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The influence of auditory background stimulation (Mozart's sonata K. 448) on visual brain activity

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Abstract

Twenty individuals solved a visual oddball task in two response conditions: while listening to the Mozart's sonata K. 448, and while listening to nothing. The recorded event-related potentials (ERP) were analyzed in the time and frequency domains. In the music response condition the ERP peak latencies on the left hemisphere increased, whereas on the right hemisphere a decrease of peak latencies as compared with the silence response condition was observed. In the theta, lower-1 alpha and gamma band increases in induced event-related coherences were observed while respondents solved the oddball task and listened to music, whereas a decoupling of brain areas in the gamma band was observed in the silence response condition. It is suggested that auditory background stimulation can influence visual brain activity, even if both stimuli are unrelated.

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1. Introduction

For centuries, music has been used for healing and stimulating emotions. The Greeks at Asclepius placed an ill person in the center of the amphitheater and used specific voices to heal that individual. Music effects on brain electrophysiology have also been reported in a number of studies (Arikan et al., 1999; Auzou et al., 1995; Sarnthein, et al., 1997). Recently, an exciting public debate has arisen over the music of Mozart, mostly due to the research findings of Rauscher et al. (1993, 1995). The so-called 'Mozart effect' refers to an enhancement of performance or change in neuro-

physiological activity associated with listening to Mozart's music. The effect can be found in the subsequently improved performance on spatial tasks (Rauscher et al., 1993, 1995). There have been several studies that replicated the Mozart effect, showing that exposure to Mozart produces an enhanced spatial performance (Rideout and Laubach, 1996; Rideout and Taylor, 1997; Rideout et al., 1998; Schreiber, 1988; Wilson and Brown, 1997). However, just as many, if not even more studies have failed to replicate the Mozart effect (Carstens et al., 1995; McCutcheon, 2000; McKelvie and Low, 2002; Newman et al., 1995; Steele et al., 1997, 1999; Stough et al., 1995).

Neurophysiological changes while listening to Mozart were mainly observed using electroenceph-

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alographic (EEG) power and coherence measures. Changes in EEG power and coherence, especially on the right temporal area while listening to music were reported by Petsche and colleagues (Petsche, 1996; Petsche et al., 1986, 1993). In another study, it was found that in three of the seven subjects right frontal and left temporal-parietal coherence activity induced by listening to the Mozart sonata (K. 448) was carried over into the solution of the spatial-temporal tasks (Sarnthein et al., 1997). This carry-over effect was not present after listening to a text. It was further reported that listening to the Mozart sonata significantly decreased epileptiform activity in patients with seizures (Hughes et al., 1998). In a follow-up study analyzing the music of Haydn, Liszt, Bach, Chopin, Beethoven and Wagner it was found that Mozart's music continued to score significantly higher than the selections from the other six composers (Hughes, 2002).

The explanation for the observed effect provided by Rauscher et al. (1993, 1995) was that complexly structured music similar to the Mozart sonata in tempo, melody, organization, and predictability may also enhance spatial-task performance. The link is subserved by similarities in neural activation between music listening and spatial reasoning, as specified by the Trion model of cortical organization (Leng and Shaw, 1991; McGrann et al., 1994; Shaw et al., 1985; Shenoy et al., 1993). Music acts as an exercise for exciting and priming the common repertoire and sequential flow of the cortical firing patterns responsible for higher brain functions. Leng and Shaw (1991) proposed that music is a 'prelanguage' available at an early age, which can access these inherent firing patterns and enhance the cortex's ability to accomplish pattern development, thus improving other higher brain functions. A similar explanation was also suggested by Bhattacharya and Petsche (2001). Some authors find such an explanation of the Mozart effect problematic because no evidence exists of cross-modal priming between unrelated stimuli (Husain et al., 2002). Studies have shown that visual events are not readily primed by pre-exposure to auditory events, even if both stimuli are related (Green et al., 2001).

The aim of the present study was to further investigate the influence of auditory background

stimulation (listening to Mozart's music) on visual brain activity employing the EEG method. In previous studies, this influence was usually studied in two sessions: first, while respondents listened to music, and second while in silence they solved spatio-temporal tasks. In the present study, a somewhat different approach was used. Respondents while listening to Mozart's music solved a simple cognitive task (the visual oddball paradigm). It was expected that the influence of music would be reflected in different components of the recorded event-related potential (ERP), as compared with a silent condition.

The oddball paradigm was used for two reasons: First, because in previous research more complex tasks were used which are less suitable for a time domain analysis, and second, because a large body of research exists analyzing the latencies at identified peaks and troughs of ERPs and their relation to intelligence (e.g. Johnson, 1995; Jaušovec and Jaušovec, 2000; Burns et al., 2000). It was suggested that early deflections in the ERP (N1 and P2) relate to lower level (less complex) cognitive processes, whereas late deflections (N2, P3 and N400) relate to higher level (more complex) processes (Burns et al., 2000; Caryl, 1994). Research relating intelligence and ERPs has shown that peak latencies correlate with IQ (Barrett and Eysenck, 1994; Caryl, 1994; Chalke and Ertl, 1965; Ertl, 1971; Shucard and Horn, 1972; Jaušovec and Jaušovec, 2000). It was further found that approximate entropy (ApEn) of the ERP—a quantification of regularity in time-series data—also correlated with intelligence (Jaušovec and Jaušovec, 2000). Based on the assumption that Mozart's music enhances performance IQ, it was expected that ERPs recorded in the music background condition would show shorter latencies and more regular—less complex (ApEn) waveforms as compared with the silent background condition.

A shortcoming of the previous neurophysiological research of the Mozart effect using coherence was that it was mainly based on the ongoing EEG. Such a method may not be sensitive enough to measure subtle changes in EEG coherence, especially when such changes occur over short times (Nunez et al., 2001). Another shortcoming of the reported EEG studies was that broad frequency

bands were used. Broadband studies of alpha frequency have compounded everything in the 8–13 Hz band into a single measure, thereby missing important cognitive effects. Analyzing the dynamics of narrow frequency bands (1 or 2 Hz) has shown that multiple rhythms interact to varying degrees in different brain states (Nunez et al., 2001). A third shortcoming was that the frequency bands were not individually determined. Research has shown that alpha frequency varies to a large extent as a function of age, neurological diseases, brain volume and task demands (Klimesch, 1999). In the present study, the method of induced event-related coherence ERCoh was used. The induced ERCoh measures were computed using the method of complex demodulation (Thatcher et al., 1994). This method allows for measurement of high-temporal resolution changes in the EEG signal. The analysis was performed on individually determined narrow theta and alpha frequency bands, as well as on a broad gamma band. These bands were chosen because research has identified their relationship to different cognitive functions. Episodic memory processes and working memory performance seem to be reflected as oscillations in the EEG theta (4–6 Hz) frequencies (Klimesch, 1996), whereas upper alpha (10–12 Hz) activity is modulated by semantic memory processes (Klimesch, 1997). The lower-1 and lower-2 alpha (6–10 Hz) bands are related to attentional task demands. The lower-1 alpha band is mainly related to the level of alertness, whereas the lower-2 alpha band is more related to expectancy (Klimesch, 1999). The role of the gamma band (>30 Hz) is associated with the binding hypothesis (Tallon-Baudry and Bertrand, 1999). Neuronal activity is expressed in spatially separate areas of the cortex, which requires processes for linking the separate nodes of activity, thereby allowing identification of the object as a whole. The linking mechanism is provided by the oscillations in the gamma-band (Singer and Gray, 1995). From this viewpoint, major differences between the two background conditions would be expected in the gamma band, as well as in the lower alpha band. These expectations were based on previous coherence (Bhattacharya et al., 2001), and induced ERCoh research (Jaušovec and Habe, in press).

2. Method

2.1. Subjects

The sample included 20 right-handed individuals (15 females and 5 males). Their mean age was 20.2 years (S.D. = 0.6; range 19–21). The participants were student–teachers taking a course in psychology.

2.2. Procedure and materials

Respondents' EEG was recorded while they solved a visual oddball task in two conditions: (1) while listening to Mozart's sonata (K. 448)—music response condition (MR), and (2) while listening to nothing—silence response condition (SR). The conditions were rotated between subjects, so that half of the students started with the MR condition followed by the SR condition, while a reverse distribution of conditions was used for the other half of students. Between the two conditions there was a 10–15 min break. The break was introduced to minimize the influence of music on the following SR condition. As reported, the Mozart effect on spatial IQ did not persist beyond the 10–15 min testing session following listening to the sonata (Rauscher et al., 1993, 1995). During the break, the respondents were asked to close their eyes for 5 min. This resting EEG was used for the individual determination of the narrow theta and alpha frequency bands.

The oddball task was presented on a computer screen positioned approximately 100 cm in front of the respondent. It consisted of infrequently presented squares ($P=0.20$) and frequently presented circles ($P=0.80$). The duration of the visual stimuli was 200 ms. In each condition, 150 stimuli were presented at fixed 3.5 s interstimulus intervals. The respondents were instructed to press a button in response to the target stimuli (square). All stimuli were generated by the STIM stimulator, which also recorded the responses made by individuals (correctness and reaction time – RT).

2.3. EEG recording and quantification

Brain wave activity was recorded using a Quick-Cap with sintered electrodes. EEG activity was

monitored over 19 scalp locations (Fp1, Fp2, F3, F4, F7, F8, T3, T4, T5, T6, C3, C4, P3, P4, O1, O2, Fz, Cz and Pz). All leads were referenced to linked mastoids (A1 and A2), and a ground electrode was applied to the forehead. Additionally, vertical eye movements were recorded with electrodes placed above and below the left eye. Electrode impedance was maintained below 5 k Ω . The 19 EEG traces were recorded in DC mode at 1000 Hz and stored on a hard disk. The DC recording mode was used to obtain a better frequency resolution of the rather long ERP averages. The digital EEG data acquisition and analysis system (Syn-Amps and Scan 4.2) had a bandpass of 0.15–50.0 Hz. Prior to analysis, all EEG records were automatically corrected for ocular artifacts using the VEOG electrodes. Epochs were comprised from the 2000 ms preceding and 1500 ms following the stimulus presentation and automatically screened for artifacts. Excluded were all epochs showing amplitudes above $\pm 80 \mu\text{V}$ ($< 1\%$).

The EEG analysis was performed only for target stimuli which were correctly identified by respondents (98.3%). Peak-to-baseline latencies were determined automatically using the following time windows: N100 (80–250), P200 (80–250), N200 (250–350), P300 (250–500 ms), and N400 (350–500 ms).

The ApEn analysis was performed using the program Simulnet-Pro. Given N data points (1000 – from stimulus onset until 1000 ms), the statistic ApEn was determined for $m=2$, and $r=0.15$ S.D. $\cdot u(i)$ data using the formula: $\text{ApEn}(m, r, N) = \Phi^m(r) - \Phi^{m+1}(r)$, where m is the length of compared runs of data, and r specifies a de facto filtering level. ApEn measures the logarithmic frequency with which blocks of length m that are close together remain close together for blocks augmented by one position (Pincus, 1994). The latencies and ApEn measures were based on electrode location collapsed into right and left hemispheric measures.

The frequency bands (alpha and theta) were individually determined based on the mean alpha peak frequency (IAF=10.23 Hz, S.D.=0.85) (Klimesch, 1999; Burgess and Gruzelier, 1999). On average, this method resulted in a band of 11.23–13.22 Hz for the upper alpha band, a band

of 9.23–11.22 Hz for the lower-2 alpha, a band of 7.23–9.22 Hz for the lower-1 alpha, and a band of 5.23–7.22 Hz for the theta band. The broad gamma band had a range from 31 to 49 Hz. For each frequency band, the induced ERCohs (also called instantaneous coherence, Thatcher et al., 1994) were determined using the method of complex demodulation with a simultaneous signal envelope computation (Andrev, 1999; Thatcher et al., 1994). In this method, the raw data for each channel are multiplied, point by point, by a pure cosine based on the selected center frequency, as well as by a pure sine having the same center frequency. Both time series are then lowpass filtered (zero-phase digital filter –48 dB/octave rolloff) by the half-bandwidth (1 Hz for the theta and alpha frequency bands and 9 Hz for the gamma band). This results in a complex bandpass-filtered time series: $y_{i,n}^{(r)}$. The time-dependent complex correlation between each pairwise combination of channels, i and k is then computed as:

$$\hat{\rho} = \frac{\sum_{r=1}^R [y_{i,n}^{(r)} - \bar{y}_{i,n}] [y_{k,n}^{(r)} - \bar{y}_{k,n}]^*}{\sqrt{\sum_{r=1}^R |y_{i,n}^{(r)} - \bar{y}_{i,n}|^2 \sum_{r=1}^R |y_{k,n}^{(r)} - \bar{y}_{k,n}|^2}}$$

where $*$ denotes complex conjugation and $\bar{y}_{i,n}$ are the complex average potentials calculated by averaging the complex time series for channel i across all trials. To reduce the large data set, the ERCoh measures were averaged for each condition (REST = –1500 ms to –500 ms—averaged over all epochs of the SR; MR condition, and SR condition 0–1000). This analysis resulted in 171 induced ERCoh measures per frequency band, which were Fisher- z -transformed and collapsed into right-, left- and interhemispheric ERCoh values.

2.4. Statistical data analysis and topographic mapping

General linear models (GLM) for repeated measures were calculated for latencies, ApEn and ERCoh measures for each frequency band. The factors and their levels were CONDITION (MR,

SR and REST – only for the ERCoh GLM), and LOCATION (Left, Right and Interhemispheric – only for the ERCoh GLM). All univariate repeated measure GLM analyses were corrected for violation of the sphericity assumption – Huynh-Feldt. A pairwise comparison for the levels of the factor CONDITION with a Bonferroni adjustment for multiple comparisons (where appropriate) was also calculated.

In order to evaluate all possible coherence differences between the selected conditions, paired Wilcoxon tests (rest vs. the two response conditions) were applied (Weiss and Rappelsberger, 2000). The test results were converted to error probabilities and presented as lines between the electrodes in schematic drawings of the brain (see Figs. 3–6). Due to multiple comparisons, the significance levels should have been adjusted to avoid enhancement of the error probability, because of the large number of variables these adjustments would lead to extremely low probabilities for rejecting the false null hypothesis. Thus, any possible coherence effects would be cancelled out. Therefore, the results of these tests are purely descriptive and not used to confirm or reject the null hypothesis.

A paired sample *t*-test was calculated for the RT data.

3. Results

3.1. RT analysis

A paired *t*-test calculated for the RT measures between the two response conditions showed no significant difference ($t(19)=0.36$; $P<0.73$; $M_{\text{silence}}=481.1$, $S.D._{\text{silence}}=86.0$; $M_{\text{music}}=485.3$, $S.D._{\text{music}}=97.5$).

3.2. Time domain analysis

The GLM for repeated measures calculated for peak latencies showed only an interaction effect between the factor CONDITION and LOCATION ($F(1, 19)=4.27$ $P<0.05$). As can be seen in Fig. 1, in the music response condition latencies on the left hemisphere increased, whereas on the right hemisphere a decrease of latencies as compared

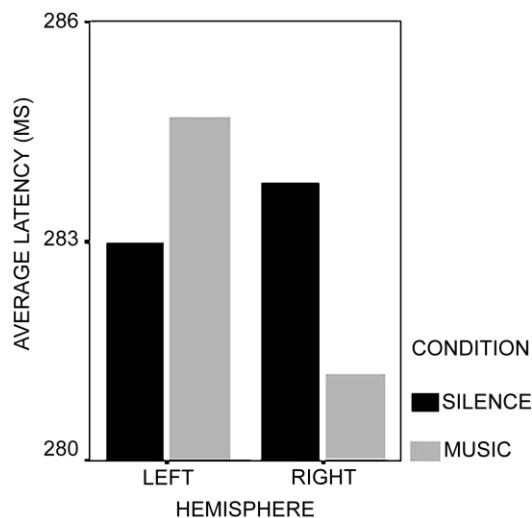


Fig. 1. Average peak latencies (N100, P200, N200, P300, N400) averaged for the left and right hemisphere while respondents solved the oddball task in the music and silence condition.

with the silence response condition was observed. This trend was present for the early deflections (N100, P200), as well as for the late deflections (N200, P300, N400).

The GLM for repeated measures conducted for the ApEn measures showed only an interaction effect between the factors CONDITION and LOCATION ($F(1, 19)=8.52$ $P<0.009$). Listening to music considerably increased the complexity of EEG activity on the left hemisphere, and only slightly on the right hemisphere (see Fig. 2).

3.3. Frequency domain analysis

The GLMs conducted for the Fisher-z-transformed induced ERCoh values showed significant main effects for the factor CONDITION in the theta ($F(2, 38)=5.01$ $P<0.012$), and gamma bands ($F(2, 38)=4.70$ $P<0.033$), whereas for the lower-1 alpha band only a significant interaction effect between the factors CONDITION and LOCATION was observed ($F(4, 76)=3.37$ $P<0.028$). In the lower-2 alpha and upper alpha band, no significant differences were observed.

In the theta band, subsequent paired comparisons between the three conditions indicated that

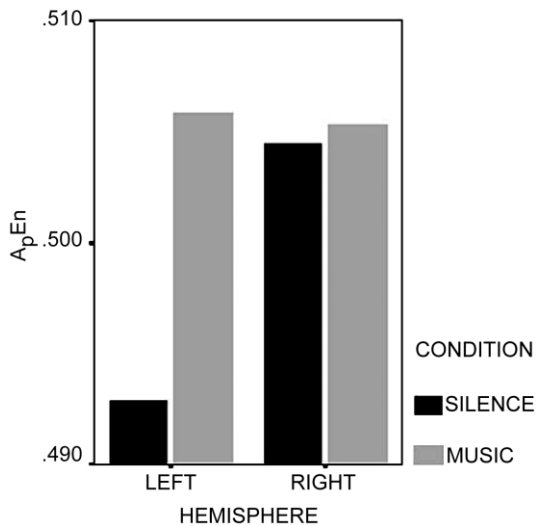


Fig. 2. Approximated entropy measures (ApEn) of 1000 ms ERPs averaged for the left and right hemisphere while respondents solved the oddball task in the music and silence condition.

only increases between the resting and music response condition were significant ($P < 0.033$). As can be seen in Fig. 3, significant increases in ERCoh could be mainly observed between inter-hemispheric and right hemispheric electrode locations. This pattern was also revealed by the error probability maps based on paired Wilcoxon tests between the two response conditions and the EEG at rest. As can be seen in Fig. 4, in the music response condition an increase in coherence could be observed between interhemispheric and right hemispheric electrode locations in the parieto-occipital and temporal brain areas. The increase in the silence response condition was less pronounced and to a greater extent affected the frontal brain areas.

In the gamma band, pairwise comparisons between conditions indicated a significant decrease in coherence between the resting and silence response condition ($P < 0.039$). This decrease was about equally significant between the interhemispheric, left and right hemispheric electrode sites, and mainly located in the parieto-occipital brain areas (see Figs. 3 and 6). Also, significant were the differences between the silence and music

response conditions ($P < 0.05$). In the music response condition an increase in gamma band ERCohs could be observed mainly between the four frontal electrode locations (F7, F3, Fz, F4, F8), and inter-hemispheric and right-hemispheric electrode locations in the parieto-occipital areas; and also with the left hemispheric central and parietal electrode locations.

Much less pronounced were the differences in the lower-1 alpha band. As revealed in Fig. 3, interhemispheric and right hemispheric ERCoh values increased in the two response conditions as compared with the resting condition. The increase was more pronounced for the music response condition (mainly in the frontal brain areas – see Fig. 5) than for the silence response condition. On the left hemisphere, a decoupling of brain areas was observed for the two response conditions as compared with the resting condition. This decoupling was more pronounced for the silence response condition.

4. Discussion

In the present study, an endeavor was made to investigate the influence that auditory background stimulation has on neurophysiological activity in the human brain engaged with a simple visual cognitive task. The observed differences in neurophysiological activity analyzed in the time and frequency domains could be explained along two lines: First, differences in brain activity provoked by increased cognitive workload, and second, differences caused by listening to Mozart's sonata K. 448. It must be further noted that no evidence was found which would point to a beneficial influence of the Mozart's sonata on the performance of the oddball task or brain activity, which is characteristic for high intelligent individuals.

It can be assumed that the music response condition, where respondents solved the oddball task while listening to music, required individuals to process more sensory input than did the silence response condition. This increase in cognitive workload was also reflected in neurophysiological differences in brain activity. In the present study, increases in peak latencies and ApEn complexity measures mainly in the left hemisphere were

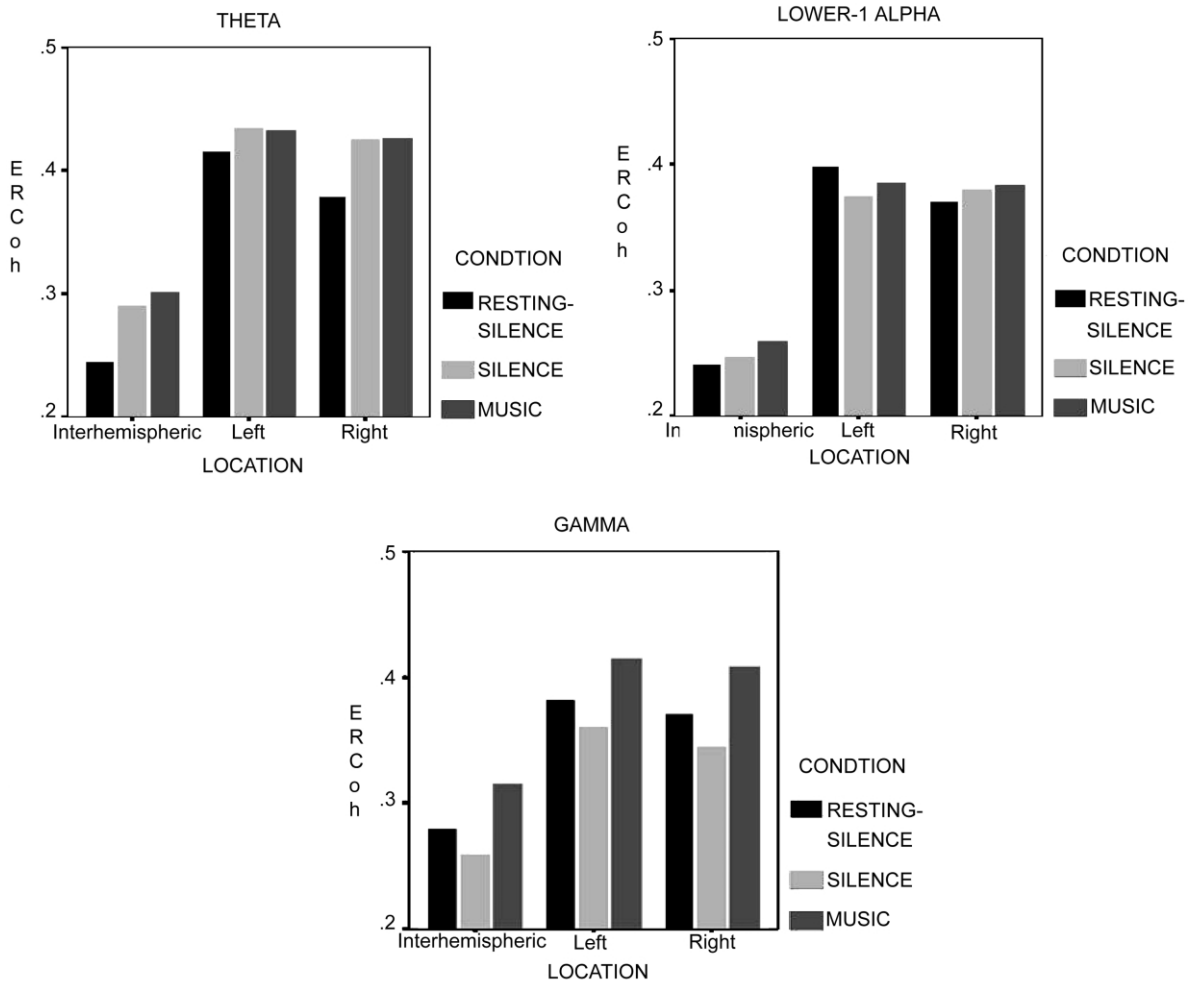


Fig. 3. ERCoH values for the resting-silence condition and the silence and music response conditions averaged for the interhemispheric, right and left hemispheric electrode locations in the theta, lower-1 alpha and gamma band.

observed. Research on peak latencies (e.g. P300) has shown that when the difficulty of stimulus identification was increased, peak latency also increased (Kutas et al., 1977; Johnson and Donchin, 1985). It was further shown that ‘less chaotic patterns’ of brain activity (or less complex ones) are associated with deep sleep or pathology, intermediate values are found during the awake (eyes closed) state, and the highest values are associated with mental activity (Varghese et al., 1987; Stam et al., 1994; Lutzenberger et al., 1992a,b).

More pronounced increases in ERCoH values between the resting and music response conditions, as compared to the resting and silence response condition, could be observed in the theta and lower-1 alpha band. Activity in the theta band is related to working and episodic memory performance (Klimesch, 1996). The differences were most pronounced between inter- and right-hemispheric electrode locations in the frontopolar, prefrontal and parieto-occipital, as well as temporal areas. Positron emission tomography (PET), and func-

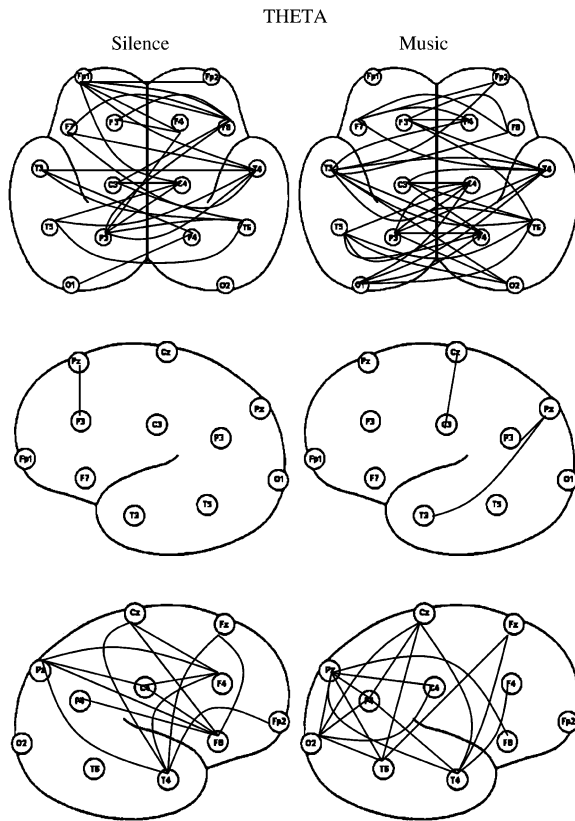


Fig. 4. Error probability maps of paired Wilcoxon tests (rest vs. the 2 response conditions) in the theta band for the interhemispheric, right and left hemispheric electrode pairs.

tional magnetic resonance imaging (fMRI) studies (for a review, see Cabeza and Nyberg, 2000) have shown that working memory performance is associated with increased activity in the prefrontal cortex, parietal regions, and in the occipital areas for visuospatial tasks. The increased ERCoh values in the temporal areas could be related to episodic memory performance as well as to music perception involving the right superior temporal cortex (Zatorre et al., 1994). The lower-1 alpha band is mainly related to attentional task demands—i.e. to the level of alertness (Klimesch, 1999). In the music response condition, an increase in ERCoh values as compared to the resting condition was observed between the prefrontal interhemispheric electrode sites. The involvement of prefrontal areas in attention has been also demonstrated by several

fMRI studies (for a review, see Cabeza and Nyberg, 2000). In the theta and lower-1 alpha band, the pattern of differences between the resting condition and the two response conditions did not differ greatly—in general more increases in ERCoh values were observed for the music response condition than for the silence response condition. The brain areas involved were also mainly the same in both response conditions. This further suggests that the main reason for the differences between the two conditions was an increase in cognitive workload provoked by simultaneously processing the auditory and visual stimuli.

By contrast, in the gamma band, beside significant differences between the resting and silence

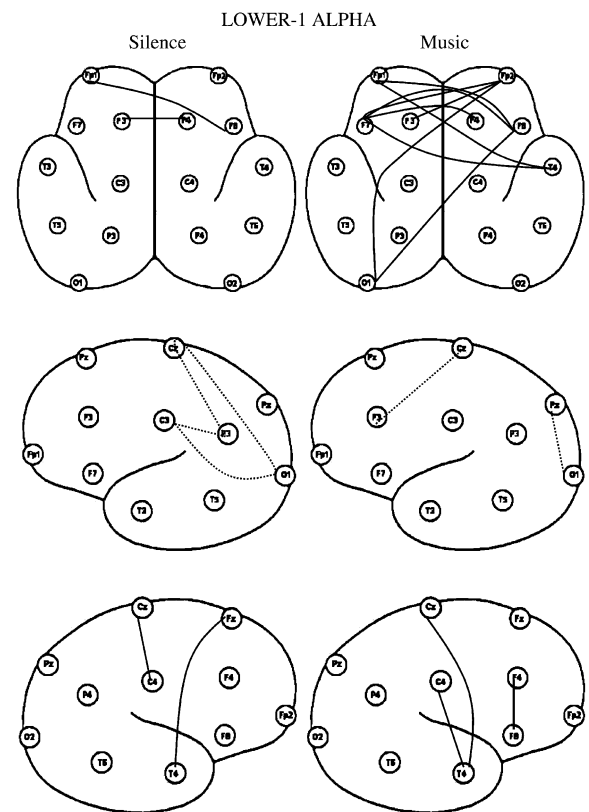


Fig. 5. Error probability maps of paired Wilcoxon tests (rest vs. the 2 response conditions) in the lower-1 alpha band for the interhemispheric, right and left hemispheric electrode pairs. The solid line represents ERCoh increases, the dotted line represents ERCoh decreases.

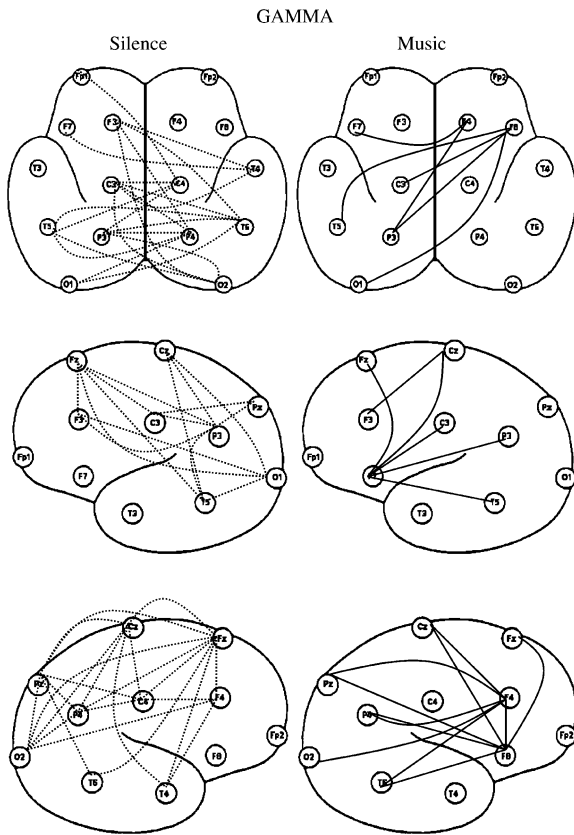


Fig. 6. Error probability maps of paired Wilcoxon tests (rest vs. the 2 response conditions) in the gamma band for the inter-hemispheric, right and left hemispheric electrode pairs. The solid line represents ERCoh increases, the dotted line represents ERCoh decreases.

response condition, considerable differences between the silence and music response conditions were also observed. This suggests that listening to music, besides increasing the cognitive workload had also a more specific influence on brain activity. The role of the gamma band in cognitive processing is a matter of intense interest within the conceptual framework of temporal coding theory and the binding hypothesis (Singer, 1993; Tallon-Baudry and Bertrand, 1999). Studies have revealed that different features of stimuli are processed in spatially separate areas of the cortex, which requires processes for linking the separate nodes of activity, thereby allowing identification of the object as a whole. The linking mechanism is

provided by the oscillations in the gamma-band (Singer and Gray, 1995). Increases in gamma coherence while listening to music have been reported by several studies (Bhattacharya et al., 2001; Bhattacharya and Petsche, 2001). Similarly, in the present study, music caused extensive decoupling of brain areas in the silence response condition to be replaced by increased coupling of brain areas. It seems that auditory background stimulation can influence visual brain activity, even if both stimuli are unrelated. This lends further supports to the general explanation of the Mozart effect, namely, that listening to music primes spatial abilities because of similarities in neural activation (Rauscher et al., 1993).

The experimental setup of the present study cannot provide a detailed explanation of this priming effect, however, some tentative conclusions are possible. Oscillations in the gamma band play a crucial role in music perception and therefore probably have a key role in enhancing spatial reasoning. It can be assumed that listening to a certain type of music (e.g. Mozart) increases the coupling of specific brain areas and in that way facilitates the selection and ‘binding’ together of pertinent aspects of sensory stimulus into a perceived whole. It can be further assumed that if such a pattern of activated brain areas coincides with the pattern needed for task completion, an increase in task performance could be the result. As shown in our study, the Mozart sonata in the gamma band increased the coupling of inter-hemispheric right frontal and left parietal, temporal and occipital brain areas, as well as right and left hemispheric frontal brain areas with parietal, temporal and occipital brain areas. In our study, the patterns of ERCohs in the gamma band between the silence and music response condition did not overlap most likely therefore no influence of music on task performance was found. A second reason for the lack of influence music had on task performance was probably also the simplicity of the visual task, which was correctly solved by almost all respondents.

To further investigate the influence music has on cognitive performance, the research should to a greater extent focus on the selection of tasks and

music, both of which provoke overlapping patterns of oscillations in the brain.

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