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The effect of stimulus expectancy on dishabituation of auditory evoked potentials

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ABSTRACT

Objectives: Having foreknowledge of the type and timing of sensory stimulation modulates the electrophysiological response and can result in short-term habituation. Here we explore if dishabituation is similarly affected.
Methods: Seventeen healthy subjects were tested with five different auditory stimuli paradigms to see if knowledge of the stimulus train length and/or deviant stimulus affects the amount of dishabituation of auditory evoked potentials. Furthermore it was determined if the degree of difference between the repeating stimulus and deviant stimulus affected the amount of dishabituation.
Results: Stimulus complexity is the main determinant of the degree of dishabituation, followed by lack of knowledge about train length. Not knowing the deviant stimulus has little or no effect on dishabituation. Also, P200 is the most affected by expectancy and P50 not at all.
Conclusions: Foreknowledge of the type and timing of sensory stimulation modulates the degree of dishabituation.
Significance: Previous reports have shown that expectancy does affect (certain) evoked potential components. Here we extend this knowledge to the effect of expectancy on dishabituation.

1. Introduction

Ensemble-averaged auditory evoked responses to tones typically contain a positive component occurring at around 50 ms (P50), a negative one at around 100 ms (N100) and P200, a positive component at around 200 ms. The amplitudes of several of these components decrease (habituate) with repeated stimulus presentation (Davis and File, 1984). Two main kinds of this phenomenon exist: short-term habituation (STH), occurring when individual stimuli are repeated with interstimulus intervals of 20 s or less, and long-term habituation (LTH), which occurs across blocks of stimuli lasting minutes (Callaway, 1973; Woods and Elmasian, 1986). An example of STH occurs when the P50 and N100 component of the auditory evoked potential are much smaller for the second of a pair of identical simple auditory stimuli than for the first stimulus, if the stimuli are separated by 500 ms. This is often attributed to sensory gating (Adler et al., 1982), and is believed to prevent the flooding of higher cortical centers with irrelevant information (Venables, 1964). Abnormalities in sensory gating have been demonstrated in a number of psychiatric conditions (Franks et al., 1983). LTH may reflect the establishment or updating of a neuronal model or template of a stimulus following repeated exposure (Sokolov, 1963). The loss of novelty associated with building a neuronal model following stimulus repetition will lead to a decrease in response amplitude. It is unclear to what degree similar processes are involved in STH, as the typical experiment involves 50 to 100 presentations of pairs of stimuli, so that the subject quickly learns what to expect.

STH, which is the subject of study here, can also be examined by presenting the subject with trains of identical stimuli (Davis et al., 1966; Fruhstorfer et al., 1970). Most studies report a rapid decrease in N100 amplitude (up to 50% for the second stimulus), with a few studies reporting that N100 amplitude reduction follows a negative exponential function, reaching an asymptotic value by the third or fourth stimulus (Ritter et al., 1968; Fruhstorfer et al., 1970). More recent studies failed to find any continued decrement from stimuli 2 through 5 (Budd et al., 1998; Rosburg et al., 2004). The latter two studies included a test for dishabituation in their design, by presenting a sixth stimulus with different stimulus characteristics than the first five. Since this sixth stimulus is novel, one would expect that it elicits a larger response than the preceding stimulus. While Budd et al. (1998) did not find a general increase in N100 amplitude for stimulus 6 relative to stimulus 5, Rosburg et al. (2004), did find such an increase for P50 and N100, but P50 for S6 was still significantly smaller than for S1. The Rosburg et al. (2004) study involved intracranial recordings, possibly resulting in a larger signal-to-noise ratio than achievable with surface electrodes.

Several factors affect the degree of habituation or sensory gating in humans, and include the temporal characteristics of stimulus sequences (Davis et al., 1966), and whether the stimuli were machine-triggered or subject-initiated (Schafer and Marcus, 1973).

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In the latter study, it was found that the N100 and P200 components of averaged cortical responses to self-delivered auditory stimuli exhibited smaller amplitude and shorter latency than identical stimuli that were machine delivered and about which the subject had no foreknowledge. No such effect was seen for P50. Reduced responses (N100) were also observed when a visual cue alerted the subjects when an externally-triggered stimulus was to be delivered (Rothman et al., 1970; Schafer et al., 1981). Clementz et al. (2002) have provided evidence that expectancy affects sensory habituation, using a paradigm with single stimuli, pairs of stimuli and triplets of stimuli. Half of the subjects had foreknowledge about the number of stimuli they were going to receive in a given trial and the others did not. In case of the subjects not having foreknowledge, the P50 and N100 amplitudes were found to be larger for the response to the second and the third stimuli as compared to the first stimulus, thus showing that the amount of habituation decreases if the subject has no knowledge about the sequence of stimuli (s)he is going to hear.

It is unclear if presenting a deviant tone following a series of identical tones truly measures dishabituation as one could argue that the deviant stimulus is irrelevant since the subject knows that one will come once the five preceding tones have been perceived. In other words, expectancy may affect the degree of dishabituation. In this context, there are two aspects that affect expectancy: knowledge about the stimuli train length, and knowledge about the deviant stimulus. Because we were unable to find reports on how foreknowledge of these aspects affects dishabituation, we decided to study them individually and jointly through a series of experiments in which healthy participants passively listened to trains of identical auditory stimuli, followed by a final different (deviant) stimulus. A test to determine if stimulus complexity affects dishabituation was included as well. We hypothesized that the final stimulus produced the smallest response if the trains were of fixed length and the final stimulus did not vary between trains, whereas randomizing train length, final stimulus, or increasing the spectral complexity of the final stimulus would lead to larger responses.

The significance of the study lies in the observation that the basic mechanisms by which the organism can cease to respond to repetitious incoming irrelevant stimuli (particularly on a physiological level) are not well-defined. A thorough understanding of this function is needed to provide a foundation for better interpretation of the implications of abnormalities of this system in psychopathological conditions. The present study adds to our knowledge base, as it shows how expectancy affects the degree of dishabituation of various auditory EP components.

2. Methods

2.1. Participants

Seventeen healthy subjects drawn from the student population from the University of Houston participated in the study. The group consisted of 8 females and 9 males, and their age ranged from 19 to 27 years (mean age: 22.7; median age: 23). The study was approved by the Institutional Review Board of the University of Houston and informed consent was obtained from all subjects.

2.2. Stimuli and procedure

Trains of auditory stimuli were presented through speakers to the subject, under the control of the Presentation (© Neurobehavior) software program. The speakers were placed in a fixed position on either side of the reclining chair in which the subjects were sitting, at a height corresponding to the subject's ear, and at a distance of 0.25 m. Pure tones and a chirp were used as stimuli, generated using MATLAB software. The duration of each stimulus was 6 ms, which included a 1 ms rise and 1 ms fall time. Tones had a frequency of 745 Hz, 1000 Hz, or 1500 Hz and the chirp had a linearly changing frequency of 700 to 4241 Hz. Since all tones were generated with the same amplitude, the hearing threshold for one tone only (we used the 1500 Hz tone) was determined for each subject separately using a handheld dB-meter, and the sound level was set at 25 db above the hearing threshold. The subjects were instructed to passively listen to the tones, and they were not informed about the nature of the paradigms.

Data were collected using a sixteen-channel Biosemi Active II (Amsterdam, The Netherlands) EEG apparatus (Fp1, Fp2, F4, Fz, F3, T7, C3, Cz, C4, T8, P4, Pz, P3, O1, Oz, and O2) referenced to the average of all channels, but in this study we analyzed the Cz data only to remain in concordance with most studies using auditory evoked responses to study habituation and dishabituation. Also, selecting the vertex removes any effect the handedness of the participants (which was not checked) may have on the results. No electrodes were dedicated specifically to measure the EOG, but the Fp1 and Fp2 leads allowed for eye-lid and general eye movement identification. The bandwidth of the amplifier was set between 0.1 Hz and 40 Hz, and sampled at 512 Hz for processing. All recordings took place in a quiet, semi-dark room, with the subject sitting comfortably in a reclining chair. EEG data were passed through a lowpass filter with cutoff at 40 Hz and a high pass filter with cutoff at 0.1 Hz, and sampled at 512 Hz.

2.3. Paradigms

Stimuli were presented in trains of three, four or five repeating, identical stimuli (pure tones of 1000 Hz) followed by a final auditory stimulus with different or equal characteristics as the previous ones. A time interval of 8 s separated stimulus trains to allow for the recovery of the neuronal pools generating the responses (Zouridakis and Boutros, 1992) and an inter stimulus interval of 500 ms was used.

Five paradigms were used and their composition is detailed in Table 1. Each paradigm contained thirty 'object' trains of length five (plus a final deviant tone) and a varying number of 'distractor' trains. The responses to the object trains were used for hypothesis testing, and the distractor trains served to modulate the degree to which the subject could develop expectancy. The SL1500 (Same Length, 1500 Hz final tone) paradigm contained 30 trains of five 1000 Hz tones, followed by a 1500 Hz tone. Because there were no distractor trains, and the train length was fixed and the deviant stimulus was always the same, this paradigm represents the high expectancy case against which the other paradigms were compared. The DLDD (Different Length, Different Deviant) and DLSD (Different Length, Same Deviant) paradigms each consisted of 90 trains, randomly varying in length with three, four or five tones of 1000 Hz per train, and followed by a deviant stimulus. In case of the DLDD paradigm, the deviant stimulus varied randomly from train-to-train and was either a 745 Hz, 1000 Hz, or 1500 Hz tone or the 700–4241 Hz chirp. Thirty of these trains contained five 1000 Hz tones followed by a 1500 Hz tone and they were used as the object trains. The DLSD paradigm was similar to DLDD, except that all trains were concluded by the same 1500 Hz deviant tone. Again thirty trains were of length five plus the final deviant tone, serving as the object trains. This paradigm was used to study the effect of not knowing the train length. The SLDD (Same Length, Different Deviant) paradigm consisted of 60 trains, all of length five, followed by a deviant stimulus which varied randomly from train-to-train in the same manner as for DLDD. Thirty of the sixty trains had the 1500 Hz tone as the deviant stimulus, comprising the object trains, and they were used to study the effect of not knowing the deviant stimulus. The SLCHIRP (Same Length, Chirp final tone) paradigm contained 30 trains of length five, each followed by the chirp tone. All these trains were object trains, and this protocol was used to study the effect of spectral complexity on dishabituation by comparing its results with the SL1500 outcomes.