

UNIVERSITY OF PÉCS

Biological Doctoral School
Comparative Neurobiology Programme

Brain synchronization processes: EEG studies

PhD Thesis

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PÉCS, 2008

Introduction

Oscillatory synchronization in different frequency bands is a ubiquitous phenomenon during cognitive processing in the human brain. Synchrony is a measure of the relation between the temporal structures of two signals generated by neuronal groups regardless of signal amplitude. If their rhythms coincide, signals are said to be synchronous (Steriade et al., 1990). Synchronous oscillations are prevalent during processing of sensory information virtually from all modalities and neuronal synchronization plays an important role also in motor processes (Engel et al., 2001; Varela et al., 2001).

EEG oscillations are rhythmic fluctuation of neuronal baseline excitability generated by synchronously oscillating ensembles of neurons (Fries, 2005; Canolty et al., 2006; Lakatos et al., 2005, 2008; Romei et al., 2007; Sauseng and Klimesch, 2008). Rhythmic changes of excitability create time windows for efficacious neuronal communication. It has been suggested that those neuronal groups are able to interact efficiently which synchronize their activity and oscillate in a coherent way, so that their time windows are simultaneously open or close for sending and receiving information (Fries, 2005). Oscillations within single cells can be generated by the interaction of excitatory and inhibitory ion channels in the cell membrane and these cells can act either as real oscillators, controlling rhythmic activity (pacemaker) or they can act as a resonator within a cell assembly with a preference for a certain frequency range (Llinás, 1988). Oscillations in a neuronal ensemble result from the network architecture and in most cases oscillations originate from the combination of these two mechanisms. Basic mechanisms of large-scale oscillatory activity in the cortex are probably maintained by a network of inhibitory interneurons between pyramidal cells. Mutual inhibitory connections of interneurons sustain rhythmic firing thus facilitate oscillations and improve synchronization (Sannita, 2000).

It has been suggested that at the core of human cognitive dynamic is a dynamic communication structure and that the neuronal substrate is the flexible neuronal coherence pattern. In case of bi-directional communication between neuronal groups, for mutual interaction axonal conduction delays are usually an order of magnitude shorter than the cycle length of the oscillations. Therefore, sending and receiving spikes probably happen within one and the same excitability peak (Fries et al., 2007; Womelsdorf et al., 2007).

Temporary synchronization between neuronal groups is a cost-effective solution for the binding problem, that is for the integration of distributed neuronal groups representing information about the same entity. As long as the linked neuronal groups oscillate at similar frequencies, synchronization can be maintained via weak synaptic links, enabling the establishment of functional connections between neuronal ensembles residing in distant brain sites (Buzsáki and Draguhn, 2004).

Understanding the exact functional role of oscillatory synchronization phenomena is an important issue, as neuronal synchronization appears to be playing a key role in cognitive functions. The common denominator of the many aspects of synchronous neural activity is binding, that is the dynamic process establishing functional links between neuronal elements at different levels of the hierarchic organisation of the brain. Synchronous oscillations play a role in bottom-up neuronal processing (feature binding) and also in top-down processes (e.g. in memory and attention), which is one of the most fundamental results in EEG research. However, in spite of the increasing number of studies addressing oscillatory synchronization phenomena there are still contradictions, competing hypotheses and unanswered basic questions in several areas of this field.

Aims

- (5) Investigation of the effect of familiarity of a visual stimulus on the inter-trial phase coherence of the early evoked gamma response with EEG.
- (6) Investigation of gamma-band EEG activity in newborn infants in response to auditory stimuli and investigation of auditory temporal grouping.
- (7) Investigation of the effect of attention on phase-synchronization between visual and auditory cortical areas during audio-visual target-detection using MEG.
- (8) Investigation of possible adverse effects of electromagnetic fields emitted by mobile phones on acoustic brainstem potentials, auditory cortical event-related potentials and early evoked gamma response.

Experiment 1. – Investigation of the effect of familiarity of a visual stimulus on the inter-trial phase coherence of the early evoked gamma response with EEG⁵

The aim of our experiment was to establish whether familiarity of a visual stimulus bears any effect on the inter-trial phase coherence of the early evoked gamma response. In this study we evaluated the hypothesis that repetition of a visual stimulus leads to the rapid formation of its dynamic neural representation. According to our hypothesis the repeating presentation activates the neural representation, which in turn results in stronger phase-locking of gamma oscillations than non-repeating stimuli without such neural representation. To test this hypothesis, we measured evoked gamma oscillations for a repeated target stimulus and for non-repeated non-targets and determined whether the early evoked gamma activity is stronger to the target than to the non-targets.

Methods

In our experiment a natural photo of a specific butterfly served as target ($p=0.25$) whereas non-target stimuli were 180 natural individual photos of butterflies ($p=0.75$) from other than the target species. The age of the ten subjects was between 20 and 26 years (mean 22.1, 5 women). EEG was recorded by eight Ag-AgCl electrodes from F3, F4, C3, C4, P3, P4, O1 and O2 sites referred to Cz according to the international 10-20 system, linked mastoids served as ground. Inter-trial coherence (ITC, phase-locking factor) and event-related spectral perturbation (ERPS) analysis was carried out using complex sinusoidal wavelets on epochs extending -400 ms before to 1799 ms after artefact rejection. ERSP reveals the amplitude of both the induced and evoked activity, whereas ITC is a measure of phase-stability across trials irrespective of signal amplitude (Tallon-Baudry et al., 1996; Debener et al., 2003).

⁵ **Stefanics G.**, Jakab A., Bernáth L., Kellényi L., Hernádi I. (2004): EEG early evoked gamma-band synchronization reflects object recognition in visual oddball tasks. *Brain Topography*, 16(4), 261-264.

Results

The 60 targets were easily recognized by the subjects (mean error 0.59; S.D. 1.15). Prominent phase-locked γ -synchronization centered at ~108 ms in 20 Hz to 50 Hz frequency range characterized target processing at parietal and occipital sites (P3, P4, O1, O2). Statistical analysis revealed significantly stronger inter trial coherence for the target stimulus compared to non-targets (ANOVA Stimulus-type \times Electrode, $F(1,9)=49.54$, $p<0.01$) and the analysis of EEG power in the same time-frequency window yielded similar results ($F(1,9)=6.36$, $p<0.05$).

Discussion

Our results showed that the repeated target stimulus evoked significantly stronger phase-locked gamma oscillations in the time window from 80 ms to 140 ms than non-repeating stimuli. The distinct feature of this study compared to previous studies (Tallon-Baudry et al., 1996, 1997; Herrmann et al., 1999; Herrmann and Mecklinger, 2000; Gruber and Miller 2002; Senkowski and Herrmann 2002) is that here individual pictures served as non-target stimuli thus preventing the reactivation of a neural representation of non-targets. In our study the target stimulus repeated throughout the experiment whereas each non-target were presented only once. We found that both the power and inter-trial coherence of the gamma response was higher for the target stimulus compared to non-targets. In the visual modality it has been shown that attention toward a target stimulus enhances the amplitude of the early evoked gamma response (Herrmann et al., 1999; Herrmann and Mecklinger 2000; Busch et al., 2006) however it does not affect the phase locking of the response (Busch et al., 2006).

Presumably the template of the target stimulus in memory influences the generation of the gamma responses. In a study by Herrmann et al. (2004) real object evoked stronger early gamma activity than non-real objects though subjects paid attention to both stimulus types and the authors suggested that the activation and matching of the neuronal representation of real objects to the incoming stimuli increased the amplitude of the gamma response compared to that evoked by non-objects which had no previous neuronal representation. Unfortunately in this study the inter-trial phase coherence was not analysed.

Considering the above studies it is likely that in line with former results (Herrmann and Mecklinger, 2000; Busch et al., 2006) attention directed toward the target stimuli in our experiment contributed to the increase of the amplitude of gamma response for targets. However, our observation of higher inter-trial coherence for the repeating target compared to unique non-targets is distinct from results of Busch et al. (2004) where phase locking did not differ for repeating target and repeating standards.

In summary our results suggest that matching a familiar target stimulus to its template in memory results in increase in the phase-stability of the early gamma-response compared to unfamiliar unique non-targets, which suggest that cognitive factors may influence not only the amplitude of the evoked gamma activity but also the phase of the early gamma response.

Experiment 2. – Investigation of gamma-band EEG activity in newborn infants in response to auditory stimuli and investigation of auditory temporal grouping⁶

⁶ **Stefanics G.**, Hádén G., Huotilainen M., Balázs L., Sziller I., Beke A., Fellman V., Winkler I. (2007): Auditory temporal grouping in newborn infants. *Psychophysiology*, 44, 697–702.

Gamma-band activity related to cognitive processing of visual binding, object representation, and perception of goal-directed action has been reported in 6–8-month-old infants (Csibra et al., 2000; Kaufman et al., 2003; Reid et al., 2007). However, little is known about gamma-band activity in newborn infants. The present study tested automatic grouping of sound pattern in sleeping neonates by comparing the responses to deviant tones between regular and random-order sequences.

In adults, oscillatory EEG activity in the gamma-band (430 Hz) has been observed in response to rare targets (Gurtubay et al., 2001), non-target deviants (Edwards et al., 2005; Kaiser et al., 2000), and stimulus omissions (Gurtubay et al., 2006) in the auditory oddball paradigm. Because rare deviants were reported to induce higher gamma-band activity than standards (Edwards et al., 2005; Kaiser et al., 2000) we expected stronger gamma-band activity in response to rare deviants in the random condition.

Methods

We recorded EEG from 12 (7 female) healthy full-term newborn infants on day 2 or 3 postpartum. Their gestational age was 38–41 weeks and birth weight was 2870–4200 g. Stimuli consisted of two complex tones, each with three harmonic frequencies added to the base frequency. The two tones differed only in frequency. The base frequency of the low tone was 500 Hz and that of the high tone 612 Hz. In two stimulus conditions, standard (S) and deviant (D) tones were delivered with a SOA of 100 ms, the D tone appearing less frequently (20%) than S tones (80%). In the random condition, tones were delivered in a pseudorandomized order with at least two standards separating successive deviants. In the grouped condition, the SSSSD pattern was cyclically repeated. The overall probability of the D tone was identical between the two conditions (20%). To eliminate possible confounds stemming from acoustic differences between the S and D tones, low and high tones serving as standards and deviants were swapped across different stimulus blocks, separately for each condition. In each of the four stimulus blocks, a total of 1000 stimuli were delivered. EEG was recorded from F3, F4, C3, Cz, and C4 scalp electrodes (according to the international 10–20 system) and from electrodes placed over the left and right mastoids. The dynamics of oscillatory EEG activity in newborns was studied by computing event-related spectral perturbation transforms (ERSP). We analysed epochs extending from 1000 ms before to 2000 ms after stimulus onset in the 6–40-Hz frequency range using Hanning-windowed sinusoidal wavelets. For statistical analysis of the gamma-band activity, a window of 140-ms duration was selected in the 30–40-Hz frequency range. The window was centered on the peak of the observable gamma-band oscillations in the grand-averaged central (Cz) ERSP response to deviants delivered in the random condition, where deviance-related gamma-band activity could be expected. For the ERP analysis the raw EEG data were filtered off-line between 2.5 and 16 Hz. For each stimulus, an epoch of 500-ms duration including a 100-ms pre-stimulus period was extracted from the continuous EEG record. For amplitude measurements, a 40-ms-long time window was selected, which was centered on the peak of the grand-averaged deviant-minus-standard difference waveform in the 172–212 ms latency range of the central (Cz) recording channel of the random condition, where mismatch negativity (MMN) elicitation was expected.

Results

Wavelet-based time-frequency analysis of the single-trial responses revealed peaks of electrical brain activity in the gamma-band, consistent with our hypothesis. In the random

condition, at approximately 200 ms from stimulus onset, strong gamma-band oscillations appeared with a centre frequency of about 36 Hz in response to deviants. In contrast, standards were followed by a decrease in the gamma-band activity amplitude. However, no such difference can be seen in the grouped condition.

The three-way ANOVA (Condition \times Stimulus Type \times Electrode) of the gamma-band activity revealed a significant main effect of Stimulus Type, $F(1,9)510.224$, $p < 0.05$, which was explained by a significant difference between the standard and deviant stimulus responses in the random condition (tested by planned comparisons, $p < 0.05$), whereas the same difference was not significant in the grouped condition. Grand-average ERPs to deviants in the random condition displayed a fronto-centrally negative wave between 150 and 250 ms from stimulus onset. No similar wave was observed in the grouped condition. The Condition \times Stimulus Type \times Electrode ANOVA of the ERP amplitudes measured in the 172–212-ms window revealed a significant Condition \times Stimulus Type interaction, $F(1,11)56.33$, $p < 0.05$, which was explained by a significant difference between the standard and deviant stimulus responses in the random condition but not in the grouped condition (tested by planned comparisons, $p < 0.05$). No other effects or interactions reached the level of significance. That is, the D tones elicited a different response when they appeared as part of the repeating pitch pattern than in the randomised sequence.

Discussion

For the first time, we observed oscillatory gamma-band activity in neonates, which was sensitive to infrequent pitch changes. Our analysis of gamma-band oscillations triggered by deviants and standards in the random condition showed a clearly discernible burst of gamma activity for deviants, whereas standards were followed by a decrease in amplitude in the 30–40-Hz frequency range 140–270 ms from stimulus onset. Induced oscillatory gamma activity with a similar time course has been observed for occasional frequency deviants (Edwards et al., 2005; Kaiser et al., 2000). Thus, similarly to adults, newborn infants show gamma-band oscillatory activity that is sensitive to stimulus probability. We found that in the random condition, deviant tones elicited a significantly more negative ERP waveform in the 172–212-ms post-stimulus interval than standard tones. Because the newborn infants were asleep during the EEG recordings, this differential negativity reflects the activation of an automatic deviance detection system, which may be similar to that underlying the MMN response in adults. The ability of the neonate auditory system to form groups from a short sequence of sounds, which was revealed by the current results, is an important prerequisite of forming auditory objects.

Experiment 3. – Cross-modal source coherence during audio-visual integration

During multimodal perception the brain integrates information from different sensory modalities to bind the various attributes of objects into a coherent percept. We studied phase-coherence as a measure of cooperation between auditory and visual cortices while subjects performed a multimodal oddball task requiring the recognition of a target in the visual modality. We hypothesized that during audio-visual integration auditory and visual cortical areas synchronize their activity establishing a large-scale functional neuronal network. We

expected higher phase synchronization between auditory and visual cortical areas for the attended audio-visual target stimulus compared to audio-visual standard stimulus.

Methods

To test our hypothesis we recorded continuous MEG signals from 11 subjects (age 19-33, mean 24,7 years, six women).

In three consecutive recordings visual (Session 1), auditory (Session 2) and audio-visual (Session 3) evoked fields were recorded. The visual standard stimulus consisted of a series of black and white checks, whereas a modified checkerboard pattern containing the figures of a pair of dolphins served as target stimulus. The auditory stimulus consisted of modulated sine wave tone resembling a dolphin's short whistle with 2 kHz frequency at its beginning, decreasing evenly to 1 kHz at its end. In Session 3 audio-visual target and audio-visual standard stimuli were presented with equal probability to ensure that subjects could not rely on auditory stimuli to correctly identify the target, which was defined in the visual modality. Subjects were required to rapidly signal the recognition of the target stimuli (visual target and audio-visual target) by pressing a button with the right index finger. Data from Session 1 and 2 were used to identify the exact location of those areas in the visual and auditory cortices, which were involved in the processing of stimuli in our experiment. Though we cannot exclude that brain sites other than we identified as auditory and visual sources were not involved in the process of cross-modal integration, in this exploratory study our goal was exclusively to address the question of cooperation between visual and auditory sensory cortices. We used data from Session 3 to investigate possible interactions between visual and auditory cortices during processing of temporally coinciding multimodal stimuli. The magnetic evoked field was recorded by using a 165 channel MEG system based on dc SQUID integrated magnetometers. We obtained magnetic resonance images (MRIs) of the subjects' heads and a set of high-resolution images was used to co-register MEG functional data with MRI anatomical images. We studied the time course of coherence between pairs of sources whose localization was based on the analysis of the evoked fields. In order to study the time course of coherence between visual and auditory cortices those brain sites, which gave rise to the evoked fields, we reconstructed the specific source waveforms from the raw waveforms of all channels throughout all the trials, i.e. the source raw activity from Session 3. To determine the degree of synchronization between auditory and visual cortices involved in the processing of multimodal stimuli, which gave rise to evoked fields, phase-coherence was calculated on cleaned, epoched source activities. Epochs extending -200 ms before to 900 ms after stimulus presentation were extracted and phase-coherence using a moving windowed FFT was calculated on single trial data in 2 Hz bins between 4 and 20 Hz, allowing the analysis of theta (4-8 Hz), alpha (8-12 Hz) and beta (12-20 Hz) frequency bands. To exclude spurious phase linkages, which may arise due to phase-locking to the synchronous multimodal stimuli, we removed the concurrent evoked response from the single-trial data before computing phase-coherence between sources localized in the primary auditory and visual cortices. The significance testing was carried out with nonparametric permutation testing on pairs of time-frequency matrices of coherence between each source in the visual and the auditory cortex.

Results

A paired-samples t-test of reaction times revealed that subjects identified more rapidly the audiovisual targets (mean reaction time 430 ms) than simple visual targets (mean reaction time 465 ms), supporting the hypothesis that audio-visual integration took place during the

processing of bimodal stimuli improving the identification of multimodal targets (Miller, 1982; Giard and Peronnet, 1999). Coherence analysis was applied to all the possible pairings between the visual and auditory sources, comprising 16 pairings for each subject. The time–frequency comparisons audio-visual target>audio-visual standard, audio-visual target>visual target and audio-visual standard>visual standard based on nonparametric permutation testing applied to the coherence values yielded significant results in the theta and alpha bands (4-12 Hz). In these bands, we observed significantly higher phase-coherence for audio-visual target than for audio-visual standard stimuli and for audio-visual stimuli than for mono-modal stimuli.

Discussion

In accordance with our hypothesis that long-range interactions would evolve between visual and auditory cortical areas via phase-synchronization during simultaneous auditory and visual stimulation, we found significantly increased coherence during processing of multimodal stimuli. Our results show that primary auditory and visual areas synchronize their activity during processing of audio-visual stimuli, which probably reflects cooperation between these distant brain areas during multimodal integration. We found higher phase coherence values for audio-visual target compared to audio-visual standard stimuli, which is presumably the facilitating effect of attention toward the target stimulus. Though we cannot exclude that brain sites other than we identified as auditory and visual sources were not involved in the process of cross-modal integration, in this exploratory study our goal was exclusively to address the question of cooperation between visual and auditory sensory cortices.

Experiment 4. – Effects of mobile phone irradiation on the latency of I, III and V components of auditory brainstem response ⁷

The aim of the present study was to advance our understanding of potential adverse effects of the GSM mobile phones on the human auditory brainstem response. In a pilot study a significant delay in the latency of the fifth wave (V) of the ABR after 15 min of exposure to electromagnetic field (EMF) emitted by a mobile phone (MP) was recorded by Kellényi et al. (1999) and the authors suggested that the observed delay might lead to a temporary 15–18 dB hearing deficiency above 2 kHz in the normal hearing frequency range.

Methods

The present experiments were carried out on 30 healthy volunteers (aged 24 ± 5 years, 15 women) with no clinical evidence of hearing disorders. We delivered three types of acoustic stimuli to the subjects: condensation, rarefaction and alternating 100 μ s click sound stimuli. With this protocol we also aimed to test for possible different effects of EMF exposure on brainstem response to the above types of acoustic stimuli.

⁷ **Stefanics G.**, Kellényi L., Molnár F., Kubinyi G., Thuróczy G., Hernádi I. (2007): Short GSM mobile phone exposure does not alter human auditory brainstem response. *BMC Public Health*, 7, 325.

We delivered 2048 clicks for each stimulus type twice to ascertain their reproducibility. The stimulus rate and intensity were set to 27 Hz and 80 dB SPL, respectively. Exposure was administered by means of a standard Nokia 6310 MP via external software control at a constant 2 W peak power for 10 min. Subjects were randomly assigned to one of the following groups: EMF group (fifteen subjects exposed to genuine EMF irradiation, eight women), Control group (fifteen subjects exposed to sham EMF irradiation, seven women). According to our experimental protocol, the administration of genuine or sham exposure was double blind. The auditory brainstem response (ABR) was recorded with three non-polarizing Ag-AgCl electrodes. The active electrode was placed on the right mastoid and the reference electrode was placed over the vertex (Cz of the international 10–20 system). The ground electrode was placed on the forehead over the nasion and was connected to the active ground of the amplifier. Continuous EEG signal was recorded with a sampling rate of 20 kHz at 12 bit resolution. For each stimulus, an epoch of 15 ms duration including a 3 ms pre-stimulus period was extracted from the continuous EEG data. After artefact rejection latencies of wave I, III and V were measured for each stimulus type and subject. We analysed the effects of stimulus condition on these values obtained before and after EMF exposure with paired Student's t tests.

Results

We found no significant effects of genuine/sham EMF exposure in any of the stimulus conditions. As statistical analysis of peak latencies yielded no significant results we performed a point-by-point t test on the evoked waveforms, however this analysis revealed no effect in any of the conditions either.

Discussion

In this study, we found no significant effects of 10 min genuine MP EMF exposure on the latencies of wave I, III and V of the auditory brainstem response for rarefaction, condensation or alternating stimuli. Our current results indirectly confirm the results of earlier investigations demonstrating that 10 minutes of GSM MP exposure does not induce measurable changes in cochlear function (Uloziene et al., 2005) in humans, possibly resulting in no deficiencies in the functioning of the central auditory pathways. The present results reporting no adverse effects are also in line with previous negative results obtained by a similar technique (Arai et al., 2003; Bak et al., 2003; Oysu et al., 2005).

Experiment 5. – Effects of mobile phone irradiation on ERP components and early gamma synchronization⁸

The number of individuals with at least one active mobile subscription was about 2.5 billion by the end of 2007. Thus, investigation of potential effects of EMF irradiation from MPs is an important environmental health issue. The UMTS 3G phone system has markedly different radio frequency signals compared with the GSM system. As the GSM system has already

⁸ **Stefanics G.**, Thuróczy G., Kellényi L., Hernádi I. (2008) Effects of 20 min 3G mobile phone irradiation on ERP components and early gamma synchronization in auditory oddball paradigm. (Neuroscience, elfogadva)

been tested for immediate effects, and there is a major difference in the nature of the two radio frequency systems, it is necessary to investigate the possible effects of the UMTS signal on auditory functions. In our study we set out to investigate the potential effects of 20 min irradiation from new generation 3G MP on cortical brain responses in an auditory oddball paradigm.

Methods

We recorded EEG from 36 healthy university students (aged 19-28 years (mean 23.08), 20 females). The hearing status of all participants for the exposed ear was measured for air conducted sound stimuli at seven standard audiometric frequencies. Two pure tones (50 ms duration) served as frequent standard (1 kHz, $p=0.8$) and rare targets (1.5 kHz, $p=0.2$). Stimulus-onset asynchrony was randomly varied between 1000-2000 ms with a mean of 1500 ms. The tones were delivered in a randomised order with at least one standard separating consecutive target tones. All subjects took part in two recording blocks (Block1 followed by Block2) per session on two sessions separated one week apart. Between the two recording blocks, subjects were exposed to either genuine or sham MP EMF irradiation for 20 min in a double-blind design. The order of the genuine and sham MP EMF exposure sessions was counterbalanced across subjects. Exposure was administered by means of a standard Nokia 6650 MP via external software control for 20 min. EEG was recorded from Fz, Cz and Pz sites. Recording was continuous with an analogue band-pass from 0.16 Hz to 150 Hz at a sampling rate of 1 kHz. For ERP analysis, continuous data were band-pass filtered between 0.5 Hz and 20 Hz and we extracted epochs from -100 to 600 ms. After averaging, four components of the evoked brain response were visually identified: N100, N200, P200 and P300 peaks. Component amplitudes were measured relative to the pre-stimulus period and peak latencies were defined as the minimum and maximum points for N100, N200 and P200, P300 components, respectively. Evoked gamma activity was analysed by applying wavelet transformation on the averaged evoked potential waveforms. This analysis reveals the amplitude of gamma-band response that is phase-locked to the stimulus. Furthermore the wavelet transformation was applied on single-trial data in order to reveal the phase stability of the gamma response across trials. The difference between the two measures lies in the fact that the analysis of the averaged evoked potential waveforms reflects the amplitude of the total activity for a given frequency range whereas analysis of inter-trial phase coherence reveals phase-locking independent of the amplitude of the EEG signal (e.g. Tallon-Baudry et al., 1996; Debener et al., 2003). For the analysis of gamma activity we extracted epochs from -400 to 1200 ms. Power changes in the averaged evoked potentials relative to the baseline period were studied by computing event-related spectral perturbation transforms (ERSP), furthermore inter-trial phase coherence (ITC) was analysed on single-trial data. Analysis of gamma responses was carried out using Morlet wavelets. For statistical analysis of the power of evoked gamma activity and inter-trial phase coherence, a window of 60 ms duration was selected in the 30-50 Hz frequency range. The window was centred on the peak of gamma-band activity in the grand-averaged responses at Cz electrode, which was observable both for ERSP and ITC measures. The effects of experimental conditions on ERP and gamma activity measures were analysed with three-way repeated-measures analyses of variance (ANOVA of SESSION [Genuine vs. Sham] \times BLOCK [Block1 vs. Block2] \times ELECTRODE [Fz vs. Cz vs. Pz]).

Results

We have found no significant effect of EMF irradiation condition (SESSION) on the amplitude or latency of any of the identified ERP components (N100, N200, P200, P300). Our results revealed a prominent evoked gamma band response which rose shortly after the onset of both stimulus types and peaked at ~70 ms at ~44 Hz (Figure 2). ANOVA of TYPE (Target vs. Standard) × SESSION [Genuine vs. Sham] × BLOCK (Block1 vs. Block2) × ELECTRODE (Fz vs. Cz vs. Pz) of evoked gamma activity in the 30-50 Hz and 40-100 ms time-frequency window revealed a significantly higher gamma amplitude for targets, ($F(1, 26)=4.79, p<0.05$). Inter-trial phase coherence analysis revealed a peak in phase-locking both for targets and standards in the gamma frequency range at ~70 ms post stimulus at ~40 Hz. However we found no effect of EMF irradiation on either measures of the gamma response.

Discussion

We replicated previous findings of no effect of MP EMF exposure on the amplitude and latency of N100, N200, P200 and P300 auditory evoked responses (Hamblin et al., 2006). Furthermore, brain mechanisms of auditory selective attention reflected by the early gamma-band response were not found to be affected by a single 20 min MP EMF exposure to the new generation (3G) MP EMF.

Summary

We applied time-frequency analysis techniques to EEG data from auditory, visual and audio-visual experiments. We analysed the amplitude of evoked and induced oscillatory activity and phase-locking values as well as phase-synchronization between distant brain sites. Furthermore we investigated the possible effects of irradiation by mobile phones on event-related responses and neural synchronization. We summarize our results in the following four points:

(1) Matching a template in memory to incoming stimulus modulates the early evoked gamma activity. In our experiments we have shown that attention toward the target stimulus influences the amplitude of the gamma response, whereas familiarity of the stimulus modulates the phase-locking of the early evoked gamma activity. Our results indicate that the matching of a known target stimulus to its template in memory increases the phase-locking of the early evoked gamma activity compared to unfamiliar standard stimuli.

(2) We studied auditory temporal grouping in newborn infants. The ERPs and induced gamma-band responses obtained in our study show that the neonate auditory system is sensitive to the large-scale structure of a sound sequence and that the sequential context can determine the way individual sounds are processed in the newborn brain. Our results demonstrate the operation of a sound grouping function in newborn infants. The gamma-band responses indicate that, similarly to adults, newborn infants show gamma-band oscillatory activity, which is sensitive to stimulus probability. As the newborn cortex is relatively immature compared to the adult cortex, our results are remarkable for we have

shown for the first time, that gamma-band activity plays a possible functional role in auditory processing at this early stage of postnatal brain development.

(3) We studied phase-coherence as a measure of cooperation between auditory and visual cortices while subjects performed a multimodal oddball task requiring the recognition of a target in the visual modality. Our results indicate, that synchronization between the auditory and visual cortex at theta and alpha frequency bands may be part of a mechanism by which multimodal integration comes about in the brain. Furthermore we found that attention toward the audio-visually presented visual target stimulus enhances phase-synchronization between modality-specific auditory and visual cortical areas compared to the audio-visually presented visual standard stimulus.

(4) As potential adverse effects of mobile phone irradiation on human brain function were not systematically studied before the widespread use of MPs, we studied the effects of 10 min irradiation on the auditory system by recording brainstem evoked potentials. We analysed the possible effects of irradiation by comparing the latency of auditory brainstem potential waves I, III and V before and after genuine/sham EMF exposure. Our results revealed no significant differences in the latency of ABR waves I, III and V before and after 10 minutes of genuine/sham EMF exposure, suggesting that 10 minute exposure of EMF emitted by a commercial mobile phone does not produce measurable immediate effects in the latency of auditory brainstem waves I, III and V.

We investigated the potential effects of 20 min irradiation from new generation 3G mobile phones on human ERPs and gamma-band synchronization in auditory oddball paradigm. We analysed the amplitude and latency of the N100, N200, P200 and P300 components for target and standard stimuli. No significant effects of EMF irradiation on the amplitude and latency of the above ERP components were found. In order to study possible effects of EMF on attentional processes, we applied a wavelet-based time-frequency method to analyse the early gamma component of brain responses, which we found to be insensitive to 20 min irradiation. Our results support the notion, that 20 min irradiation from new generation 3G mobile phone does not induce measurable changes in ERP components and oscillatory gamma-band activity in auditory oddball paradigm.

Acknowledgement

I would like to thank my supervisor **Dr. István Hernádi** for his friendly support to my work. I thank my consultant **Dr. Lóránd Kellényi** for helping me designing and performing the brainstem experiments. I would like to express my thanks to **Dr. Róbert Gábel**, **Dr. Ernő Fischer**, **Dr. Mária Csoknya** and Dr. György Thuróczy for their help and contribution to my work. I thank the team in Chieti, Italy: Stefania Della Penna, Raffaella Franciotti, Maria Stavrinou, Carlo Sestieri, Livio Finos, Francesco Cianflone, Luca Ciancetta, Vittorio Pizzella, Gian Luca Romani. Grazie! I would like to thank also my colleagues at the Institute for Psychology, Hungarian Academy of Sciences: István Winkler, László Balázs, Gábor Háden and Erika Váradiné Józsa. I am grateful beyond expression to my family.

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8. **Stefanics G.**, Lakatos P., Ulbert I., Hangya B., Hernádi I. Attentive expectancy modulates human delta EEG oscillations (előkészületben).

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