Temporal Processing of Cyclopean Stimuli: A Psychophysical Study

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Abstract

In the clinical practice, the evaluation of binocular vision is carried out with the traditional Worth-4-dot test, which is based on his classic theory, suggesting three hierarchical stages of stereovision (Worth, 1906). However, according to research nowadays, binocular vision rather involves parallel pathways. We do not know how the hierarchical organizational principles set forward in the Worth model can be related to the parallel processing pathway theory. We aimed to use reaction time (RT) measurement, a traditional psychophysical method, in a series of experiments, to examine the processing time of mechanisms in stereovision by using different types of cyclopean stimuli that are only visible binocularly by individuals who have intact stereopsis. We tested the effect of correlation, disparity and contrast on RT. Overall, the results suggest that the processing of cyclopean stimuli is more time consuming than non-cyclopean ones and that the speed further depends on the disparity and contrast of the stimuli. We have failed to prove that the processing of the different types of cyclopean stimuli takes a hierarchical order, rather, the results support the idea of parallel systems.

Keywords: cyclopean reaction time; disparity; dynamic random dot correlograms; dynamic random dot stereogram

Introduction

The two images, seen by the two eyes are somewhat different, resulting in the so-called disparity, which the brain uses for judging depth in space. Stereovision enables to see the world as one uniform 3D percept, instead of two separate images coming from the two eyes.

The first, thoroughly elaborated model of binocular vision was worked out by Worth (Worth, 1906). The model is widely used in clinical practice and suggests a hierarchical organization in stereopsis. According to the model, there are three grades of binocular vision: (1) simultaneous macular perception, where the person sees both images in the stereoscope, but is unable to maintain fusion; (2) true binocular fusion, where the person can keep the fused image, but only if they are the same, therefore in case of two, slightly different images, one will eventually be suppressed, and; (3) stereopsis, in which case slightly different images promote the effectuation of stereo-perception and the judgment of depth, and fusion is maintained (Worth, 1906). The existence of these grades are evaluated clinically by the Worth 4-dot test (Worth, 1906), which is able to confirm binocular vision only up until the level of the second grade, true binocular fusion. Even though it is used for the clinical evaluation of binocular vision, it is still unknown exactly what neurophysiological processes operate at each stage and what is the temporal relationship between the neural mechanisms of the different grades. The Worth theory presumes a hierarchical relationship between the grades, but latest research finds that there are at least two separate, lower level parallel mechanisms of stereoscopic visual processing that provide inputs into higher level vision (Julesz & Tyler, 1976; Mishkin, Ungerleider, & Macko, 1983; Parker, 2007; Wolfe, 1986).

A pioneer in the examination of stereovision was Béla Julesz, who constructed random dot stereograms and correlograms (Julesz, 1980). These stimuli are special patterns that consist of random dots that do not show any obvious pattern when viewed monocularly, but evoke a sensation of depth or a percept of shape separated from the surface (i.e., located behind or in front of) of the monitor, when viewed binocularly by a person who has intact stereovision. Julesz and our laboratory have both published Visual Evoked Potential (VEP) studies using these stimuli, to explore different aspects of stereo processing (Markó, Kiss, Mikó-Baráth, Bártfai, Török, et al., 2009, Julesz et al. 1980). These studies examined the existence and the robustness of the visually evoked response by these so-called cyclopean stimuli. These studies, however are not designed to measure the exact time of processing of DRDC and DRDS stimuli, since it is well known that it is highly debatable to conclude processing time from them, because it is not always clear which VEP component represents which processing stage, so we cannot identify the point in time when perception takes place and when is it completed. The relative changes in the wave latencies of VEP correlate with cortical processing, but the absolute and accurate processing time cannot be determined. For this reason, we have chosen RT measurement, a psychophysical approach that is traditionally used when processing time needs to be explored.

There is a relationship between the speed of response and the complexity of the stimulus. As a general rule, simple mechanisms take a short time, whereas more complex and higher order mechanisms take longer time to complete (Thorpe, Fize, & Marlot, 1996). In general, neural mechanisms that operate at different processing speeds could be separated based on RT measurements (Julesz & Tyler, 1976). Therefore, we decided to initially approach these problems by measuring RTs, because it is a traditionally used method for measuring neural processing speed in psychophysics. By definition, RT is the time elapsed between the presentation of a stimulus and the subsequent behavioral response. RTs have two components; the detection and processing of stimuli and the motor response, i.e., the press of a button. Since the duration of the motor response, in well cooperating subjects, can be regarded as more or less invariable for a given individual; any intra-observer variability in RT provides information about the stimulus processing in question.

We were interested to explore the speed of processing for cyclopean stimuli in healthy observers, and how RTs depend on certain stimulus parameters when it comes to binocular vision.

Methods

Our laboratory uses DRDC and DRDS stimuli that were originally developed by Julesz (Julesz et al. 1980). We modified these stimuli to suit our purposes, to enable psychophysical RT measurements. Julesz originally developed an anaglyph technique, where cyclopean stimulus presentation was done on CRTs, exploiting the red and green phosphors of the monitor and the observers were wearing red-green goggles (Julesz, Kropfl, & Petrig, 1980; Julesz & Tyler, 1976). In our initial RT experiments we used the same technique, but a significant disadvantage of the anaglyphic technique is the low luminance, shifting the visual perception in the mesopic range. Therefore, we have recently started using LCD monitors with polarizing glasses, which allow to measure RTs for the different types of stimuli at much higher average luminance levels in the photopic range. The main data presented here was collected with the new technique we developed for 3D LCD monitors using polarizing glasses. When measuring reaction times, the stimuli have to be easily noticeable by the observer, and there has to be an objective change in the stimulus, or a different one has to appear which subjects can easily to indicate with a button press. In case of DRDC and DRDS, this issue can be addressed by presenting a cyclopean pattern that emerges on a neutral background. Only observes with intact stereovision can see the pattern, since only random dot noise is seen with one eye. In this study we measured RTs for DRDC and DRDS patterns that appeared from a dynamic random dot noise background, the type Julesz also used (Julesz et al. 1980). In the main experiment, we examined the effect of certain stimulus parameters, such as contrast and disparity on RTs. The stimuli in all cases were devoid of monocular artifacts.

Results

Here we present results of currently ongoing experiments together with some previous data that have been presented as a conference poster before (Gyenge, Mikó-Baráth, Török, Jandó, 2011), and is currently submitted and is under review at a scientific journal. This set of data serves as the basis for the currently ongoing experiments and helps to put new results into context. In both VEP and psychophysics, latencies and RTs for DRDC and DRDS stimuli are substantially longer compared to non-cyclopean patterns, respectively. In case of the second, main experiment we present here, we found that reaction time depends on disparity, showing longer RTs for small and large disparities with a definite minimum at disparities around the transition between fine and coarse stereopsis and contrast shifted this pattern. In general, higher contrast levels at a given disparity resulted in shorter RTs.

Discussion

Our findings imply that the visual processing of non-cyclopean information is faster than cyclopean information and the data confirms that our RT measurement method is reliable, showing consistent results. Furthermore, the speed of binocular information processing is disparity and contrast dependent and it seems that the visual system has a preference for a certain disparity range, as confirmed by shorter RTs.

To our knowledge, there is so far no experimental evidence that would relate the Worth model to other theories of binocular vision. It is also possible that in order to detect dynamic correlograms and dynamic stereograms, we need the same level of stereopsis. The reason why these random dot stereograms cannot be accurately positioned within the Worth model, is that we do not know how they relate to each other. Can the grades defined by Worth be used in a wider context as well? Are they served by different pathways, or by the same ones but with different weighed inputs? Are there more processing stages? A further confounding factor to note is that DRDS and DRDC are dynamically moving stimuli and it is still not known whether dynamic stimuli can be fit into the Worth model at all, which use static images.

We were also interested to test if there is a hierarchical organization between our different dynamic cyclopean stimuli. Our preliminary data showed that some amblyopic patients who clinically have the second Worth grade binocular vision, true binocular fusion, are unable to perceive dynamic random dot correlograms. Therefore, most probably, the perception of correlograms require the highest level of stereopsis according to Worth, but surely at least the 2nd grade for DRDC and the 3rd grade for DRDS. However, we can assume that there exists a theoretical neuronal network which is sensitive to binocular correlation (DRDC) but not necessarily sensitive to disparity (DRDS). According to our data, DRDC RTs are consistently longer, therefore the processing of DRDC cannot be considered as a hierarchically lower stage in binocular information processing implying that binocular correlation mechanisms and stereopsis might not be organized in a sequential order.

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