

Brain DC Potentials Evoked by Listening to Mozart's Sonata K. 448, Albinoni's Adagio, Schubert's Fantasia, and Brown Noise: Indications of a Mozart Effect Independent of Mood and Arousal

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Abstract

Context: The Mozart effect describes that after listening to Mozart's sonata K. 448 spatial reasoning was superior. Up to now there is puzzling evidence on the validity of this effect and controversial explanations are offered.

Objective: Based on the findings which indicate that Mozart's sonata activates brain circuits related to attention and cognitive processing, changes in brain DC potentials induced by Mozart's sonata and three control conditions were investigated.

Design: According to a repeated ANOVA design brain DC potential changes, autonomic arousal, and mood were compared in four conditions of stimulation: Mozart's Sonata K. 448, Albinoni's Adagio, Schubert's Fantasia, and brown noise.

Setting and Interventions: Participants listened to three pieces of music and to brown noise which were presented in a balanced order while electrophysiological signals were recorded (electroencephalogram, heart rate, and skin conductance). After 4 min of stimulation ratings of mood were initiated.

Participants: A total of 38 (19 females) non-musicians participated in the study.

Main outcome measures: For stimulation with Mozart prefrontal and frontal brain potentials shifted negatively, whereas for all other stimulations positively. No relevant differences of autonomic arousal were observed. Mood ratings were comparable for musical pieces and negative for brown noise.

Results: Negative brain DC potentials, most pronounced at prefrontal sites in the Mozart condition, only indicate an attention-related activation which primes spatial information processing.

Conclusions: Results support the Mozart effect independent of mood and arousal. The specific stimulation of two different but similar musical streams is offered as a new explanation of the Mozart effect.

Keywords: Electroencephalography; Brain waves; Music; Mood; Arousal; Attention

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Introduction

Rauscher et al. [1] reported a superior performance in spatial reasoning after listening to Mozart's Sonata for Two Pianos in D-Major, K. 448. This was an interesting finding for practical

applications and a compelling message, in particular to discover its psychological and physiological basis, which is still unsolved, although having been investigated by numerous studies and methods including neurophysiological approaches.

The initial findings [1] are still under discussion, as on the one

hand, they were successfully replicated [2-9], and on the other hand, there were also attempts which were unable to replicate the so called Mozart effect [10-12]. As one reason for the confusing observations methodological reasons like between subjects and within subject designs [11,13], besides other methodological shortcomings and the validity in particular were discussed [13]. Another reason of contradictory results comes from a misconception that listening to Mozart enhances intelligence, this was not claimed; the Mozart effect was described for spatial-temporal tasks involving mental imagery and temporal ordering [1,14].

The sustained or even growing interest on the functional properties of Mozart's sonata K. 448 is motivated by the application in diverse areas of applications, which were successful in the treatment of epilepsy in children [15-20] and adults [20] as well as in Long Evans rats [17], and there are also positive effects, like in geriatric patients with mild cognitive impairment in which the spatial-temporal performance remains to be constant in time [21], in patients suffering from Alzheimer's disease, where spatial-temporal reasoning improved [22], and also a better acquisition of laparoscopic skills [23]. However, there are also reports with no significant effects caused by the Sonata K. 448, like in the adenoma detection rate in endoscopists by comparing K.488 with music from four other genres [24], or on recognition of upright or rotated Chinese characters during listening to K.448 [25], on the reliability of the Humphrey visual field test in persons with glaucoma [26], thus indicating that the Mozart effect seems not to be a universal method to enhance cognitive performance, although it seems that the Mozart effect may extend beyond cognitive tasks and includes sensorimotor adaptation for strategic movement control but not for adaptive recalibration [27].

In addition to the puzzling evidence on performance effects of the sonata K. 448, various interpretations of the fundamental functional mechanisms were offered as explanations as well. The first framework [1,2] was the trion model [28], a structured mathematical model based (and extended) on the organizational principle in which cortical columns are the basic neural networks of the cortex [29] and comprised of subunit minicolumns, the idealized trions. Proposing that music is a prelanguage, it was suggested that firing patterns initiated by music may improve other higher brain functions [2].

In the following, (radical) alternative interpretations were also proposed, as the claim that compelling evidence suggests that the Mozart effect is an artifact of arousal and mood [4]. Indeed, based on activation theory and the proposed relationship of arousal and performance [30], changes in arousal caused by music may appear as effects caused by the intervening variable arousal. The importance to control studies on the Mozart effect for arousal and mood was pointed out shortly after the first publications in that topic [31], in particular as response to early replications comparing the effect of Mozart's Sonata K. 448 to relaxation or silence [32,33]. As there is evidence that mood enhancing music can increase working memory performance [34], it is worth to notice that there is also empirical evidence that the Mozart effect is not (necessarily) associated with changes in mood [7]. However, when comparing listening to Mozart's sonata K. 448

with listening to the – sad – Adagio in g-minor by Albinoni, an affective working memory effect was suggested for the observed effect [8].

To investigate which brain mechanisms might be responsible for the Mozart effect, various neurophysiological investigations were conducted. Early attempts in analyzing neurophysiological indications of brain activity of persons stimulated with Mozart's Sonata K. 448 were already done by means of the electroencephalogram (EEG) to understand the performance in a spatial task [35]. There is convincing evidence of event-related desynchronization in the alpha band and enhanced gamma activity in the EEG. More precisely, when comparing the Sonata K. 448 with Brahms' Hungarian Dance No. 5 and Haydn's symphony No. 94, results indicate an event-related desynchronisation in the lower EEG alpha band [36]. Also after listening to the sonata K. 448 in healthy young and elderly adults, contrary to listening to Beethoven's piano piece "Für Elise", changes in the EEG alpha band were observed [37]. But an enhanced EEG gamma activity was observed as well, and it was concluded that listening to the Sonata K. 448 facilitates neurophysiological binding of sensory stimuli to a perceived whole in perception [38]. It was concluded that changes in the EEG might be interpreted that listening to Mozart's sonata K. 448 is activating relevant brain areas, and that may enhance the learning of spatio-temporal rotation tasks [39]. That interpretation is in high concordance with a study indicating that rats, after a long term exposure to the Sonata K. 448, displayed a better performance in maze learning than rats exposed to Beethoven's "Für Elise" [5]. A recent study confirmed this finding and further explores the underlying mechanisms: the exposure of developing rats to Mozart's Sonata K. 448 enhanced learning performance in the water maze test; that was accompanied by an enhanced brain-derived neurotrophic factor (BDNF) expression level in the dorsal hippocampus, suggesting that a spatial memory improvement may be associated with the enhanced BDNF/TrkB level of dCA3 and dDG [9].

These results are also in line with an early fMRI study [40] indicating that the Sonata K. 448 lead to an activation of networks important for spatial reasoning, contrary to Beethoven's "Für Elise" and 1930s piano music [40]. Such changes, together with the observed changes in the EEG bands [36,37] and in EEG coherence measures [36], are interpreted as an expression of induced attention processes [36] or as an activation of neuronal cortical circuits related to attentive and cognitive functions [37].

As brain DC potentials are a neurophysiological measure of activation processes [41-48] which reflect attention-related activation [49], they were chosen as the dependent variable to assess the stimulation by Mozart's Sonata K. 448. To investigate the specificity of this stimulation, three control conditions were applied and measures of subjective experience as well as physiological measures of autonomic arousal [50,51] were used to control for mood and arousal. It was expected that Mozart's sonata K. 448 would display attention-related cortical activation.

Methods

Subjects

Due to the observation that musicians differ in strategies of music perception [52] and furthermore, that the Mozart effect is rather demonstrable in non-musicians [53] only, thirty-eight right-handed non-musicians without hearing devices and normal

or corrected to normal vision participated voluntarily and unpaid in the laboratory experiment. The age of the 19 males and 19 females ranged from 21 to 62 years, with an average of 30 years. Because of storage problems, the data of one person could not be included in the analysis.

Ethics

Written informed consent was obtained from all participants and the study protocol confirms to the ethical guidelines of the "World Medical Association Declaration of Helsinki – Ethical Principles for Medical Research Involving Human Subjects" adopted by the 18th WMA General Assembly, Helsinki, Finland, June 1964 and amended by the 59th WMA General Assembly, Seoul, South Korea, October 2008 as approved by the institutional committee of the University Vienna, Vienna, Austria.

Experimental design

Brain DC potential shifts were investigated according to a 4 (Conditions: Mozart's Sonata K. 448, Albinoni's Adagio in g-minor, Schubert's Fantasia D. 940, and brown noise) × 4 (Time of stimulation in minutes) × 8 (Recording location: Fp1, Fp2, F3, F4, C3, C4, P3, P4) repeated measures ANOVA. Ratings of mood and scores of autonomous activation (heart rate and skin conductance) were investigated according to a repeated measures ANOVA design with 4 Conditions (Mozart's Sonata K. 448, Albinoni's Adagio in g-minor, Schubert's Fantasia D. 940, and brown noise).

Tasks

Four acoustical stimulations (Mozart's Sonata K. 448, Albinoni's Adagio in g-minor, Schubert's Fantasia D. 940, and brown noise) were presented, of each of those 4 minutes were analyzed. The order of the presentation was balanced across test persons to avoid position effects, sequence effects, and cross-over effects. The presentations were separated by a break of 3 minutes, of which the 30 seconds before starting the stimulation served as baseline.

The acoustical stimulation in detail: Mozart's sonata K.448 for two pianos (D-major; 1st movement, allegro con spirito; interpreted by Murray Perahia and Radu Lupu). Albinoni's Adagio for organ and strings in g-minor (soloist Wolfgang Meyer, conductor Herbert von Karajan of the Berlin Philharmonics) was chosen because an earlier investigation [4] reported that Albinoni's music would lead to a sad mood with a reduced arousal and that was to be compared to Mozart's Sonata K. 448. Schubert's Fantasia for piano duet, D. 940, in f-minor (interpreted by Murray Perahia and Radu Lupu) was selected because an earlier investigation [54] found a comparable mood and level of activation to that of Mozart's sonata K. 448. Silence served as a control condition in a number of studies about the Mozart effect [1,2,4,12,54], but such a condition seemed uncontrollable because of background noise caused by PCs in the laboratory. The audio materials had been transformed to wave files (44.1 kHz, 16 bit) and were presented in stereo by loudspeakers. The acoustical excerpts had been normalised, so that the maximum peak of the music pieces (Mozart, Albinoni, and Schubert) was at 70 dBA and the maximum peak of brown noise was at 50 dBA. The energy equivalent sound

pressure level (LEQ) was 63.3 dBA for Mozart's sonata, 66.6 dBA for Albinoni's Adagio, 60.1 dBA for Schubert's Fantasia and 49.2 dBA for brown noise.

Subjects listened passively four minutes of the acoustical stimulations and did the ratings thereafter, while the stimulation continued.

In each condition, three dimensions of experienced mood – good mood versus bad mood, alertness versus tiredness, and calmness versus agitation – were assessed by the mood questionnaire "Mehrdimensionaler Befindlichkeitsfragebogen" (multidimensional mood questionnaire, MDBF) [55].

Recording of autonomous arousal

Parameters of autonomous arousal were recorded by a Holter recording device (Physiologger; med-Natic GmbH, München, Germany). In order to record skin conductance electrodes were attached on the palm of the person's non-dominant hand. Heart rate was recorded by electrocardiogram with a modified Lead II configuration according to Einthoven [56].

EEG recordings

The EEG was recorded by a 32-channel DC amplifier (TBZ, Ing. Zickler Ges.m.b.H., model 2320) with high baseline stability and an input impedance $\geq 100 \text{ G}\Omega$ in the range from DC to 30 Hz [57] and signals were sampled with 62.5 Hz. After careful cleaning and sterilization of recording sites and skin puncturing [58] electrodes were attached to the subjects' scalps with collodion, according to the 10-20 system [59] at least 1.5 hours before the recording [41] in order to avoid electrode artifacts caused by adjustment processes of the electrode-electrolyte-skin interfaces. A noncephalic sternovertebral reference of two electrodes from skin punctured locations, one at the 7th cervical vertebra and the other on the right sternoclavicular junction with a 5 k Ω potentiometer connecting these two electrodes, individually adjusted, to minimise electrocardiographic components in the EEG, was used [60].

EEG analysis

To analyse brain DC potential changes the EEG data were sampled down by calculating median values for epochs of 1 second. The mean amplitude of the 30 second lasting pre-stimulus period served as baseline. Mean values for each of the four minutes of stimulation had been calculated for the statistical analysis. Brain DC potentials were topographically mapped for each minute of exposure using the spherical spline interpolation algorithm [61,62].

Results

Mood

A 4 (Condition) × 3 (Scale: good mood, alertness, and calmness) ANOVA for repeated measures showed a significant effect for condition ($F(3,108)=7.65$; $p=0.000$; $GGe=0.928$) and for scale ($F(2,72)=84.04$; $P=0.00$; $GGe=0.631$). Mean values and 95% CI **Figure 1** indicate no significant differences for the scale calmness and for good mood and alertness no differences were observed for

musical conditions by 95% CI, but brown noise was experienced different than stimulation by music.

Autonomous activation

A 4 (Condition) × 3 (Time) repeated ANOVA for heart rate revealed only a significant effect for Time ($F(3,108)=34.77$; $p=0.000$; $GGe=0.764$) indicating a condition independent heart rate fluctuation with a higher heart rate in the fifth minute than in the first and third minute and no differences between the first three minutes. Neither the main effect of Condition ($F(3,108)=0.001$; $p=0.998$; $GGe=0.923$) nor the interaction of Condition × Time ($F(9,324)=1.29$; $p=0.274$; $GGe=0.456$) reached statistical significance.

A 4 (Condition) × 3 (Time) repeated ANOVA for skin conductance revealed a significant effect for Time ($F(3,108)=21.17$; $p=0.000$; $GGe=0.606$) indicating a higher conductance in the fourth minute than in the first minute and no other significant differences. Neither Condition ($F(3,108)=0.852$; $p=0.446$; $GGe=0.606$) nor the interaction of Condition × Time ($F(9,324)=0.668$; $p=0.654$; $GGe=0.579$) reached statistical significance.

Brain DC potential shifts

DC potential shifts had been analysed by a 4 (Condition) × 8 (Location: Fp1, Fp2, F3, F4, C3, C4, P3, P4) × 4 (Time: 4 epochs of 1 minute) ANOVA for repeated measures. The analysis revealed a significant 3-way interaction of Condition × Location × Time ($F(84,3108)=2.39$; $P=0.029$; $GGe=0.070$) accompanied with a significant interaction of Condition × Location ($F(21,777)=2.73$; $p=0.019$; $GGe=0.245$) and a main effect for Time ($F(4,148)=9.14$; $p=0.002$; $GGe=0.327$). Thus all significant effect can be seen in the 3-way interaction of Condition × Location × Time, of which the mean values and 95% CI are displayed in **Figure 2**. Confidence intervals reveal that at FP1, FP2, F3, and at some points in time (minute 2 and 4) DC potential of the Mozart condition is more negative than DC potentials of all other conditions. DC potentials of the Mozart condition is also more negative on some other location compared to conditions at some time points. However, the main effect of condition ($F(3,111)=2.93$; $p=0.062$; $GGe=0.638$) failed two-tailed statistical significance of $p=0.05$.

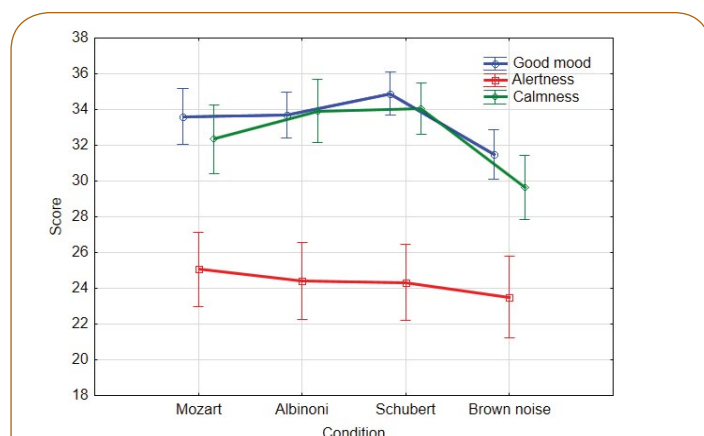


Figure 1 Mean values and 95% CI of scores of the three dimensions of rated moods by experimental conditions.

The topographical mappings of DC potential shifts are presented in **Figure 3**.

Discussion

Results display negative brain DC potential shifts for Mozart's sonata K. 448 and positive potentials for the two other pieces of music, namely Albinoni's Adagio in g-minor and Schubert's Fantasia in f-minor for Piano Duet, D. 940, as well as for brown noise. This indicates a specific activation pattern for the stimulation by Mozart's sonata only. The pattern of negative shifting DC potentials relative to the baseline is widespread, but most pronounced at prefrontal and frontal sites. A comparable pattern was observed in a foregoing study investigating brain DC potentials under conditions of environmentally vs. internally oriented attention [49] for the environment oriented direction of attention. However, the negative shifted DC potential disappeared under conditions of environmental background noise, which was interpreted as a filter mechanism activated by attention switching. In analogy to the present study this would indicate that Mozart's sonata induced enhanced attention for processing environmental information, whereas the other pieces of music and also the brown noise stimulation activated an environmental rejection mode of attention. Such an environmental rejection mode associated with positive brain DC potentials was already observed in an animal study, as a response to an aversive stimulation [63] and also in humans working on a computer task under environmental background noise conditions contrary to the condition without background noise [64].

The significance of negative brain DC potentials, or at least of negative potential shifts, was already demonstrated for a complex cognitive task of concept formation [43] but also for accuracy and speed in psychomotoric response [65,66] and fit well in the framework of the activation theory as proposed by Lindsley [67] for which specific brain potentials were suggested [42].

In particular the activation of prefrontal (and frontal) cortical areas fits well in foregoing studies by means of other measures like EEG brain waves [36,37], EEG coherence analysis [68], near-infrared spectroscopy [6], or with fMRI data [40]. There is also a converging view that the activation of networks important for spatial reasoning would be primed by Mozart's sonata K. 448 [6,37,39,40,69].

If one asks why in particular Mozart's Sonata K. 448 has the property to activate neuronal cortical circuits related to attentive and cognitive functions, a speculative explanation should be offered. A unique characteristic of hearing Mozart's Sonata K. 448 is the very specific stimulation by two different, but highly similar musical streams coming from two pianos. One may speculate that the brain is splitting this spatial information in an automatic mode and by thus the unconscious processing primes the processing of spatial information. Consequently, after priming the brain with the Sonata K. 448, a better performance in a subsequent spatial task may be observed.

As this study was well controlled by three control conditions, the specificity of the observed effect seems obvious. Moreover, as there were no significant differences in autonomous activation

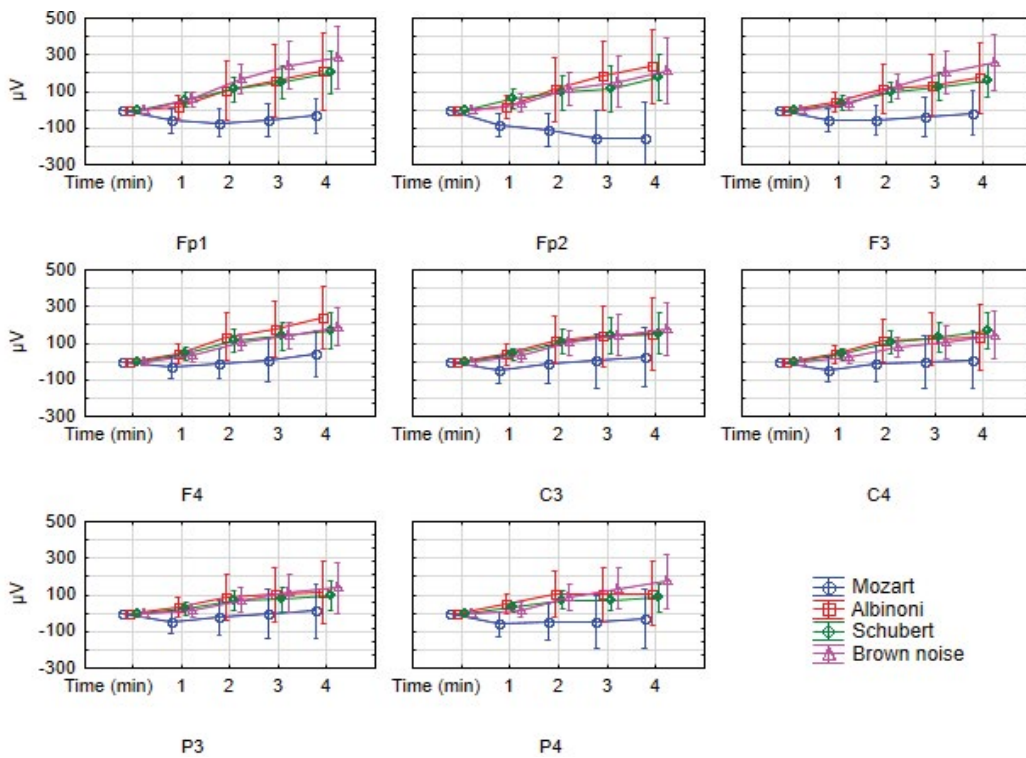


Figure 2 Mean values and 95% CI of brain DC potential shifts for the four experimental conditions by recording location and time.

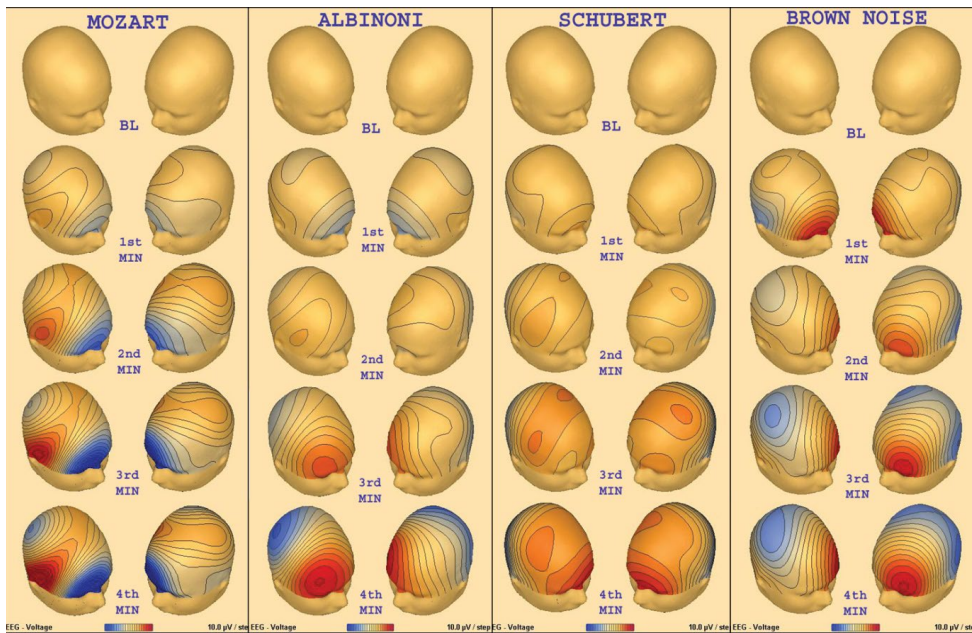


Figure 3 Topographical mappings of DC potential shifts for the 4 conditions and for the time course of stimulation.

observed between the four conditions, this indicates that the observed Mozart effect may – at least – be present without an autonomic activation as proposed earlier. Also, mood was not related to the observed effect for the stimulation by Mozart’s sonata, as there was no relevant difference between the three music pieces, but brain DC potentials differed, and mood for

brown noise was negative but brain DC potentials were not different to the two other control conditions. Thus, the present study does not support the view that mood [34] or arousal [4,12,54,70] would be the underlying factors of the Mozart effect as also suggested by others [7].

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