Dynamics of Continuous Conditioning Light Effect on the Visual Evoked Potentials of the Guinea Pig

Kobay Görsel Uyarılmış Potansiyelleri Üzerinde Süregiden Koşullandırıcı Işık Etkisinin Dinamik Özellikleri

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ABSTRACT Objective: In this study, dynamics of binocular interaction was evaluated using bioelectrical activities in the guinea pig. **Material and Methods:** Epidural electrodes were implanted to the skulls by stereotaxic methods and recordings were made from chronically prepared awake animals. Continuous white light was used as the conditioning stimulus and the flash as the transient imperative stimulus. Compound activities of binocular interacting neurons were calculated by a subtraction method and a difference potential was derived as the indicator of the binocular interaction. The effects of alterations in the starting time of the continuous conditioning light relative to the flash were evaluated. The starting time of the continuous conditioning light was changed within the range of 150 ms before and 420 ms after the application time of the flash, with 30 ms steps. **Results:** When the continuous conditioning light was started 60 ms before the flash, or even earlier, the latency of the negative wave in the difference potential was around 65 ms. When the continuous conditioning light was started later than the flash, the latency of the difference potential was delayed approximately to the same extent as the delay in the continuous conditioning light. **Conclusion:** These findings imply that an interaction does not exist between the highest bilateral functional centers responsible for the processing of visual stimuli and it can be speculated that most of the spatial visual processes take place at relatively lower cortical centers.

Key Words: Guinea pigs; evoked potentials, visual; vision, binocular

ÖZET Amaç: Bu çalışmada, kobaydaki gözler arası (binoküler) etkileşimin dinamik özellikleri biyoelektrik potansiyeller kullanılarak incelenmiştir. **Gereç ve Yöntemler:** Potansiyeller, kafalarına stereotaksik yöntemler kullanılarak epidural vida elektrotlar yerleştirilmek suretiyle kronik preparat haline getirilmiş uyanık hayvanlardan kaydedilmiştir. Koşullandırma uyarısı olarak süregiden beyaz ışık, asıl uyaran olarak da ani flaş kullanılmıştır. Gözler arası etkileşimden sorumlu nöronların bileşik potansiyeli niteliğindeki fark potansiyeli bir aritmetik çıkarma işlemi kullanılarak elde edilmiştir. Bu çalışmada, süregiden beyaz ışığın başlatılma zamanında, flaşın uygulanma zamanına göre yapılan değişikliklerin neden olduğu etkiler değerlendirilmiştir. Süregiden beyaz ışığın başlatılma zamanı, flaşın uygulanma anından 150 ms öncesi ile 420 ms sonrası arasındaki aralıkta 30 ms'lik adımlarla değiştirilmiştir. **Bulgular:** Süregiden beyaz ışık, flaşdan 60 ms veya daha önce başlatıldığında fark potansiyeli üzerindeki negatif dalganın latansı yaklaşık 65 ms idi. Süregiden beyaz ışık, flaşdan sonra başlatıldığında ise fark potansiyeli üzerindeki negatif dalganın latansı, süregiden ışığın başlatılma zamanına paralel bir gecikme gösterdi. **Sonuç:** Bu bulgular, beyinde görsel uyarının işlenmesinden sorumlu en üst fonksiyonal merkezler arasında karşılıklı bir etkileşim bulunmadığına ve uzaysal görme işlevinin göreceli olarak daha alt merkezlerin bir fonksiyonu olduğunu düşündürmektedir.

Anahtar Kelimeler: Kobay; uyarılmış potansiyeller, görsel; görme, iki gözle

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Sensory interactions in the vertebrate brains are classified in 2 groups: while 'inter-modal interaction' refers to the interaction between different senses, 'intra-modal interaction' defines the interaction between

the centers that contribute to the processing of a particular sense.[1-13] Intra-modal interactions are usually between the sides of bilateral sensations like vision or audition. Thus, binaural and binocular interactions form the majority of intra-modal interactions.

Inter- and intra-modal interactions are modeled with neurons that work according to the and/or logic and receive inputs from multiple centers. Electrophysiological methods are very important for revealing the functional and dynamic properties of the interacting neurons, as well as providing proof for their presence.[3,6,7,12-15] Both single cell and compound potentials can be recorded for this purpose.[2,4,5,14,16-20] While single cell recordings can prove the presence of the aforementioned interactions, gross potential recordings are thought to be more informative for evaluation of their functional and dynamic specifications.

The most important limitation for the interaction studies is the impossibility of selective stimulation of the interacting neurons. This condition necessitates utilization of indirect methods, which require arithmetic operations. The most frequently used indirect method for this purpose is the subtraction method. This method depends on the extraction of the responses of a neuron group, which cannot be stimulated selectively, through calculation of the difference between potentials recorded in different sessions: if any two neuron groups are independent of each other, the response to dual stimulation should be equal to the sum of responses when these two neuron groups are stimulated separately. Therefore, the existence of a difference between summed and compound potentials is the clear evidence of an interaction between these two neuron groups. This logic has since been employed in various inter- and intra-modal interaction studies in different vertebrates.[4,7,9-12,14,19,21-23]

There are many binaural interaction studies in the literature, performed on various experimental animals including guinea pigs, as well as human studies.[10-12,19,22,24-26] Although vision is one of the major sources of data for the brain, there are very few studies on binocular interaction.[1,13,21,23] Determination of the dynamic properties of an interaction is almost as important as the proof of its presence.[3,14,25,27,28] The disparity between the number of studies conducted on binaural and binocular interactions is also reflected on the number of dynamic studies in these subjects. Although there are many dynamic studies on binaural and audio-visual interactions, it has not been possible to find any studies about the dynamics of binocular interactions.[3,11,14,24,27,28] The main purpose of this study was to reveal novel information about the functional properties of the visual system by assessing the dynamic properties of the interactions in the processing of responses to bilateral visual stimuli.

The guinea pig brain is considered a good model to study intra- and inter-modal interactions. Because of the suitability for stereotaxic surgery, it is a convenient experimental animal for electrophysiological studies. The well-known calm nature of the guinea pig further facilitated making movement artifact-free recordings even from an awake animal without anesthesia. Considering these facts, guinea pigs are frequently used in the interaction studies including binocular interactions.[5,8,10,11,14,17,21,23,26-35] There are two studies that give notable information about the binocular interactions in the guinea pig brain.[21,23] In both studies, electrophysiological methods were used and the potentials of binocular interacting neurons were obtained by the subtraction method. In one study, the difference potential was calculated by subtracting the arithmetic sum of monocular responses from the binocular one and this difference potential was named as the binocular difference potential (BoDP).[21] This difference was accepted as the reflection of extra activity of binocular neurons, which remained silent when either side was stimulated and only discharged upon bilateral stimulation. The other study suggested that the response to a flash applied to an eye was affected by the continuous light applied to the other eye.[23] Findings of these two studies give some information about the mechanisms responsible for binocular vision, which is, however, insufficient to discriminate whether a single mechanism or multiple mechanisms are responsible for such difference potentials. Therefore, clarification of this uncertainty, which is important to define the structural specifications of the visual system, is also expected by the help of the results of the current study.

MATERIAL AND METHODS

ANIMALS

Ten albino guinea pigs weighing 550 to 880 g were used. All experiments were performed in accordance with The Guide for the Care and Use of Laboratory Animals (www.nap.edu/catalog/5140.html). Care and use of the animals were approved by the institutional ethical committee.

SURGERY

The stereotaxic surgical operations for implanting recording electrodes to the skulls of the animals were conducted under anesthesia with 4 mg/kg Xylazine and 40 mg/kg Ketamine.[36] Preventive measures for stress were taken before surgery. After placing the animal in the stereotaxic frame (Stoelting; Illinois/USA) a midline incision was made to the scalp and periosteum; then, 9 holes, each 0.85 mm in diameter, were drilled. Epidural stainless steel screw electrodes, with a shaft diameter of 1 mm, were screwed into the holes. Coordinates of the electrodes were chosen according to the information in the interaction studies of guinea pigs and the stereotaxic atlases of the guinea pig brain.[23,35,37-40] The ground electrode was placed 6 mm anterior to the bregma and 0.5 mm to the right of the midline and the reference electrode 1 mm posterior to the bregma and 0.5 mm to the right of the midline. The remaining seven electrodes served as active recording electrodes: three in the midline (6, 10 and 14 mm posterior to bregma) and four in bilateral temporal regions (8 and 10 mm posterior to bregma, 6 mm lateral to midline over both hemispheres). The connection socket, electrodes, and cables were firmly cemented onto the skull with dental acrylic. Eyes of the guinea pigs were kept moist during the operations.

STIMULATION AND RECORDING PROCEDURES

All recordings were made from awake guinea pigs in the present study, as also reported in other studies in the literature.[8,14,23,30-32] A specially designed restrainer was used to avoid large movements of the subject (Figure 1a). Changes in stimulation due to possible head movements of the animal were avoided by fixing the goggles to the socket mounted on the skull (Figure 1b). Thus, by virtue of these measures and the calm temperament of the guinea pig, it was possible to make recordings without anesthesia. To avoid effects of surgical anesthesia after the stereotaxic surgery, at least 72 hours of recovery time was allowed for each animal before data collection.

For both eyes, the stimuli were applied by the high illumination LEDs in the center of the conic reflectors of the goggles (Figure 1d,e). The potentials were amplified 5000 times and the filters were set to

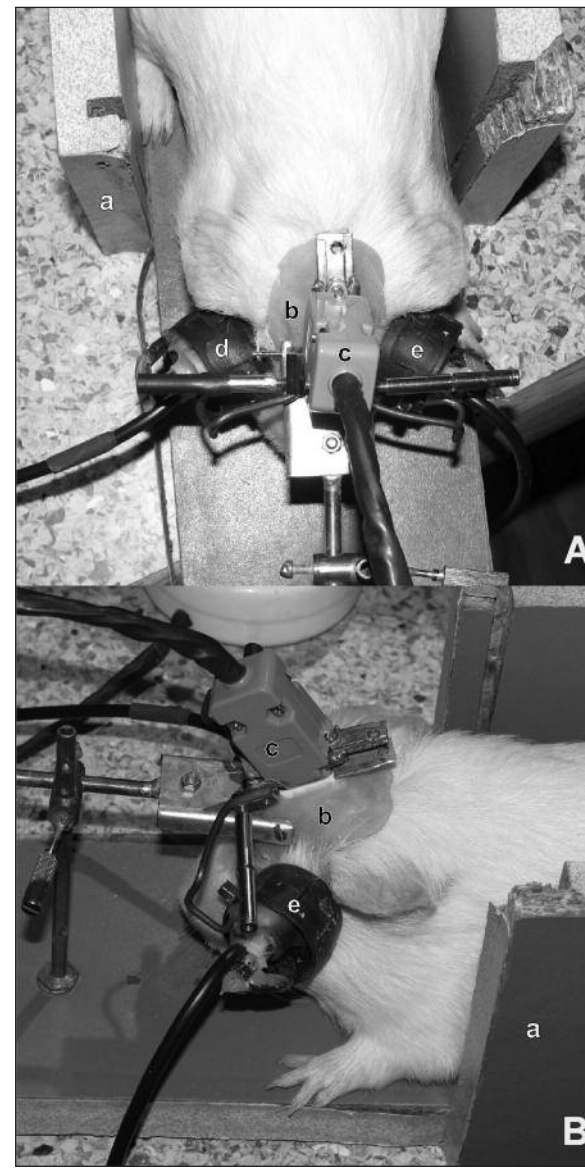

FIGURE 1: A. Top view, **B.** side view of a guinea pig during a recording session: Restrainer (a); electrode connector cemented to the skull by stereotaxic surgery (b); connection socket of the recording system (c); the right and left goggles, mounted to the connection socket, containing white LEDs and conic reflectors (d, e).

1.59 and 70 Hz (Glonner NeuroSys 2000; Krailling/Germany). Potentials larger than 600 μV were automatically rejected by the software during recording sessions. The sampling interval was 3 ms and 256 points were recorded in each sweep; thus, a period of 768 ms was recorded in each sweep. The inter-sweep interval was set to 2 seconds (768 ms recording and 1232 ms waiting periods, Figure 2a). The sweeps were averaged up to 2100 times in each recording session. The potentials were digitized in 16-bit resolution (Advantech PCL-816; Cincinnati/USA). A dark, electrically shielded electrophysiological recording chamber was used for the experiments.

STIMULATION EVENTS

As mentioned in the introduction, two alternatives are available for electrophysiological examination of binocular interactions: (1) Applying bilateral stimuli both in flash form is preferred for proving the existence of the binocular neurons.[21] (2) By stimulating one eye with flash (transient, imperative) and the other with continuous light (conditioning), it is possible to discriminate which response is affected and which one is affecting since a background activity is produced by continuous conditioning.[23] As this study aimed the evaluation of the dynamic specifications of binocular interaction, the latter alternative was preferred.

Bilateral visual stimulation was planned as follows: while flash was applied to an eye as a transient imperative stimulus to evoke a visual response, continuous white light was applied to the other eye as the conditioning stimulus. Each recording session consisted of repeated recording cycles and each recording cycle consisted of three events (Figure 2a). The sequence of three events in cycles was systematically changed in order to avoid unwanted interference between responses because of the prolonged effect of the rhythmic after discharge seen in the visual evoked potentials (VEPs) of the guinea pig. These three events were:

- Stimulus (Stm): In this event, a transient flash with 100 μs duration and 130 mCd intensity was applied to the right eye as the imperative stimulus. The flashes were always applied at 168 ms of the Stm sweeps in all recording sessions.
- Conditioning (Con): Continuous white light with an intensity of 80 mCd was applied to the left eye as the continuous conditioning. The starting time of the continuous conditioning light was kept constant in a recording session.
- Conditioning & Stimulus (ConStm): In this event, both flash and continuous white light were applied to the same eyes as they were applied in the Stm and Con events. The flash, again with 100 μs duration and 130 mCd intensity, was applied to the right eye at 168 ms of the ConStm sweep. The starting time of the continuous conditioning light was the same as that in the Con event of that particular recording session.

RECORDING SESSIONS AND NAMING

The time between the starting of the continuous conditioning light and application of the flash was named conditioning onset time (COT). The COT value of a recording session was determined by the starting time of the continuous conditioning light because the application time of the flashes was constant in all recording sessions. Recording sessions were named according to their COT values. A recording session was tagged with a minus sign if the conditioning was started before the flash and with a plus sign if the conditioning was started after the flash (Figure 2b, 2c).

Each recorded event was averaged separately and these averaged potentials were used in the calculations and analysis. In Figure 3, a set of recorded and calculated potentials in a sample recording session was depicted for demonstration. The topmost three tracings show the averaged potentials recorded in the three different events. As mentioned above, flashes were applied at 168 ms of the Stm and the ConStm events and this application point was set as the zero on the time scale. In this example, the COT value was -90 ms because the continuous conditioning light had been started 90 ms before the flash in the Con and ConStm events.

Twenty recordings were made from each animal with different COT values ranging between -150 ms to +420 ms in 30 ms steps: -150, -120, -90, -60, -30, 0, +30, +60, +90, +120, +150, +180, +210, +240, +270, +300, +330, +360, +390 and +420 ms.

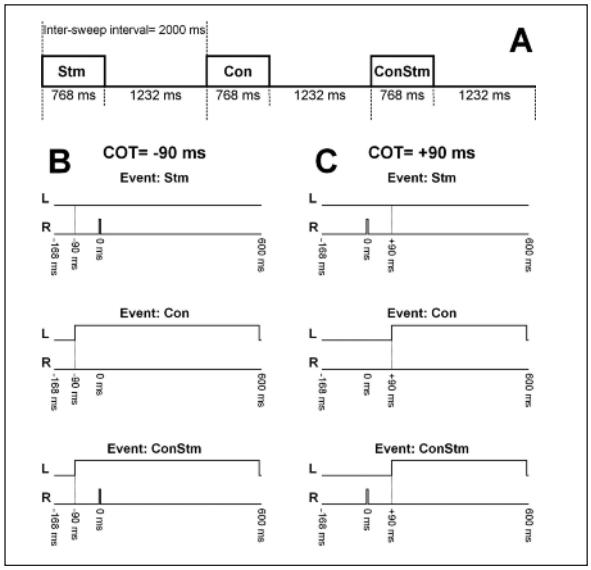

FIGURE 2: A schematic view of a sample recording cycle consisting of three events (a). Applications of the stimuli in these three events with -90 ms (b) and +90 ms (c) COT values. In the (b) example, the COT value is -90 ms because the continuous conditioning light was initiated 90 ms before the flash in the Con and ConStm events. The continuous conditioning light was initiated 90 ms after the flash in the example (c), therefore the COT value is +90 ms.

As can be anticipated, the onset of the continuous conditioning light and application of flash is synchronous in the 0 ms COT recording session. The method for calculation of the difference potential, illustrated in Figure 3, was applied to all potentials recorded with different COT values from the animals. Therefore, a difference potential was obtained for each recording in this study.

Statistical Analysis

Recordings were classified according to their COT values. The base-to-peak amplitudes between the peak of the negative wave and the baseline of the difference potential were calculated for each recording in this study. These base-to-peak amplitudes were normally distributed and they were used in the evaluation of the significance for each COT group by Student's *t* test. The significance level was determined as $p< 0.05$.

RESULTS

Among the 7 active recording electrodes placed on the skulls of the guinea pigs, the most prominent binocular interaction was recorded from the electrode placed 10 mm posterior to the bregma on the midsagittal line. All results presented below were derived from the potentials recorded from this electrode.

CALCULATION OF THE DIFFERENCE POTENTIALS

In the electrophysiological sense, the Stm tracing is a standard flash stimulation VEP. The Con tracing shows the 'on response' caused by the starting of the continuous conditioning light. In the ConStm tracing, since both the flash and the starting of the continuous conditioning light are in the same sweep, the VEP and the 'on response' are recorded together with 'binocular interaction activity' in the same tracing (Table 1). In the ConStm, the 'on response' and VEP, which also contains the 'binocular interaction activity' can be distinguished easily by the latency difference in Figure 3 and this is why the -90 ms COT recording session is preferred for demonstration in this figure. For example, if a 0 ms

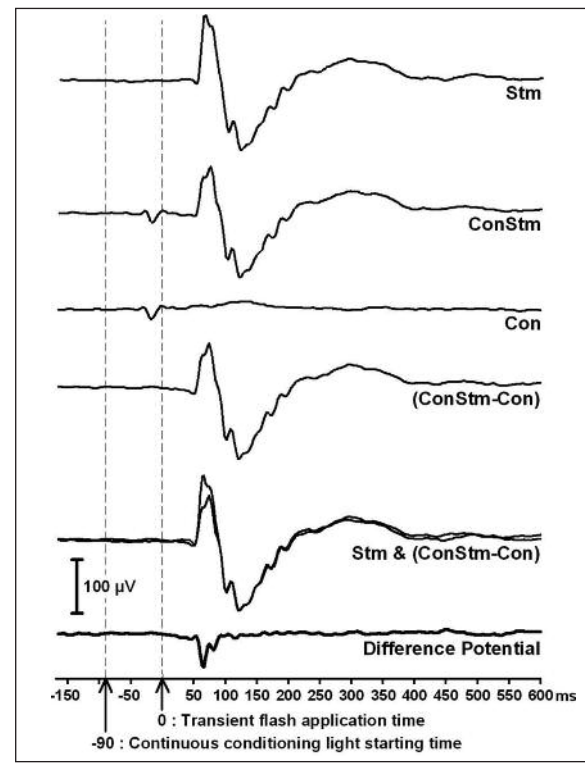

FIGURE 3: Average sweeps, recorded in Stm, ConStm and Con events for a COT value of 90 ms were given in the top three rows of the figure. The fourth row shows the arithmetical difference between the ConStm and the Con sweeps. The fifth row is the superimposed presentation of the difference potential (ConStm-Con) and the Stm. The lowermost row is the difference potential of the two superimposed traces in the fifth row.

TABLE 1: Neurophysiological contents of the recording events and the difference potentials.

Events		Neurophysiological Contents
Stm		VEP
Con		On response
ConStm		VEP + On response + Binocular Interaction Activity
Subtractions		
First Step	: [ConStm – Con]	= VEP + Binocular Interaction Activity
Second Step	: [ConStm – Con] – Stm	= Binocular Interaction Activity

COT recording session had been chosen for the demonstration instead of the -90 ms, the 'on response' would have been embedded into the VEP, making their distinction impossible.

A two-step subtraction method was used in each recording session to extract the binocular activity under scrutiny (Table 1). In Figure 3, the lowermost three rows demonstrate the calculation steps. If the continuous conditioning light applied to one eye did not modify the response to the flash applied to the other eye, the ConStm would be equal to the sum of the Con and the Stm. However, the inequality between ConStm and (Con + Stm) implies that continuous conditioning light applied to one eye modifies the response to the flash applied to the other eye. This two-step subtraction method was designed to reveal the interaction (Table 1): the first step difference potential, obtained by subtracting the potential recorded in the Con event from the one recorded in the ConStm event, is presented in the fourth row in Figure 3. This first step difference potential is the sum of the responses to the flash and the potential of the interaction being studied. To display the difference between Stm and (ConStm-Con), both traces are shown in superimposed form in the fifth row. The difference between these two superimposed tracings, the second step difference potential, which is the indicator of the interaction being studied, is presented in the lowermost row. The superimposed tracings in the fifth row are largely overlapped, except for the region between 50 and 100 ms; hence, the prominent wave in the difference potential, presented in the lowermost row, falls in the region between 50 and 100 ms.

SCANNING THE COT RANGE

Figure 4 depicts the average values of latencies of the negative waves in the difference potentials, as calculated from the recordings obtained with different COT values. The latencies of the negative waves in the difference potentials for the COT values between -150 and -60 ms make a plateau with an average of 64.75 ± 1.89 ms. The latency of the negative wave was delayed to 75 ms in the recording session with -30 ms COT value. The latency in the recording session with zero COT value (the flash and the starting of the continuous conditioning light synchronized) was 101 ms. For positive COT values, latency delays were directly proportional to the increase in the COT. No prominent waves were observed in the difference potentials for the recording sessions with COT values greater than +420 ms.

Sample difference potentials recorded with relatively important COT values (between -120 and +120 ms) were presented in Figure 5. Amplitudes of the tracings were normalized to the trace with the greatest peak-to-peak amplitude in Figure 5 in order to allow for easier inspection of waveforms and latencies. The tracings in this figure are concordant with the values of the graph presented in Figure 4. It can be observed that the latencies of the negative waves in the difference potentials recorded with

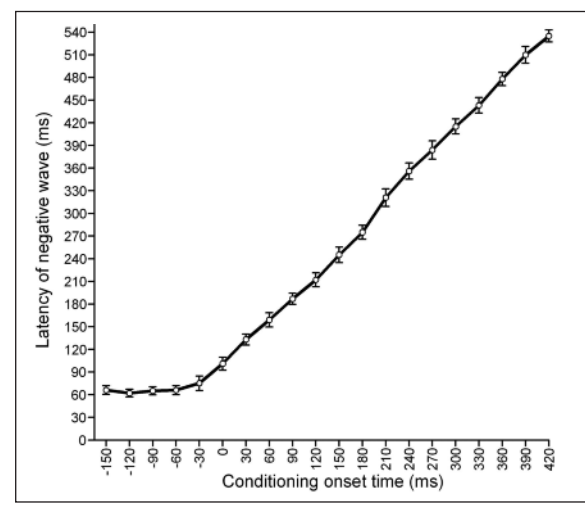

FIGURE 4: Averaged values and standard deviations of the latencies of the negative waves in the difference potentials calculated using the potentials recorded with different COT values.

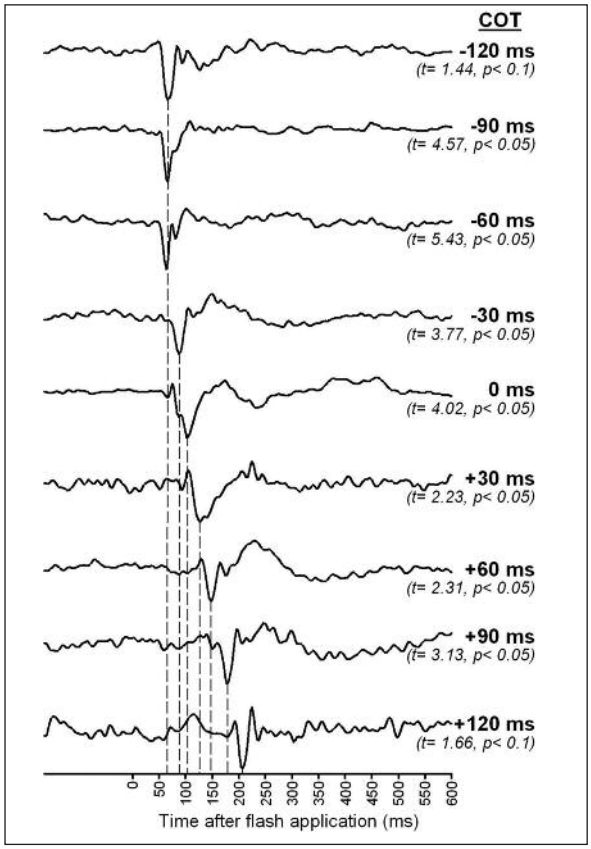

FIGURE 5: Demonstrative calculated difference potential samples obtained from the electrodes placed 10 mm posterior to the bregma on the midsagittal line with COT values between -120 and +120 ms. The statistical results of each averaged COT group are given with traces.

the COT values of -120, -90 and -60 ms remain unchanged while they are gradually delayed in the following recordings.

When the findings presented in Figure 4 and Figure 5 are evaluated together, these results can be reached: (1) Starting the continuous conditioning light 60 ms before the flash or earlier does not modify the latency of the difference potential; (2) Recordings with the COT value of -30 ms are in a transition period; (3) For the rest of the recordings, the delay in the latencies were directly proportional to the increase in the COT.

Latency is accepted as a more reliable parameter than amplitude in the evaluation of this potential because a number of physical and physiological conditions influence the amplitude of an evoked response. Small amplitude potentials, such as the calculated difference potentials in the present study, are especially affected by these conditions. Furthermore, as expected, there was no statistically significant relationship between the amplitudes of the difference potentials and the COT values. So, no data related to the amplitudes were presented.

DISCUSSION

It is widely recognized that only the activities of temporally and spatially organized neurons can reach the skull.[2,4,6,20,25] Although various types of potentials are generated in the brain, only some can be recorded from the skull. In this study, the activities of organized binocular interacting neurons were recorded by epidural electrodes and the interaction was presented by a difference potential. Although existence of a difference potential is considered a clear evidence of a binocular interaction, it does not provide information about the types and numbers of interacting neurons and the types of the mechanisms responsible for binocular vision. Another finding is the presence of a difference potential that reflects the extra activity of a group of interacting neurons which remain silent when a single stimulus arrives from either side and only fire upon discharges coming from both sides.[4,6,7,10,30]

COMPARISON OF THE BINOCULAR INTERACTIONS

As mentioned in the introduction section, there are two major reference studies in the literature for the present study. When these two studies are compared, although different electrophysiological methods were used, it is possible to reach similar or different findings (Table 2). The major common finding in the two studies is the revelation of a binocular interaction. The presence of similar monophasic negative waveforms in both difference potentials may be considered another similar finding. The major difference between the methods of these two studies is the application of flashes to both eyes in one of the studies while continuous conditioning light was applied to only one eye in the other. Nevertheless, bilateral flashes were applied synchronously, while continuous conditioning light was initiated at least five seconds before the

TABLE 2: Comparison of the methods and results of the two studies.

	Goksoy et al,*	Ates et al,**
Interaction type	Binocular	Binocular
Stimulation types and directions	Transient flash to one eye, continuous light to the other eye	Transient flashes to both eyes
Timing of stimuli	Flashes are applied at least 5 seconds after the onset of conditioning	Synchronized
Recording location	On the posterior temporal region	On the midsagittal line
Nature of the difference potential wave	A monophasic negative wave	A monophasic negative wave
Latency of the wave in the difference potential	58 ms after the flash	106 ms after the flash

*References 23, **References 21.

flash. Thus, this difference in stimulation paradigms may have activated different mechanisms as well. The active recording electrode was on the midsagittal line in one study and it was on the posterior temporal region in the other. The most striking difference between the findings of these two studies is the difference between the latencies of the negative waves in the calculated difference potentials (58 ms versus 106 ms), which implies two different mechanisms. If these two difference potentials reflect the activities of different regions, it may be suggested that there are at least two binocular centers. However, the findings of these two studies are insufficient to discriminate whether a single mechanism or multiple mechanisms are responsible for such difference potentials.

When the results of the two studies mentioned above comparatively and the present study are evaluated together, the following results can be achieved: (1) When the continuous conditioning light is initiated 60 ms before or even earlier than the flash, the latency of the negative wave in the difference potential is measured as 65 ms.[21,23] This value is very close to the result (58 ms) of the study in which continuous conditioning light was used.[23] The difference between the results (approximately 7 ms) was so small that it could be caused even by individual differences of the animals used in the present and the mentioned studies. (2) The latencies of the negative waves in the recording sessions with 0 ms COT value were 101 ms in average and this value was very close to the latency of the (106 ms) in the study in which bilateral synchronous flashes were applied.[21] It can be speculated that the starting point of the continuous conditioning light is perceived as a kind of transient stimulus by the brain and activates the same mechanisms as with a transient stimulus. Thus, it can be stated that there is no notable difference between synchronous application of bilateral flashes and synchronous application of continuous conditioning light and flash.

In light of the findings of the present study, we think there is sufficient data to conclude that the difference potentials observed in the two studies are the products of the same binocular mechanisms, despite the differences mentioned in the introduction.[21,23]

TWO HYPOTHETICAL MODELS FOR BINOCULAR INTERACTION

It is well known that there are many functional and structural differences between visual and auditory systems. From this point of view, anatomical pathways and functional processes for auditory and visual stimuli are also very different. Nevertheless, since both vision and audition are structured bilaterally, even in a hypothetical situation, binaural interaction models can be adapted to the visual system. Among the binaural interaction studies conducted to date, studies that evaluate the responses to changing the timing of the stimuli (Interaural Time Difference: ITD) applied to the ears have an important place.[11,24,25,28] In the literature, there are two proposed models to explain how a change in the ITD value affects the latency of the binaural difference potential:

The delay line-coincidence detector model: In this model, impulses coming from bilateral regions arrive at the array of neurons in a binaural center with successive axonal delays due to the two delay lines constituted by the afferent fibers running in opposite directions.[41] Because of the hypothetical definition of this model, the shifts in the latency of

the binaural difference potential should be equal to ITD/2.

The nucleus laminaris model: According to this model, the delay line is strictly in the projections from the contralateral side and the axonal delays in the fibers projecting from the ipsilateral side are all equal to each other.[42] Thus, the binaural difference potential should be delayed by just the ITD.

Similar studies were conducted in several vertebrates including the human being and results for and against both of these models were obtained.[24,25,28] There are similarities between the application methods of the COT used in the present study and the ITD mentioned earlier. As the optic fibers cross over only in the optic chiasm and do not make any synapses in this region, the delay line-coincidence detector model is not likely to be valid for the visual system. Moreover, the nucleus laminaris model is more likely to be valid for the findings presented in Figure 4, especially for the positive COT value recording sessions where the delay in the latency of the difference potential was directly proportional to the COT. When the above-mentioned important differences between visual and auditory systems are concerned, it is possible to speculate that the nucleus laminaris model is more acceptable for the anatomical specifications of the visual system of the guinea pig. The fact that approximately 95% of the optic fibers of the guinea pig cross over in the optic chiasm also makes the nucleus laminaris model more convincing for the guinea pig visual system.[43]

DYNAMICS OF BILATERAL STIMULATIONS

If the continuous conditioning light is started early enough (60 ms or more) before the application of the flash, the shortest possible latency (approximately 65 ms) of the negative wave in the difference potential is elicited. However, when the continuous conditioning light was started less than 60 ms earlier or after the flash, the latency of the difference potential was delayed almost to the same extent as the delay in the COT. These results of the experiments with different COT values can be interpreted as follows:

COT = -60 ms: If the continuous conditioning light is started 60 ms prior to the flash, the effects of the flash and the continuous conditioning light reach the binocular neurons concomitantly. In this condition, the latency of difference potential is 65 ms.

COT < -60 ms: If the continuous conditioning light is started prior to the 60 ms time point before the flash, the flash effect causes a binocular response as soon as it reaches the binocular neurons as it finds the binocular neurons ready to discharge under the effect of the continuous conditioning light. In this condition, the period between the flash and the difference potential does not change and the response occurs with the minimum latency, which is 65 ms.

-60 ms < COT < +420 ms: If the continuous conditioning light is started later than the 60 ms time point before the flash, its effect reaches the binocular neurons before the flash effect does. In this situation, the binocular response is delayed approximately to the same extent as the delay in the continuous conditioning light.[14]

COT > +420 ms: Hypothetically, the reason why COT values greater than +420 ms do not cause a difference potential could be that, in this condition, the flash effect disappears before the continuous conditioning light effect reaches the binocular neurons and the binocular response is not observed because the effects do not coincide.[14]

AN ASSUMPTION ABOUT THE BINOCULAR INTERACTION

Although the findings of this study were discussed only in the context of general neurophysiological principles and speculations about anatomical localizations were avoided, a remark can be made about the location of this mentioned interaction in the functional structure of the visual system.

CONCLUSION

Cortical response activities obtained from the guinea pig are known to be in the 55-300 ms time window after the flash stimulus.[21,34,35,43] If it is accepted that these activities caused by the flash reach the binocular neurons in 65 ms, then the

results of this study would imply that this latency value is related to relatively lower centers of the visual system and earlier stages of the cortical process. This finding has led us to consider that an interaction does not exist between the highest bilateral functional cortical centers responsible for the processing of visual stimuli at least for this time window (e.g., association areas). Thus, it can also be speculated that most of the spatial visual processes take place at relatively lower cortical centers.[21,34,35]

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