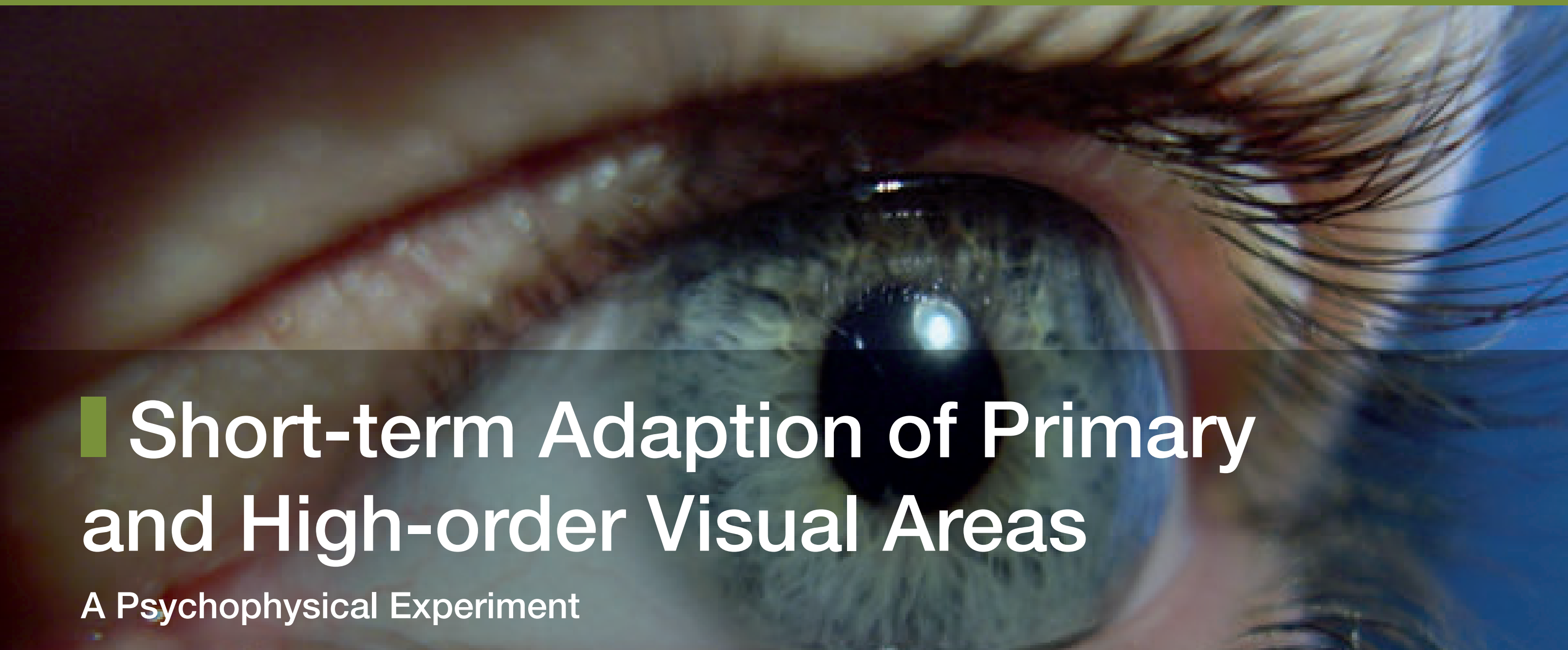

Short-term Adaption of Primary and High-order Visual Areas

A Psychophysical Experiment

Visual adaptation is a known phenomena induced when the visual system is exposed to the same stimulus for a prolonged time. When the stimulus is turned off one of the systems' calibration mechanisms are caught off-guard and visual perception is briefly perturbed. In our study, we conducted for the first time a psychophysical experiment on short-term adaptation of primary and high-order visual areas.

1 Introduction

Vision is the most dominant sensory modality of primates. When light enters the eye, photoreceptors in the retina transform the energy into electrical signals. These signals are then sent by interneurons to ganglion cells. The fibers of the ganglion cells cross at the optic chiasm and terminate in the lateral geniculate nucleus (LGN). Visual information is then transferred to the primary visual cortex (V1). V1 is one of the most studied cortical areas, it is also called the striate cortex or area 17, located in the occipital lobe at the back of the brain, two millimeters thick and densely packed with 6 layers of cells.

From V1, information is sent to other areas of the visual cortex for further, higher analysis. Visual information is then divided into two paths known as the ventral and dorsal stream. The ventral "what" stream controls recognition, object representation and memory while the dorsal "where" stream runs motion and object locations.

A variety of experimental procedures has been developed for demonstrating the cortical architecture and the unique pattern of activation for each group of cells. In their pioneering electrophysiological studies of monkeys and cats, Hubel and Wiesel worked out the appropriate light stimuli for various cortical cells [5]. It was found that V1 has neurons with elongated receptive fields which respond best to simple stimuli such as bars, lines and edges. V1 neurons also have spatial-frequency seletivity and respond to luminance changes. Visual cortical neurons are highly tuned and specialized for processing a certain aspect of

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visual information such that any given neuron only responds to a subset of stimuli in its receptive field.

Recognizing an object in the human brain takes only a fraction of a second. The neural mechanisms underlying this remarkable ability are not well understood. Until the mid-1990s, little was known about the functional organization of human visual cortex. This landscape has changed dramatically with the invention of functional magnetic resonance imaging (fMRI), a powerful tool for the noninvasive mapping of the normal human brain.

Recent studies have shown that there are regions in the cortex which specialize in specific visual stimuli recognition. Using fMRI techniques, Malach and colleagues delineated an area that showed a preferential activation to images of objects, compared to a wide range of texture patterns [9]. This area was termed the lateral occipital cortex (LOC).

Kanwisher and co-workers have suggested that this area and some other regions located at the ventral temporal cortex, contain a limited number of modules specialized in specific category recognition such as faces (fusiform face area; FFA), places (parahippocampal area; PPA), and body parts (extrastriate body part area; EBA). ([6]; [10], [11].

Vision is the most dominant sensory modality of primates. The visual system is almost constantly exposed to new images and thus it is forced to adjust the visual coding to the characteristics of the image currently presented. Visual adaptation is a known phenomenon induced when the visual system is exposed to the same stimulus for a prolonged time. Processes of visual adaptation manipulate the sensitivity of the cells in the visual cortex. Exposure to an adapting pattern for several seconds causes a decrease in the sensitivity of neurons tuned to the pattern's specific properties. This phenomenon lasts a few more seconds after the stimulus is turned off, and thus defines the adaptation effect. In that period the exposed subject recalls striking changes in the perception of shape, color and motion. Adaptation involves a variety of visual attributes and stages of visual processing.

Long-term visual adaptation and its effects have been extensively studied for many years. It is known that due to adaptation, our brain is forced to bias any new information to alternative non-adapted neurons which is why our perception is briefly perturbed. Very little is known though about short-term adaptation.

Our project is divided in two parts: we intend to contribute to a better understanding of short-term adaptation mechanisms in – on the one side – primary visual areas and – on the other side – in high order face-related visual areas. As we can see clearly, there is a hot debate on the neural mechanisms that are fundamental to face perception and yet, a major consensus regarding cortical areas that are most activated by viewing faces.

We, therefore, used 2D geometrical shapes with grayscale grating pattern and 2D grayscale face images as the most captivating and tuned stimuli. Our main assumption was that short-term adaptation affects the ability to receive and analyze new coming stimuli. In order to prove it, we conducted a psychophysical experiment testing the impact of short-term adaptation on subjects' ability to distinguish changes in contrast and figural properties of a stimulus.

2 Methods

Two psychophysical experiments were conducted which were aimed to find out the influence of short-term adaptation on the ability to note minor changes in the presented stimuli. It is important to note that without adaptation those modifications could be easily detected. The experiments were conducted serially as the order was controlled.

2.1 Participants

Twenty subjects (eight males and twelve females) participated in the experiment, five of them were eliminated (two males and three females) due to some environmental factors while conducting the experiment. All of them were students at the age of 16 - 33 years. All were regular users of computers and had normal or corrected-to-normal vision. Except for one, all the subjects were right-handed. The amount of sleeping hours during the night before the experiment varied between 4 - 9 hours. Three of them have participated in psychophysical experiments before.

2.2 Stimuli of the experiment on primary visual areas

To examine the effect of short-term adaptation in primary visual areas, stimuli were chosen which most activate the primary visual cortex (Experiment A). While constructing our experiment we used motives resembling to those found in previous research dealing with long-term adaptation. These kinds of stimuli are proved to activate mainly primary areas in visual cortex. We used four different 2D geometrical shapes with grayscale grating pattern; each had four different types of modification (Fig. 1): the original image, same image with modified spatial frequency (figural modification), both with original and different level of contrast (contrast modification). All modified parameters were controlled such that in each image the modification level is comparable to the other.

2.3 Stimuli of the experiment on high-order visual areas

As our second aim was to examine the effect of

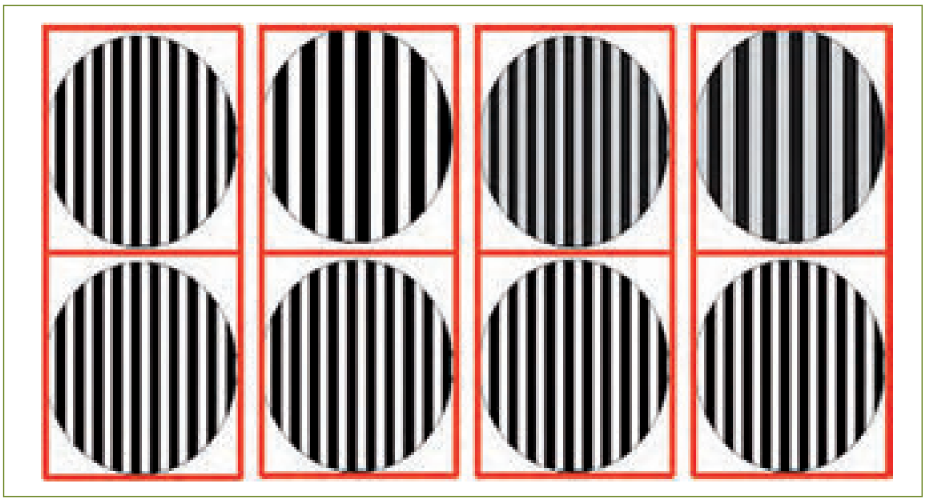

Figure 1: Experiment A: Bottom row-original images, upper row-different modifications a) no modifications, presenting the same image again. b) spatial frequency modification. c) contrast modification. d) a combined modification of both contrast and spatial frequency

Figure 2: Experiment B: Bottom row-original images, upper row-different modifications a) no modifications (presenting the same image again), b) face properties modification c) contrast modification d) a combined modification of both contrast and face-properties.

short-term adaptation in high order visual areas, we chose stimuli which most activate high order visual cortex (Experiment B). As social primates, faces are the most common stimuli which we are exposed to in our life span. These kinds of stimuli are proved to activate mainly secondary areas in visual cortex. We decided to use unfamiliar faces to avoid any other effect. Four different images were used; each had four different types of modification (Fig. 2): the original image, a modified face, both with original and different level of contrast. Face modification was performed using 'Morphases' program (www.morphases.com). All modified parameters were controlled such that in each image the modification level is comparable to the other.

2.4 Presentation

The experiments were conducted using 'Presentation©' program package.

2.5 Procedure

We were interested in the viewer's performances both in accuracy and speed aspects. Since there is a trade-off between the two, our instructions were to pay attention to both of them but accuracy should be more important than speed. Eight images were presented in a pseudo-random block sequence. Image presentation within each block was controlled in a way that preserves a constant ratio between different "events" (Fig. 3).

For every stimulus four block types were created presenting only one kind of stimuli (with the needed modifications in the needed order according to the block type) in it. In the first block (type 1) adaptation was acquired by exposing the subject to the same image eight times. The second block (type 2) was composed of images with only minor changes. The third one (type 3) contained pictures with different aspects of modifications; original (non-modified), spatial frequency modifications, contrast modifications and with modifications both in contrast level and in spatial frequency. The purpose behind this approach was that these changes interrupted the adaptation so we could use the fourth block (type 4) (which was quite similar to the second one concerning the types and numbers of different events) as a control. As the most important point was to have the first two and second two blocks to follow each other, we shuffled the blocks a bit so that our subject will not get bored and find any rules about the procedure of the experiment.

Subjects were asked to perform 'one-back-match' task. The question to answer was to decide whether they consider the presented image the same (pressing button 'yes'), or they note any changes in the picture's figural properties comparing to the previously presented image (pressing button 'no'). We directed them to consider only figural modification as remarkable change. As subjects were not informed about the aims of the block types, they were instructed to perform the task during the whole experiment.

A fixation point was shown during the whole experiment. Visual epochs were alternated with 5-s blanks. Four cycles of the stimulus were shown (one for each image). As we had altogether 16 blocks the total time was 336s.

3 Results

Data analyses included several different aspects; all refer to the accuracy of performances regardless of subjects' response time.

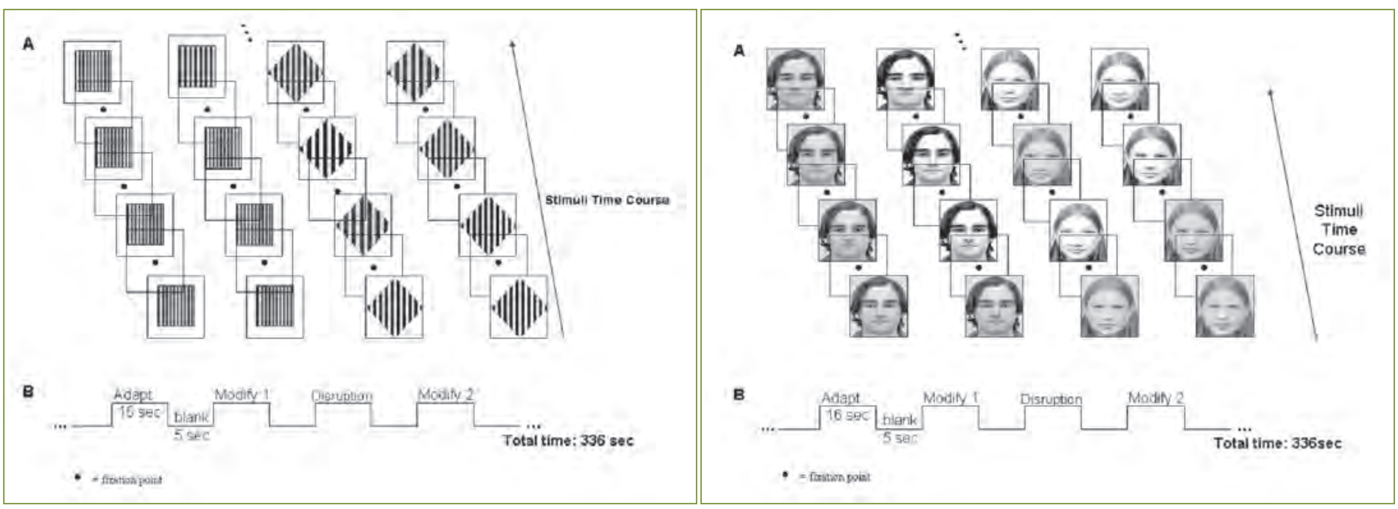

Figure 3: Experimental paradigm for experiment A (left) and B (right): (A) Four types of blocks (left to right): adaptation, control_1, adaptation interruption, control_2. (B) A segment from the time axis of the experimental run of an overall duration of 336s.

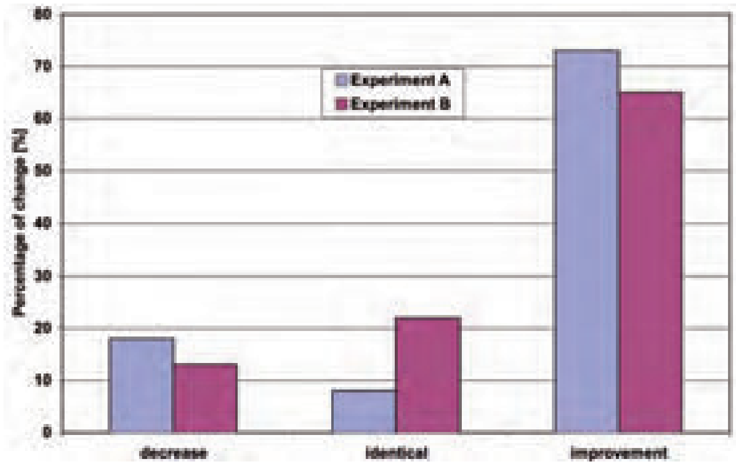

Figure 4: The percentage of change in accuracy between the second and the fourth blocks. A significant improvement in performances was indicated after interrupting adaptation.

3.1 The influence of adaptation / interruption (of adaptation) on response accuracy

The first block in both experiments was supposed to generate adaptation and the third one was supposed to interrupt adaptation. The second and fourth blocks were similar which enabled us to use them as internal controls. We, therefore, focused on the responses given in the second and fourth block, assuming that significant differences in performances between these two homologue blocks result from the primer block.

Experiment A: As we can see in figure 4, in 73 % of the events, the subjects' ability to note minor changes in the displayed picture is increasing after the interrupting block. In 18 % of the events, the value of accuracy remained the same and in 9 % of the events accuracy level decreased.

Experiment B: The same analysis was done on the data derived from Experiment B, where we found that in 65 % of the events the subjects' ability to note minor changes in the displayed picture is increasing after the interrupting block. In 22 % of the events, the value of accuracy remained the same and in 13 % of the events accuracy level decreased.

3.2 Error analysis

Tracing the most confusing event, we examined the distribution of error types in experiment A and B. From these results (see Fig. 5) it can be clearly seen that in both experiments most of the errors were due to contrast modifications. The properties of the first error after adaptation effect were investigated. It was found that in both experiments errors due to changes in contrast level were the most dominant (see Fig. 6).

3.3 Comparison of the two experiments

First of all, we compared the number of errors in the two experiment types. The average percentages of total errors did not show any significant differences.

We also compared the average percentages of errors due to different contrast levels. As it can be seen, the errors due to contrast levels in both the primary and high-order experiment had no significant difference (see fig 7).

3.4 'Training' effect

Half of the subjects participated first in the high-order adaptation experiment and half of the subject participated first in the primary-visual-areas adaptation experiment. For each subject the total accuracy level was calculated for both experiments and a total average was calculated. A minor improvement trend was demonstrated in the second experiment, regardless of experiment-type. This might be due to some 'training' effect, in which the subjects are more familiar with the task and thus achieve better performances.

4 Discussion

There have been many studies on adaptation effects using fMRI but hardly any psychophysical experiments on short-term adaptation. The study of short-term adaptation is important because it can aid in understanding neuronal mechanisms better and can also help scientists in mapping the functional properties of cortical neurons. The behavioral analyses performed in this experiment, which successfully showed adaptation, can be carried out through fMRI for a more detailed description of underlying neuronal activity. The experiment proved adaptation occurred when the subject responded to the second block of images less accurately after looking at a repeated image than after looking at a block with altered images. This adaptation, indicated by other scientists, was due to fatiguing neurons responding less than normal.

We assumed that the response time of a subject after acquiring adaptation would grow due to the conflict between the adapting stimulus and

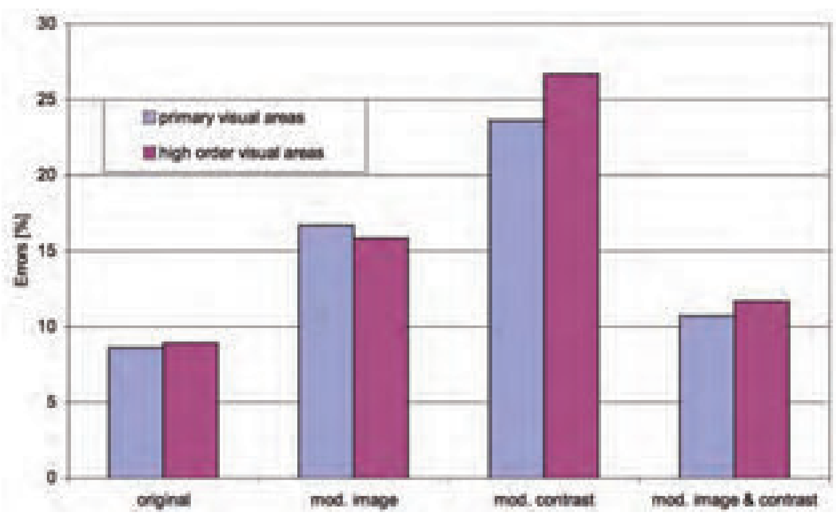

Figure 5: Distribution of error types. The total number of errors was analyzed according to its "event" type. The percentage of each group was calculated for each subject separately and was averaged across subjects.

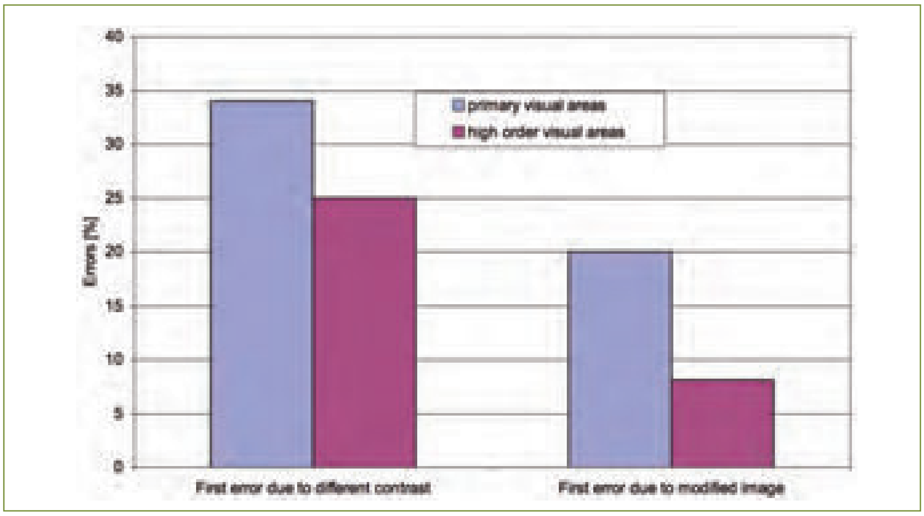

Figure 6: Percentage of the errors in first exposure to modified image after acquiring adaptation (block 2). Two different optional error types: caused due to an image modification or a contrast modifications.

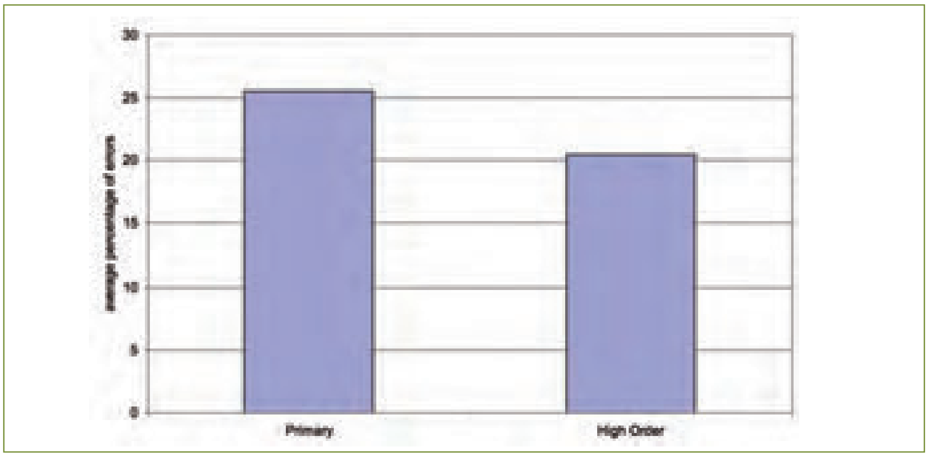

Figure 7: Percentage of the errors in first exposure to modified image after acquiring adaptation (block 2). Two different optional error types: caused due to an image modification or a contrast modifications.

the changed ones. We collected information about response times during the experiment but did not analyze it in order to face this question, which remains open for further research.

5 Conclusion

We showed for the first time that short-term adaptation behavior achieved by the psychophysical experiment is correlated with the results achieved by long term adaptation experiments, and also consistent with results achieved in fMRI-adaptation experiments.

Due to time limitations, only the accuracy aspect of our results was analyzed. This aspect of the results is compatible with our basic assumption: Short-term adaptation causes a decrease in the accuracy of reaction to changes in stimuli. The most ambiguous behavior was demonstrated after contrast modifications. It was found that errors due to changes in contrast level were most dominant, and thus imply that the system is aware of some change but fails to specify it.

Conducting two parallel researches, one dealing with "complex" stimuli, activating high order cortical areas, and the other with "simple" stimuli, stimulating primary visual areas, we correlate the results of the studies. This unique comparison revealed a vast resemblance in the results of the two. We therefore suggest that the behavioral mechanisms underlying short-term adaptation effect are similar in both types of visual areas.

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