A brain electrophysiological correlate of depth perception

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ABSTRACT

الأهداف: التحقيق من نشاط المخ الكهربائي المصاحب لعمق الإدراك. وقد تم استخدام النقطة العشوائية stereograms. مزيد من التجارب أجريت للتأكد من هذا التحديد لعمق التصور.

الطريقة: أجري في هذه الدراسة ثلاث تجارب مختلفة ومستقلة عن 34 موضوع والتي من شأنها أن تسمح لنا بإثبات عمق العلاقة بين التصورٍ والقشرية الكهربائية المتطابقة. أثارة الإمكانيات البصرية رداً على التحفيز البصري العشوائي بين النقطة stereograms وقد تم تسجيلها. لتحقيق هذا الهدف وهو الحصول على البيانات وتحليلها، تم استخدام نظام مختلف عن عام البصرية أثار احتمال نظم التسجيل التي تتألف من اثنين من الحواسيب الشخصية. واحداً من هذه الحواسيب تم استخدامها لتحفيز الأنماط البصرية والأخر للتسجيل الرقمي لمتوسط إمكانيات إثارة المنشطات. أجريت هذه دراسة في قسم الفيسيولوجيا – جامعة مهابط – كلية الطب – أزمير – تركيا، خلال عام 2006م.

النتائج: عنصر السلبية المحتمل والذي يعتقد أنه ينشئ بالاشتراك مع عمق التصورٍ، تم تسجيلة من منطقة القفوية لـ30 شخصاً من أصل 34. عادتاً ما يكون لها من 211.46ms وسعة 6.40µV.

خاتمة: لقت هذه النتائج الدعم من قبل بياناتٍ سابقة لعاملين وجدوا إمكانية لمصاحبة عمق التصور. إضافتاً إلى ذلك، مزيد من التجارب أظهرت أن خصوصية العنصر الثاني من النظرة المتعمقة ليصبح واضحا لا شك فيه.

Objectives: To investigate brain electrical activity accompanying depth perception using random-dot stereograms. Additional experiments were conducted to ascertain the specificity of this potential to depth perception.

Methods: In the present study, we performed 3 different and independent experiments on 34 subjects to establish the relationship between depth perception and its cortical electrophysiological correlate. Visual evoked potentials in response to visual stimulation by random-dot stereograms were recorded. To achieve this goal, a data acquisition and analysis system, different from common visual evoked potential recording systems, consisting of 2 personal computers, was used. One of the computers was used to generate the visual stimulus patterns and the other to record and digitally average the potentials evoked by the stimuli. This study was carried out at the Department of Biophysics of Ege University Medical School, Izmir, Turkey, from April to December, 2006.

Results: A negative potential component, which is thought to arise in association with depth perception, was recorded from the occipital region from 30 of the 34 subjects. Typically, it had a mean latency of 211.46 ms and 6.40 µV amplitude.

Conclusion: The negative potential is related to depth perception, as this component is present in the responses to stimulus, which carries disparity information but is absent when the stimulus is switched to no disparity information. Additional experiments also showed that the specificity of this component to depth perception becomes evident beyond doubt.

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The random-dot stereogram (RDS) has been widely used in stereovision research for around 40 years. As a result, physiological studies investigating depth perception have gained a great impetus.[1] A derivative of the RDS is the autostereogram. There is a hidden, meaningful object in an autostereogram pattern. The hidden object concealed in the pattern can be perceived through convergence-divergence efforts of left and right eyes. However, this process requires training. In the present study, autostereographical RDS patterns have been used as visual stimuli. The electrophysiology of depth perception is not well understood.[2-5] A large negative occipital potential with an average latency of approximately 200 ms related to depth perception has been reported in previous studies using RDS patterns as stimuli. Several investigators claimed that potentials of this nature are always recorded in response to RDS patterns.[6] The aim of the present study was to ascertain that such potentials are specific to depth perception, and that they are not elicited by other causes, for example by certain features of the image hidden in the RDS pattern. For this purpose 3 different independent experiments were performed to eliminate other effects that may elicit such potentials.

Methods. Visually evoked potentials were recorded from a group of 34 healthy adult subjects (19 female, 15 male) between the ages of 22-47 (mean age: 31.03 ± 6.94) as they were shown RDS patterns. The inclusion criteria for subjects were as follows: not to have any neurological or psychological pathology, not to have a problem such as strabismus, which can hamper depth perception, not to be dependent on devices for refractive correction such as lenses or glasses. According to the declaration of Helsinki, all subjects gave written informed consent. The experimental procedures were approved by the internal Ethics Committee of the Medical School of Ege University (Date: April 21, 2006 Number: 06-3.1/6). The study was conducted at the Department of Biophysics of Ege University Medical School, Izmir, Turkey during April-December 2006. The signal acquisition system used was somewhat similar to the systems used for recording pattern shift visually evoked potentials (PSVEP), but differed from them in one important aspect. It consisted of 2 computers, one of which generated the stimulus patterns and the other recorded the EEG activity, simultaneously (**Figure 1**). To synchronize the stimulus image computer and the recording computer, 2 photodetectors each consisting of a lamp-type phototransistor of 5 mm diameter were placed on the left and right lower corners of the display monitor. These two photodetectors sent signals to the recording computer via a triggering circuit each time the stimulus pattern on the screen changed. Simultaneously, the EEG signal was diverted to the data channel assigned to responses to that stimulus pattern. The phototransistors had a response time of 15 microseconds thus providing an ideal synchronization between the stimulus-generating computer and the recording computer. They were insensitive to ambient light. The record length was adjusted to 512 milliseconds. Details of the technique were given in a previous publication.[7] A photodetector output is at 0 volt (logic state "0") when the small screen area underlying the transistor is dark. When the pattern is changed, this dark area becomes lit, and the photodetector output goes to 5 volts (logic state "1") while the opposite phototransistor goes to the off (0 volt) state. Thus, as stimulus patterns on the screen are shifted from one to the other one, the photodetector goes from the "0" state to the "1" while the opposite phototransistor does the opposite. Ouput state "1" activates a triggering circuit (Block A or B in **Figure 1**), which in turn triggers the analog-to-digital-converter (ADC). The ADC then starts converting the EEG signal and sends it to the appropriate data channel. In the experiments designated as experiment 1 and experiment 2 below, 2 different visual patterns, one called pattern A, which contains depth information, and the other called pattern B, which does not contain depth information, were used (**Figure 2**). These patterns were displayed on the monitor alternately with a slide-show program, and the EEG response to each pattern was diverted to the appropriate data channel via the triggering circuit. In experiment 3, 2 other patterns were presented alternately. For all records, a differential EEG amplifier with a gain of 20,000 (preamplifier: 10, amplifier: 2000) was used (Dagan Corporation, Model EX4-400, Minneapolis, MN, USA). The preamplifier (Dagan Corporation, Model 4001, Minneapolis, MN, USA) had an input impedance of 10 MΩ and was connected to the input stage of the amplifier. The input impedance of the amplifier was 1 MΩ. An active band-pass filter was placed between the preamplifier output and the amplifier input. Filter low and high cut-off frequencies were set at 0.1 Hz and 300 Hz. The analog signals at the amplifier output were converted to

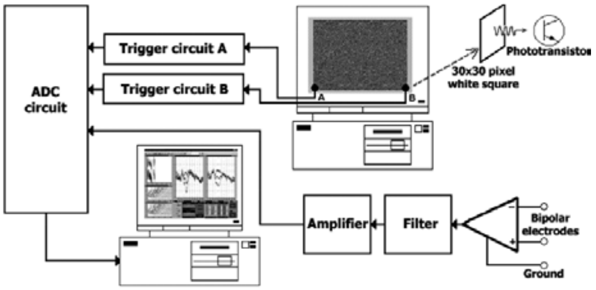

Figure 1 - Recording system employing 2 computers.

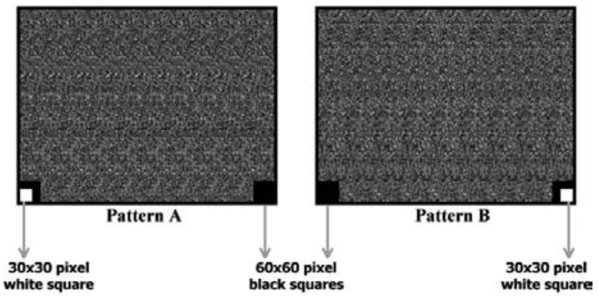

Figure 2 - Patterns used in the first and second experiments. Pattern A contains depth information (left) and Pattern B has no depth information (right).

digital signals by an ADC (Advantech PCL-818HGL, Advantech Co. Ltd., Miltipas, CA, USA) with 12 bit resolution at a sampling rate of 1024 per second, and downloaded into the PC. All data acquisition and analyses steps were carried out under computer control using the DasyLab (Version 5.03) software. The EEG leads used were as follows: Oz (active electrode) and Fpz (reference electrode); grounding electrode was fixed to the left ear lobe with an EEG ear clip. Three different experiments were conducted with each subject. These experiments were designed for the following purposes.

In experiment 1, a RDS pattern with disparity (in which was hidden the image of a square shown in **Figure 2a**) was presented to the subject and the presence of a specific potential component related to depth perception was investigated. In experiment 2, the same RDS pattern with disparity was presented but the subject was instructed not to seek depth clues in the pattern. The aim of this experiment was to find out whether the EEG signal obtained during this experiment was any different from that obtained in experiment 1. Although the same visual pattern was used, the subject was instructed not to make use of the depth information hidden in the pattern. In other words, experiment 2 served as a control for experiment 1 using the same subject. In experiment 3, a square (the image in **Figure 2a**), which was hidden in the RDS patterns of experiments 1 and 2 itself was directly presented to the subject. The aim of this experiment was to find out whether a specific potential expected to occur accompanying depth perception in experiment 1 would also be observed in this experiment.

Experiment 1. Subjects with the scalp electrodes attached were asked to look at the RDS pattern (**Figure 2a**) on the display monitor and try to perceive the hidden image in the pattern. The subjects who succeeded to perceive the hidden image were included in the test. Those who failed were put on a training program. If the subject reported that he/she could perceive the object clearly, the display computer was switched from the standby mode to the active mode and the data acquisition program (DasyLab) in the recording computer was started. Patterns A and B were presented alternately 80 times, each lasting 900 milliseconds. The EEG activities during pattern A and B presentations were recorded as 512 millisecond long data blocks in the allocated channels.

Experiment 2. This experiment was the same as experiment 1 in all aspects except that the subject was instructed not to strive to perceive the hidden object in pattern A (**Figure 2**) but just gaze at the screen. At the end of this experiment, as in experiment 1, 80 + 80 = 160 EEG data blocks were recorded concomitantly with presentations of patterns A and B.

Experiment 3. This experiment was also similar to experiments 1 and 2 in all respects except that the object itself and a dark grey blank screen were presented alternately. The stimuli used, and type of data recorded in each experiment (6 sets of data, 2 for each of the 3 different experiments) are summarized in **Table 1**.

Table 1 - Summary of experiments conducted with each subject and type of data obtained.

Experiment	Conditions
1	Channel: A Stimulus: Figure 2 pattern A (disparity information and depth perception)
	Channel: B Stimulus: Figure 2 pattern B (no disparity information)
2	Channel: A Stimulus: Figure 2 pattern A (disparity information but no depth perception)
	Channel: B Stimulus: Figure 2 pattern B (no disparity information)
3	Channel: A Stimulus: Image of the hidden object (no disparity information)
	Channel: B Stimulus: Blank screen (no disparity information)

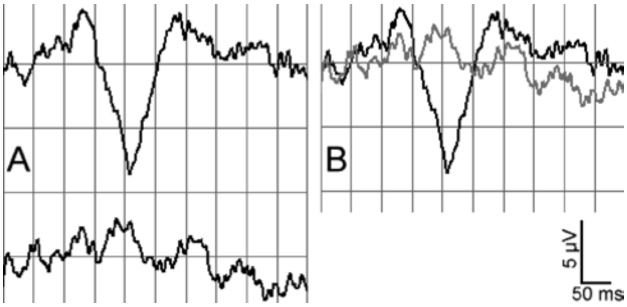

Figure 3 - An EEG showing **A)** Average of EEG traces accumulated in A channel with depth perception (upper trace), and average of EEG traces obtained from B channel without depth perception (lower trace). **B)** Superimposition of averaged traces in channel A (bold trace) and channel B (light trace).

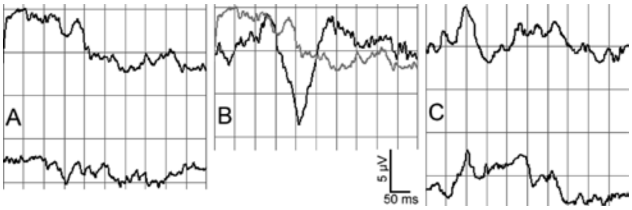

Figure 4 - An EEG showing **A)** Total of EEG records accumulated in channel A (upper trace) and the total of EEG records accumulated in channel B (lower trace). **B)** Results of 2 different experiments in which the same A pattern were used (bold trace from experiment 1, light trace from experiment 2). **C)** Average value of EEG records accumulated in channel A (upper trace), and average value of EEG records accumulated in channel B (lower trace).

Results. In experiment 1, a negative potential component (Nd) with an average latency of 211.46 ± 25.88 ms and amplitude 6.40 ± 1.57 µV appeared in the averaged activity recorded in response to pattern A from 30 of the 34 subjects (**Figure 3a**, top trace). Pattern B did not elicit any noticeable potential component (**Figure 3a**, bottom trace). The two traces of **Figure 3a** are shown superimposed in **Figure 3b**. The Nd component was not present in signals averaged from any of the 34 subjects in experiment 2. The top trace of **Figure 4a** shows the potential recorded in response to pattern A in experiment 2 from a subject whose response to pattern A in experiment 1 is the top trace of **Figure 3a**. The bottom trace of **Figure 4a** shows the potential recorded in response to pattern B in experiment 2. The averaged potential obtained from one subject in response to pattern A in experiment 1, and the potential obtained from the same subject in response to the same pattern (but this time not using disparity information) in experiment 2 are shown as superimposed in **Figure 4b**. An example of the potentials recorded in experiment 3 is shown in **Figure 4c**. As seen from this figure, the Nd component is not present in these records either.

Discussion. In view of the results obtained from experiment 1, it can be stated that the Nd component present in the averaged potentials obtained from 30 of the 34 subjects is related to depth perception, because this component is present in the responses to pattern A, which carries disparity information, but is absent when the stimulus is switched to pattern B. The results obtained from experiment 2 further support the relationship between the Nd component and depth perception. In addition, when the results of experiment 2 are interpreted in light of the results of experiment 3, the specificity of the Nd component to depth perception becomes evident beyond doubt. Indeed, a negative component similar to the one recorded in the present study has also been observed in previous studies.[6,8-11] Fenelon et al,[6] conducted studies on depth perception where RDSs were employed as stimuli, and reported high negative potentials having a mean latency of 200 ms.

In the present study, we confirmed the relationship of the Nd component with depth perception using a modified triggering (time-locking) technique, which consisted of a triggering circuit activated by a phototransistor that provided an almost perfect synchronization between stimulus presentation and onset of data acquisition because the trigger signal transmission from the photodetector to the recording computer took only a few microseconds.

The visual evoked potential recording system designed and used successfully in this study can easily be adapted to applications in neurology and ophthalmology clinics. For example, alternating checkerboard patterns can be used in lieu of A and B patterns of this study and the stimulus presentation scheme can be managed by a slide-show program to record PSVEPs. The recording system developed in this study can be used to investigate the different physiological aspects of vision such as color, luminance, contrast, and movement perception. The system can also be modified so as to allow monitoring various visual parameters simultaneously by increasing the number of photodetectors to be triggered by stimuli of several different patterns. For example, advanced visual event related potential (ERP) studies can be conducted by varying pattern (stimulus) display durations on the monitor and adding randomization as needed.

Due to the limitations of technology, multi-channel depth perception could not be investigated in this study. A multi-channel recording system can be created by increasing the number of channels in the amplifier and the ADC, and by developing the software. In future studies, by using the multi-channel recording system and increasing the analysis time: 1. The latency, amplitude, and form changes of the Nd component from a wider region of the brain can be investigated and, 2. Brain mapping of depth perception can be made.

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