Available online at www.sciencedirect.com
ScienceDirect

International Journal of Psychophysiology 65 (2007) 152–161

INTERNATIONAL JOURNAL OF PSYCHOPHYSIOLOGY

www.elsevier.com/locate/ijpsycho

Stimulus intensity affects early sensory processing: Sound intensity modulates auditory evoked gamma-band activity in human EEG

Jeanette Schadow, Daniel Lenz, Stefanie Thaerig, Niko A. Busch, Ingo Fründ, Christoph S. Herrmann *

Department of Biological Psychology, Otto-von-Guericke University of Magdeburg, P.O. Box 4120, 39016 Magdeburg, Germany

Received 26 October 2006; received in revised form 16 March 2007; accepted 19 April 2007
Available online 4 May 2007

Abstract

We studied the effect of different sound intensities on the auditory evoked gamma-band response (GBR). Previous studies observed oscillatory gamma activity in the auditory cortex of animals and humans. For the visual modality, it has been demonstrated that the GBR can be modulated by top–down (attention, memory) as well as bottom-up factors (stimulus properties). Therefore, we expected to find a sound intensity modulation for the auditory GBR.

21 healthy participants without hearing deficits were investigated in a forced-choice discrimination task. Sinusoidal tones were presented at three systematically varied sound intensities (30, 45, 60 dB hearing level). The results of the auditory evoked potentials were predominantly consistent with previous studies. Furthermore, we observed an augmentation of the evoked GBR with increasing sound intensity. The analysis indicated that this intensity difference in the GBR amplitude most likely arises from increased phase-locking.

The results demonstrate a distinct dependency between sound intensity and gamma-band oscillations. Future experiments that investigate the relationship between auditory evoked GBRs and higher cognitive processes should therefore select stimuli with an adequate sound intensity and control this variable to avoid confounding effects. In addition, it seems that gamma-band activity is more sensitive to exogenous stimulus parameters than evoked potentials.

Keywords: EEG; Gamma-band oscillations; 40 Hz; Phase-locking; Sound intensity

1. Introduction

Synchronous neuronal firing in the range from 30–80 Hz appears to be involved in binding different features of an object so that it is perceived as a single, coherent one (Eckhorn et al., 1988; Singer, 1993; von der Malsburg, 1995). This phenomenon is well investigated for animals and humans in the visual modality (Gray et al., 1989; Singer and Gray, 1995; Tallon-Baudry and Bertrand, 1999). Furthermore, the individual stimulus features such as size, spatial frequency, and contrast have a noticeable influence on the human gamma activity (Busch et al., 2004; Tzelepi et al., 2000; Schadow et al., submitted for publication to IJP). The mentioned studies reported a systematic variation of gamma-band amplitude with changing stimulus features.

Different types of oscillatory activity have been distinguished in the auditory, visual, and somatosensory modalities. The evoked gamma-band response is characterized by precise phase-locking to stimulus onset and can be detected by averaging the single trials. In the auditory system, the evoked gamma-band response has been observed at 20–130 ms after stimulus onset. In contrast to the evoked gamma activity, induced responses jitter in latency from trial to trial (non-phase-locked) and are thus cancelled out by classic averaging techniques. For this reason, specific analysis methods are required for detecting the induced gamma-band response which occurs in a later time interval around 200–400 ms (Galambos, 1992; Tallon-Baudry and Bertrand, 1999).

---

* Corresponding author. Tel.: +49 391 6718477; fax: +49 391 6712222.
E-mail address: christoph.herrmann@nat.uni-magdeburg.de (C.S. Herrmann).

0167-8760/$ - see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.ijpsycho.2007.04.006

The auditory evoked gamma-band response (GBR) has been investigated with different methods in animals and humans (Başar et al., 1987; Pantev et al., 1991; Galambos, 1992; Başar-Eroglu et al., 1996). A number of studies argue about whether the auditory evoked gamma-band activity represents an independent brain response functionally distinct from the auditory middle latency response (MLR) and long latency response (e.g. N1) (Başar et al., 1987; Bertrand and Pantev, 1994; Pantev, 1995; Jacobson et al., 1998; Müller et al., 2001). Since several studies observed a similar amplitude increase with an increasing interstimulus interval for evoked gamma-band responses as shown for the MLR and long latency response (Makeig, 1990; Pantev et al., 1993), Başar et al. (1987) reasoned that the 40 Hz response is a consistent part of the auditory evoked potential. However, dipole localizations suggested that generators underlying the gamma-band field (GBF) are spatially distinct from those underlying the MLR Pa component as well as the N100 (Pantev et al., 1993). In this regard, the spatial separation of the GBF, MLR, and N100 provides evidence that they may arise from different processes in the auditory pathway (Pantev, 1995).

Animal studies with intracranial recordings have shown oscillations with a frequency around 40 Hz, both in the primary and secondary auditory cortex that occurred spontaneously and in response to sensory stimulation (Franowicz and Barth, 1995; MacDonald and Barth, 1995; Brett et al., 1996; Brosch et al., 2002). In humans, GBRs elicited by auditory stimulation were intensively studied in a variety of perceptual and cognitive tasks (Karakas and Başar, 1998; Crone et al., 2001; Kaiser and Lutzenberger, 2005b; Karakas et al., 2006). In different experiments, gamma-band activity was functionally related to Gestalt perception and attention as well as memory processing (Tiitinen et al., 1993; Yordanova et al., 1997; Knief et al., 2000; Debener et al., 2003; Kaiser and Lutzenberger, 2005a). However, the effects of auditory stimulus features on gamma-band activity such as loudness, pitch, timbre, or the combination of multiple frequencies have not yet been reported. Knowing and controlling such effects is necessary even for investigations of auditory cognition in order to yield optimal gamma-band responses and not to confound task (cognitive) effects with stimulus effects (see Busch et al. [2004] for a similiar discussion in the visual modality).

Processing of different sound intensities has already been investigated for auditory evoked potentials (AEPs). These studies consistently found a strong intensity dependency of the early AEP (Rapin et al., 1966; Beagley and Knight, 1967; Polich et al., 1996; Carrillo-de-la-Peña, 1999; Neukirch et al., 2002). All of them have reported a shortening of N1 latency and a pronounced increase of the N1–P2 peak-to-peak amplitude as the intensity of pure sinusoidal tones was increased. This loudness dependence phenomenon has also attracted much interest in psychiatric research, since several studies examined the serotonergic modulation of the cortical loudness dependency (Hegerl and Juckel, 1993; Hegerl et al., 2001; Debener et al., 2002). While Hegerl and colleagues stated that low serotonergic neurotransmission is associated with an enhancement in N1–P2 amplitude with increasing stimulus intensity, recent studies have demonstrated contradictory findings (Dierks et al., 1999; Debener et al., 2002; Massey et al., 2004). These studies manipulated the cerebral levels of serotonin by using tryptophan depletion and did not find significant effects of tryptophan depletion on intensity dependence of AEPs. Thus, it remains questionable whether the loudness dependency of AEPs is a specific biological marker of serotonergic activity.

The present study compared gamma-band activity in response to different sound intensity levels of a pure sinusoidal tone. This study represents a counterpart to the visual experiment analyzing the effects of stimulus contrast (Schadow et al., submitted for publication). We analyzed the gamma-band responses in an early and late time interval. In the early time window, evoked and total GBR as well as the strength of phase-locking were calculated. Presenting the phase-locking values and the total GBR completes the description of the evoked GBR and might give an important explanation for amplitude differences in the early GBRs (Busch et al., 2006). These three measures might resolve the question of whether stronger evoked gamma-band responses arise from stronger phase-locking of ongoing oscillatory activity or from signal increases. Based on the theoretical considerations, we expected to find enhanced GBRs with increasing intensity of the auditory stimulus. In addition, we aimed to replicate the aforementioned results for auditory evoked potentials.

2. Method

2.1. Participants

Twenty-one paid subjects (13 females, 8 males, mean age 26.2±5 years) participated in the study. They had no history of hearing impairments and showed no signs of psychiatric or neurological disorders. All subjects received a written task instruction and gave informed consent to participate. Two subjects were excluded from the entire data analysis due to numerous eye artifacts. The ethical principles of the Declaration of Human Experimentation (1964) concerning human experimentation were followed.

2.2. Stimuli and task

Two pure sinusoidal tones (2000 Hz, 4000 Hz) were generated using Adobe Audition V1.0 (Adobe Systems Inc., 2004) and delivered binaurally through insert earphones (EARTone 3A). The duration of each stimulus was 500 ms (10 ms rise and fall time) with a randomized interstimulus interval (ISI) between 1200–2000 ms. For each participant and each sine tone, the individual hearing threshold for the left and the right ear was determined in intensity steps of 1 dB. Based on the individual hearing level (HL), three intensities (30, 45, 60 dB) were selected for the high and the low frequency tone. A calibrated attenuator was used to control the sound levels (Tucker-Davis Technologies, model PA5). This attenuator has two channels — one for each ear. The attenuator is set before the presentation of every sinusoidal tone. Thus, we can adjust for each ear and each tone individually.

The present experiment was constructed as a forced-choice discrimination task. The frequent stimulus ($p = 0.8$) was a