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Research paper

Direct comparison between properties of adaptation of the auditory nerve and the ventral cochlear nucleus in response to repetitive clicks

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Abstract

The present study was designed to complete two previous reports [Loquet, G., Rouiller, E.M., 2002. Neural adaptation to pulsatile acoustical stimulation in the cochlear nucleus of the rat. Hear. Res. 171, 72–81; Loquet, G., Meyer, K., Rouiller, E.M., 2003. Effects of intensity of repetitive acoustic stimuli on neural adaptation in the ventral cochlear nucleus of the rat. Exp. Brain Res. 153, 436–442] on neural adaptation properties in the auditory system of the rat. Again, auditory near-field evoked potentials (ANEPs) were recorded in response to 250-ms trains of clicks from an electrode chronically implanted in the ventral cochlear nucleus (VCN). Up to now, our interest had focused on the adaptive behavior of the first one (N_1) of the two negative ANEP components. A re-examination of our data for the second negative component (N_2) was now undertaken. Results show that the adaptation time course observed for N_2 displayed the same three-stage pattern previously reported for N_1. Similarly, adaptation became more pronounced and occurred faster as stimulus intensity and/or repetition rate were increased. Based on latency data which suggest N_1 and N_2 to be mainly due to the activity of auditory-nerve (AN) fibers and cochlear nucleus neurons, respectively, it was concluded that neural adaptation assessed by gross-potentials was similar in the AN and VCN. This finding is meaningful in the context of our search to restore normal adaptation phenomena via electro-auditory hearing with an auditory brainstem implant on the same lines as our work in cochlear implants.

Keywords: Auditory evoked potentials; Brainstem; Click; Rat; Unanaesthetized

1. Introduction

Adaptation properties of primary auditory neurons have been assessed by several authors having recorded either compound action potentials (Peake et al., 1962a,b; Eggermont and Spoor, 1973; Gorga and Abbas, 1981; Abbas, 1984; Chimento and Schreiner, 1990, 1992) or firing patterns from single auditory-nerve fibers (Kiang et al., 1965a; Smith and Zwislocki, 1975; Smith, 1977, 1979; Harris and Dallos, 1979; Westerman and Smith, 1984; Yates et al., 1985; Rhode and Smith, 1985; Chimento and Schreiner, 1991; Javel, 1996; Taberner and Liberman, 2005), in response to either long pure tones or trains of repetitive tone bursts or clicks. The adaptation time course displayed by primary auditory neurons was described to consist essentially of three stages: a rapid decrease of compound-action-potential amplitude or firing rate during the first few milliseconds of stimulation (rapid adaptation), followed by a slower decrease (short-term adaptation) and, finally, a steady state. Using

Abbreviations: AN, auditory nerve; ANEP, auditory near-field evoked potential; CF, characteristic frequency; CN, cochlear nucleus; N_1, first negative ANEP component; N_2, second negative ANEP component; P_1, first positive ANEP component; pps, pulses per second; VCN, ventral cochlear nucleus

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even longer stimuli, a long-term (s) and a very-long-term (min) adaptation component were also described (Javel, 1996).

As opposed to those of primary auditory neurons, adaptation patterns of cochlear nucleus (CN) units to pure-tone bursts are very diverse. Many different response types are generated in the CN, such as primary-like, primary-like with notch, and chopper units, among many more (e.g. Kiang et al., 1965b; Pfeiffer, 1966; Evans, 1975). Evoked potentials recorded from the ventral cochlear nucleus (VCN) displayed an adaptive behavior also in response to short repetitive pure-tone bursts (Huang and Buchwald, 1980; Huang, 1981) or click trains (Loquet and Rouiller, 2002; Loquet et al., 2003). These latter two studies carried out in our laboratory demonstrated that the first negative component (N_1) of the auditory near-field evoked potentials (ANEPs) recorded from the VCN at various stimulus repetition rates and intensities displayed three adaptation stages comparable to those described above for primary auditory neurons (rapid adaptation, short-term adaptation, steady state). Based on the location of the recording electrode (in the VCN), one may be tempted to conclude that primary auditory and VCN neurons exhibit similar adaptive behaviors. However, the ANEPs recorded from the VCN were characterized by the presence of multiple consecutive components whose precise origins remain a matter of debate (e.g. Møller, 1983; McMahon et al., 2004). In particular, when recorded from the VCN, the ANEPs exhibit a prominent second negative component (N_2), nearly as large as the first negative component. Moreover as will be argued in the discussion section, when comparing our latency data to that of single-unit recordings carried out by various authors, it seems most probable that the first and the second negative components of ANEPs recorded from electrodes in the VCN are mainly due to the activity of AN fibers and VCN neurons, respectively. The present study aimed at investigating the adaptation properties of N_2, allowing for a direct comparison in the same experimental conditions with the properties derived from N_1 (Loquet and Rouiller, 2002; Loquet et al., 2003). The working hypothesis is that, if the adaptive properties of N_1 and N_2 were comparable, the conclusion that primary auditory and VCN neurons do not differ with respect to adaptation would receive stronger support. In contrast, if N_1 and N_2 exhibit different adaptive properties, the possibility that the synaptic transmission between primary auditory neurons and VCN neurons may modify the adaptation to repetitive acoustic stimuli has to be considered.

The clinical implication of these adaptation studies lies in the field of cochlear and brainstem auditory implants. Recently, in a study carried out in our laboratory, a stimulus paradigm consisting basically of varying repetitive electrical pulses rates was developed to stimulate the AN (via a simplified cochlear implant) and evoke AN-fiber response envelopes resembling those observed in response to repetitive acoustic stimulation as closely as possible (Loquet et al., 2004). Based on the results of the present study, we think that the testing of such a stimulus paradigm may yield realistic adaptation response envelopes in local neurons also when applied directly to the VCN (via a simplified auditory brainstem implant).

2. Materials and methods

The methodological procedures are the same as those described in detail in two previous reports (Loquet and Rouiller, 2002; Loquet et al., 2003). Briefly, experiments were conducted on male adult Long-Evans rats (Janvier Laboratories, France) weighing approximately 300 g ($n = 6$). ANEPs were recorded from a chronic electrode implanted in the left VCN (Fig. 1a). During stimulation, animals were not anaesthetized but only lightly sedated (levomepromazin, 10 mg/kg i.p.). The experimental procedure was approved by the Swiss veterinary authorities and was performed in accordance with the "Principles of laboratory animal care" (NIH Publication No. 86-23, revised 1985) and the 1964 Declaration of Helsinki for animal care.

ANEPs were recorded in response to trains (250 ms duration) of repetitive clicks (100 μs duration) delivered at six different repetition rates (100, 200, 400, 600, 800, and 1000 pulses per second (pps)) and five different intensities (5, 10, 30, 50, and 70 dB SPL). TDT (Tucker Davis Technologies) System II acoustic stimulation and data acquisition software (BioSig32) was used to automate ANEP averaging over 50 stimulus-train presentations and to store the recorded traces for off-line analysis. Each click train was separated from the next one by a pause (silence) of 250 ms (50% duty cycle). ANEPs were amplified (2×10^3) and bandpass-filtered between 30 Hz and 3 kHz. A typical recording is presented in Fig. 1b. The goal of the present study was to analyze the N_2 component of the ANEPs recorded from the VCN by assessing the voltage difference between the peaks P_1 and N_2. At repetition rates higher than 400 pps, responses to individual clicks started to overlap so that the amplitude of a given response was influenced by the preceding one. In order to circumvent this contamination, a subtraction method was used (Wilson et al., 1997; Loquet and Rouiller, 2002; Loquet et al., 2003, 2004). This method consisted in presenting series of n clicks followed by series of $n + 1$ clicks (50 presentations of each), averaging them, and then subtracting the former from the latter, thus exposing the response to the $n + 1$ click. However, this technique would, especially at high repetition rates, require a very large number of stimulus sequences to isolate the ANEPs to every click in a given train. Therefore, in order to avoid over-stimulation during recording sessions, ANEPs were collected for all consecutive clicks during the initial 20 ms of stimulation, then for one click every 10 ms during the next 60 ms, and for only three individual clicks during the remaining 170 ms of a click train (Fig. 1c). All $P_1 - N_2$ amplitudes evoked by a given stimulus train were normalized relatively to the highest response in the sequence (usually the first one) and then