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A case study of the precedence effect in a sample of auditory hallucinating schizophrenics

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Contents

Abstract

In a reverberant environment, a direct sound is followed by several reflections. As a result, we are often presented with multiple signals coming from different directions. Yet we are normally aware of just the first sound, the direct sound, and are able to tell the direction of it´s source. This is due to a phenomenon called the *precedence effect*, also called the "law of the first wavefront". Earlier studies have shown that schizophrenic individuals have dysfunctions in their ability to localize sounds. The aims of this study where to contribute to the survey of sound localization by studying the precedence effect with auditory brainstem response (ABR) on hallucinating schizophrenics and healthy individuals. It was assumed that schizophrenic subjects may show aberrations in the function of the precedence effect. For this report, the precedence effect was studied in two schizophrenic individuals by recording the auditory brain stem response as a result of sound stimulation. The main finding is an increased amplitude of the precedence effect in wave V, originating from the inferior colliculus (IC), compared to the healthy subjects.

The schizophrenics aberrant amplitude can perhaps be explained as dysfunctions on a psychophysiological level.

Introduction

Schizophrenia and psychoacoustics

Schizophrenia is a severe, chronic and disabling brain disease. Some characteristic symptoms are delusions, hallucinations and disordered thinking (Ottosson, 2000). Schizophrenia can develop in any person of almost any age, but the most common time is during the late adolescence or early adult life. There is no single cause of schizophrenia. It may be a result from an interplay of genetic, behavioral and other factors, such as chemical or physical abnormalities in the brain. Many studies of schizophrenics have shown abnormalities in brain structure, such as enlarged ventricles, and decreased size of certain brain areas. Also, decreased metabolic activity in certain regions of the brain is an example of abnormalities in brain functioning.

Several perceptual deficits regarding psychoacoustical functioning in schizophrenics have been discovered, such as findings regarding streaming (Nielzén and Olsson, 1997), restoration of missing sounds and abnormal final perception after complex sound stimulation (Olsson and Nielzén, 1999).

For the auditory environment to be understandable, extensive filtering and sorting is needed among all auditory impressions registered by the brain. Schizophrenic individuals have defects in these mechanisms, hence a changed perception (David and Busatto, 1998).

Psychoacoustics and localization

The psychological science in Germany around 1850 gave rise to the origin of the experimental field called psychophysics, that studied relations between variations in stimulation, on the one hand, and subjective impressions on the other. From this originated psychoacoustics, which treats the auditory perception. Basically, psychoacoustics deals with relations between the physical sound and the way we perceive sounds (Plomp, 1976).

Earlier studies have shown that schizophrenic individuals have dysfunctions in their ability to localize sounds. Results from a test on contralateral induction by frequency spectrum in hallucinating schizophrenics by Olsson and Nielzén (1999) demonstrated that the schizophrenic subjects deviated from the reference group in several aspects. Contralateral induction means that a sound is illusively heard as coming from a location where it belongs according to its spectral content. When, according to the brain´s interpretion, the right sound spectrally belongs to the left, the listener experiences a movement of the sound, from the right to the left. Some of the schizophrenics in that investigation did not hear the sound being induced to the contralateral side, something all reference subjects did, and some of the schizophrenics noticed the induction unusually early and a few of them experienced the induction now and then. These aberrations were interpreted as rigidity of adaption on one hand and as effects of an enhanced sensitivity on the other.

Psychoacoustics and the precedence effect

The precedence effect is a phenomenon that plays an important role in our perception of everyday sounds. When sound waves are reflected many times by the room surfaces, a listener is exposed to multiple signals coming from many different directions in space. The auditory system can, due to the precedence effect, cope with this otherwise confusing experience. The term precedence effect was originally coined by Wallach et al. (1949), who investigated in their classic study how the auditory system handles echoes in experiments by using both headphones and sound sources in free field.

Many studies have investigated the precedence effect, and some characteristics of the effect are explained in a similar way in most studies: Two brief sounds that reach the ears in close succession are heard as a single sound if the interval between them is sufficiently short. The sounds are "fused" together, hence the name fusion. The interval over which fusion takes place is not the same for all types of sounds. The upper limit of the interval is about 5 ms for single clicks, but may be as long as 40 ms for sounds of a complex character, such as speech or music (Moore, 1997).

When two sounds are heard as fused into a single sound, the location of the total sound is determined largely by the location of the first arriving sound. This is what is known as the precedence effect, and also sometimes called "the law of the first wavefront" (Blauert, 1983). The effect is reflected in the finding that the ability to detect shifts in the location of the reflecting sound (the echo) is reduced for a short time following the onset of the leading sound (Zurek, 1980; Perrot et al., 1989). In other words, the perception of early-arriving reflections as echoes is suppressed when the precedence effect comes into play.

The reflecting sound, henceforth called the lagging sound, can be shown to have a small but demonstrable influence on the leading sound. If the location of the lagging sound departs more and more from the location of the leading sound, it "pulls" the total sound along with it up to a maximal amount (about 7 degrees) and then it becomes progressively less effective. Also, if the lagging sound is made sufficiently intense (10-15 dB higher in level than the leading sound), it overrides the precedence effect (Moore, 1997).

It can take a few seconds for the precedence effect to become fully established, and a repetitive click train allows the precedence effect to reach a maximum. This is called build-up, and it is commonly encountered in auditory illusions as well.

Litovsky and Yin (1998) have studied the neural correlates of the precedence effect in cats. Their study on individual neurons in the inferior colliculus (IC) has shown that these neurons are sensitive to interaural time- and level differences. Once a neuron has been excited, it has a certain refractory recovery period. These neural responses in the inferior of the scull are not easily accessible in humans. At the surface of the scull, however, responses can be recorded. Voltage potentials at the surface are present due to the fact that when the neurons of the human brain process information, they do so by changing the flow of electric currents across their membranes. These changing currents generate electromagnetic fields that can be picked up from the surface of the scalp, and the voltage differences between different positions on the scalp are recorded. Certain acoustic stimuli cause, or evoke, certain response patterns and the response is therefore called auditory evoked potentials (AEP). These auditory evoked potentials can be picked up with different recording devices, for example by brainstem response audiometry.

The region of interest for the present study is electrophysiological experiments in which neuronal responses to auditory stimuli, in this case the precedence effect, are analysed. Evoked potential abnormalities have been described in a majority of psychiatric disorders (Jansen et al., 2003). In a study using auditory brain stem response (ABR), Lindström et al. (1987) demonstrated a significant relationship between ABR pathology and auditory hallucinating schizophrenics. The results implies, according to the authors, that brain stem dysfunction is involved in the psychopathology of schizophrenia.

Aims of study

The aims of this study are to contribute to the survey of sound localization by studying the precedence effect with auditory brainstem response (ABR) on hallucinating schizophrenics and healthy individuals. It is assumed that schizophrenic subjects may show aberrations in the function of the precedence effect.

Method

Stimuli

A train of click pairs composed the stimuli. Each pair consisted of two clicks, one that simulated a direct sound, and the other click was delayed and simulated the first click´s reflection. The first click, called the lead, and the second click, called the lag, had the same duration, 0.1 ms, and amplitude corresponding to 55 dB nHL at the listening position.

The rate of repetition was 3.61/s, or in other words, the stimuli were repeated 3.61 times per second. The interstimulus delay (ISD) between the leading and the lagging click was 3 ms. The stimuli were constructed using MATLAB (5.1), and the brain stem audiometer (BRA) used in the test was an Interacoustics EP25.

Procedure

Before the test was performed the subjects were verbally informed about the procedure. They were comfortably seated and the electrodes were attached, one to the top of the forehead, and one behind each ear, on the mastoid bone. Also, a ground electrode was placed on the forehead. The test required no part-taking or contribution other than listening.

The experiment was performed in a semi anechoic room, and two loudspeakers were used to simulate the direct sound and its reflection. The clicks were presented via loudspeakers, one positioned directly in front and the other 45 degrees azimuth angle to the left of the listener. The distance between the loudspeakers and the listener was 1.14 m (Fig. 1). The distance was due to the spacial boundaries of the room.

The experiment was performed in two tests, or sessions. The first set of stimuli was presented diotically, that is, the click pairs were only presented from the frontal loudspeaker. In the second test, the precedence effect was created with the second set of stimuli by "moving" the lagging click to the left loudspeaker, so, the leading click originated from the frontal loudspeaker and the lagging click from the left loudspeaker. In both sessions, the stimuli were identical; they were only presented differently to

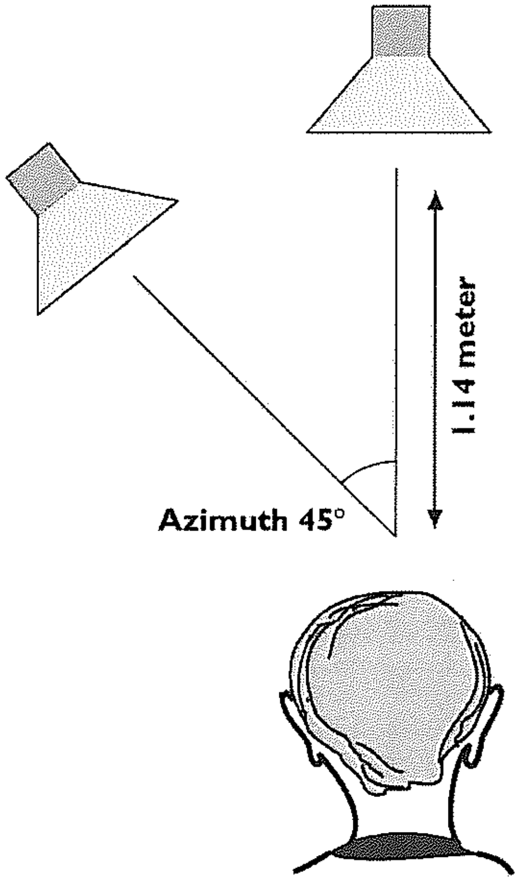

Fig. 1. Illustration of the positions of the loudspeakers

simulate diotic listening versus the precedence effect. The click pairs had an interstimulus delay of 3 ms and an intensity level of 55 dB nHL. The diotic presentation, which can be considered as an ordinary ABR curve, was done as a reference that enabled the two curves (diotic vs. precedence) to be compared.

The activity of the nervous system produces electrical signals, or evoked potentials, that are picked up by the electrodes. During both tests, the auditory brain stem responses of approximately 1400 click pairs were amplified, filtered, recorded and averaged in a time window of 0-30 ms. Each test took approximately 8 minutes. An ABR-curve normally consists of five to seven wave peaks that represent the neural activity in the auditory pathways during the first 10-12 ms after stimuli onset.

Subjects

Two Schizophrenic individuals were recruited from an inward patient unit at the University hospital in Malmö. Only patients with auditory hallucinations in their case history were asked to participate and they had to comply with the diagnostic criteria of DSM-IV (American Psychiatric Association, 1994, pp. 285-286) for schizophrenia. Exclusion criterions were patients with a history of organic brain desease, alcohol or drug abuse, or the presence of additional psychiatric diagnosis. An equal number of healthy individuals were used as reference subjects. The schizophrenics were 38 and 42 years old respectively, and the reference subjects were 26 and 59. All subjects reported normal hearing.

All subjects agreed to take part according to the requirements of the ethical committee at the Medical faculty of Lund university (LU 171-94).

Results

The ABR waveform is usually described and interpreted in terms of the latencies and amplitudes of the peaks. A given wave's absolute latency is the time delay from 0 ms, where the click is presented, until its peak occurs. The amplitude of each wave is described by its value from one peak of a wave to its following trough.

The schizophrenic individuals showed higher amplitude values for wave V of the precedence effect (Figure 3a and 3b) presentation compared to the healthy subjects (Figure 2a and 2 b). The schizophrenics had values of 119% and 104% respectively, and the healthy subjects values on the same was 76% and 57% respectively. The percentage measure is the result of the difference in amplitude (wave V) between the diotic and the precedence effect presentation. A value of 100% would mean no difference at all. There were no differences of latencies between the two groups.

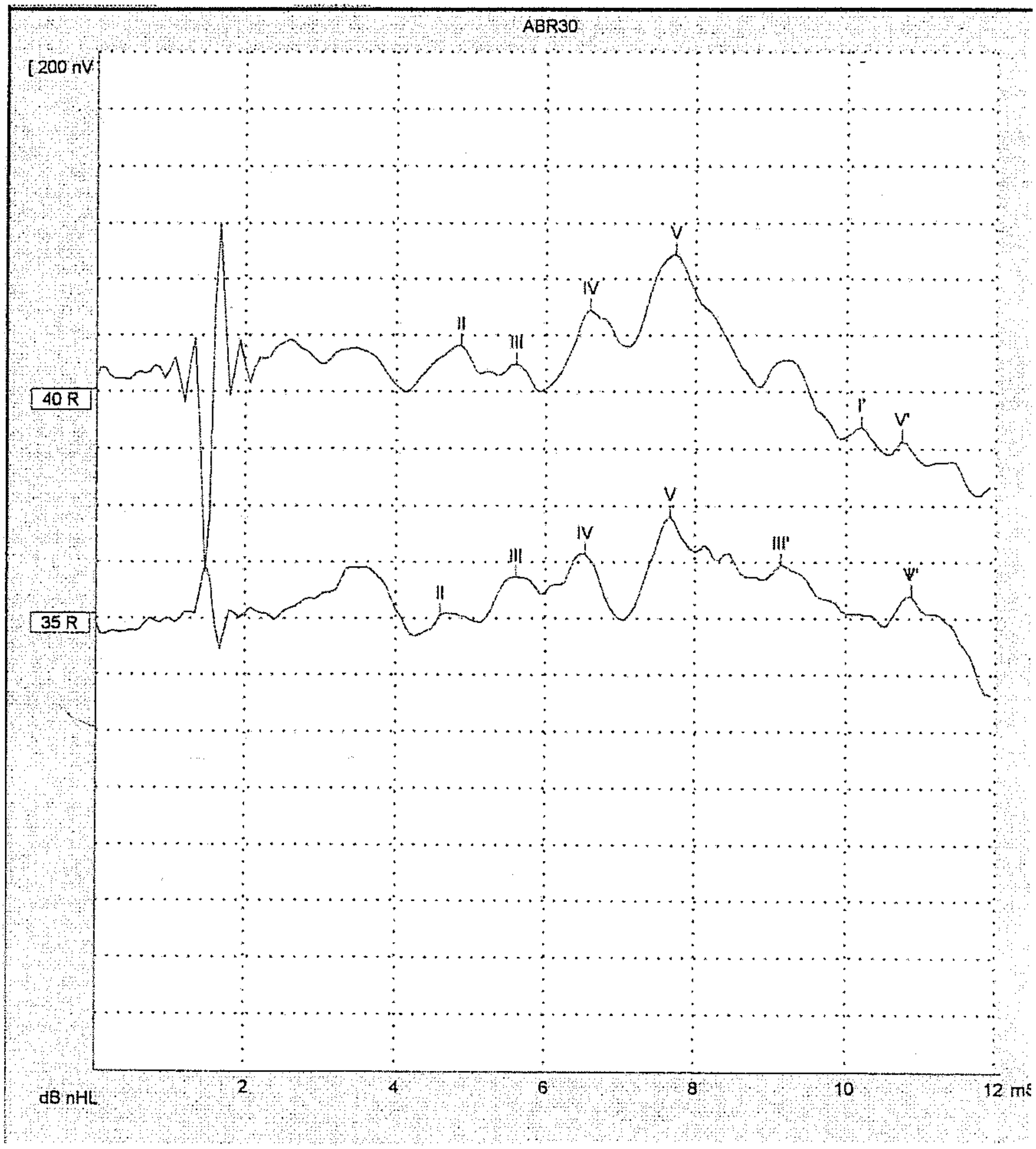

Fig. 2a. ABR-curve of the first reference subject. The upper curve is from the diotic presentation and the curve below is from the precedence effect presentation.

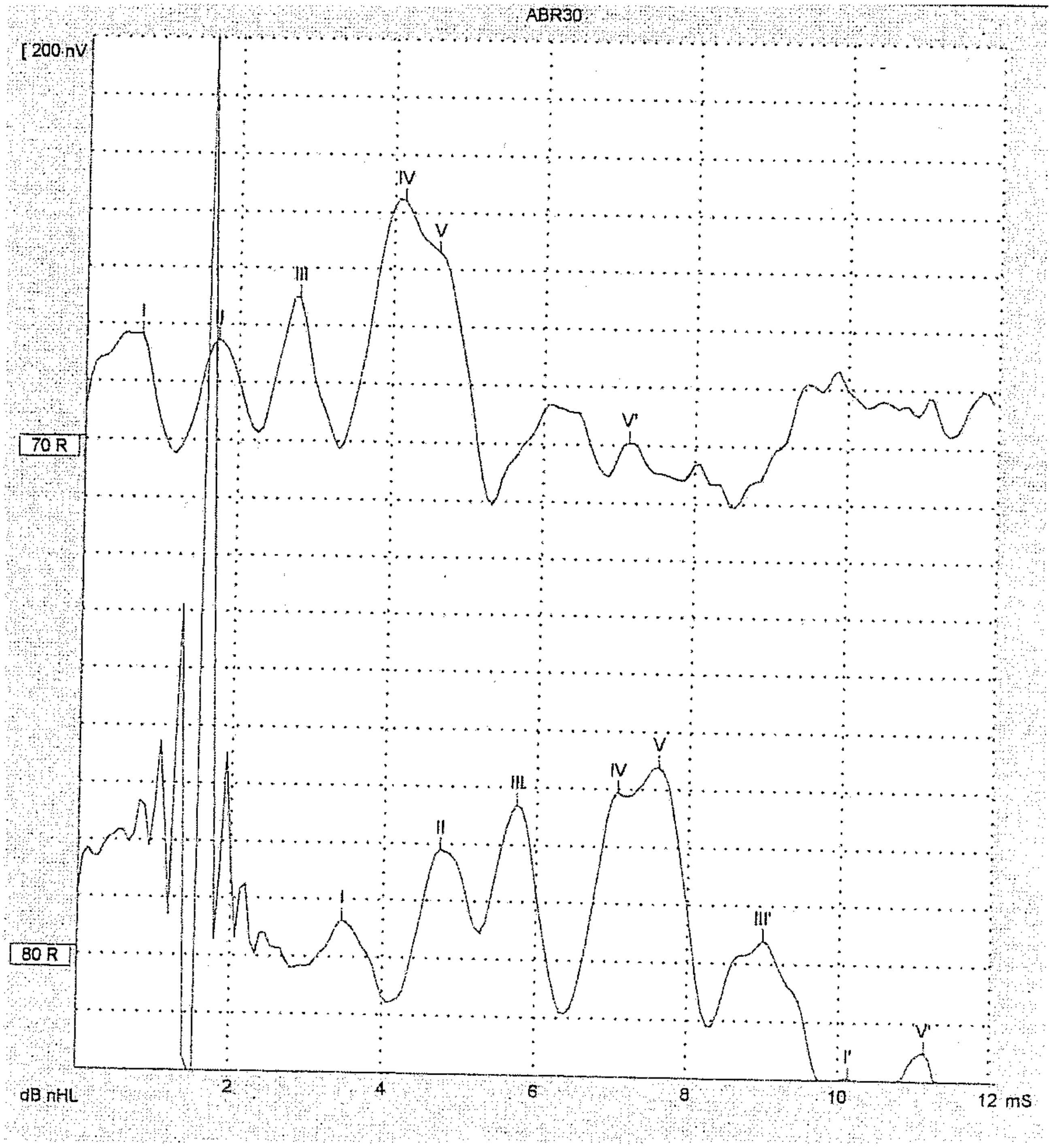

Fig. 2b. ABR-curve of the second reference subject. The upper curve is from the diotic presentation and the curve below is from the precedence effect presentation.

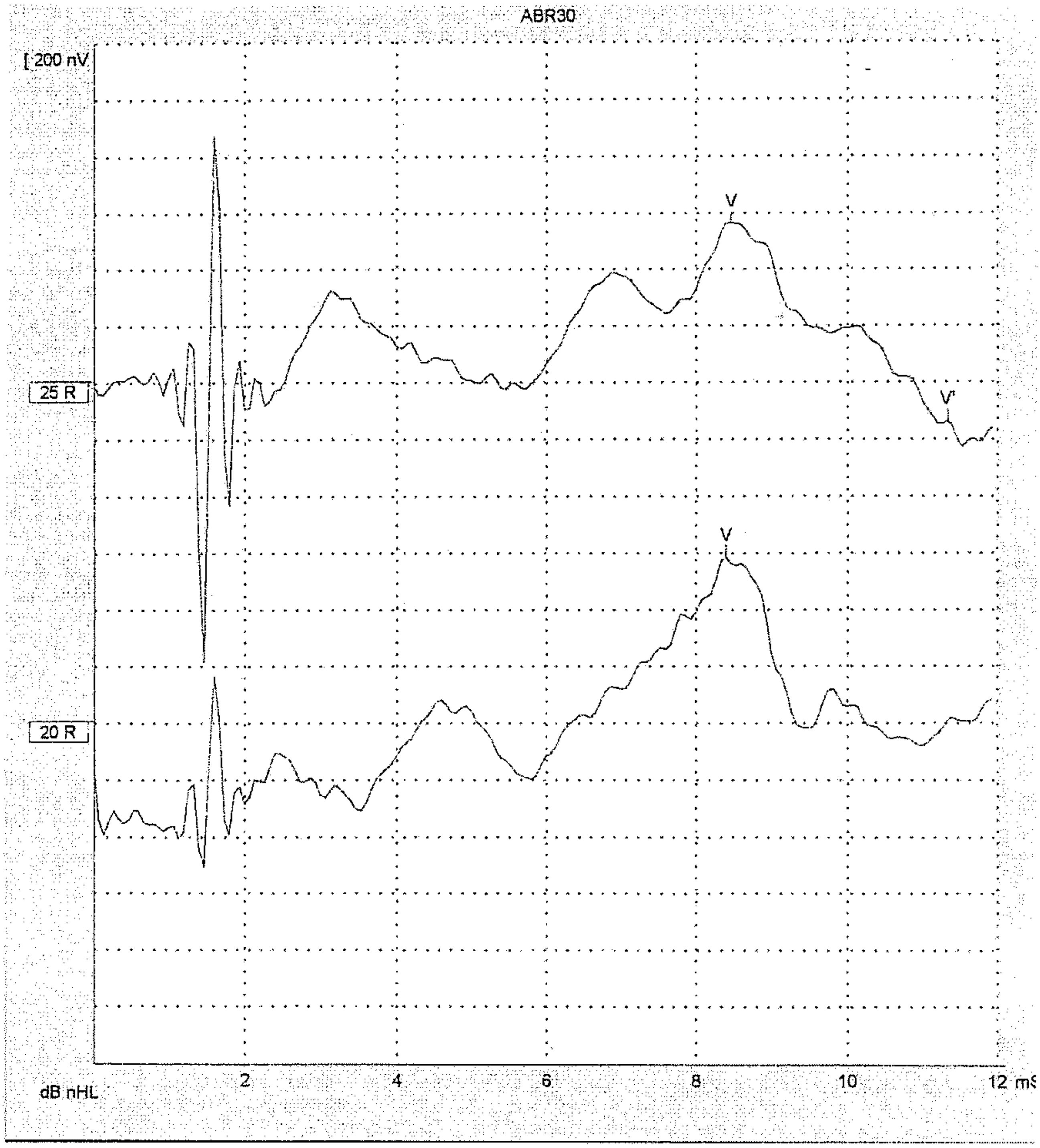

Fig. 3a. ABR-curve of the first schizophrenic subject. The upper curve is from the diotic presentation and the curve below is from the precedence effect presentation.

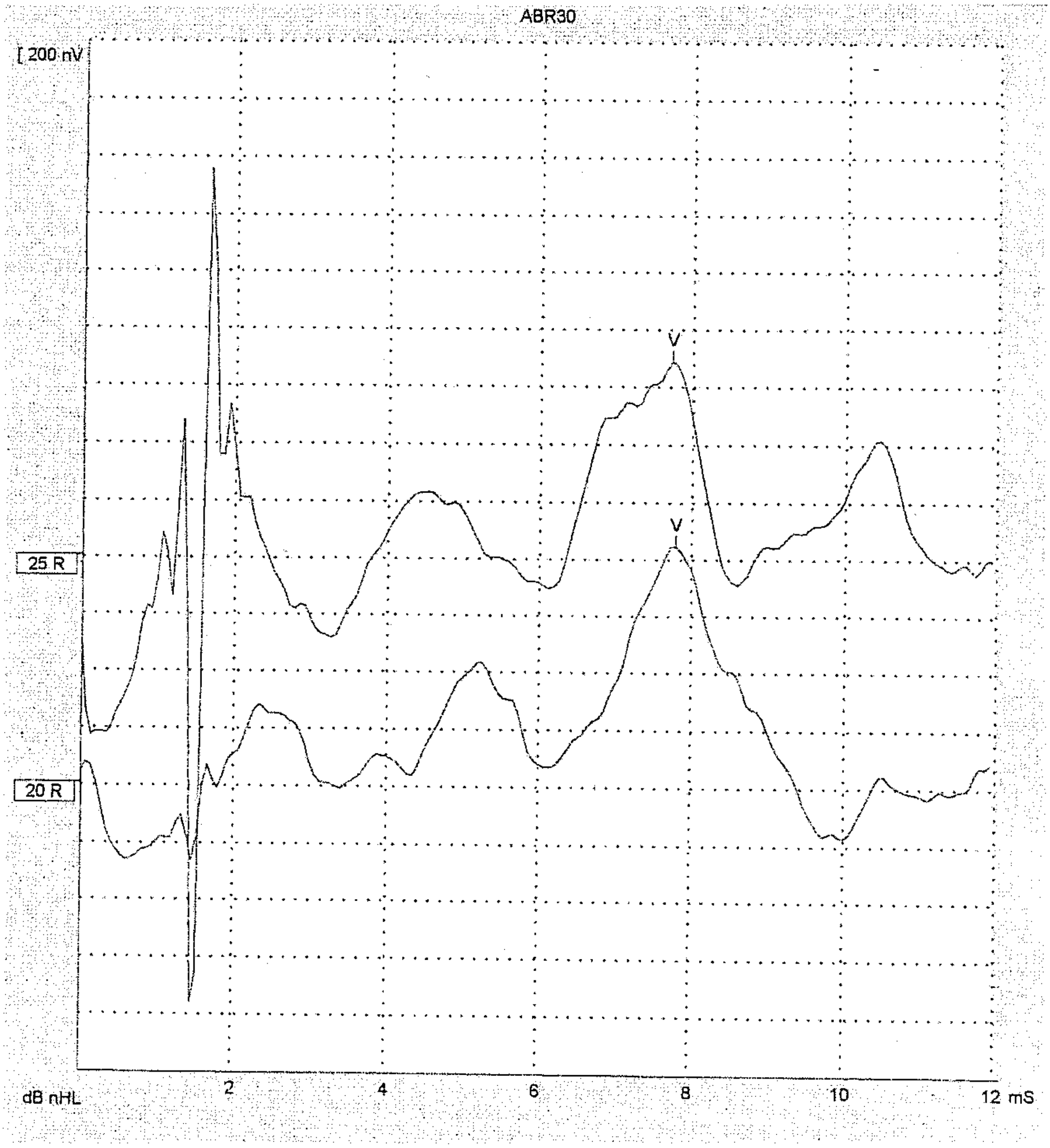

Fig. 3b. ABR-curve of the second schizophrenic subject. The upper curve is from the diotic presentation and the curve below is from the precedence effect presentation.

Discussion

In recent years there has been a re-growing interest in the precedence effect by psychoacousticians and physiologists, which has led to new literature. Zurek (1987) provides a review of the work through the mid-1980s, and related chapters can be found in a recent book by Gilkey and Andersson (1997). An extensive review to date on this topic is in Blauert´s book "Spatial Hearing" from 1997. Yost and Clifton are also names frequently encountered in this context.

Method

Before mentioning the main findings there will be a few comments on the test design. There are always dependent and independent factors to consider in experimental design and testing. Some known factors that are connected to the auditory brainstem audiometry, are the subjects age and gender and also the application of the electrodes. Others that are difficult to control are the subjects mood and stress level at the time of the testing. These factors have been considered and accounted for. As an example, the electrodes were identically attached on all subjects. Such procedures and factors have to be further considered when expanding this study in the future.

In this study, the stimuli were presented via loudspeakers. Headphone experiments differ from normal listening conditions in important respects. For example, with headphones, stimuli are abnormal and usually appear to have a source located within the listeners skull rather than out in the environment (Blauert, 1997). By using loudspeakers in free field, a more realistic and closer to real-life environment is created. Also, the precedence effect is known to be stronger in free field compared to by headphone presentation. Diotic presentation of signals via headphones assures with great accuracy that the signals at both ears will be identical, or, in other words, that interaural signal differences will be absent. However, there is one instance where sound in free space approximates the diotic condition. This is when the sound source lies in the median plane. If it is assumed that the head is symmetrical, then identical signals are to be expected at both ears (Blauert, 1997). In this case, when the delay is zero and the speakers are stimulated equally, the stimuli to the two ears of the listener are approximately equal, a single fused image is perceived approximately straight ahead of the listener.

In the present study, when the precedence effect is created with the two loudspeakers by breaking the image into two images, one at each speaker position, the normal perception is that a single sound source originates from the frontal loudspeaker, or in other words, the location of the sound is the loudspeaker straight ahead of the listener. The two sound sources are perceived as fused into one image since the interstimulus delay is so short (3 ms), and the sound from the loudspeaker to the left is not perceived. However, the subjects subjective perception is not accounted for in this study.

The reason for performing a diotic presentation in the median plane was to compare the result from the diotic presentation to the precedence effect result to be able rule out the influence of masking in the precedence effect, since a leading sound is known to being able to suppress a lagging sound. The results from the diotic presentation can be considered as a normal ABR-curve. Since the results from the precedence effect presentation differed from the diotic result, it can be concluded that it really is the effect of precedence that is measured in the precedence effect presentation, and not an effect of ordinary masking.

According to Lindström et al. (1987) it is generally agreed that peak I of the ABR derives from the activation of the acoustic nerve, whereas peaks II-V originate from the brain stem, with peak V as the most prominent and identifiable component of the response. The structures involved from wave I to V are the acoustic nerve (N VIII), the cochlear nucleus (CN), the superior olivary complex (SOC), the lateral lemniscus (LL) and the inferior colliculus (IC).

Results

The ABR-curves were interpreted as follows. The waves are evoked potential responses to the lagging sound. The amplitude of wave V in the precedence effect result was investigated. A low amplitude may mean that the lagging sound has been suppressed by the leading sound. If the lagging sound is sufficiently suppressed, a listener perceives one single sound coming from where the leading sound originated. In such case, the precedence effect is strong, which makes it easier for the listener to concentrate on the direct sound and localize it correctly.

A high amplitude, on the other hand, may mean that the lagging sound is not sufficiently suppressed and dominated by the leading sound. The lagging sound then has some influence, which makes the localization of the leading sound more difficult, hence a weaker precedence effect.

The schizophrenics had a stronger amplitude of wave V compared to the healthy subjects and therefore it is implied that the precedence effect is not as strong for the schizophrenics as for the healthy subjects. It would mean that the schizophrenics have difficulties in suppressing the lagging sound and hence some difficulties in localizing the direct sound correctly.

As mentioned earlier, extensive filtering and sorting among all auditory impressions registered by the brain is needed in order to make the auditory environment understandable. A suggestion is that the schizophrenics increased amplitude depends on their filter dysfunction, meaning that the response of the lagging sound does not become suppresed as in healty subjects. The lagging sound is not suppressed enough, and therefore it is more difficult to localize the leading sound. When perception involves time processes and build-up mechanisms, they fail to filter and sort out the stimuli accurately.

These suggestions are based upon what the results imply is happening in the auditory pathways in the brain, and especially in the inferior colliculus. How the schizophrenics and healthy subjects really perceive the sound is, as mentioned earlier, not accounted for in this study. However, it is of much interest, and will be investigated in a near future study.

Conclusion

To summarize, on the basis of the present study, and previous, it can be assumed that hallucinating schizophrenic individuals have dysfunctions in their ability to localize sounds. The result imply that a further evidence for filter dysfunction in inferior colliculus in schizophrenia has been presented.

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