Flickering illusion as a possible method for the investigation of the binding problem

Ph.D. Thesis (handout)

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Design of multisensory stimuli - Raising the problem

The multisensory integration covers multiple problems. Multisensory integration is when we try to combine the information of the same object perceived trough several channels, if we separate the object from the background and if we study the interaction of several information when one information has a profound impact on the processing of another one. Visual stimuli, presented simultaneously can interfere with each other, even if they are positioned far away from the attended stimulus. Effects on the perception of the attended stimulus can also be demonstrated if the two stimuli belong to different modalities, for example, visual and auditory (Wilson, 1987), or even visual and haptic (Ernst *et al.*, 2000; Wozny *et al.*, 2008). A high-frequency visual flicker, for instance, may change the subjectively perceived pitch of a sound (it will seem to be higher; (Welch *et al.*, 1986; GEBHARD & MOWBRAY, 1959). Thus, the problem is complicated, and, according to this, a large arsenal of methods was used to answer several aspects of the topics. The results, however are difficult to compare and to interpret due to the different methods and stimuli used. The first step in my work was to choose a method, based on reviewing the literature. This should be easy to use and should enable one to study the widest range of problems by changing only one parameter. I choose the flicker illusions. I describe what kind of research was performed in order to know whether this phenomenon can be used in the planned studies.

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 *et al.*, 2011). Such illusions are especially suited for the investigation of the temporal binding of information. The above-mentioned, so-called unimodal flicker illusion has been less researched in contrast with the illusion where 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, 1966). The key novelty in our paper is that we calculated the individual criterion level for each subject and determined whether the illusion appears in subsequent perceptions. We set out to investigate the possible mechanisms and principles subserving the flicker illusion. We first clarify whether a sound is 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,) in a dark room and were presented using a ViewSonic CRT monitor (21-inch, 800 × 600 pixel resolution, 60-Hz refresh rate; ViewSonic, Walnut,). 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, M) using the Psychophysics Toolbox extensions (Brainard, 1997; Pelli, 1997).

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. 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 (F). 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, $\Delta 2 = FA2 - FA1$.

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, 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. Criterion level calculation was based on the ration of correct hits and false alarms as described in the literature (GardnerR.M., 1984) and d' was calculated from the hit rate (H) and the distribution of the FAs via the formula $d' = z(\mathrm{F}) - z(H)$ 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 (GeisserS, 1958) and Dunnett's multiple comparisons tests were used (DunnettC.W, 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 3). 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 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.

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). 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. 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) 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 1) 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% (KingdomA.A.F, 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 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 1 shows the separation of the lines illustrating the number of phantom flashes starting from the type 3 condition.

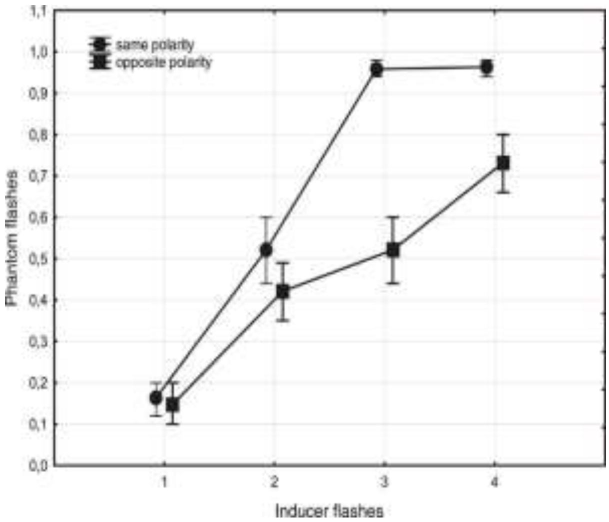

Figure 1.: *The mean number of phantom flashes as a function of the number of inducer flashes in the light condition. The line with the circles relates to the subcondition in which the contrast polarity was the same as that of the flash of the target stimulus. The line with the squares relates to the subcondition in which the contrast polarity was the opposite of that of the flash of the target stimulus. Data points are means ± SEM.*

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 2), one flash of the inducer in the same-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 opposite-polarity subcondition, one flash of the inducer resulted in $\Delta = 0.163$; two flashes in Δ

= 0.466; three flashes in Δ = 0.893; and four flashes in Δ = 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.

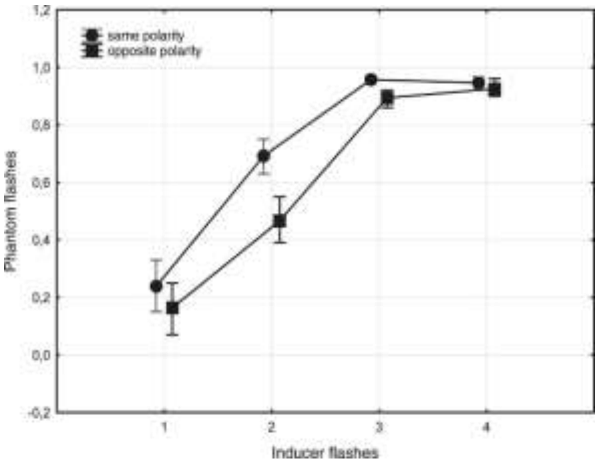

***Figure 2.**: The mean number of phantom flashes as a function of the number of inducer flashes in the dark condition. The line with the circles relates to the subcondition in which the contrast polarity was the same as that of the flash of the target stimulus. The line with the squares relates to 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 *et al.*, 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 (SchwartzJ.L., 2014). 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 (Bhattacharya *et al.*, 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 Δ = 0.131, type 3 stimuli in Δ = 0.426, and type 4 stimuli in Δ = 0.442, $F(2.244, 20.19) = 25.34$, $p < 0.0001$. Two flashes triggered flicker illusion (Figure 3A). When the target stimulus was positioned in the periphery, the illusion became weaker, but did not disappear. Two flashes resulted in Δ = 0.326, three flashes in Δ = 0.368, and four flashes in Δ = 0.315, $F(1.977, 17.79) = 12.09$,$p = 0.0005$ (Figure 3B). In the second condition, where the target was at the center, low-contrast peripheral flashes did not induce the illusory flash (Δ = 0.115), $F(1.571, 14.14) = 2.562$, $p = 0.1207$ (Figure 3C). 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 Δ = 0.147, three flashes in Δ = 0.336, and four flashes Δ = 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 3D). 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 *et al.*, 2004), we did not observe any fusion effect, $F(1, 9) = 0.008876$, $p = 0.9270$.

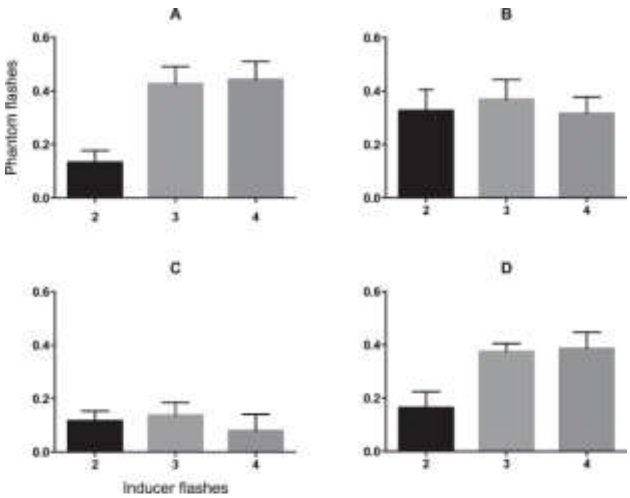

Figure 3.: *The mean number of phantom flashes as a function of the number of inducer flashes in Experiment III. Columns show means ± SEM. (A) High-contrast central target, high-contrast peripheral inducer. (B) High-contrast central inducer, high-contrast peripheral target. (C) High-contrast central target and low-contrast peripheral inducer. (D) High-contrast central inducer, low-contrast peripheral target.*

Conclusion

Different senses collect information from different dimensions of the outside world. Vision uses light, an electromagnetic radiation that can be seen by the human eye and spreads rapidly in a straight line. Hearing uses sounds mediated by the vibrations of air. The sense of smell detects airborne chemical particles, and so on. Each sensor has different advantages and disadvantages; each of them is able to describe an object in another way.

There are permanent features of objects. There is so-called invariant information. This is a “general characteristic” such as intensity, spatial position, speed, rhythm, texture, size, and so on. This information can be made independent of the detection system and can be interpreted in any system (Lewkowicz, 2000). The invariance of sensory modalities appears in early detection during development (Lewkowicz, 1994). In contrast, associations between intermodalities defining the object properties are not so obvious. There is no consistency between information from the various dimensions of the object, for example, without prior experience. In addition, if you have learned associations between the unimodal characteristics, it does not give any information about the other external relations. The rose's smell has no information on the visual appearance of the flower (Lewkowicz, 2000). From these different dimensions and bits of information, the picture is put together. Doing so may not only make it possible to eliminate the others' deficiencies but also can form a better picture quality, thus blurring the boundaries between the senses, as was written above already, at the level of the primary cortex. However, this does not necessarily abolish the existence the unisensory areas. Think again some more! The backbone of processing such information is in the areas of the corresponding senses. Other sensory experiences or opportunities for action or intentions only modulate these areas in the operation, even if it is substantial. It simply draws attention to the need to think with much more variability.

It is obvious from what has been spoken of above that multi-sensory stimulus processing can be modified by a great many factors. In this case, if we are unable to control the key variables or at least take them into account, it is easy to observe artifacts or misunderstand the results of others. Studies on integration are showing more and more results. It is still difficult to see a bigger picture, due to the use of a large variability of stimulus packages. We have to consider, for example, that stimuli and tasks cannot be neglected. An important example is the complexity of the task. The more complex the task to be performed, the more complex the response expected, and the higher the latency, and the multisensory integration window also shows an increase (Karns *et al.*, 2012).

In my work, I wanted to find a tool with which the different hypotheses can be examined step by step, changing only one variable at a time. I expect that a more transparent set of experiments can be set up. The choice fell on the flicker illusions described above. In order to properly use this illusion, some basic research was needed.

In the unimodal form of the illusion, not surprisingly, and in accordance with our hypothesis, we experienced a substantial change in the responses; that is, an increase in the number of flashes of the inducers resulted in an increased probability of the indication of several flashes by the participants (McCormick & Mamassian, 2008). Moreover, our results led us to the conclusion that the increase in the number of perceived flashes in the illusory condition were based, at least partly, on a real perceptual phenomenon (a visually based decision), as in the case of multimodal, audiovisual (Shams *et al.*, 2002) and haptic visual illusion studies (Violentyev *et al.*, 2005). Since the subcondition involving the same polarity increased the perceived number of 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 were the case, the perceived number of flashes would have been increased with 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 the stimulus continuity and reliability rather than the better temporal resolution of the periphery that lies behind the phenomenon. Nonetheless, it must be noted, that the picture is far from complete. Attention directed to the periphery may well be a more difficult task. The components of our paradigm that were not targeted to the control of 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 suppose the participation of subcortical structures, such as the SC, 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 underway in our laboratory, may be informative.

In the multimodal form of the illusion, we found that the robust double-flash illusion can be induced in both M and P pathways. The flash-fusion illusion can be induced in the P pathway, while the M pathway does not support it. Although the difference could be observed only at the peripheral condition, the incidence of flash fusion seems to be pathway-specific, depending on the temporal resolution of the given pathway. Thus the origins of activity related to the flash-fusion and double-flash illusions in the STS seem to not be identical, and it presumes different mechanisms of integration. According to the latest results of MRI studies, the flicker illusion could produce physiological results that also draw distinct processing according to P and M pathways (during edition). Research on this topic at the moment is being conducted at the institute. The results show that the flicker illusion can be used in the field of information connection.

Reference List

Bhattacharya J, Shams L, & Shimojo S (2002). Sound-induced illusory flash perception: role of gamma band responses. *Neuroreport* **13**, 1727-1730.

Brainard DH (1997). The Psychophysics Toolbox. *Spat Vis* **10**, 433-436.

Chatterjee G, Wu DA, & Sheth BR (2011). Phantom flashes caused by interactions across visual space. *J Vis* **11**, 14.

DunnettC.W. A multiple comparison procedure for comparing several treatments with a control. 50, 1096-1121. 1955. *Journal of the American Statistical Association*.

Ref Type: Generic

Ernst MO, Banks MS, & Bulthoff HH (2000). Touch can change visual slant perception. *Nat Neurosci* **3**, 69-73.

GardnerR.M. Table of criterion values (â) used in signal detection theory. DalsingS., ReyesB., and BrakeS. 16, 425-436. 1984. *Behavior Research Methods, Instruments, and Computers*.

Ref Type: Generic

GEBHARD JW & MOWBRAY GH (1959). On discriminating the rate of visual flicker and auditory flutter. *Am J Psychol* **72:521-9.**, 521-529.

GeisserS. An extension of Box's results on the use of the F distribution in multivariate analysis. GreenhouseS.W. 29, 885-891. 1958. *The Annals of Mathematical Statistics*.

Ref Type: Generic

Green DM. Signal detection theory and psychophysics. 1966. New York, Wiley.

Ref Type: Generic

Hove MJ, Fairhurst MT, Kotz SA, & Keller PE (2013). Synchronizing with auditory and visual rhythms: an fMRI assessment of modality differences and modality appropriateness. *Neuroimage* **67:313-21.** doi: 10.1016/j.neuroimage.2012.11.032. Epub@2012 Nov 30., 313-321.

Karns CM, Dow MW, & Neville HJ (2012). Altered cross-modal processing in the primary auditory cortex of congenitally deaf adults: a visual-somatosensory fMRI study with a double-flash illusion. *J Neurosci* **32**, 9626-9638.

KingdomA.A.F. *Psychophysics: A practical introduction*. PrinsN. 2009. Amsterdam, Academic Press.

Ref Type: Generic

Lewkowicz DJ. The development of intersensory perception: Comparative perspec tives. Lickliter, R. 1994. Hillsdale, NJ. Erlbaum.

Ref Type: Generic

Lewkowicz DJ (2000). The development of intersensory temporal perception: an epigenetic systems/limitations view. *Psychol Bull* **126**, 281-308.

McCormick D & Mamassian P (2008). What does the illusory-flash look like? *Vision Res* **48**, 63-69.

Pelli DG (1997). The VideoToolbox software for visual psychophysics: transforming numbers into movies. *Spat Vis* **10**, 437-442.

SchwartzJ.L. Ten years after Summerfield: A taxonomy of models for audio-visual fusion in speech perception. Robert-Ribes J. and Escudier P. *Hearing by eye: The psychology of lipreading*, 85-108. 2014. UK, Lawrence Erlbaum Associates.

Ref Type: Generic

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). Visual illusion induced by sound. *Brain Res Cogn Brain Res* **14**, 147-152.

Shams L, Kamitani Y, Thompson S, & Shimojo S (2001). Sound alters visual evoked potentials in humans. *Neuroreport* **12**, 3849-3852.

Stein BE & Meredith MA (1990). Multisensory integration. Neural and behavioral solutions for dealing with stimuli from different sensory modalities. *Ann N Y Acad Sci* **608:51-65; discussion 65-70.**, 51-65.

Stein BE & Stanford TR (2008). Multisensory integration: current issues from the perspective of the single neuron. *Nat Rev Neurosci* **9**, 255-266.

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

Watanabe K & Shimojo S (2001). When sound affects vision: effects of auditory grouping on visual motion perception. *Psychol Sci* **12**, 109-116.

Welch RB, DuttonHurt LD, & Warren DH (1986). Contributions of audition and vision to temporal rate perception. *Percept Psychophys* **39**, 294-300.

Welch RB & Warren DH (1980). Immediate perceptual response to intersensory discrepancy. *Psychol Bull* **88**, 638-667.

Wilson JT (1987). Interaction of simultaneous visual events. *Perception* **16**, 375-383.

Wozny DR, Beierholm UR, & Shams L (2008). Human trimodal perception follows optimal statistical inference. *J Vis* **8**, 24-11.

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I. List of publications providing the basis

Csibri P, Kaposvari P, Sary G
Illusory flashes and perception.
***JOURNAL OF VISION* 14:**(3) *p. 6.* (2014)
IF: 2.479

Kaposvári P, Bognár A, Csibri P, Utassy G, Sáry G.
Fusion and fission in the visual pathways.
Physiol Res. 2014 Jun 5.
IF: 1.555

Kaposvári P, Csibri P, Csete G, Tompa T, Sáry G
Auditory modulation of the inferior temporal cortex neurons in rhesus monkey
***PHYSIOLOGICAL RESEARCH* 60:**(Suppl. 1) *pp. S93-S99.* (2011)
IF: 1.555

II. List of publications related to the topic of the thesis

Nemeth D, Sefcsik T, Németh K, Turi Z, Dye CD, Csibri P, Janacsek K, Vörös E, Vecsei L, Sztriha LK
Impaired language production in asymptomatic carotid stenosis
***JOURNAL OF NEUROLINGUISTICS* 26:**(4) *pp. 462-469.* (2013)
IF: 1.115