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The influence of Mozart's music on brain activity in the process of learning

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Abstract

Objective: The study investigated the influence Mozart's music has on brain activity in the process of learning. A second objective was to test Rauscher et al.'s (1993) priming explanation of the Mozart effect.
Methods: In Experiment 1 individuals were first trained in how to solve spatial rotation tasks, and then solved similar tasks. Fifty-six students were divided into 4 groups: a control one – CG who prior to and after training relaxed, and three experimental groups: MM – who prior to and after training listened to music; MS – who prior to training listened to music and subsequently relaxed; and SM – who prior to training relaxed and afterward listened to music. The music used was the first movement of Mozart's sonata (K. 448). In Experiment 2, thirty-six respondents were divided into three groups: CG, MM (same procedure as in Experiment 1), and BM – who prior to and after training listened to Brahms' Hungarian dance No. 5. In both experiments the EEG data collected during problem solving were analyzed using the methods of event-related desynchronization/synchronization (ERD/ERS) and approximated entropy (ApEn).
Results: In the first experiment the respondents of the MM, MS, and SM groups showed a better task-performance than did the respondents of the CG group. Individuals of the MM group displayed less complex EEG patterns and more α band synchronization than did respondents of the other three groups. In Experiment 2 individuals who listened to Mozart showed a better task performance than did the respondents of the CG and BM groups. They displayed less complex EEG patterns and more lower-1 α and γ band synchronization than did the respondents of the BM group.
Conclusions: Mozart's music, by activating task-relevant brain areas, enhances the learning of spatio-temporal rotation tasks.
Significance: The results support Rauscher et al.'s (1993) priming explanation of the Mozart effect.

Keywords: Mozart effect; Learning; Memory; Problem-solving; Event-related desynchronization; Approximated entropy

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. Much later the beneficial influence of music on epileptiform activity in patients with seizures (Hughes et al., 1998; Hughes, 2002), as well as in individuals with hearing loss (Tomatis, 1996) and early childhood autism (Rimland and Edelson, 1995) was reported. It was further suggested that music can accelerate learning of foreign languages, reading and mathematics (Lozanov, 1978), retention of terminology (Panksepp, 1998), and creative ability (Jaušovec, 1994; Adaman and Blaney, 1995). The effect specific musical pieces have on human behavior was usually explained as a consequence of their impact on positive mood and arousal (Nantanis and Schellenberg, 1999; Thompson et al., 2001; Husain et al., 2002; Panksepp and Bernatzky, 2002). Listening to music affects arousal (degree of physiological activation), mood (long lasting emotions), and listeners' enjoyment, which in turn influence performance on a variety of cognitive tasks.

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Rauscher et al. (1993, 1995), provided a different explanation for the beneficial influence music has on human performance. The link between listening to music and spatio-temporal reasoning is subserved by similarities in neural activation, as specified by the Trion model of cortical organization (Shaw et al., 1985; Leng and Shaw, 1991; Shenoy et al., 1993; McGrann et al., 1994). 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. This explanation was based on the so called 'Mozart effect', an enhancement of performance or change in neurophysiological activity associated with listening to Mozart's music. The effect can be found in the subsequently improved performance on spatial IQ tests (Rauscher et al., 1993, 1995). College students who had spent 10 min listening to Mozart's Sonata (K. 448) had Stanford–Binet spatial subtest IQ scores 8–9 points higher than students who had listened to a relaxation tape or listened to nothing. The IQ effects did not persist beyond the 10–15 min testing session.

Rauscher's explanation markedly differs from the neuro-affective explanations and was criticized 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). In a recent study by Jaušovec and Habe (2004) it was found that auditory background stimulation can influence visual brain activity, even if both stimuli are unrelated. Students who solved a simple visual task while listening to Mozart's music displayed (mainly in the γ band) more coherent brain activity, whereas a decoupling of brain areas in the γ band was observed while respondents solved the same task in silence. Oscillations in the γ band play a crucial role in music perception (Bhattacharya et al., 2001a; Bhattacharya and Petsche, 2001), and are also associated with the binding hypothesis – the linking of separate nodes of activity in the cortex and thereby allowing the identification of the object as a whole (Singer and Gray, 1995; Tallon-Baudry and Bertrand, 1999). 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. This hypothesis was also supported by a recent study by Jaušovec and Habe (2005). They showed that Mozart's music had a beneficial influence on respondents' performance of spatial rotation tasks, and a slightly negative influence on the performance of numerical tasks. On the physiological level a general effect of Mozart's music on brain activity in the induced γ band was observed, accompanied by a more specific effect in the induced lower-2 α band which was only present while respondents solved the numerical tasks.

Further support for Rauscher's priming theory is provided by several fMRI and PET studies (for a review see Janata and Grafton, 2003; Patel, 2003) showing a considerable overlap of regions implicated in the perception-action cycle of music and areas involved in the perception, memorization and production of abstract sequences as well as language and syntax. In addition, significant differences in activation by the Mozart sonata (in comparison to Beethoven's Für Elise) in the dorsolateral pre-frontal cortex, occipital cortex and cerebellum (all expected to be important for spatio-temporal reasoning) were reported in a recent fMRI study (Bodner et al., 2001).

One aspect, which in our opinion has been neglected in studying the Mozart effect, is the interaction between different learning stages and music. Changes in the synapses resulting from the simultaneous (or near-simultaneous) activation of the neurons that form them is generally thought to be the basis of all changes in behavior due to experiences, including those that involve learning. Hebb's (1949) notion of the cell assembly was based on evidence suggesting that memory is a time-dependent process, thus it can be influenced in different stages. Priming refers to the facilitative effect of performing one task on the subsequent performance of the same or similar tasks; whereas consolidation refers to the post-training period during which the hypothesized process of synaptic change occurs and transforms from a labile state into a more permanent one. Most of the studies investigating the Mozart effect (e.g., Rideout and Laubach, 1996; Rideout and Taylor, 1997; Rideout et al., 1998; McKelvie and Low, 2002; Jaušovec and Habe, 2005) used a procedure in which the same participants were exposed to the control and experimental conditions. These conditions were counterbalanced, and therefore music – beside its priming effect – could also have had an influence on the consolidation of memory. A second shortcoming of the studies investigating the Mozart effect was that their conclusions were mainly based on behavioral data and only few of them combined behavioral with physiological data (e.g., Sarnthein et al., 1997).

The aim of the present study was to investigate the influence music has on brain activity of individuals in different stages of learning – priming and consolidation. In general it was expected that music would have a beneficial influence on both learning stages and that this influence would be reflected in brain activity. Brain activity patterns during the testing phase similar to those observed in high intelligent individuals were expected.

2. Experiment 1

In a parallel groups experimental design, comparison was made of the behavioral and psychophysiological data (EEG power and non-linear dynamical measures of network complexity), of respondents who prior to and/or after learning listened to Mozart's sonata (K. 448), or just relaxed in silence.

2.1. Method

2.1.1. Subjects

The sample included 56 right-handed student-teachers (mean age 20 years and 8 months; 28 male and 28 female students) taking a course in psychology. The students were assigned to 4 groups ($n = 14$; 7 males, and 7 females) equalized with respect to gender, verbal and performance intelligence (WAIS-R), emotional intelligence (experimental version of MSCEIT, Mayer et al., 2002), and the personality factors of extraversion and neuroticism (BFQ, Caprara et al., 2002). This equalization was done because a great body of research indicated that differences in intelligence (e.g., Haier et al., 1988; O'Boyle et al., 1995; Haier and Benbow, 1995; Anokhin et al., 1999, 1992; Jaušovec, 1996, 1998, 2000); emotional intelligence (Jaušovec et al., 2001; Jaušovec and Jaušovec, 2005); and personality factors (Eysenck, 1967; Eysenck and Eysenck, 1985) are reflected in brain activity. The respondents were selected from a sample of 1225 individuals who were tested with the WAIS-R, MSCEIT and BFQ tests. From this group, 233 individuals (152 females and 81 males) with an average score on all three tests (±.5 SD), were selected and randomly allocated to the four groups.

2.1.2. Material and Procedure

All four groups of individuals were first trained in how to solve different spatial rotation tasks (training session) and then asked to solve similar tasks (test session) to those they have previously learned. The spatial rotation tasks were based on a well-established Slovene intelligence test–BTI (Mihelič, 1972), on the spatial-temporal animation reasoning tasks (STAR) designed by Peterson (2000), and on the PF & C subtest of the Stanford–Binet IQ measure (Rideout and Laubach, 1996). The training session consisted of 45 items which in a stepwise presentation showed the solution principles (see lower part of Fig. 1). The test also consisted of 45 items (see upper part of Fig. 1). Respondents had to judge which of the four figures on the right corresponded to the figure in the left frame. All items were presented on a computer screen positioned about 100 cm in front of the respondent. The tasks were presented at fixed 11 s interstimulus intervals. They were exposed for 7 s following a 2 s interval, when a cross was presented. During this time the students were instructed to press a button (1–4) which indicated their answer. All pictures were generated by the STIM stimulator.

Respondents of all four groups received the same instruction. They were told that they would first learn how to solve different spatial tasks, which they would solve after a short break. They were shown the three types of items and provided with a brief explanation of the solution principles.

As can be seen in Fig. 2, the respondents of the control group (CG), prior to and after the training session, were instructed to close their eyes and relax for approximately 8 min. The respondents of the other three groups, either prior to (MS), or after the training session (SM), or prior to and after the training session (MM) listened to music. The music excerpt consisted of the first movement of Mozart's sonata for two pianos in D major (K. 448 – 8 min duration). It was presented through headphones (SPL 60–70 dB) while listeners sat in a reclining chair with their eyes closed. In order to become familiar with the testing procedure prior to the real test a short trial of 5 items was presented to the subjects. When finished with testing all respondents were asked to close their eyes and relax. During this period the respondents' resting EEG was recorded. This resting EEG was used to determine the mean α peak frequency (IAF) – which was used as an individual anchor point to determine the α narrow frequency bands.

2.1.3. EEG recording and quantification

EEG was recorded using a Quick-Cap with sintered electrodes. Using the Ten-twenty Electrode Placement System of the International Federation, the EEG activity was monitored over nineteen scalp locations. All leads were referenced to linked mastoids (M1 and M2), and a ground electrode was applied to the forehead. Additionally, vertical eye movements were recorded with electrodes placed above and below the left eye. The 19 EEG traces were digitized online at 1000 Hz and stored on a hard disk. Epochs were comprised from the 3000 ms preceding and 8000 ms following the stimulus presentation and automatically screened for artifacts. Excluded were all epochs showing amplitudes above ±50 μV. All together 2.1% of epochs were excluded from further analysis.

The alpha frequency bands were individually determined based on IAF (IAF = 10.03 Hz, SD = .93) (Klimesch, 1999; Burgess and Gruzelier, 1999). On average, this method resulted in a band of 10.03–12.02 Hz for the upper-α band, a band of 8.03–10.02 Hz for the lower-2 α, and a band of 6.03–8.02 Hz for the lower-1 α. The broad γ band had a range from 31 to 49 Hz. These bands were chosen because research has identified their relationship to different cognitive functions. The upper-α (10–12 Hz) activity is modulated by semantic memory processes (Klimesch, 1997). The lower-1 and lower-2 α (6–10 Hz) bands are related to attentional task demands. The lower-1 α band is mainly related to the level of alertness, whereas the lower-2 α band is more related to expectancy (Klimesch, 1999). The role of the γ band (>30 Hz) is associated with the binding hypothesis (Tallon-Baudry and Bertrand, 1999).

The event-related desynchronization/synchronization (ERD/ERS) were determined using the method of complex demodulation with a simultaneous signal envelope computation (Andrev, 1999; Otnes and Enochson, 1978; 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

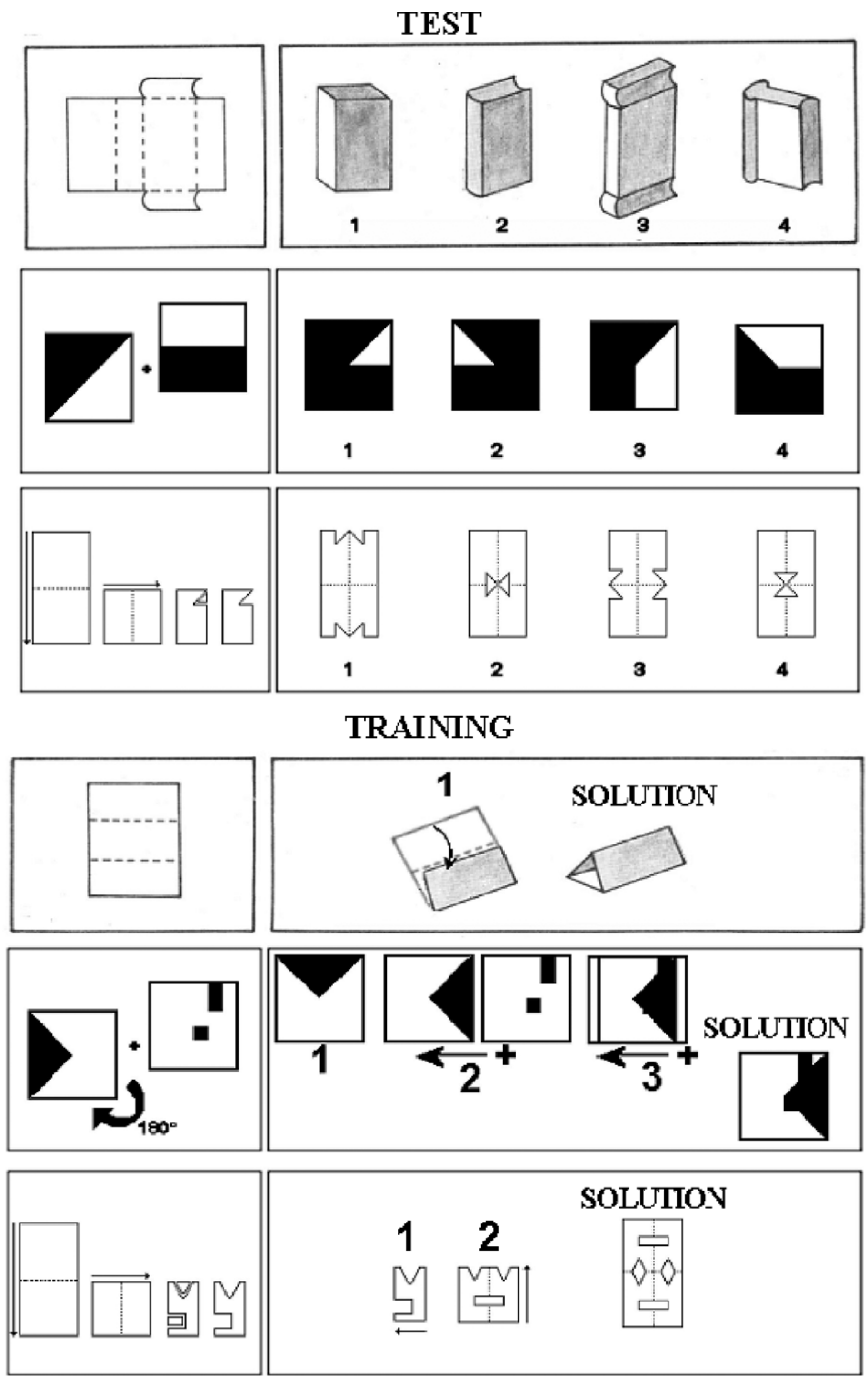


Fig. 1. Examples of the spatial rotation tasks used in the test and training sessions: based on the Slovene intelligence test–BTI (Mihelič, 1972), on the spatial-temporal animation reasoning tasks (Peterson, 2000), and on the PF & C subtest of the Stanford–Binet IQ measure (Rideout and Laubach, 1996). In the test session (see upper part of figure), respondents had to judge which of the four figures on the right corresponded to the figure in the left frame. For example, the third test item (PF & C) in the left frame shows how a piece of paper is folded and cut out, while in the right frame there are 4 unfolded pieces of paper. The question was, which of the four unfolded pieces of paper in the right frame corresponds to the one folded in the left frame? The correct answers for the three test tasks are: 2, 3 and 4. The training session items in a stepwise presentation showed the solution principles (see lower part of figure).

the same center frequency. Both time series (multiplied by a pure sine and cosine) are then lowpass filtered by the half-bandwidth (1 Hz for the α frequency bands, and 9 Hz for the γ band).

The quantification of induced ERD was done using the intertrial variance method (induced, non-phase-locked activity). The formulas used were as follows (Pfurtscheller, 1999):

Priming	Training	Consolidation	Test
Music – 8 min	45 trainig items	Music – 8 min	MM
		Silenc – 8 min	MS
Silenc – 8 min	45 trainig items	Music – 8 min	SM
		Silenc – 8 min	CG

Fig. 2. Research design of Experiment 1. EGG analyzed in the present study was recorded during the test phase.

$$\mathrm{IV}_{(j)} = \frac{1}{N-1}\sum_{i=1}^{N}\{y_{f(i,j)} - \bar{y}_{f(j)}\}^2 \tag{1}$$

In Eq. (1) N is the total number of trials, $y_{f(i,j)}$ is the jth sample of ith trial data, and $\bar{y}_{f(j)}$ is the mean of the jth sample over all trials. The ERD (IV) data were used to calculate the ERD/ERS values which were defined as the percentage change of the power at each sample point (A_j), relative to the average power in the resting 1000 ms reference interval (R) preceding the stimulus onset (−1500 to −500 ms):

$$\mathrm{ERD}_{(j)}\% = \frac{R - A_j}{R} \tag{2}$$

A positive ERD indicates a power decrease, and a negative ERD a power increase (Pfurtscheller, 1999). The ERD/ERS values were determined for five 1000 ms time windows (from stimulus onset till 5000 ms). The ERD/ERS values were collapsed for different electrode locations, distinguishing the hemispheres as well as frontal, central and parietal brain areas. The electrode positions were aggregated as follows: frontal left (Fp1, F3, F7), frontal right (Fp2, F4, F8), central left (T3, C3), central right (T4, C4), parietal left (T5, P3, O1), and parietal right (T6, P4, O2).

Approximate entropy (ApEn) has been recently introduced as a quantification of regularity in time-series data. It has been shown that ApEn can distinguish a wide variety of systems ranging from multi periodic, to stochastic and mixed systems; furthermore, it is applicable to noisy, medium-sized data sets (Pincus, 1994, 1995). Measures of dimensional complexity reflect the complexity of neural generators – the relative number of concurrently oscillating neuronal assemblies and degrees of freedom in the competitive interaction between them. Dimensional complexity appears to be relatively independent of EEG spectral power and inversely related to coherence, suggesting that it may reflect qualitatively different aspects of brain dynamics which cannot be detected by traditional spectral power measures (Lutzenberger et al., 1992; Pritchard and Duke, 1995; Anokhin et al., 1999; Kirsch et al., 2000; Stam, 2005). Mathematically, ApEn measures the likelihood that runs of patterns which are close in one observation remain close on the following incremental comparisons. The ApEn analysis was performed using the program Simulnet-Pro. Given N data points (5000 – from stimulus onset till 5000 ms), the statistic ApEn was determined for $m = 2$, and $r = .15$ SD u (i) data using the formula:

$$\mathrm{ApEn}\ (m, r, N) = \Phi^m(r) - \Phi^{m+1}(r), \tag{3}$$

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. The ApEn was calculated for each electrode separately for the α frequency band (6–12 Hz) and for the γ band (31–49 Hz). The data were collapsed with respect to both hemispheres and three brain areas (in the same way as for the ERD/ERS measures).

2.2. Results

The data were analyzed using the statistical package SPSS for Windows 12. All univariate repeated measure analyses of variance were corrected for violation of the sphericity assumption Huynh–Feldt (Jennings, 1987). The behavioral data were analyzed by a general linear model (GLM) univariate analysis with the factor variables of group (CG, SM, MS, MM) and gender. For the ERD/ERS and ApEn measures a GLM for repeated measures for each frequency band was calculated. The factors and their levels were: time (5 × 1000 ms); hemisphere (left, right); area (frontal, central, parietal); group (CG, SM, MS, MM). All between group differences were analyzed for correctly and incorrectly solved tasks, only trials in which the participant gave no answer were excluded from the analysis. Between group differences were analyzed with Tukey post hoc tests. Only statistically significant differences relating to the factor group are reported.

2.2.1. Behavioral data

The GLM univariate analysis conducted for the between groups and gender differences for the correctly solved test items showed a significant between groups ($F(3, 48) = 5.65$; $p < .002$), and between gender ($F(1, 48) = 5.40$; $p < .024$) difference. No significant group by gender interaction effect was observed. A Tukey post hoc test for the factor group indicated that the CG group scored significantly lower than the other three groups which prior to the training or test sessions, or prior to both sessions had listened to music ($p_{MM} < .002$; $p_{SM} < .022$; $p_{MS} < .034$). As can be seen in Fig. 3, males scored higher than did females.

2.2.2. Psychophysiological data

2.2.2.1. ApEn. In both frequency bands, (α and γ), a significant main effect of the factor group was observed ($F_{\alpha}(3, 52) = 4.87$; $p < .005$; $F_{\gamma}(3, 52) = 5.47$; $p < .002$). Tukey post hoc tests revealed that the MM group in the α ($p_{MS} < .008$; $p_{CG} < .012$; $p_{SM} < .048$), as well as γ ($p_{MS} < .002$; $p_{SM} < .017$; $p_{CG} < .049$) frequency bands showed a less complex EEG pattern than the other three groups. In the α frequency band also a significant area by group interaction effect was observed ($F(6, 104) = 2.70$; $p < .018$). As can be seen in Fig. 4, in the parieto-occipital area the respondents of the CG, MS and SM groups displayed a similar pattern of EEG complexity, whereas the MM group showed a markedly less complex EEG pattern. In the frontal area all four groups differed in the level of ApEn, again the MM group showed the lowest ApEn, followed by the SM, CG and MS groups.

2.2.2.2. Induced ERD/ERS. The analysis of ERD/ERS data in the lower-1 α band showed a significant main effect of the factor group ($F(3, 52) = 3.33$; $p < .027$). The MM group showed lower-1 α ERS, whereas the other three groups showed lower-1 αERD. The difference was significant for the MS group (Tukey post hoc test $p < .017$). Also significant was the area by group interaction effect ($F(6, 104) = 2.73$; $p < .024$), revealing that the difference in ERD/ERS was more pronounced in the frontal and parieto-occipital areas. In both areas the MM group showed lower-1 α ERS, whereas the other three groups showed more lower-1 α ERD (see Fig. 5). To establish whether the lower-1 α band ERS/ERD significantly differed from zero a one-sample t-test was conducted. The t-test was significant for the MM (ERS) group ($t(13) = 2.19$; $p < .047$; $M = -10.36$; SD $= 17.69$); and the other three groups (ERD) ($t(41) = 2.46$; $p < .018$; $M = 7.28$; $SD = 19.20$).

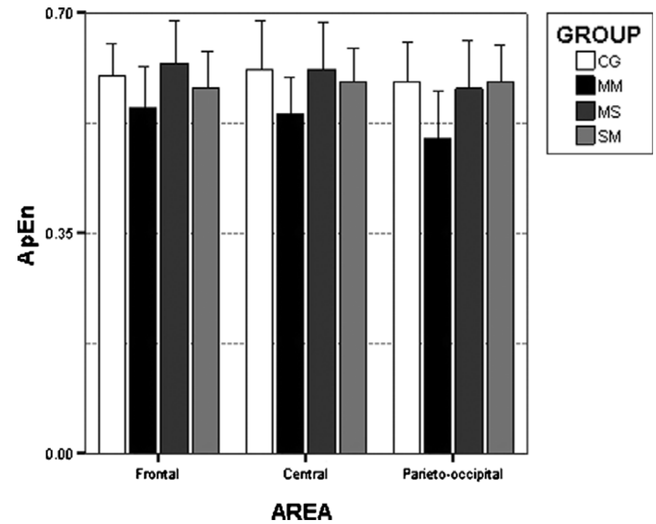


Fig. 4. Means and standard deviation (error bars) of Approximate entropy measures (ApEn) of EEG data in the alpha frequency range displayed by respondents of the four groups (CG, MM, MS, SM) during problem solving.

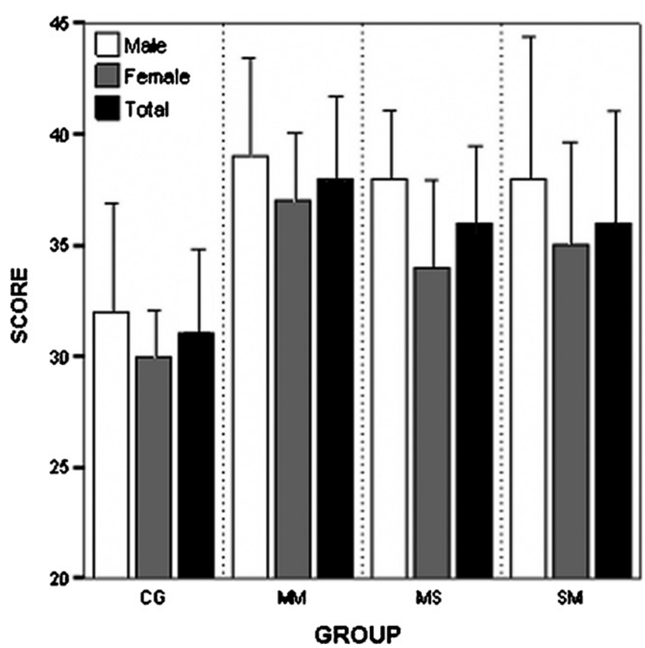


Fig. 3. Number of correct responses given by respondents of the four groups (CG, MM, MS, SM).

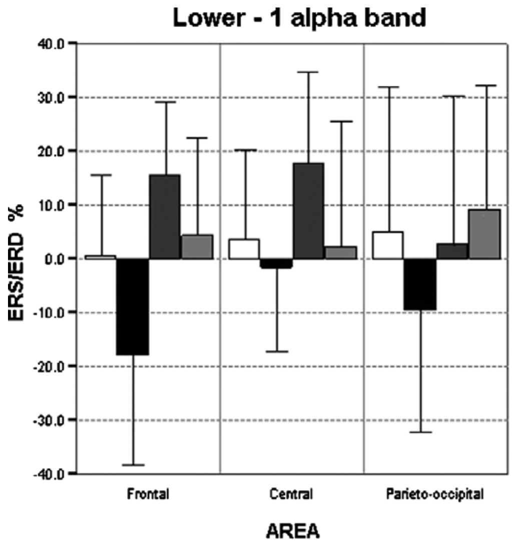
In the lower-2 α band for the ERD/ERS data a significant interaction effect between the factors of time, area and group was observed ($F(24, 416) = 2.68$; $p < .00002$). The MM group showed less lower-2 α ERD than did the other three groups. This difference was most pronounced in the frontal brain areas and less pronounced in the parieto-occipital areas. The greatest differences were observed in the first 2000 ms of problem solving.

In the upper-α band the ERD/ERS data showed a significant time by group interaction effect ($F(12, 208) = 2.67$; $p < .022$). The MM group showed upper-α ERS, whereas the other three groups showed upper-α ERD. The difference was especially pronounced for the period from 1000 to 3000 ms of problem solving (see Fig. 5).

2.3. Discussion

The behavioral data showed that all conditions involving Mozart's music had a beneficial influence on the solution of the spatio-temporal rotation tasks. On the physiological level a measurable influence on EEG activity was only observed for respondents of the MM group who prior to and after training listened to music.

The displayed patterns of ApEn in the α and γ bands suggest that listening to Mozart's music reduced the overall



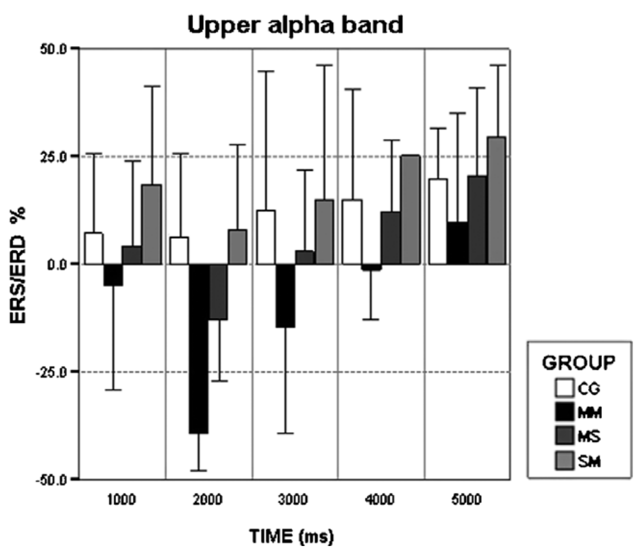


Fig. 5. Means and standard deviation (error bars) of Event-related synchronization/desynchronization (ERS/ERD) of EEG data in the lower -1 and upper-α frequency range displayed by respondents of the four groups (CG, MM, MS, SM) during problem solving.

complexity (degree of randomness, or degrees of freedom) of neural dynamics, thus decreasing the relative number of concurrently activated and competitively interacting neuronal assemblies. This pattern is similar to findings reported in studies investigating neurophysiological differences in brain activity related to intelligence. Less complex EEG patterns have been observed in more intelligent individuals (Jaušovec, 1998; Anokhin et al., 1999; Jaušovec and Jaušovec, 2000a), and in more creative ones (Mölle et al., 1999). It was assumed that the displayed reduction of the complexity of neural dynamics in high intelligent individuals is due to the inhibition of irrelevant and competitive activity. Alternatively, less intelligent individuals are characterized by more diffuse neural dynamics when performing the same task. Therefore it can be speculated that Mozart's music provoked a differentiation of neural activity enhancing spatio-temporal reasoning. This assumption is further supported in a recent study by Bhattacharya and colleagues (2001b). They reported that musicians showed greater phase coherence (inversely related to dimensional complexity) than non-musicians while performing a mental rotation task.

The analysis of the ERD/ERS in the three narrow α bands displayed by respondents of the MM group further supports the above explanation. It is believed that the α band represents oscillations of postsynaptic potentials in the neocortex, and is reduced in amplitude by moderate to difficult mental tasks (Nunez et al., 2001). It is further assumed that the amplitude of the EEG is mainly influenced by the number of synchronous synaptic generators and much less by asynchronous generators, or the total number of generators. Thus, the patterns of ERD/ERS displayed by respondents of the MM group would suggest a decreased level of brain activity. Again these patterns are similar to several studies reporting a negative correlation between brain activity (mainly upper-α ERD/ERS) under cognitive load and verbal and performance components of intelligence (e.g., Jaušovec, 1996, 1998; Jaušovec and Jaušovec, 2000b; Neubauer et al., 1995, 1999, 2002; Neubauer and Fink, 2003). One interpretation of such increases in α amplitude (ERS) in high intelligent individuals is a reduced neural network activity in regions not relevant for task performance – the neural efficiency hypothesis (Haier, 1993).

A second characteristic of brain activity displayed by respondents of the MM group was that several of the EEG parameters analyzed showed an interaction effect with the factor of brain areas, thus suggesting a more intense involvement of the parieto-occipital brain areas (e.g., in the parieto-occipital area less complex EEG patterns were observed, in the lower-2 α band more ERS in the frontal area and more ERD in the parieto-occipital areas was observed). Several PET and fMRI studies have shown that parieto-occipital brain areas play a central role in spatial encoding and retrieval, as well as spatial perception and imagery, while frontal areas are more involved in monitoring and manipulating information held in the working memory (for a review see, Cabeza and Nyberg, 2000). From this viewpoint the greater involvement of the parieto-occipital brain areas could point to a more adequate strategy use, which to a greater extent focused on the figural information provided by the spatio-temporal rotation tasks.

The behavioral data suggest that Mozart's music had a beneficial influence on both learning stages (priming and consolidation). However, this positive influence was not reflected in the EEG measures analyzed. Only respondents of the MM group, who prior to and after training listened to music, showed a clear cut difference in EEG activity in comparison with the other three groups. One possible explanation could be that the longer exposure to music of the MM respondents – in comparison with the SM and MS respondents – might have had a more marked and permanent influence on brain activity subserving spatio-temporal reasoning, which could be detected by the EEG methodology used. This question was further addressed in the second experiment introducing an additional music condition.

3. Experiment 2

With respect to the alternative explanations of why music has an influence on brain functioning outlined in the introduction – (1) as an artifact of preference, mood and arousal, or (2) as patterns of neural activation that facilitate cognitive functions – the results of the first experiment provided only slight indices that favor the second explanation. The EEG data showed no indicator pointing to an increased level of arousal (degree of physiological activation) in the MM group. By contrast, respondents in the MM group displayed more lower-1 and lower-2 α band ERS. Because these two bands are related to attentional task demands – level of alertness and expectancy (Klimesch, 1999) – an opposite pattern of brain activity would have been expected in individuals with an increased level of physiological activation.

A second unsolved question of the first experiment was the inconsistency between behavioral and physiological data (e.g., on the behavioral level all three music groups outperformed the control group, whereas only the MM group showed reliable physiological changes). Another possible explanation for this inconsistency – beside the one provided in the discussion above – could also be that EEG methodology was not sensitive enough to measure the music induced behavioral changes in the three experimental groups, and that the EEG patterns observed in the MM group are only the result of prolonged listening to music and are not related to the better spatio-temporal task performance of the respondents.

The aim of the second experiment was to further investigate these two questions. For that purpose an additional music condition was introduced. The music used was Brahms' Hungarian dance No. 5. This music clip was chosen because in a previous study (Jaušovec and Habe, 2003), naive and expert listeners, comparing the Brahms clip to other music pieces (including Mozart's sonata K. 448), indicated that the most pleasant mood was induced by the Brahms clip. It was further shown that the clustering of the music clips based on EEG measures distinguished between the Mozart clip on the one hand, and the Brahms clip on the other. Therefore, in Experiment 2 it was hypothesized that the arousal-mood theory would predict a more beneficial influence of the Brahms clip on respondents' task performance as compared with the Mozart music clip, whereas, the priming theory – suggesting that music excites the sequential flow of the cortical firing patterns responsible for higher brain functions – would predict no influence of the Brahms clip on respondents' task performance.

It was further expected that behavioral and physiological data would show a consistent pattern of differences – groups who differ with respect to task performance would also display different patterns of brain activity.

3.1. Method

3.1.1. Subjects

The sample included 36 right-handed student-teachers (mean age 20 years and 6 months; 18 male and 18 female students) taking a course in psychology. The students were assigned to 3 groups ($n = 12$; 6 males, and 6 females). As in Experiment 1 they were equalized with respect to gender, verbal and performance intelligence, emotional intelligence and the personality factors of extraversion and neuroticism.

3.1.2. Material and procedure

The same training and test materials as in Experiment 1 were used. The procedure for the CG and MM groups was identical to the procedure used in Experiment 1. The BM group prior to and after training listened to Brahms' Hungarian dance No. 5, which was continuously played for 8 min.

3.1.3. EEG recording and quantification

The EEG recording and quantification of ApEn and ERD/ERS was the same as in Experiment 1.

3.2. Results

The same statistical analyses as in Experiment 1 were conducted. Only significant differences related to the factor group are reported.

3.2.1. Behavioral data

The GLM univariate analysis conducted for the between groups and gender differences for the correctly solved test items showed a significant between groups ($F(2, 30) = 17.10$; $p < .1.1\text{E–}05$), as well as between gender ($F(1, 30) = 5.76$; $p < .023$) difference. No significant group by gender interaction effect was observed. A Tukey post hoc test for the factor group indicated that the MM ($M = 38.67$; SD = 3.60) group scored significantly higher than did the CG ($M = 30.30$; SD = 3.55), and BM ($M = 29.42$; SD = 5.99) groups ($p_{\mathrm{CG}} < .0001$; $p_{\mathrm{BM}} < .0001$).

3.2.2. Psychophysiological data

3.2.2.1. ApEn. In both frequency bands, (α and γ), a significant main effect of the factor group was observed ($F_\alpha(2, 33) = 6.17$; $p < .005$; $F_\gamma(2, 33) = 4.76$; $p < .015$). A Tukey post hoc test showed that in the α band the MM ($M = .51$; SD = .16) group displayed significantly less chaotic EEG patterns than did the CG ($M = .60$; SD = .12; $p < .017$), and the BM ($M = .60$; SD = .14 $p < .011$) groups. The same trend was observed in the γ band. The MM ($M = .33$; SD = .12) group displayed less chaotic EEG patterns than did the CG ($M = .45$; SD = .11), and BM ($M = .45$; SD = .12), groups ($p < .01$).

Table 1
Means, SD, and Tukey post hoc tets for the ERD/ERS in the lower-1 α and γ bands for the CG, MM, and BM groups

Frequency	CG		MM		BM		Tukey post hoc
	M	SD	*M*	SD	*M*	SD	
Lower-1 α	4.83	9.36	−7.25	10.45	13.93	11.33	BM > MM $p < .026$
γ	−1.47	14.44	.78	11.16	15.18	17.28	BM > MM $p < .026$
							BM > CG $p < .009$

3.2.2.2. Induced ERD/ERS. The analysis of ERD/ERS data in the lower-1 α and γ band showed a significant main effect of the factor group ($F_{\alpha}(2, 33) = 3.93$; $p < .03$; $F_{\gamma}(2, 33) = 5.88$; $p < .07$). As can be seen in Table 1 the BM group displayed significantly more lower-1α desynchronization than did the MM group; as well as more γ band desynchronization than did the MM and CG groups. To establish whether the lower-1 α and γ band ERS/ERD significantly differed from zero a one-sample *t*-test was conducted. The *t*-test for the lower-1 α was significant for the MM (ERS) group ($t(11) = 4.54$; $p < .002$; $M = -13.86$; $SD = 10.57$), and the BM group (ERD) ($t(11) = 2.63$; $p < .023$; $M = 13.87$; $SD = 18.28$). The *t*-test for the γ band was only significant for the BM group ($t(11) = 3.80$; $p < .003$; $M = 15.15$; $SD = 13.83$).

In the upper-α band only an interaction effect between the factors time and group was observed ($F(8, 33) = 3.22$; $p < .018$). As can be seen in Fig. 6, respondents of the MM group displayed more upper-α ERS during the first 3000 ms of problem solving than did respondents of the BM and CG groups.

3.3. Discussion

The behavioral data showed that only the condition involving Mozart's music had a beneficial influence on the solution of the spatio-temporal rotation tasks. This beneficial influence was on the physiological level accompanied by less complex brain activity, a decreased level of alertness and less semantic memory processes. With respect to the questions addressed in the second experiment, the results lend support to Rauscher et al.'s (1993) priming explanation of the Mozart effect suggesting that the link between listening to music and spatio-temporal reasoning is subserved by similarities in neural activation. The consistency between observed differences in behavioral measures on the one hand and physiological on the other, support our assumptions that the observed patterns of EEG activity are the result of the influence of Mozart's music on spatio-temporal reasoning, and not just a consequence of listening to music in general.

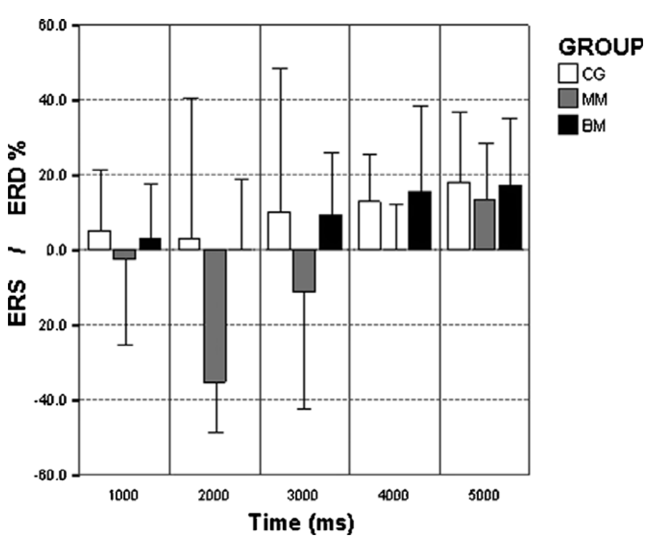


Fig. 6. Means and standard deviation (error bars) of Event-related synchronization/desynchronization (ERS/ERD) of EEG data in the upper-α frequency range displayed by respondents of the three groups (CG, MM, BM) during problem solving.

4. General discussion

The aim of the present study was to investigate the influence Mozart's music has on different phases of learning – represented by Hebb's recurrent activation phase and memory consolidation. The behavioral data support the hypothesized beneficial influence of Mozart music on both learning phases. However, the results showed that all experimental groups outperformed the controls, hence the test of the priming/consolidation dichotomy was not positive. A possible reason for this could be that the tasks used were not sensitive enough to measure the potential differences. The same seems true for the physiological measures used – no differences in EEG patterns between the control group and the two experimental groups SM and MS were observed. Only the MM respondents showed reliable physiological changes in relation to the behavioral data. One probable explanation (which was also confirmed in the second experiment) could be that the prolonged exposure of the MM respondents to music might have had a more marked and permanent influence on brain activity subserving spatio-temporal reasoning, which could be detected by the EEG methodology used.

The displayed pattern of brain activity (lower α and γ ApEn, more α and γ band ERS) of the respondents who prior to and after learning listened to Mozart's music is similar to findings reported in studies investigating neurophysiological differences in brain activity related to verbal and performance components of intelligence (Jaušovec, 1996, 1998; Anokhin et al., 1999; Jaušovec and Jaušovec, 2000a,b; Neubauer et al., 1995, 1999, 2002; Neubauer and Fink, 2003), creativity (Mölle et al., 1999), emotional intelligence (Jaušovec and Jaušovec, 2005), as well as research comparing brain activity between musicians and non-musicians while performing different tasks (e.g., listening to music or text, and mental rotation). Musicians while listening to music and during spatial imagination displayed higher levels of γ band synchronicity than did non-musicians (Bhattacharya et al., 2001a,b).

Considering the functional relevance of the frequency bands for various cognitive processes, Klimesch et al. (1999) suggested that local reductions in α amplitudes occur in task relevant brain areas, whereas task-irrelevant regions may be unchanged or even produce larger α amplitudes. Doppelmayr et al. (2005) applied this hypothesis to the brain-intelligence research suggesting that a weaker ERD for more intelligent subjects can either be interpreted in terms of a more efficient processing (neural efficiency), or in terms of a task specific inhibition of irrelevant processes (inhibition hypothesis).

In the light of this theoretical background it could be speculated that Mozart's music facilitated the activation of specific brain areas relevant for spatio-temporal reasoning. Based on the specific temporal and spatial distribution of brain activity displayed by individuals of the MM group in the narrow α and broad γ bands a hypothetical model of cognitive processes involved in the superior problem solving of the MM respondents could be proposed. Respondents who listened to Mozart's music showed less lower-1 α band ERD which is mainly related to the level of alertness (Klimesch, 1999). This decreased alertness was accompanied by less upper-α ERD in the first 3 s of problem solving and an overall γ ERS. This activity was mainly located in the parieto-occipital brain areas. Given that: (1) the upper-α band activity is modulated by semantic memory processes (Klimesch, 1997), (2) the γ band is associated with the binding hypothesis (Tallon-Baudry and Bertrand, 1999; Bhattacharya et al., 2001a,b), and (3) the parieto-occipital brain areas play a central role in spatial perception and imagery (Cabeza and Nyberg, 2000), one could suggest that the solution strategy of the MM respondents at the beginning of the solution process was more figural and less verbal-semantic, whereas at the end of the solution process – when respondents were prompted to provide an answer – their strategy became more semantic.

With respect to the alternative explanations of why music has an influence on brain functioning, the results of the present study support Rauscher et al.'s (1993) priming explanation. The EEG data provided no indicator pointing to an increased level of arousal (degree of physiological activation) in the MM group. By contrast, respondents in the MM group displayed a decreased level of alertness, nevertheless they significantly outperformed respondents of the CG and BM groups.

Overall, the data suggest that the increased performance in spatio-temporal reasoning was a result of the activation of specific task-relevant brain areas, as well as the inhibition of task irrelevant brain areas provoked by listening to Mozart's sonata (K. 448). In music, spatial and temporal sequence information must be unified thus activating specific brain areas which might overlap with areas involved in other cognitive processes (Janata and Grafton, 2003; Patel, 2003). A still unsolved question is what specific characteristics of Mozart's sonata (K. 448) might have had provoked the above described changes in brain activity. Thus, a challenging question for further research would be: Are there certain music pieces which are beneficial for specific cognitive processes?

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