

Effects of pathway-specific visual stimulation on perception

Ph.D. Thesis

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Szeged

2018

Publications related to the thesis

Kaposvári P, Bognár A, Csibri P, Utassy G, Sály G.

Fusion and fission in the visual pathways.

Physiological Research 2014;63(5):625-35. IF: 1.293

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Transcranial stimulation of the orbitofrontal cortex affects processing of magnocellular information.

Frontiers in Neuroscience 2017;11:234 IF: 3.566

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Brain Research Bulletin 2015;110:76-83. IF: 2.572

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Tinta Könyvkiadó 2016; pp.103-112

Introduction

Our visual system analyses several aspects of our surrounding, the contrast and rapid changes in illumination, motion, form, depth and colour information. These features are processed by parallel visual pathways which originate parallel networks of different retinal ganglion cell types, the parasol or magnocellular (M), midget or parvocellular (P) and bistratified or koniocellular ganglion cells. The M cells, which primarily transfer achromatic information of the rod system project to the deep two “M” layers of the lateral geniculate nucleus (LGN) , while the P ganglion cells, which connected to the cone system transfer chromatic differences with good spatial resolution projecting to the upper four “P” layers of the LGN. According to the projection layers of the LGN we call these parallel networks as M and P pathways. The cells in M layers are not able to respond to colour contrast, but are very sensitive to luminance differences. As low as 2% of luminance contrast can be perceived by these cells, while the P layers have high colour contrast sensitivity, but start to respond over 10% of luminance contrast. There are also differences in the coding of spatial and temporal information. The M has good temporal resolution, but low spatial resolution, while the P pathway is responsible for the transmission of the colour information, the fine details of visual information which build up from the high spatial frequency (HSF) elements, but is not sensitive to the information having high temporal resolution. While the P cells get detailed information from the central visual field, the M cells are more sensitive to the stimuli presented at the periphery. Another important difference between the two pathways is the speed of their transmission. The information arriving to the LGN via P ganglion cells has a 20 ms delay as compared to M. The fast information conductance of the M pathway is the basis of detecting changes with high temporal frequencies, e.g. quick changes in the positions of objects and motion which information coded by the parietal cortical areas. However, the P pathway provides the main input for the temporal higher order visual areas responsible for object recognition. The axons of the two pathways terminate in different sublaminae of the primary visual cortex and according to the original view this information feeds separately into the extra striate pathways, the dorsal and ventral pathway, which convey information to the higher-order visual areas. Although the basis of the existence of the parallel systems is strongly supported by track-tracing and electrophysiological recordings investigating the selectivity of the neurons, nowadays more and more scientific results prove that the dissociation of the two pathways is not absolute; there are direct connections between the different stages of the visual system. These interactions between the two pathways are essential; although the dorsal

pathway can independently execute simple visuomotor functions, the schematic information coded by the ventral pathway is essential for complex behavioural responses. To clearly understand the functions of the interactions between the parallel pathways and their role in the integration of other modalities to provide a stable representation of our surrounding, we have to stimulate the pathways selectively while running pathway specific paradigms. We need to learn the contribution to visual perception of the pathways separately to understand the whole image.

According to the aforementioned feature preferences of the two pathways, achromatic information with low contrast and spatial frequency content presented on the periphery can activate the M pathway, however chromatic HSF stimuli or chromatic isoluminant stimuli presented on the central visual field can be detected solely by the P system.

Goals

The aim of our studies were to examine the parallel pathways of visual system to obtain information about their contribution in the representation of our surrounding.

The following questions were addressed:

- How do the segregated visual pathways establish the perception in our multimodal environment?
- What interactions between the two pathways can explain the fast categorization? In situations, where fast decision is essential, through what route is the fast information of the M pathway provides possible top-down effects?

Experiment I.

In this study, we investigated how the M and P pathways contribute to the development of multisensory percept using the double flash and flash fusion illusions. These illusions can be perceived when the nervous system has to establish a stable perception from uncertain information e.g. when one briefly flashed visual stimuli is presented together with inconsistent number of short tones. In some cases, it can lead to the perception of illusions like fusion or fission of the visual events according to the auditory stimulation. Our goal was to understand how the different visual features processed by the parallel visual pathways and the different temporal characteristics of the pathways can act on perception when integrating with auditory information.

Methods

Subjects

Thirty-four healthy naive volunteers participated in the study. Seventeen (12 females; mean age: 22.6 years) of thirty-four subjects participated in the test with central visual stimulation, and the other seventeen subjects (13 females; mean age: 22.2 years) with peripheral visual stimulation. They had normal or corrected to normal vision and normal hearing, with no known neurological disorders. Their colour vision was tested by Ishihara colour perception test. Each participant signed an informed consent before the test. The experiment fulfilled the requirements of the Ethical Committee for Experimental Procedures of the University of Szeged.

Stimuli and procedure

Subjects were seated in a sound-attenuated dark room. Their heads were rested on a chin and forehead support to ensure a fixed viewing distance. The eyes of the subjects were 57cm away from the computer screen and the speakers; from this distance 1 cm on the monitor corresponds to 1° of visual angle. The stimuli were presented on a CRT monitor (ViewSonic PF815). The diameter and the resolution of the screen were 21" and 800 x 600 at 60 Hz, respectively. The two computer speakers were positioned on both sides of the monitor, symmetrically, at 25° eccentricity from the fixation point. Subjects had to fix their gaze at the middle of the monitor, thus the size and position of the visual stimuli were held constant on the retina. A disc subtending a visual angle of 1.5° was displayed in a central or peripheral position as visual stimulus for the two groups of the subjects (central and peripheral stimulation, respectively). All stimuli were presented on a uniform green background (8.9 cd/m^2). In the peripheral task a fixation point was placed in the middle of the screen and the stimulus was presented at 9.25° eccentricity. In the central task, the disc was presented in the middle of the screen without using fixation point.

We used four conditions with high contrast (HC) with white disc (63 cd/m^2 , contrast 75%), low contrast (LC) with grey disc (9.7 cd/m^2 , contrast 9%), subjective isoluminant (S-iso) and (P-iso) physically isoluminant (8.9 cd/m^2 , without contrast difference) with red disc in both positions.

The central and peripheral tasks contained four blocks (four main conditions, HC, LC, S-iso, P-iso), and followed each other randomly to reduce the chance of fatigue or learning. One

block contained 6 subconditions: 6 variations of flashes and tones (one flash, one flash with one tone, one flash with two tones, two flashes, two flashes with one tone, and two flashes with two tones). One subcondition consisted of 40 repetitions of trials, thus one block contained 240 semi randomly presented trials.

In the intertrial interval a grey background was presented for 1000 ms. The presentation of the trials started with the colour change of the background to green which was matched in luminance to the previous one. On this background, after 200 ms one or two discs were presented successively for 17 ms with one or two tones, according to the given condition. The stimulus onset asynchrony between two flashes was 85 ms. The duration of the tones (3.5 kHz, 70 dB SPL) was 10 ms and the first one was presented at the same time as the first flash. After the presentation of flashes and tones the subject was asked to decide whether one or two discs were displayed and press the left (one flash) or right arrow (two flashes) button on the keyboard with the dominant hand as quickly and accurately as he or she can. After the subject pressed a button, the isoluminant grey background (8.9 cd/m^2) appeared as an intertrial interval for 1000 ms. Feedback was not provided about the correctness of the response.

Analysis

Signal detection theory was used to analyse the behavioural results since it can verify that the reports on illusory percept are not only caused by response bias. To see the power of illusions we compared the control d' value to the d' for fusion or double flash using paired t -test with Bonferroni correction in each condition. Thus, we accepted results as significant when the $p < 0.025$. Since the strength of the illusions are characterised by this difference, we used these values to test the variance between the conditions with one-way repeated measures ANOVA in central and peripheral conditions using Bonferroni post-hoc test.

Results

Central presentation: in the high contrast condition, no significant fusion effect was shown, $t(16)=1.71$, $p=0.10$), but there was a significant double flash effect after Bonferroni correction, $t(16)=5.06$, $p < 0.001$. In the low contrast condition, no significant fusion effect was shown, $t(16)=2$, $p=0.05$, but there was a significant double flash effect, $t(16)=4.29$, $p < 0.001$, with the same test. In the subjective isoluminant condition, both significant fusion, $t(16)=5.167$, $p < 0.001$, and significant double flash effect, $t(16)=3.72$; $p < 0.01$, were shown. In

the physically isoluminant condition, both illusions, the fusion, $t(16)=2.771$, $p<0.05$, and also the double flash, $t(16)=2.74$, $p<0.05$, were significant).

The repeated measures ANOVA of the difference scores for the central conditions did not reveal any significant differences between the different conditions (high-contrast, low contrast, subjectively or physically isoluminant), either for the fusion ($F(2.676, 42.81) = 1.748$, $p=0.17$) or for double flash ($F(2.472, 39.55) = 1.287$, $p=0.29$) illusions.

Peripheral presentation: in the high contrast condition, significant fusion effect $t(16)=3.47$, $p<0.01$, and double flash effects $t(16)=4.86$, $p<0.001$, were shown. In the low contrast condition, no significant fusion effect was shown $t(16)=0.93$, $p=0.36$, but there was a significant double flash effect $t(16)=3.66$, $p<0.01$. In the subjective isoluminant condition, no significant fusion effect was shown, $t(16)=1.83$, $p=0.08$, but there was a significant double flash effect $t(16)=3.68$, $p<0.01$. In the physically isoluminant condition, significant fusion effect $t(16)=4.42$, $p<0.001$ and also double flash effect $t(16)=4.52$, $p<0.001$ were shown.

The repeated-measures ANOVA of the difference scores for the peripheral conditions showed significant differences between the different conditions (high-contrast, low contrast, subjectively or physically isoluminant) for the fusion effect ($F(2.286, 36.58) = 3.898$, $p<0.05$), but there were no significant differences between the different conditions for the double flash ($F(2.684, 42.94) = 1.653$, $p=0.19$) illusion. In case of the fusion effect the Bonferroni multiple comparison test showed that in the LC condition the difference between the control d' and d' for fusion is bigger than these values in P-iso conditions.

Experiment II.

In the second study we investigated the role of parallel visual pathways in the fast categorization. The idea that the M information could play essential role in categorization originated from studies demonstrated that the accuracy of decision making about the presented stimuli do not decrease if the stimuli are achromatic containing only LSFs, presented very briefly or reflected to the peripheral part of the retina. Furthermore, the information reaches the cortical areas via the M pathway earlier than the P. The researchers agree that this first available, coarse information can accelerate the processing of fine details, but what cortical pathway is used for it is unknown. On the cortical level almost one half of the M inputs projects to the inferotemporal cortex (IT) parallel to the ventral pathway and the other half of it gives input to the dorsal pathway projecting to the parietal and frontal areas.

Our goal was to investigate if the M projections reach the IT via the dorsal pathway activating the orbitofrontal areas (OFC) or via the ventral pathway. For answering this we used a categorization task presenting pathway specific visual stimuli and we used transcranial direct current stimulation (tDCS) over the OFC to modulating its function. We hypothesized that if stimulation of the OFC does not have an effect on decisions concerning both M and P optimized stimuli, or if the effects are similar using both stimuli that would support the idea that fast M information is processed through the ventral pathway avoiding the OFC. If, on the other hand, decisions about M stimuli were affected selectively, it would support the hypothesis that M information reaches the OFC, passes through it and is available for top-down modulation.

Methods

Subjects

Forty-eight healthy subjects (university students, 19 females; mean age: 22.7 years) participated in the study. They were divided in three equal groups for cathodal, anodal and sham stimulation. Each subject had to perform the task before and after the stimulation (see below). All had normal or corrected-to-normal vision, including normal colour vision and none of them suffered from any neurological or psychiatric disorders. None of them had a history of excessive drug/alcohol/caffeine consumption. A questionnaire was provided regarding previous diseases, handedness, sleep time, medication, mental and physical status. All study participants gave written informed consent in accordance with the Declaration of Helsinki; the study was approved by the ethical committee of the University of Szeged (Ref. no.: 165/2014).

Stimuli

The stimulus set contained 200 achromatic images of everyday objects, like a truck, ashtray, pen, piano, etc. Stimuli were modified using Matlab and GIMP 2.8 programs. Stimuli were cut out from the original pictures, were standardized in the sense that all had the same size in their largest dimension ($4,5^\circ$ viewed from 57 cm) placed on the same background, transformed to grayscale images. Shine Toolbox was used to equalize the contrast and luminance values before filtering. Images had resolutions of 72 pixels per inch and size of 500*500 pixel. The visual stimuli were modified to selectively stimulate the M or the P; they were filtered by Gaussian filter (12 pixel kernel, as lowpass filter) and highpass filter (0.5

radius) to attenuate the high and low spatial frequencies, respectively. The M optimized stimuli contained LSF (<0.9 cycles per degree), while the P stimuli consisted of HSF (>4.7 cycles per degree.). This method is similar to the one used by Bar M et al. (2006). All stimuli had a mean luminance between 8-9 cd/m². No luminance matching was used after filtering. The images of the objects could be divided into two groups according to their real life size. One half of the objects were larger, while the others were smaller than an average shoe box. All stimuli were presented on a uniform grey background (8.9 cd/m²).For stimulus presentation a 23-inch LCD (Tobii Pro TX300) monitor was used having screen resolution of 1920 x 1080 and vertical refresh rate of 60 Hz.

Behavioural test

The subjects were seated in a sound-attenuated, dimly lit room, and viewed the computer screen from 57 cm. For stimulus presentation a custom made MATLAB code (MathWorks, Natick) and the Psychtoolbox Version 3 (Brainard DH and S Vision 1997) was used.

At the beginning of the experimental procedure all subjects received instructions on the computer screen to make sure that everyone was given identical instructions on how to solve the task. There were two sessions during the test, thus each subject was tested twice. In the first session, before the tDCS, half of the stimulus set (100 images) was presented, which contained an equal number of small, large, M and P optimized object images in a pseudorandom order. The second session started just after tDCS (or the sham stimulation) and the rest of the stimuli (other 100 images) were presented again in a pseudorandom order. During the psychophysical sessions the participants were required to make decisions about the object size and to answer the question whether the object displayed on the screen was larger or smaller than a shoebox. The left arrow key on the computer keyboard was associated with smaller, the right arrow key with larger objects. Size decisions were tested in a preliminary psychophysical experiment. The trials started with a centrally presented fixation-cross (250 ms) appearing before the stimulus in the centre of the screen, followed by the test stimulus. The trials were machine paced: if no response key was pressed for 3 s, the next image was presented. There was no feedback on the correctness of the responses

Stimulation protocol

To modulate prefrontal cortical activity, transcranial direct current stimulation was applied. Two rubber electrodes (surface: 5x7 cm) were used with a neuroConn DC-stimulator (neuroConn GmbH). The electrodes were arranged according to the study of Manuel AL et al. (2014). They reported a significant modulation of the OFC function (reality filtering) upon direct current stimulation. In their study, the electrical fields induced by tDCS were modelled to predict whether significant current reached the OFC. The model reached a significant current flow in the OFC when the electrodes were placed over the glabella and the vertex (Fpz and Cz of the 10–20 EEG system, respectively) and the electrical field values were calculated for 1 mA of inward current. In our study, the electrodes were placed on the midline; the centre of the relevant active tDCS electrode was over the putative OFC cortex (Fpz), while the reference electrode was over the vertex (identified by the standard 10-20 system). Stimulation was applied for 20 minutes with 1mA current intensity using 10 s fade in and fade out phase in cathodal and anodal stimulation protocol, respectively. Sham stimulation consisted of placing the electrodes on the skull, but no tDCS was applied with the exception of the 10 s fade in and 10 s fade out phases. This stimulation does not have any effect on cortical excitability, but causes the same itching sensation under the electrodes. The total duration of the sham phase was also 20 min. The study was a single-blind experiment: the experimenter was fully informed, but participants were not informed about the type of stimulation they received.

Statistics

To see the differences in processing time for the M and P optimized stimuli, SPSS Inc. software was used to compare response latencies and accuracies before stimulation (since the conditions were the same for each participant in this period); a paired t-test was applied, differences were considered as significant if the type I. error was <0.05 . To evaluate the effects of transcranial stimulation we used repeated measures three-way ANOVA with between group factors being type of stimulation and within group factors being time of behavioural test, and pathway (M, P). We compared the response accuracy and the reaction times before and after the stimulation.

Results

Accuracies and response latencies before the stimulation:

The three groups of volunteers performed the task under identical conditions (n=48). Paired t-test was used for the statistical evaluation. The percentage of correct answers was $91.50 \pm \text{SD}=4.05$ using M stimuli, comparing with accuracy of P stimuli (mean 90.06, $\pm \text{SD}=4.69$) the difference was not significant $p=0.12$ (df=47, $t=1.58$). Decisions about stimuli optimized for the M yielded shorter response latencies than those for P stimuli (mean M latency = 0.90 s, $\pm \text{SD}=0.20$ s, mean P= 0.98 s, $\pm \text{SD}=0.23$ s, M). These results suggest that the reaction time differences originate from the different processing times needed for M and P optimized stimuli, not from the differences in the recognising ability of the M and P stimuli sets. This test verified that M optimized stimuli are associated with shorter response latencies.

Effect of stimulation on response latencies

A repeated measures three-way ANOVA was used to test main effects and possible interactions between changes in response latencies according to the types of stimulation. The within factors were the pathway (M, P), time of the behavioural test (before and after the stimulation) and group factor was type of stimulation (anodal, cathodal, and sham). All possible interaction terms were taken into account. Concerning the response latency times we did not find significant effects in the cases of stimulation type [$F_{(2, 45)} = 1.336$, $p = 0.273$, partial eta-squared = 0,06]. The reaction times showed differences according to the pathway factor [$F_{(1, 45)} = 28.46$, $p < 0.01$, partial eta squared = 0.39] and the time factor [$F_{(1, 45)} = 8.69$, $p < 0.01$, partial eta-squared = 0.16]. The after stimulation reaction times became faster in the case of all stimulus type, and the response latencies for M stimuli were faster throughout the test. While analysing the interactions, we did not find interaction between the pathway and stimulation type factor [$F_{(2, 45)} = 0.59$, $p = 0.56$, partial eta-squared = 0.03], time and stimulation type factor [$F_{(2, 45)} = 0.36$, $p = 0.69$, partial eta-squared = 0.016] and pathway and time factors [$F_{(1, 45)} = 0.65$, $p = 0.42$, partial eta-squared = 0.014]. Furthermore, there was no significant interaction between the three factors examined [$F_{(2, 45)} = 1.99$, $p = 0.15$, partial eta-squared = 0.81].

Effect of stimulation on accuracies

To see how transcranial stimulation of the OFC affected accuracy levels three-way ANOVA with repeated measures was used to test main effects and possible interactions between the changes in accuracy and types of stimulation. The factors again were the pathway (M-P), type of stimulation and time (before or after the stimulation). All possible interaction terms were taken into account. The interaction of all factors was significant [$F_{(2, 45)} = 5.81$, $p < 0.01$, partial eta-squared = 0.21]. Using stimulation type factor we found significant difference between the groups [$F_{(2, 45)} = 4.77$, $p < 0.01$, partial eta-squared = 0.18]. In the case of pathway factor we also found significant difference [$F_{(1, 45)} = 13.74$, $p < 0.01$, partial eta-squared = 0.23], but the interaction of the aforementioned factors was not significant [$F_{(2, 45)} = 1.03$, $p = 0.36$, partial eta-squared = 0.04]. Examining the effect of time factor we did not find significant differences [$F_{(1, 45)} = 1.79$, $p = 0.19$, partial eta squared = 0.04]. The interaction of time and stimulation type factor was significant [$F_{(2, 45)} = 9.64$, $p < 0.01$, partial eta-squared = 0.30] but there were no significant interactions between the time and pathway factors [$F_{(1, 45)} = 2.78$, $p = 0.10$, partial eta-squared = 0.06]. The existence of the three-factor interaction suggests that the interaction between time and stimulation depends on the level of pathway factor (P and M stimuli, representing two levels), with other words, the dependence between change in time and the stimulation (representing three levels) differs in the P and M stimuli, therefore the relationship between change in time and stimulation was evaluated at the levels of stimulus. We used Bonferroni post-hoc test to examine between which groups and conditions the significant effect can be found. The most important differences were found between accuracies measured before and after stimulation when presenting M stimuli and using anodal ($p < 0.01$) and cathodal stimulation ($p = 0.015$). The accuracy increased when anodal stimulation was used, while the cathodal stimulation decreased the percentage of correct answers. Comparing on the level of pathway factor we found significant differences between the sham group after stimulation values ($p < 0.01$) and anodal group after stimulation values ($p < 0.01$). Furthermore, there were differences between the different groups, the accuracy for the M stimuli after the stimulation differed between the sham and anodal groups ($p < 0.01$) and anodal and cathodal groups ($p < 0.01$).

Conclusion

In the first experiment we investigated how the temporal resolution of the selectively stimulated visual pathways plays a fundamental role in the establishment of coherent multimodal perception. Inconsistent information from different modalities can be misleading for perception. This can be observed with simultaneously presented inconsistent numbers of briefly presented visual stimuli and short tones. The conflict of bimodal information is reflected in double flash or fission, and flash fusion illusions, respectively.

As the parallel visual pathways have different temporal resolution we presume that these pathways play different roles in the integration of conflicting information from different modalities. To test this hypothesis, we used the above mentioned multimodal illusions using pathway specific stimuli. Our results show that both pathways support the double flash illusion, while the presence of the fusion illusion depends on the activated pathway. The M pathway, which has better temporal resolution, does not support fusion illusion, while the P pathway which has worse temporal resolution shows the fusion percept strongly.

In our second study we investigated the role of the two pathways in a categorization task. However fast categorization is essential in everyday life, the neuronal background of the fast and efficient information processing required has not been established yet. There are two main hypotheses known, both agree that primary, global impressions are based on the information supplied through the M pathway, but they have different hypotheses about the possible cortical pathways behind their findings.

We used a categorization task in which the subjects had to make decisions about size of the presented objects. LSF and HSF stimuli was used for driving the M and P pathways on the basis of their spatial frequency preference.

Our psychophysical results were in line with the previous studies suggesting that the faster categorisation is possible based on M information. Furthermore, using transcranial direct-current stimulation over frontal areas, one of the possible targets of the M pathway we could influence the decisions on M, but not the P pathway. Our results support the hypothesis that fast visual categorization processes rely on top-down mechanisms that promote fast predictions through coarse information carried by M pathway via the orbitofrontal cortex.

In these studies, we demonstrated how the M and P pathways play different roles in the formation of a stable representation of our sensory surrounding

Acknowledgements

I would like to thank prof. Dr.GyulaSáry, the head of the Department of Physiology and my supervisor his kind support and valuable guidance.

I respectfully thank prof. Dr.GáborJancsó for accepting me in the Neuroscience Ph.D. program.

I would like to say thanks to my colleagues, Dr.PéterKaposvári, Dr.PéterCsibri, GyörgyiUtassy for the help they provided during the experiments and analysis.

Special thanks go Dr.ZsigmondTamásKincses, Dr.GergőCsete and all the members of Neuroimaging Research Group for providing the opportunity of cooperation.

I am grateful to the former and present students: Dr.MárkCsabaAndrás, Margit Németh, SzabolcsSáringér.

I would like to thank all my colleagues in the Department of Physiology to provide an excellent atmosphere for my work.

Finally, my greatest thanks go to my friends and parents who support and encourage me.

This work was supported by TÁMOP 4.2.4. A/2-11-1-2012- 0001 and UNKP-17- 3 awarded to Anna Bognár.