.

Stimuli

The stimuli used in Experiment I were modified: after the first flash of the target, the target continued to flash on its original location simultaneously with the inducers, but it was changed to have a lower contrast.

Two conditions were produced this way. If the first flash of the target was physically brighter than the background, the condition was called bright, and if it was darker than the background, it was called dark. In terms of Weber's law, in the first condition the stimulus had a positive contrast value, while in the second it had a negative contrast value.

Each of the conditions had two subconditions. Depending on whether flashes following the first flash of the target had the same polarity (i.e., in the bright condition, they were still brighter than the background)

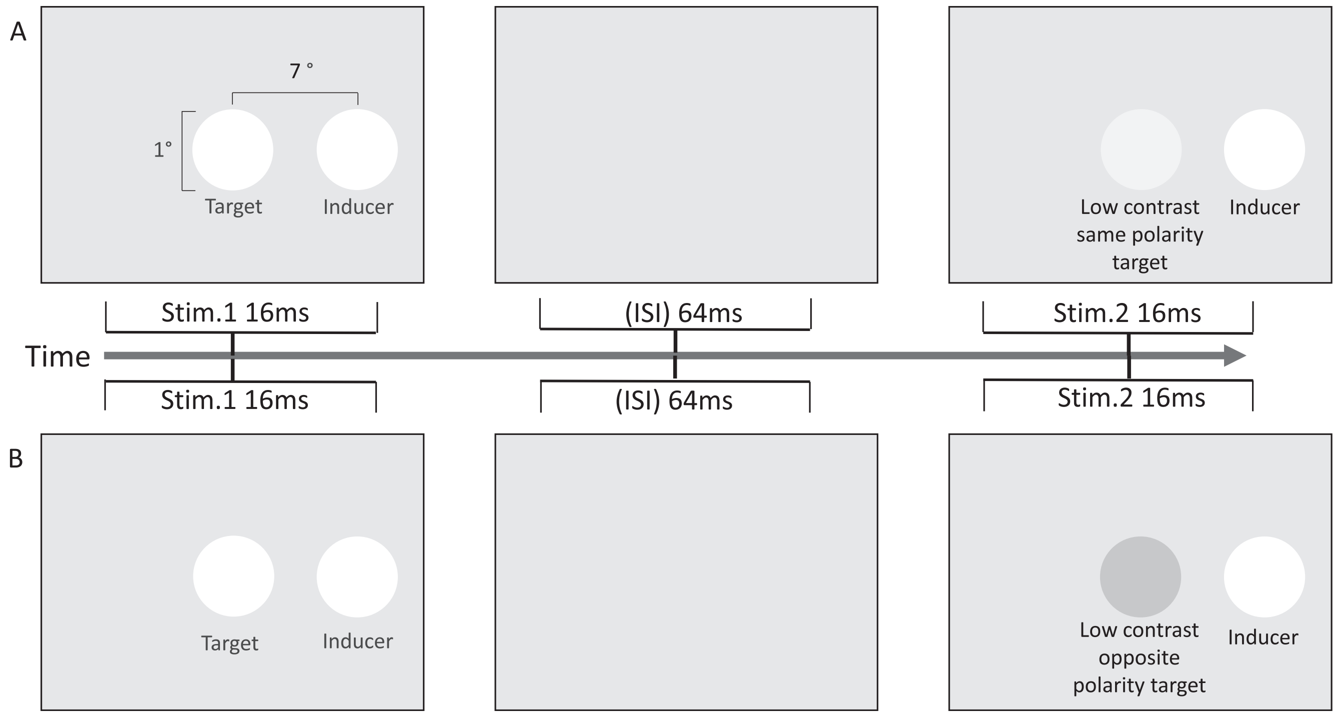

Figure 3. Stimulus arrangement in Experiment II. The figure shows the stimuli used in the light condition, in which the first stimulus was a light spot of circle with high contrast. Please note, that for clarity the stimulus size is largely exaggerated. The two subconditions show the same-polarity subcondition (A) and the opposite polarity subcondition (B). Time scale shows timing of the first stimulus, the target, simultaneously with the inducer (stimulus 1). Both were presented for 16 ms (one frame). This is followed by the interstimulus interval (ISI), which lasted for 64 ms (four frames). Stimulus 2 (target and the inducer) was presented for 16 ms (one frame). Stimulus 2 either consists of a low-contrast target, having the same polarity as the high-contrast target (A), or the opposite polarity (B). Depending on the stimulus (i.e., how many low contrast flashes are presented after the high contrast flash), stimulus 2 can be presented zero to three times.

or not, they were called same-polarity and opposite-polarity subcondition, respectively.

Thus, in the first (bright) condition the first, high-contrast "target" (lighter than the background) flash was followed by low-contrast target flashes, with either the same (same-polarity subcondition) or the opposite (opposite-polarity subcondition, Figure 3) polarity as compared to the first target flash.

In the second (dark) condition, the first, high-contrast (darker than the background) flash was followed by a low-contrast flash, with either the same (same-polarity subcondition) or the opposite polarity (opposite-polarity subcondition). Depending on the number of inducer flashes each of the subconditions contained four stimulus types, as described in Experiment I and were presented in a pseudorandom order.

Stimuli having a high contrast are easy to separate from the background (ceiling effect), while success rate in separating stimuli having a low contrast is only 79.37% (Kingdom & Prins, 2009). For every participant, contrast values were individually determined in a pilot experiment, for both the light and the dark conditions. In this test, the participants had to report when the target stimulus flashed more than once. When the contrast was determined, the high-contrast target stimulus and the peripheral inducer were always flashed; in 50% of the trials, a second stimulus was flashed at the location of the target stimulus the parameters of this second stimulus varying with the performance of the participants. In this way, the contrast value of the second flash stimulus was determined for both the light and dark, same-polarity conditions. Inducers were flashed one to four times. The inducer was not modified in this experiment.

Results and discussion

While evaluating the results, we investigated the detectability of low-contrast flashes, with the same or opposite polarity following the high-contrast flashes.

In the light condition, in which the first flash was brighter than the background, in the same-polarity subcondition one flash of the inducer resulted in $\Delta = 0.163$, two flashes resulted in $\Delta = 0.521$, three flashes resulted in $\Delta = 0.957$, and four flashes resulted in $\Delta = 0.963$ phantom flashes, respectively. The numbers of phantom flashes were significantly different when

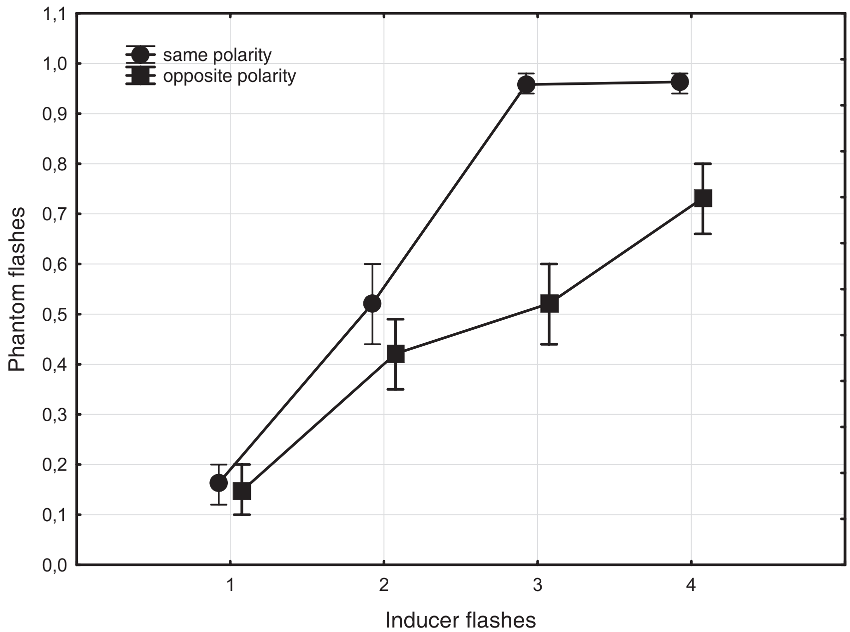

Figure 4. The mean number of phantom flashes as a function of the number of inducer flashes in the light condition. The line with the circles relates to the subcondition in which the contrast polarity was the same as that of the flash of the target stimulus. The line with the squares relates to the subcondition in which the contrast polarity was the opposite of that of the flash of the target stimulus. Data points are means ± SEM.

compared to the one-flash case, $F(1.544, 13.90) = 77.22$, $p < 0.0001$. In the subcondition involving opposite polarities, one, two, three, and four flashes of the inducer resulted in $\Delta = 0.147$, $\Delta = 0.421$, $\Delta = 0.521$, and $\Delta = 0.731$ perceived flashes, respectively. The latter three values of perceived flashes were significantly different from that in the type 1 condition, $F(2.554, 22.99) = 23.88$, $p < 0.0001$.

Our results confirm the literature claim (Chatterjee et al., 2011) that statistically verified illusory flashes were likely to occur when the inducer is flashed three times. Figure 4 shows the separation of the lines illustrating the number of phantom flashes starting from the type 3 condition.

In the opposite-polarity subcondition, the detectability of the target stimulus did not change when the inducer flashed three times, but a moderate increase was seen in the case of four flashes, $F(2.554, 22.99) = 23.88$, $p < 0.0001$. On the other hand, in the same-polarity subcondition the number of perceived flashes in the case of three inducer flashes was significantly higher than when the inducer flashed only twice, $F(1.544, 13.90) = 77.22$, $p < 0.0001$. There was statistically no significant difference in the perception between the type 1 stimuli of the opposite-polarity subcondition and the same-polarity subcondition (mean difference = 0.015). Neither was there significant difference in the perception between the type 2 stimuli of the same subconditions (mean difference = 0.257). In the same subconditions, using the type 3 stimuli, however, we found significant differences (mean difference = –0.357). This was to be expected since previous results in this study indicated the emerging of the illusory flashes. Further, using the type 4 stimuli in the same subconditions resulted in significant differences as well (mean difference = –0.568), ANOVA $F(3,72) = 4.833$, $p = 0.004$. We therefore hypothesize that the illusory flash is perceptually similar to a real flash.

In the dark condition (Figure 5), one flash of the inducer in the opposite-polarity subcondition resulted in $\Delta = 0.238$; two flashes in $\Delta = 0.691$; three flashes in $\Delta = 0.957$; and four flashes in $\Delta = 0.946$ perceived flashes. The latter three numbers of perceived flashes were significantly different from that in the one-flash condition, $F(1.714, 15.42) = 44.18$, $p < 0.0001$. In the same-polarity subcondition, one flash of the inducer resulted in $\Delta = 0.163$; two flashes in $\Delta = 0.466$; three flashes in $\Delta = 0.893$; and four flashes in $\Delta = 0.925$ perceived flashes. The latter three numbers of perceived flashes were once again significantly different from that in the one-flash case, $F(1.472, 13.25) = 42.63$, $p < 0.0001$. There was no significant difference (interaction) between the subconditions, $F(3, 72) = 1.021$, $p = 0.3885$. Since the results obtained in the two subconditions did not differ significantly, we concluded that an illusory flash was not induced in this condition, and therefore no further analysis was performed.

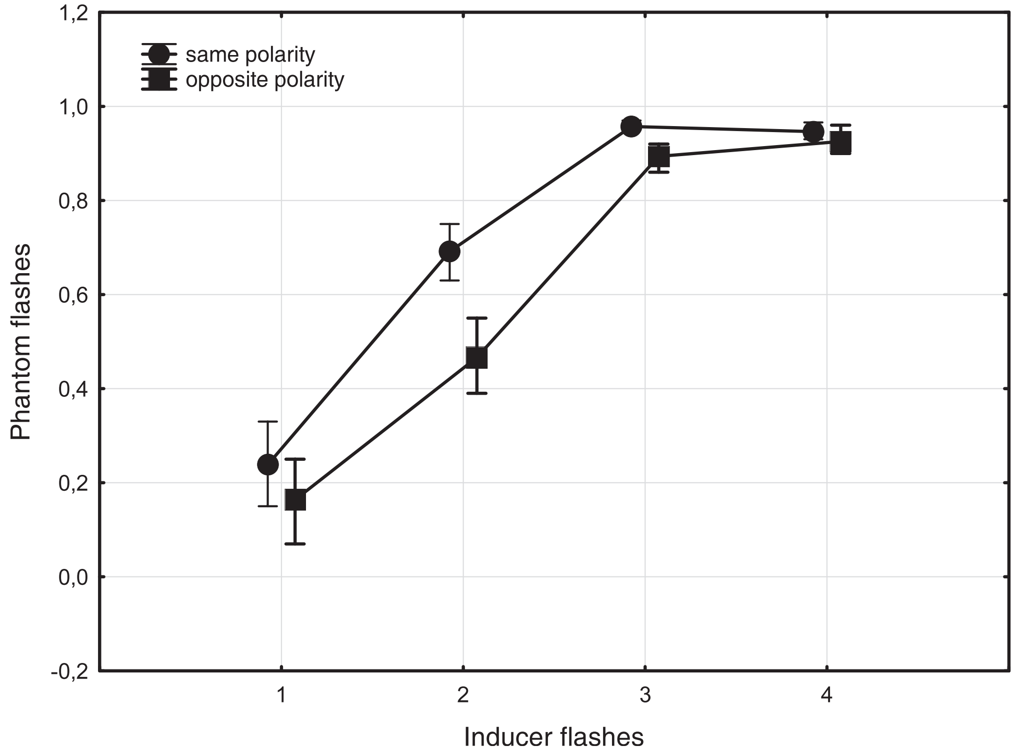

Figure 5. The mean number of phantom flashes as a function of the number of inducer flashes in the dark condition. The line with the circles relates to the subcondition in which the contrast polarity was the same as that of the flash of the target stimulus. The line with the squares relates to the subcondition in which the contrast polarity was the opposite of that of the flash of the target stimulus. Data points are means ± SEM.

Experiment III

This experiment was designed to determine the logic of processing behind the phenomenon. There are several potential explanations as to how one stimulus can influence the perception of another. While the modality appropriateness hypothesis explains the dominance from the receptor side, the information reliability hypothesis and the discontinuity hypothesis do so from the stimulus side (Hove, Fairhurst, Kotz, & Keller, 2013). To decide what principle is involved, we performed a factorial experiment to test these three hypotheses.

Modality appropriateness

The characteristics of the visual areas that process a particular stimulus can clearly influence the processing (Schwartz, Robert-Ribes, & Escudier, 1998). A good example in multimodal stimulus perception is when the better temporal resolution of hearing complements the processing of visual stimuli in the temporal domain (double flash illusion), or, in the opposite case, when the better spatial resolution of visual processing complements the perception of auditory stimuli (ventriloquism). In these cases, the particular modality that dominates in the given situation is usually the one with the better resolving power. According to this logic, illusions triggered in both the fovea and the periphery of the retina could argue against this hypothesis; the triggering of an illusion at the periphery of the visual field by flashes in the center would argue against the idea that better temporal resolution at the periphery promotes predominance of the center.

Information reliability

Modality predominance can also be explained by the quality of the stimuli. A predominant modality is determined not only by the more precise processing capability, but also by the reliability of the information (Welch & Warren, 1980). This is naturally closely related to the previous hypothesis, since the more accurate the processing of a given dimension in a modality, the more reliable the information will be, even if it is ambivalent. As described previously a 79.37% threshold was determined overall for the peripheral stimuli, and this was used as low-contrast stimulus for the tests. Theory predicts several changes. First, the use of a low-contrast inducer should result in a weaker central illusion. Further, the illusion should also be present in the periphery when low-contrast flashes are used, since the stimulus coming from here is less reliable if a high-contrast stimulus is used at the same time, in the center.

Discontinuity

Another explanation could be the discontinuity hypothesis (Shams, Kamitani, & Shimojo, 2002), which emphasizes the temporal parameters of the stimulus rather than the strength of the double flash illusion. According to this idea, discontinuous stimuli (individual flashes in our case) predominate in interactions, as do peripheral flashes over foveal flashes. In other words, a periodic modality has a larger impact on the sensory systems than a continuous one. This hypothesis could explain the robustness of the illusion, for an illusion should be expected at the periphery, too. If illusions follow this logic, we could expect this independent of the retinal location; several flashes on the fovea should induce illusory flashes on the periphery, and fusion should not be observed.

Methods

Participants

A new group of 10 volunteer university students (mean age: 24.1 years, four males) with normal or corrected to normal vision participated in this study. As in the previous experiments, no subjects and no data were excluded.

Stimuli

As in the previous experiments, the participants were asked to detect flashes of the target stimulus (flashed once only) in the presence of one to four flashes of the inducer. They were requested to fixate the central stimulus; the target could be the central or the peripheral stimulus. The experiment had two conditions. In the first, both the central and the peripheral stimuli had high contrasts (high-contrast condition). In the second, the peripheral stimuli had the previously individually determined contrast (low-contrast condition).

Results and discussion

The number of illusory flashes was determined as in Experiment I. To obtain the phantom flash Δ, the number of FAs under the nonillusory conditions was subtracted from that under the illusory conditions. In the first condition, type 2 stimuli resulted in $\Delta = 0.131$, type 3 stimuli in $\Delta = 0.426$, and type 4 stimuli in $\Delta = 0.442$, $F(2.244, 20.19) = 25.34$, $p < 0.0001$. Two flashes triggered flicker illusion (Figure 6A). When the target stimulus was positioned in the periphery, the illusion became weaker, but did not disappear. Two flashes resulted in $\Delta = 0.326$, three flashes in $\Delta = 0.368$, and four flashes in $\Delta = 0.315$, $F(1.977, 17.79) = 12.09$, $p = 0.0005$ (Figure 6B). In the second condition, where the target was at the center, low-contrast peripheral flashes did not induce the illusory flash ($\Delta = 0.115$), $F(1.571, 14.14) = 2.562$, $p = 0.1207$ (Figure 6C). Feedback derived from the responses of the participants to flashes at the periphery indicated that a central stimulus elicited a weak illusory flash. Two flashes resulted in $\Delta = 0.147$, three flashes in $\Delta = 0.336$, and four flashes $\Delta = 0.347$, $F(1.977, 17.79) = 12.09$, $p = 0.0005$. The low-contrast target was flashing at the periphery, and the high-contrast inducer at the center (Figure 6D). The illusion was induced both at the center and at the periphery, which supports the discontinuity hypothesis. Even though the illusion was not present when the low-contrast inducer was used, the peripherally presented, low-contrast target stimulus with the central low-contrast inducer did induce the illusion. This supports the information reliability hypothesis. The modality appropriateness hypothesis can be excluded since illusions were successfully triggered in the periphery.

To check the discontinuity hypothesis, we created a fused condition in which four flashes of the target stimulus were linked to zero to four flashes of the inducer. In accordance with an earlier report (Andersen, Tiippana, & Sams, 2004), we did not observe any fusion effect, $F(1, 9) = 0.008876$, $p = 0.9270$.

Conclusions

According to our results an increase in the number of flashes of the inducers resulted in an increased probability in indicating several flashes by the participants. Moreover, our results led us to the conclusion that the increase in the number of phantom flashes in the illusory condition were based, at least partly, on a real perceptual phenomenon (a visually based decision), similar to the case of multimodal, audiovisual (Shams et al., 2002), and haptic visual illusion studies (Violentyev, Shimojo, & Shams, 2005).

Since the subcondition involving the same polarity increased the number of phantom flashes in the light condition, while the opposite polarity decreased it, we hypothesize that the illusion has a real polarity that matches the preceding flash. We may therefore reject the hypothesis of a decreased sensitivity of negative after-images behind the multiple flashes. If this was the case, the perceived number of flashes would have been

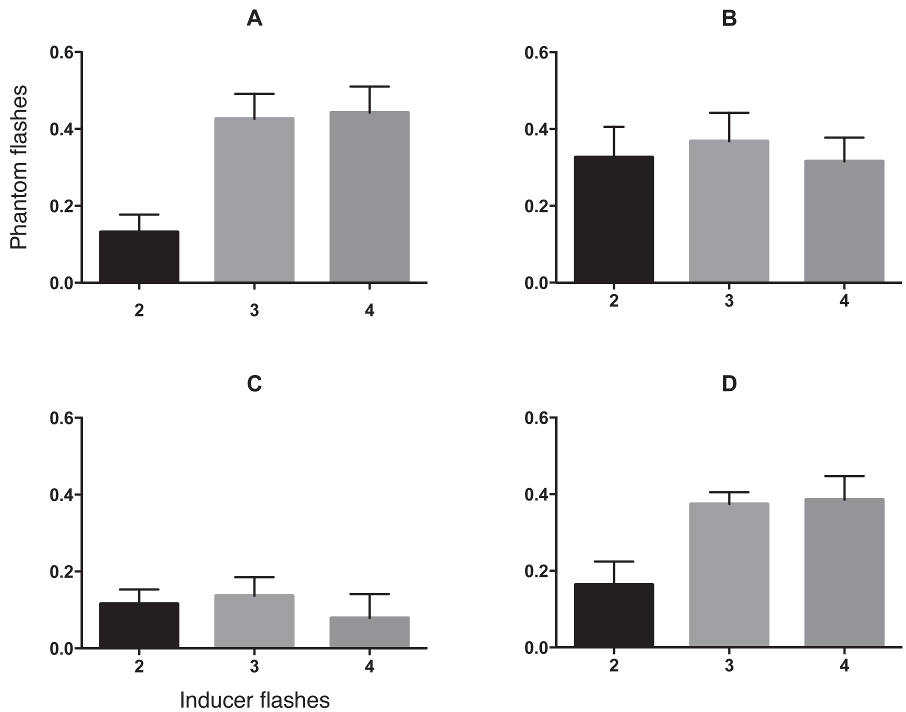

Figure 6. The mean number of phantom flashes as a function of the number of inducer flashes in Experiment III. Columns show means ± SEM. (A) High-contrast central target, high-contrast peripheral inducer. (B) High-contrast central inducer, high-contrast peripheral target. (C) High-contrast central target and low-contrast peripheral inducer. (D) High-contrast central inducer, low-contrast peripheral target.

increased by the low-contrast flashes that had the opposite polarity to that of the high-contrast flashes.

The mechanism of the illusion might be explained by the results of the third experiment. Centrally evoked successful illusions at the periphery disprove the theory of modality appropriateness and support the information reliability theory. This seems to be in accord with the finding that the probability of inducing the illusion is clearly dependent on the reliability of the target and inducer stimuli. Stimulus reliability seems to be a factor that influences the degree of predominance in forming the percept. These results also support the stimulus discontinuity effect as a possible factor elevating the predominance of a particular stimulus, especially since we failed to detect a fusion effect. Thus, we consider that it is rather the stimulus continuity and reliability than the better temporal resolution of the periphery that lies behind the phenomenon.

Nonetheless, it must be noted, that the picture is far from being complete. Attention directed to the periphery may well be a more difficult task. The components of our paradigm that were not aimed to control attention may have caused bias. In this case, we could not control the attentional effects.

It is well known that stimuli presented simultaneously tend to be perceived as arriving from the same source (Watanabe & Shimojo, 2001) and that stimuli processed in a parallel fashion may be linked together in a rather long temporal window (Stein & Meredith, 1990). Our illusions might rest on perceiving the stimuli from the same source. This effect is not random; faced with an ambiguous or conflicting situation, the system will build the percept based on the most reliable information.

The character of the results might also suggest the participation of subcortical structures, such as the superior colliculus, but the cause is more likely a link within the primary sensory cortex. For a better understanding of the mechanism and the neurophysiological background, EEG and single-cell recordings currently under way in our laboratory may be of importance.

Keywords: flicker, contextual, illusion, temporal vision, integration

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Corresponding author: Gyula M. Sáry.
Email: sary.gyula@med.u-szeged.hu.
Address: Department of Physiology, Faculty of Medicine, University of Szeged, Szeged, Hungary.

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