Topographic EEG Changes Accompanying Cannabis-Induced Alteration of Music Perception– Cannabis as a Hearing Aid?

Jörg Fachner

ABSTRACT. An explorative study on cannabis and music perception is presented, conducted in a qualitative and quantitative way in a habituated setting. EEG-brainmapping data (4 subjects; rest–pre/post listening; 28 EEG traces; smoked cannabis containing 20 mg delta-9-THC with tobacco) were averaged and analyzed with a T-Test and a visual topographic schedule. Compared to pre-THC-rest and pre-THC-music, the post-THC-music EEG showed a rise of alpha percentage and power in parietal cortex on four subjects, while other frequencies decreased in power. Comparing pre/post music EEGs, differences ($p < 0.025$) were also found in the right fronto-temporal cortex on theta, and on alpha in left occipital cortex. Results represent an inter-individual constant EEG correlate of altered music perception, hyperfocusing on the musical time-space and cannabis-induced changes on perception of musical acoustics. Cannabis might be of help for hearing impaired persons.

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INTRODUCTION

In the context of pop cultural developments, drugs with euphoric, sedative and psychedelic effects have been discussed to influence life-style and artistic manners of musicians (Boyd 1992; Shapiro 1988). The effect of cannabis on auditory perception and musicians' creativity has been a crucial issue since the early days of jazz (Mezzrow 1946; Sloman 1998). However, there has been little research accomplished on cannabis and music perception.

Webster (2001) discussed one reason in an earlier issue of this *Journal*. Research is part of the social life–world and researchers are social beings with reflected societal attitudes, values or prejudices. Research on stigmatized cultural lifestyle issues, consciousness and drugs is surely not a theme to open doors to a serious scientific reputation. Research should be a neutral way to the "truth of the story," but researchers are most often part of an institution with specified goals and politics, so, research in aesthetics and culture of cannabis consumption was abandoned for a long time (Webster 2001).

One of the most prominent cannabis effects is that on auditory perception. For Lindsay Buckingham, cannabis seemed to refresh his listening abilities and a break-down of pre-conceptions (Boyd 1992, p. 201), "If you've been working on something for a few hours and you smoke a joint, it's like hearing it again for the first time." George Harrison seemed to agree (Boyd 1992, p. 206), "I think that pot definitely did something for the old ears, like suddenly I could hear more subtle things in the sound." Casual listeners also seem to be convinced that cannabis enhances auditory perception (Aldrich 1944; Tart 1971). In terms of cannabis as a medicine, this issue raises the question whether or not cannabis might be used as a hearing aid.

BACKGROUND

Cannabis and Auditory Perception

Research on musical acoustics (Risset 1978) considers four parameters: pitch, duration, loudness and timbre. Defined pitch differences form melody intervals and harmony patterns. Duration is needed to identify rhythm patterns and tone length. Loudness and timbre form certain characteristics of instruments and sound sources.

Duration: Aldrich observed a small change on the Seashore-Rhythm-Scale (Aldrich 1944) produced by cannabis, a result that was replicated with higher changes by Reed in the 1970s (Reed 1974). Music as a multi-dimensional auditory *Zeitgestalt* (Zuckerkandl 1963) appears in time. Melges explained cannabis-induced effects on time perception as a speeding up of the internal clock (Melges et al. 1970; Melges et al. 1971) that is experienced as time expansion (Tart 1971). Time expansion may temporarily allow an increased insight into the "space between the notes" (Whiteley 1997). This might help experienced individuals (Becker 1963) to perceive acoustic sound structures more effectively.

Loudness: Cannabis seemed to change metric units of auditory (intensity) perception in audiological tests (Caldwell et al. 1969; Globus et al. 1978). Caldwell reported changes on intensity thresholds. Globus suggested an intensity expansion of the auditory measuring units as responsible for the experience of an enhanced intensity perception.

Pitch: In the 1940s, Aldrich observed no changes in pitch discrimination after administering oral doses of pyrahexyl, a synthetic cannabinoid (Aldrich 1944). By choosing between two different pitches, cannabis induced dose-related preferences for higher frequencies as a function of frequency (de Souza, Karniol and Ventura 1974). Higher frequencies represent the location of sound sources and the overtone spectrum of sounds. Martz investigated frequency thresholds and reported improved thresholds at 6000 Hz after cannabis intoxication (Martz 1972). For a review on audiological tests, see Fachner (1998a) and Fachner (2001).

Timbre: Thaler, Fass and Fitzpatrick (1973) investigated speech discrimination rates after cannabis intoxication and reported significant changes on different sound levels, even with hearing-impaired subjects and similar results in a follow-up study. Subjects showed an increased speech perception rate at 10 dB SL and at 40 dB SL, even when tones were covered with noise (Thaler, Fass and Fitzpatrick 1973). Another study reported no improvements during speech perception tests (Lindenman 1980). Both results suggest alterations in cerebral processing.

Rodin reported a change of prosodic structure and a change to a "sing-song-type-pattern" of subjects' responses during his experiments (Rodin and Domino 1970). Tart observed that people "understand words of a song better" and that "quality of own voice changes" after cannabis consumption. Effects were statistically ranked as characteristic and common effects (Tart 1971, p. 75). It seems that cannabis has a stimulating effect on the perception and production of prosodic and suprasegmental parts of speech, which might have had an influence on developing certain slang, a personal sound and timbre of jazz artists (Mezzrow 1946). De Souza's change of preference styles reported above might indicate a change of overtone recognition in frequency spectra of sound sources.

Moskowitz reported an increasing number of false alarms in a task where subjects were asked to detect a randomly occurring 1000 Hz tone embedded in noise. It seemed that cannabis was stimulating tone imagination and subjects heard tones that were not there (Moskowitz 1974). Tart's subjects also reported an intensification of auditory images (Tart 1971).

Thus, cannabis seems to enhance auditory perception throughout a temporary change in the metric frame of reference and allows a larger intensity scaling of perceived musical components. This might help experienced musicians to play more intensively during improvisations (Fachner 2000). Cannabis seems to act as a psycho-acoustic enhancer, exciter, equalizer, or attentuator, used in modern recording studios, making sounds more transparent and sound sources more distinct. Greater spatial separation of sound sources and perceptions of more subtle changes in the sound were other characteristic cannabis effects in Tart's study (Tart 1971). Baudelaire's and Tart's descriptions of synesthetic effects, weakened censorship of visual depth perception (Emrich et al. 1991) and a transition to a field-dependent style of thinking (Dinnerstein 1968), suggest intensification of individual cerebral hearing strategy. This type of learning strategy promotes hyperfocusing on acoustic space, musical time-structure, and a more effective attention on auditory information (Becker 1963; Curry 1968).

This short overview on cannabis and auditory perception, more fully explored in the author's doctoral thesis (Fachner 2001), clearly suggests that there is potential for the use of cannabis as medicine for the hearing impaired. Changes in auditory test give us reason to argue that perception of acoustic shapes and higher frequencies, spatial relationship of sound sources and even speech perception, seem to be enhanced.

Will it be possible to show this subtle change in auditory perception with an EEG brain imager, which visualizes the topographic electrophysiological changes in the brain? Do we have a chance to relate cannabis-induced auditory changes to an altered individual hearing strategy?

Cannabis, Music Perception, and Brain Imaging

Cannabis effects on human behavior and lifestyle are complex issues that cannot be easily generalized or proved in a time-locked laboratory setting. Furthermore, collection of experimental EEG data about what occurs in the brain while listening to music under the influence of cannabis seems to offer many confounding variables. Results could be affected by differing inter-individual perceptual strategies of listening to music (Aldridge 1996) as might be observed in the topographic EEG, the subjective history of drug experiences and tolerance effects, pharmacokinetics and dynamics of the specific substance absorbed (Grinspoon 1971; Julien 1997).

Furthermore, the nature of the brain imaging method and the produced data themselves (Revonsuo 2001) show different patterns of brain activity. Hemodynamic aspects, as revealed in cerebral blood flow techniques, do not necessary correlate with electrophysiological changes.

Consciousness states are variable (Tart 1975). To believe that there is something like a "normal state of consciousness" and an "altered state" after administering a drug is a more scientific way of assuming that a comparison of quantitative data of a laboratory experiment would reveal the difference of consciousness states. "Consciousness states" end up as small slices of data, artifact-free epochs of the process in a laboratory setting. Here the timeline of the actual experience might be lost or fragmented in the process of editing comparable data-epochs and eliminating artifacts. Moreover, the testing apparatus and protocol cause behavioral discomfort with necessary cables, electrodes, blood sampling with syringes, postural restrictions, etc. Furthermore, somewhat tedious or abstract test batteries, which are felt as being not adequate to the "state you're in," double blind structures with non-verbal gesturing perceived more intensely and other behavioral context interactions make this situation different from "normal."

Critiques by social scientists on these behavioral measuring procedures have addressed the situation and process of measuring which have an impact on the quality of the data (Deegener 1978). Humanistic critiques are based on the uniqueness and contextual nature of the human experience, which is dependent on biographical time and place, and uniqueness of the situation in which subjects are involved (Rätsch 1992). Leary, therefore, emphasized the importance of set and setting in a research paradigm on psychedelic substances (Leary 1997).

Situation, Ethnography and Experience of Music

The auditory perception of musical acoustics as described above is surely not the musical experience itself. What constitutes the process of music listening as a holistic musical experience of a person?

To understand what makes a certain musical experience of one composition different from another, musicologists analyze musical content by using scores. Score analysis to explain varieties of music experience has been questioned from the stance of situated performing and listening (Small 1998; Tagg 1982). Attending a concert or listening to music on the radio, adds the contextual dimension of personal experience in an ongoing situation onto perceptual processes (Buytendijk 1967; Hall 1996). This influences intention and selection of what has been heard, selected and perceived consciously during perception.

Situationism refers to "the inseparability of action and context, the relation between the social and material conditions of action, the need to theorize the 'higher psychological functioning' in relation to situated action and the tension between the emphasis on situation and the scientific ideal of abstraction" (Costall and Leudar 1996: 101).

Research on popular music stressed semiotics of signs used in artistic context, which produce meaning for performer and audience. Thus, music becomes a mediator of cultural symbols (Tagg 1987). Therefore, several issues of identity, place and performance, musical practice and production styles, mediating experience of a certain song or classic composition in a specific listening or music production situation, are taken into account to understand the aesthetic experience (Barber-Kersovan 1991; Frith 1998).

As a consequence, we should measure music perception in the context of real world cannabis culture, because the context of listening seems to be important for the situated experience of music. This method of research accompanies the cannabis smoker in an ethnographic manner. In this perspective, the manifold meaning of the data gained is context-generated and part of the actual music experience.

Music and the EEG

Research on music and the EEG reflects the problem of inter-individually different music experiences. EEG coherence analysis showed intra-individually constant EEG-coherence profiles during music perception, but profiles spread inter-individually over the whole cortex (Petsche 1994). Music listening seems to involve many different areas, but is pragmatically believed to have a right hemispheric dominance (Kolb and Whishaw 1996; Springer and Deutsch 1987) as results in EEG research conveyed (Auzou et al. 1995; David et al. 1989; Duffy, Bartels, and Burchfiel 1981; Petsche 1994; Walker 1977). However, in a review on human brain mapping methods of music perception, Sergant insisted that there is no real evidence that music seems to be processed dominantly in the right cerebral cortex (Sergant 1996). Even dichotic listening methods, auditory evoked potentials (AEP) (David et al. 1989) or positron emission tomography (PET) scan vary in stimulus-locked localization strategies of individual perceptions. Davidson concluded that variations reflect individual perceptual differences that can be observed in the baseline measuring before administering sound bits, music fragments or words (Davidson and Hugdahl 1996). Therefore, we should look closely at structural similarities of rest and music EEG Gestalt in the visual analysis of brain images.

Cannabis and EEG

Even though it is now possible to link the mechanism of cannabis action to density of cannabinoid receptors in the brain and immune system (Joy, Watson, and Benson 1999), topographic pre/post EEG studies of cannabis-induced changes are not available. Transient cannabis-induced EEG changes have been previously reported in laboratory studies. Most EEG studies that exist, however, were oriented toward finding brain damage with casual or long-term use.

Quantitative EEG measuring in the 1970s commonly used 1 or 2 electrodes attached to the right occipital or parietal areas (Hollister, Sherwood, and Cavasino 1970; Rodin, Domino, and Porzak 1970; Roth et al. 1973; Volavka et al. 1971; Volavka et al. 1973; Volavka, Fink, and C.P. 1977). Results of this research are somewhat contradictory. Hanley's quantitative EEG study, done with 8 electrodes from frontal to occipital areas, found only decreased amplitudes and percentage over the whole spectrum (Hanley, Tyrrell, and Hahn 1976). Others reported an increase in relative α-percentages (alpha) and power, a decrease in main or central frequency and a transition to theta (θ) during contemplation, as well as a decrease of relative theta- or beta (β)-percentage and power (Struve and Straumanis 1990). However, only in the work of Hess and Koukkou has music been part of the experimental setting (Hess 1973; Koukkou and Lehmann 1976; Koukkou and Lehmann 1978). Both reported results that were spread in a certain order corresponding to music over the time-course of drug action. Lukas correlated euphoria and higher alpha-index during the first 20 minutes (Lukas, Mendelson, and Benedikt 1995).

Results remind us to be aware of an inter-individual implicit order of electrophysiological signal processes during personal cannabis experiences. The psychoactive action of THC induces identifiable EEG signatures, but some frequency ranges seem to be more indicative for the quality of the actual experience.

THE EXPERIMENT

Aims

The aim of this explorative pre/post-EEG study was to examine the manner in which subjects smoked cannabis and listened to music in a habituated setting of a living room.

Cannabis induces a field-related perceptual style (Dinnerstein 1968). Most EEG laboratory studies demonstrate a lack of sensitivity to the experimental setting. To reduce the laboratory-setting bias in EEG results, the field-dependence of drug action in personal set and experimental setting has to be considered by conducting research according to a suitable paradigm (Weil 1998). The topographic changes induced by cannabis while listening to music may well be radically different in the laboratory setting as compared with one in which the subject normally listens to music.

An obvious reason to use the EEG in researching cannabis and music perception is based on the high time-related resolution of the data. We can observe synchronous electrophysiological traces of cognitive activity in the EEG (Petsche 1994). While the synchronous correlation of the EEG is its big advantage, it lacks spatial resolution of data origin. We can only observe summations of generating units below the surface of the brain. With the NeuroScience BrainImager®, source information is interpolated, and provides spatial information about the distribution of cerebral changes. Amplitude and significance mapping (Duffy 1986; Maurer 1989) can be used to identify and localize changes of cerebral areas and their function during perceptive states.

With these limitations in mind, a research project, which compares pre/post-THC-EEG changes gains topographical EEG data, gives us spatial information on the cortex distribution of cannabis-induced electrophysiological changes of neural activity. But the "map is not the landscape" (Machleidt, Gutjahr, and Mügge 1989), and so we can only conclude that the frequency changes accompany cannabis-induced alteration of music perception in this particular case. After all, EEG research has gained lots of experimental data that can be compared to similar experimental topics. To research the real world situation of auditory changes an ethnographic exploration in cannabis culture seems to be a priority. These results could be compared subsequently with laboratory data.

Methods

To ensure a minimum of laboratory-setting bias, a non-blind pilot study was conducted with a mobile bedside EEG-Brain-mapping system in the consumers' habituated setting, a living room. Four subjects (3 male/1 female) smoked a tobacco joint mixed with Nepalese hashish (hereafter phrased as "THC") and listened with closed eyes to three pieces of rock music in a comfortable armchair. EEG was recorded throughout rest and music listening periods (Figure 1).

The aim to do EEG research in a naturalistic setting with minimum limitations introduced by the researcher evokes problems in estimating the quality of the data. Results of this explorative study should be regarded as a kind of physiologically correlated ethnographic description of cannabis culture in Europe. This methodology may evoke questions that should be addressed at the outset. How can we ensure visualization of substance-related music perception during a brain imaging study in an ethnographic setting?

Closed Eyes Music listening and EEG Recording

Following Baudelaire's description of cannabis intoxication stages, this study accompanies the second contemplative stage (Solomon 1966). This ethnographic setting of cannabis consumption while listening to music, goes

FIGURE 1. Experimental Schedule

Baseline State: Pre-THC-EEG (music and rest-eyes closed)

Listening to 3 Rock music pieces (defined order)

1 minute silence/rest between the songs

30 minutes intermission

Smoking 0.3 g cannabis (20 mg THC) in tobacco joint

After 10 minutes EEG start

Altered State: Post-THC-EEG (music and rest with THC)

Listening to the same music/same measuring situation and setting

4 Subjects (3 male/1 female)

back to Chinese drug culture and Harlem Tea Pads of the '30s (Digest 1934; Jonnes 1999: 119f). Nowadays a "chill-out room" in modern rave parties has the same setting characteristics. It permits a relaxed contemplative experience of music with closed eyes in the way David described physiological types of music listeners (David, Berlin, and Klement 1983). Listening to music with closed eyes was also the method used in a music therapy approach called Guided Imagery developed in psychedelic therapy (Grof 1983; Leary 1997), wherein music and psychedelic drugs were used to stimulate the unconscious to evoke individual imagination and associations (Bonny 1975; Bonny and Pahnke 1972). EEG recording with closed eyes is a common procedure in pharmacoencephalography (Struve and Straumanis 1990).

Tobacco Joint

A guideline of research in an ethnographic field in an ethno-methodological manner is to accept and describe habits, ritualistic aspects and settings of the consumer life-world (Rätsch 1992). One of the bad habits associated with cannabis consumption in Europe is the custom of mixing hashish with tobacco in a joint. The use of tobacco in this experiment is surely a crucial aspect, because the hashish-tobacco mixture causes different pharmacokinetic and dynamic action of THC compared to smoking only herbal cannabis or hashish. Furthermore, the hashish as obtained on the black market (subjects brought their own cannabis) cannot be expected to be pure. Qualitative gas chromatography testing of the smoked substance was accomplished, and quality was estimated as "medium," with approximately 20 mg Δ^9-THC in the 0.3 gram hash ("Black Nepalese") consumed. The aim of this study was to find out whether smoking induces changes on the EEG, not to reveal a dose-related THC action profile during music perception.

No specific inhalation technique was employed to ensure a comparable smoke uptake, because this would distract from the naturalistic experimental setting. Subjects sat in an armchair and smoked at their own customary pace. Subjects obviously attained a cannabis high, said they felt "stoned" and attributed the experienced altered state of consciousness to by the smoked joint with hashish.

Music and Subjects

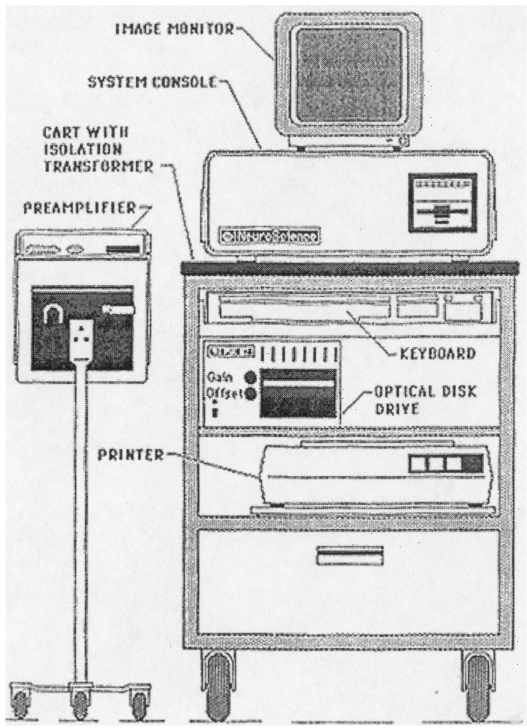
Three male subjects chosen for this explorative experiment reported themselves as experienced smokers of cannabis and tobacco. One female subject was a frequent smoker of cannabis. All of the subjects refrained from smoking cannabis previously on the day of the experiment.

None of the subjects were musicians, but regarded themselves as music lovers with a preference for alternative rock music. Musicians differ in their perception of music as EEG studies have shown (Altenmüller and Beisteiner 1996; Petsche, Pockberger, and Rappelsberger 1987). The music used in the current experiment was chosen from a single case study (Fachner, David, and Pfotenhauer 1995) with follow-up (Fachner 1998b; Fachner, David, and Pfotenhauer 1996). The first selection in the experimental sequence sounds like classical music. It is string ensemble chamber music with no vocals, drums or electric instruments, the instrumental "Prelude" by "King Crimson" (King Crimson 1974). The second, "Obsessed," is a folk-punk song with vocals, acoustic guitars, drums and bass, recorded by "Dogbowl" (Dogbowl 1989). The third piece is a live recording cover version of the Beatles' song "We Can Work It Out" performed by "King Missile" (King Missile 1989). Songs were played in the same order during pre- and post-THC conditions (Figure 2).

The NeuroScience BrainImager® samples 28 EEG traces with a 12 Bit analogue/digital converter. This produces 4096 dots per second within a dynamic range (DR) of 256 μV, providing a sample accuracy of 1/16th μV. Average maps interpolated between the 28 EEG trace sample points are processed every 2.5 seconds. The Imager is equipped with an isolation transformer and shielded pre-amplification, as well as a notch filter on 50-60 Hz to reduce the influence of electromagnetic fields in hostile environments.

Impedance levels were kept under 11 Kohms. Cut-off filters were set to 40 and 0.3 Hz. EOG (electrooculogram), ECG (electrocardiogram) or EMG (electromyography) traces for artifact control were not applied to avoid laboratory bias. Artifact control was done visually by a time-coded video protocol. After removing potential artifact maps (fronto-polar δ threshold at 105 μV on 256 μV DR), Individual (IA) and Group Averages (GA) were processed using

FIGURE 2. NeuroScience BrainImager®



- 28 Electrodes; 12 Bit A/D (4096 d/s @ 256 µV DR); Notch Filter; Cut-off: 0.3 + 40 Hz
- Average Maps over 2.5 seconds
  - Delta (0.39-3.9 Hz);
  - Theta (4.3-7.8 Hz);
  - Alpha (8.2-11.7 Hz);
  - Beta I (12.1-16.0 Hz);
  - Beta II (16.4-30.0 Hz); Spectral Map;
  - Roll-off (3 dB in 0.25 Hz)
- Individual and Group Averages Sub-Avg; Standard Deviation Mapping; T-Test (Significance Mapping)

the statistics software package of the NeuroScience BrainImager®. More details of data editing can be found in a doctoral thesis (Aldridge 2001) (Figure 3).

Pre/post rest and pre/post music listening results were averaged and subjected to a T-Test. Each piece of music and one minute of silence before the music was recorded and individually averaged. The investigation included one extended single case study with a follow-up. Research focus for each person was on individual drug and music reactions by comparing the pre/post individual averages (IndAvg) and the total group average (Gavg) of the pre/post rest and music sessions over the sample. Amplitude mapping does not provide dynamical changes of the music but represents average electrophysiological activity while listening as reflected in the maps, allowing identification of difference in the pre- and post-conditions.

RESULTS

The first illustration shows the T-Probability mapping of the EEG changes from pre- to post-THC listening for the first piece of music for one subject (Figure 4). The reference file was pre-THC listening and it was compared to post-THC music listening. From the upper left to the right we see δ-, θ-, and α-probabilities, below β I + II and the spectral mapping. The view is from above the head. What seems to be of interest for a possible cannabis-induced auditory perception style are the obvious α-changes in the left and especially in the right temporal cortex. The temporal cortex hosts the auditory system and main association areas.

While listening to the first piece of music highly significant changes ($p < 0.001$) with 3 subjects in the pre/post-comparison from pre-THC-music to the first post-THC-music average have been observed. These high significant changes after ten minutes of smoking mark the first plateau of drug action and a changed listening state. It shows that subjects experience and process music in a different way than previously. In all subjects, significance decreased with the second and third song in the sequence (Figure 5).

Upon examination of T-Test changes of the second piece of music, we can see δ-, θ- and β-changes, as well as spectral frequency speed changes on left side of brain. The left side hosts motor and sensory speech centers, which seem to change more when listening to Rock songs with words.

The map in Figure 6 shows highly significant changes from pre-THC-rest to the post-THC-music EEG of the first piece in the series. As we observed before, this T-Test again shows α-changes over the temporal regions. This might indicate changes in auditory cerebral processing. However, α-mapping showed remarkable changes in amplitude levels, as we can observe in the following illustration.

FIGURE 3. Individual (IndAvg) and Group (Gavg) Averages

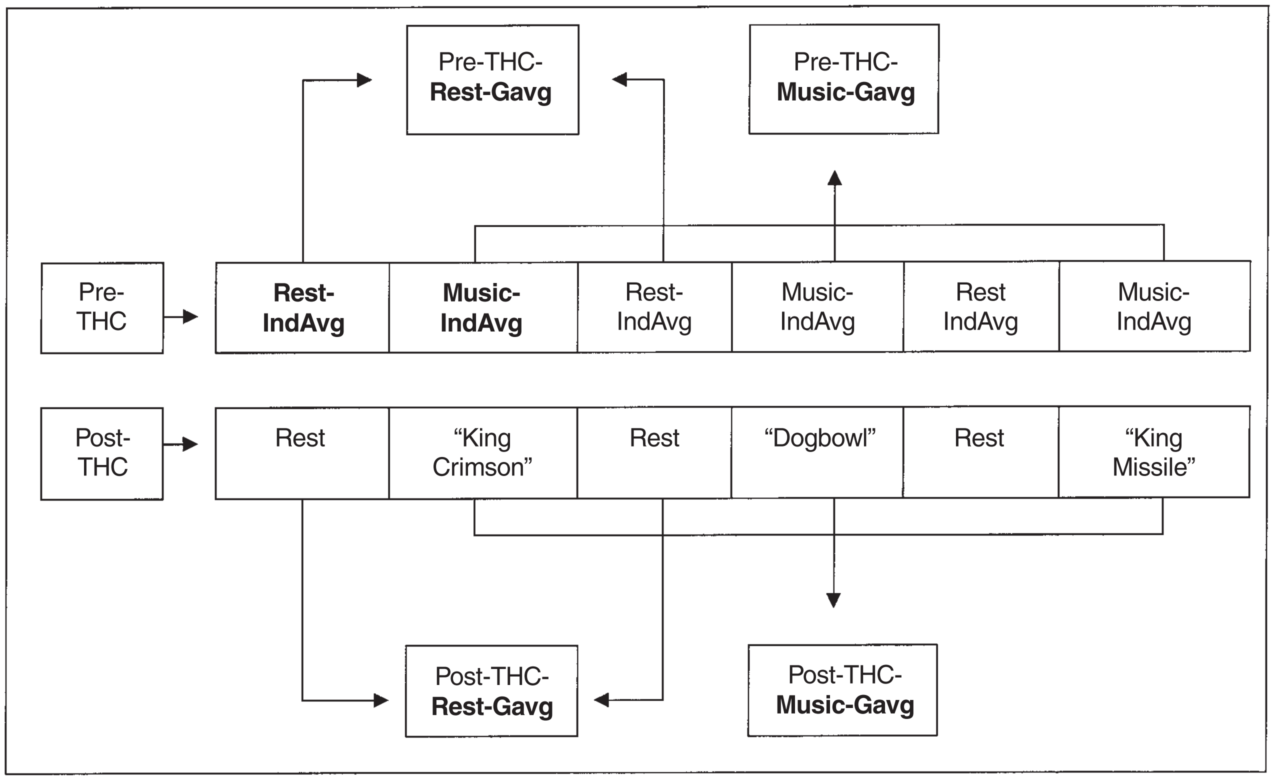


FIGURE 4. Significance Mapping T-Probabilities EEG-Changes Music

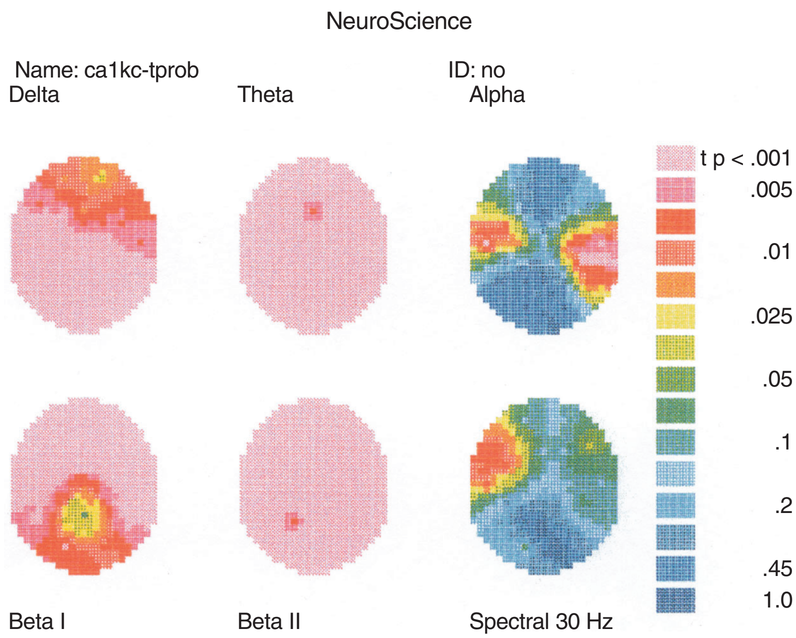


Figure 7 shows the α-GA over four subjects for the pre/post rest condition. In this figure, the 16 colors of the 30 μV Scale represent a 2-μV step on a dynamic range of 256 μV. Comparing pre/post-rest visually, a decrease of α-percentage and amplitude in the post-THC-rest-EEG was observed with all four subjects. The post-THC-rest amplitude decrease in the parietal areas showed an individual range from 6-10 μV. The GA over four subjects seen here shows a difference of 2 μV. Decrease of amplitudes in rest over the whole frequency range was reported by Hanley (Hanley, Tyrrell, and Hahn 1976) and is similarly observed in the present study.

In Figure 8 we see the pre/post α-GAs of listening to music. An increase of relative α-percentage in parietal regions was observed in the post-THC-music GA for all four subjects. Compared to the pre-THC-music EEG, the individual increase of amplitudes ranged from 2-4 μV. The α-range even indicated changes on higher and lower frequency ranges. Mapping of α-standard deviance showed highest deviance in the parietal regions.

A decrease of α-amplitudes in post-THC-rest and an increase in the post-THC-music EEG has been observed with all subjects, as well as a decrease of percentage and power of the other frequency ranges.

FIGURE 5. Significance Mapping T-Test Pre/Post Dogbowl, Second Piece of Music in the Sequence

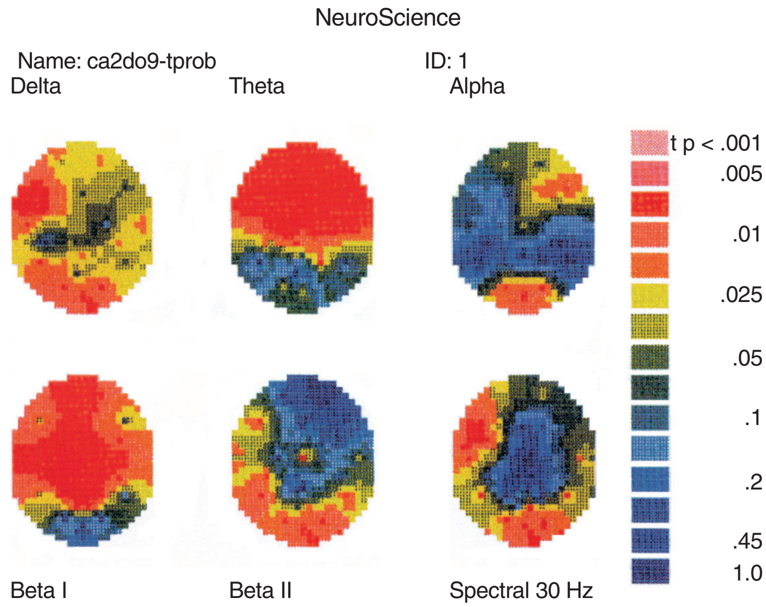


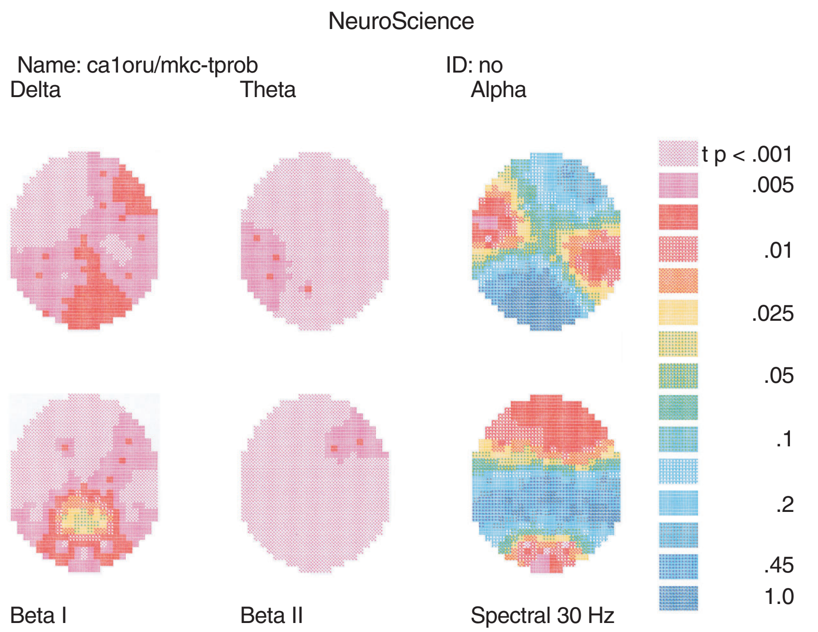
Figure 9 shows the pre/post cannabis music changes in the GA mappings for the four subjects. Post-THC-decrease of δ-, θ-, and β-amplitudes was a constant observation throughout the individual averages of the four subjects and was observed in GA of the four persons, as well. Comparing the left with the right mapping, higher amplitudes, especially on δ- and θ-range in the upper row, but also on central parietal β areas below, were observed in the left pre-THC mapping. In temporal areas, the θ-decrease is remarkable (Figure 10).

Pre-THC-music listening caused an increase of θ-percentage compared to the resting state. In the post-THC-music maps, the percentage decreased in central and frontal regions more than in rest condition, but most decreases appear in both temporal regions.

As seen before, significance mapping of individuals showed highly significant changes ($p < 0.001$) between pre-THC-rest, pre-THC-music and post-THC-music (Figure 11).

Comparing the GA of the 4 subjects a significance of $p < 0.025$ on α-range for the left occipital region was detected. Pre-THC-rest compared to post-THC-music showed a small change in the left occipital area, as well as the comparison of pre/post GA of music listening. This particular region around

FIGURE 6. Significance Mapping T-Probabilities EEG-Changes Rest to Music



O1 (left occipital electrode) showed a faster frequency in the spectral map. The occipital region is known to show changes under the influence of music (Konovalov and Otmakhova 1984; Petsche 1994; Walker 1977). In this context, the change of occipital alpha might indicate changes in visual association linked to music. This region should be investigated with further studies (Figure 12).

Comparing pre/post music listening over four subjects, a significant change ($p < 0.025$) at electrode T4 (right temporal lead) was observed. It seems that the θ-decrease over the temporal lobe reported above is more prominent in the right hemisphere. Comparing post-THC-rest and post-THC-music GA, a small change in this temporal area was also observed on β-1. This region seems to change constantly with all four subjects and should be regarded as a region of interest with combined methods such as PET and EEG. Several studies noted observed changes in the right temporal fronto-temporal lobe, but with varying frequency ranges (Auzou et al. 1995; Bruggenwerth et al. 1994; David et al. 1989; Duffy, Bartels, and Burchfiel 1981; Petsche 1994; Petsche, Pockberger, and Rappelsberger 1986; Petsche, Pockberger, and Rappelsberger 1987). Even results of dichotic listening indicate changes in the right hemisphere (David et al. 1969; Davidson and Hugdahl 1996; Kimura 1967). Alterations in the temporal lobe EEG might represent changes in the hippocampus region as

FIGURE 7. Amplitude Mapping Rest Alpha Changes

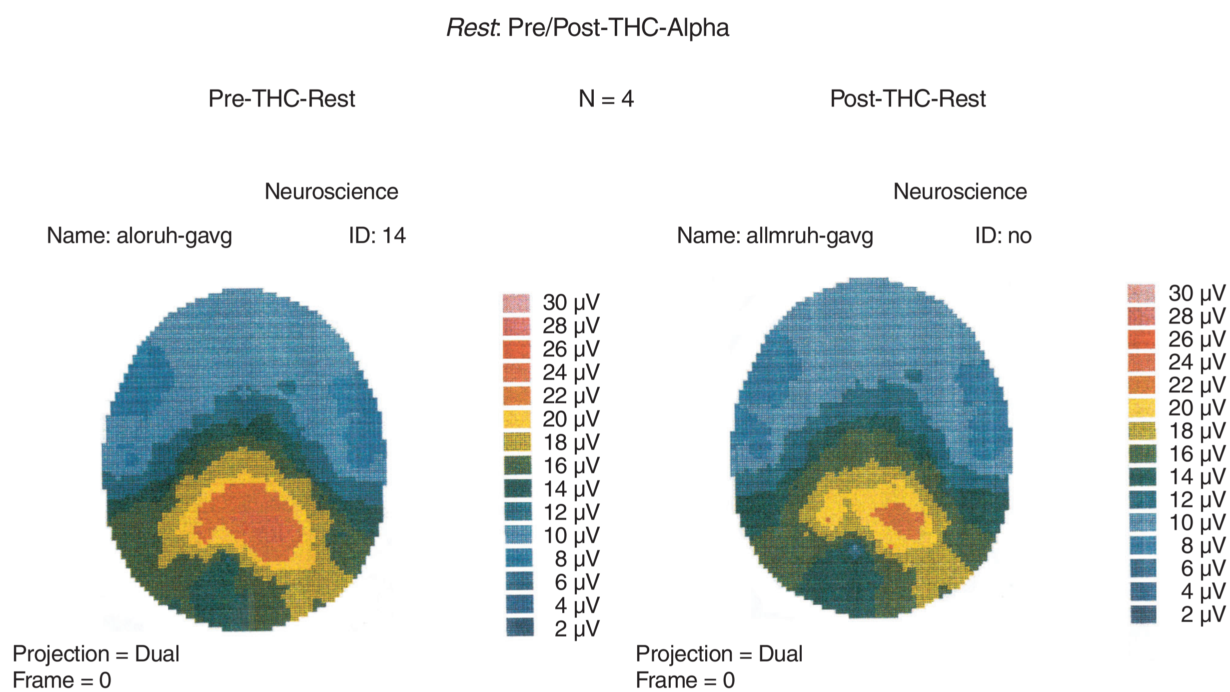


FIGURE 8. Amplitude Mapping Music Alpha Changes

Music: Pre/Post-THC-Alpha

Pre-THC-Music N = 4 Post-THC-Music

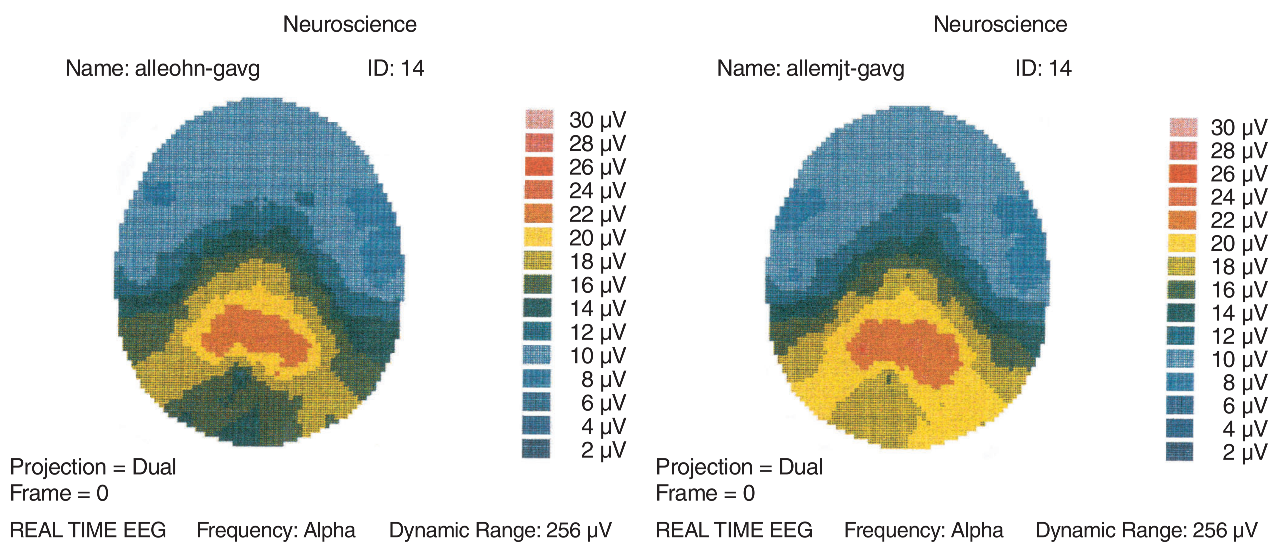


FIGURE 9. Amplitude Mapping Pre/Post-THC Music Changes

Music: Pre/Post-THC-Changes

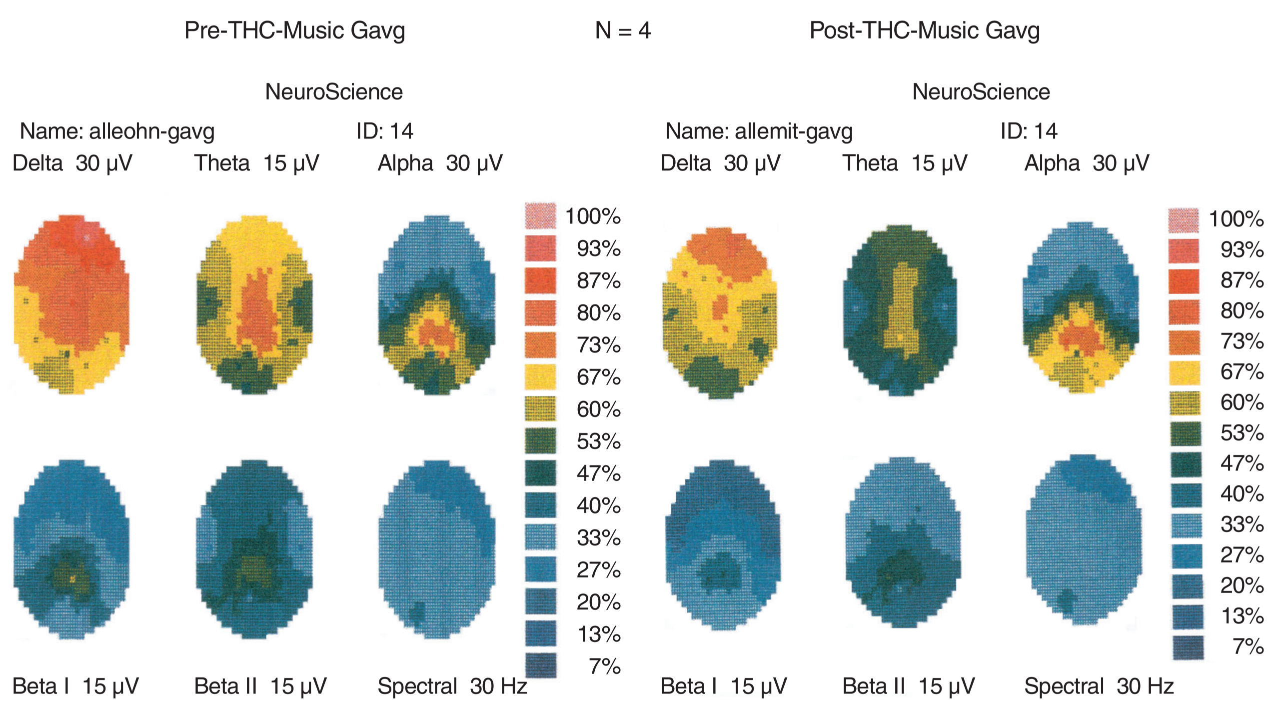
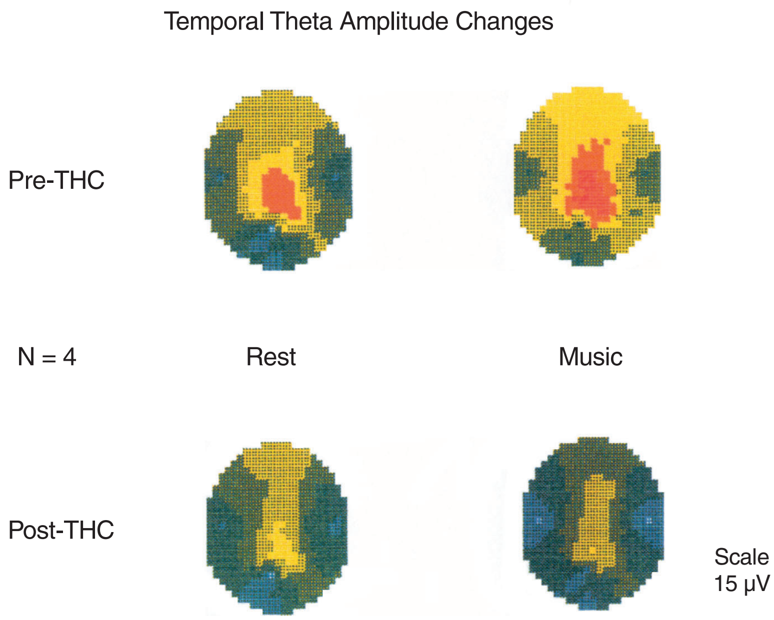


FIGURE 10. Amplitude Mapping Theta Pre/Post-Music and -Rest



well. It is rich in cannabinoid receptors and has a strong impact on memory functions and information selection.

DISCUSSION

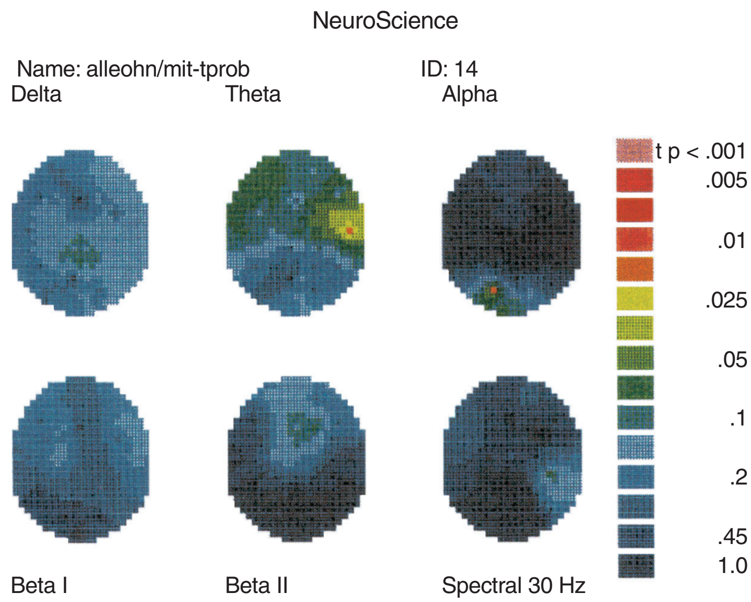
Changes in Temporal Areas

Comparing pre/post-THC-music, differences ($p < 0.025$) were found in the right fronto-temporal cortex on theta, and on alpha in the left occipital cortex. During pre-THC-music listening theta-percentage increased, but decreased more in post-THC-music than during rest. In both temporal lobes, theta-amplitudes decreased during post-THC-music as well. Significant ($p < 0.025$) changes in temporal and occipital areas and increasing alpha signal strength in parietal association cortex seem to represent a neural correlate of altered music perception and hyperfocusing on the musical time-space.

Holonomic Memory Function, Time and a Metric Frame of Reference

Webster has claimed a "different manner of retrieval" in memory function during states of cannabis consciousness that are not organized in a sequential

FIGURE 11. Significance Mapping, Temporal and Occipital Areas (p < 0.025), T-Test Pre/Post-THC-Music, (N = 4)



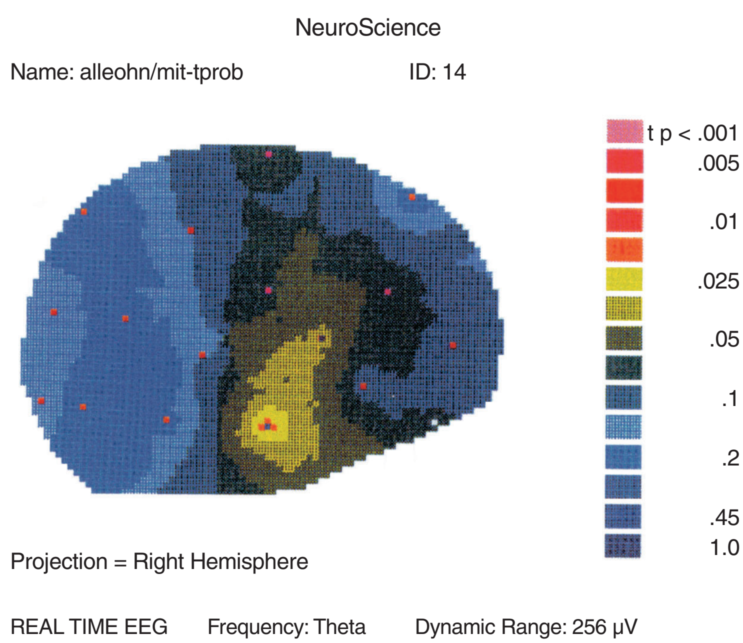
linguistic, but a more holonomic order (Webster 2001, p. 98) and in music, as an aesthetic and gestalt-oriented manner during music perception. Weakening of hippocampal censorship function and overload competing of neuronal conceptualizations during information selection (Emrich et al. 1991) might be connected to cannabis-induced prolonged time estimation and intensity scaling. This metric reference promotes functions of a divergent cognitive strategy to overlook the Gestalten of musical holonomic symbolization on one hand and to lose track (Webster 2001) on the other, because convergent perception of sequential information parts is reduced.

Mathew reported a cannabis-induced change of time sense CBF correlated with changes of cerebellum blood flow (Mathew et al. 1998). Cerebellum is associated with movement organization and time-keeping functions. Music as a *Zeitgestalt* (Zuckerkandl 1963) is an art that is connected to the act of performing (Aldridge 1996), to a playing of an instrument or, rather of a musically used sound source. Music can only be heard in time. One gestalt that might be perceived more intensely in "cannabis consciousness" (Webster 2001, p. 99) is one fundamental element of music, the rhythm. A good picture of these processes was given by one of Anslinger's co-workers (Sloman 1998, pp. 146-7):

> Yeah, but why would he [Anslinger] want to get after them?" Sloman wondered. "Because the chief effect, as far as they were concerned, is that it lengthens the sense of time, and therefore they could get more grace beats into their music than they could if they simply followed a written copy." Munch had completely lost Sloman right out of the gate. "In other words, if you're a musician, you're going to play the thing the way it's printed on a sheet. But if you're using marijuana, you're going to work in about twice as much music between the first note and the second note. That's what made jazz musicians. The idea that they could jazz things up, liven them up, you see.

Rhythm is connected to internal kairological and external chronological time processes (Aldridge 1989). Those expanded auditory metric units as proposed by Globus et al. (1978) promote a frame of reference that seems to fit more precisely into an audio-visual way of perceiving acoustic relations. The drummer Robin Horn said (Boyd 1992, p. 205), "it (pot) does create a larger vision, and if that's the case, then it would apply to your instrument because

FIGURE 12. Significance Mapping T-Test Pre/Post-THC-Music (Red dots represent electrode positions) N= 4, Right Hemisphere Theta Change ($p < 0.025$)



the more you see, the more you can do." Changed left occipital and right temporal EEG activity might represent such a change of auditory perspective on musical acoustics as reported above. It seems that this change of auditory perspective in perceiving musical *Gestalten* (Webster 2001) is mediated throughout an extension of auditory metric scaling during internal sound staging of music perceived. Listening to a record via headphones becomes a much more 3-dimensional moving soundscape, there seem to be "greater spatial relations between sound sources" as Tart identified a characteristic cannabis experience in the state of "being stoned" (Tart 1971, p. 75).

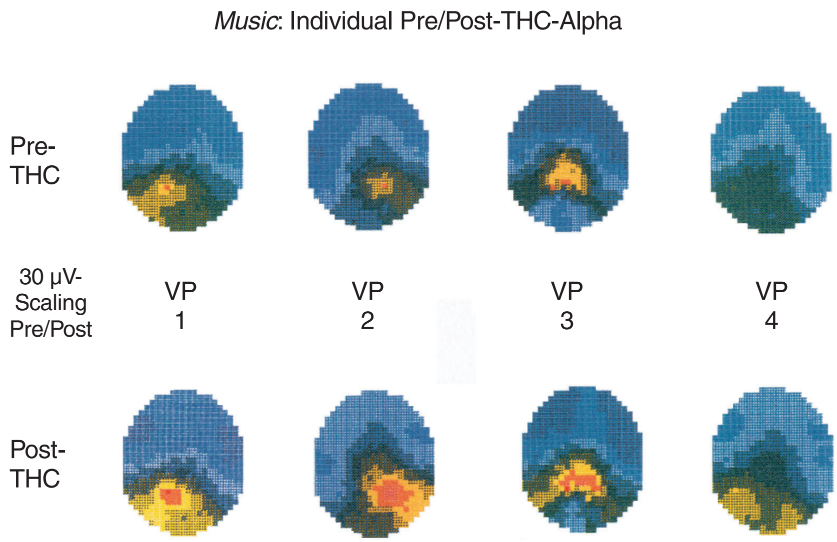
Hyperfocusing on Sound

A comparison of the individual pre/post averages subjects showed intra-individual stable EEG-Gestalt, for one subject even in the follow-up. Intra-individual stability of the whole EEG-Gestalt in rest and activation replicated findings on personality and situational sensitivity of the EEG (Davidson and Hugdahl 1996; Hagemann et al. 1999; Koukkou and Lehmann 1978; Machleidt, Gutjahr, and Mügge 1989). The α-focus in parietal regions showed individual topographic shapes of receptive activity. This indicates personality factors represented in the EEG, but changes on α-amplitude clearly suggest a functional intensification of individual hearing strategy (Figure 13).

Following Jausovec (1997a,b), we can observe more effective information processing. Alpha amplitude changes show a marked similarity to "reverse alpha" findings in studies with gifted individuals. Jausovec associated higher α-scores with a more efficient information processing strategy, less mental workload and flow. Curry (1968, p. 241) proposed a "hyperfocusing of attention on sound" as an explanation for changes in the figure-ground relationship while listening to music. This cognitive change of hearing strategy might be mediated via changed time perception for the rhythmical grid and synchronically expanded intensity scaling for frequency patterns in acoustic relationships. de Souza described a cannabis-induced change of preference for higher frequencies (de Souza et al. 1974). High frequencies represent overtone patterns and provide, along with time delay patterns, localization information about sound sources in acoustic space. This preferred focusing on higher frequencies might result in the way an enhancer or exciter in studio technology works.

No wonder some dub and psychedelic music is produced with virtually moving soundscapes with reverb and delay effects. It permits the creation and manipulation of "sound staging effects" (Moylen 1992) adequate to the state of a cannabis high. A distinct handling of sound effects is basic for good music recording and shows the skills of an experienced engineer. The development of audio-technical studio equipment and popular music in the 1960s went hand

FIGURE 13. Amplitude Mapping Pre/Post-THC-Music Alpha Gestalt (VP = Subject 1, 2, 3, 4)



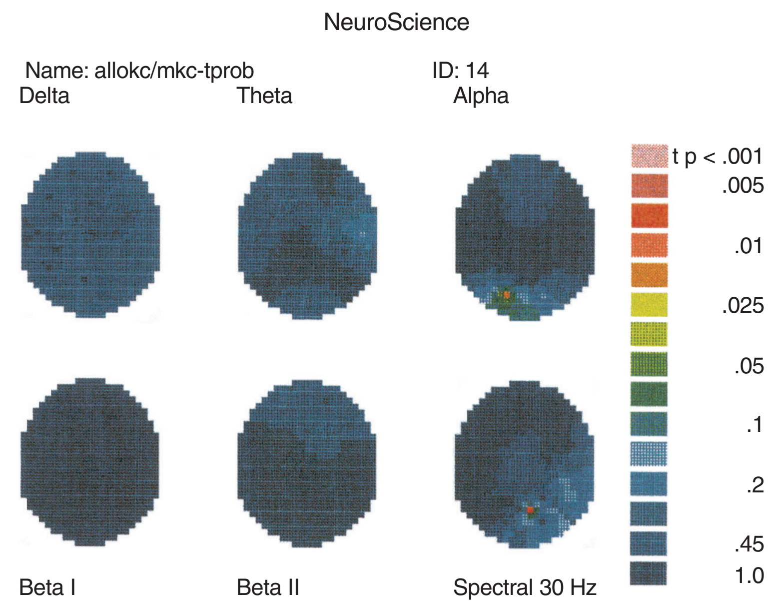
in hand. Ideas in soundscape creation stimulated discovery of new techniques in audio engineering. Intensive exploration, design and staging of sound sources in their spatial relation are essential for attainment of a certain sound of the recorded music (Martin and Pearson 1995).

"Are You Experienced?"–Learning and Cerebral Listening Strategdy

Looking at the process of listening, highly significant pre/post changes ($p < 0.001$) while listening to the first piece of music have been observed comparing individual averages in the T-Test, but significance decreased for the second and third piece in the experimental sequence (Figure 14). Changes in temporal areas on α-frequency indicated a change in auditory processing. A significant change ($p < 0.01$) comparing GAs of spectrum frequency at the right parietal-occipital electrode PO2 suggested a change in neural processing speed in this area. This right parietal-occipital change was observed for the first piece of music in the sequence and might indicate the onset of a changed cerebral listening strategy.

The experienced user of cannabis effects might be able to use the cannabis-induced altered auditory meter and intensity as an artist for aesthetic purposes. Becker in his analysis of jazz musician behavior and drugs explained how cannabis effects have to be perceived, learned, and domesticated before

FIGURE 14. Significance Mapping Pre/Post-THC for the First Piece of Music (King Crimson) N = 4



using them effectively (Becker 1963), and being able to switch those relation patterns off when needed (Weil 1998; Weil, Zinberg, and Nelsen 1968). A skilled and trained musician might benefit from "losing track" (Webster 2001) during an improvisation and even while playing composed structures. This method of reducing irrelevant information offers spontaneous rearrangement of a piece, vivid performance with enlarged emotional intensity scaling, and the opening of improvisational possibilities by breaking down pre-conceptions and restructuring habituated listening and acting patterns (Fachner 2000).

However, the cultural and aesthetic use of these inspirational possibilities is illegal, and was one reason for prohibition and incarceration of many jazz musicians, painters and actors (Musto 1997; Sloman 1998). The potential use of cannabis-induced perceptual functions for medical purposes seems to be obvious. Hearing loss could be affected by stimulating the cannabinoid receptor function for retraining purposes, as suggested from tinnitus research. Tinnitus patients suffer from continuously present frequency patterns, which could be mentally reduced by systematically ignoring them (Jastreboff, Gray, and Gold 1996). Conversely, it might be useful to investigate described cannabis-induced psycho-acoustic enhancing effects for re-training high frequency ranges in hearing loss.

CBR Activity, "Reverse Alpha" and the Cannabis High

Compared to pre-THC-rest and pre-THC-music in the post-THC-music EEG a rise of alpha percentage and power was observed in the parietal cortex on four subjects, while other frequencies decreased in power. Alpha amplitude changes are similar to "reverse alpha" findings in studies with gifted individuals (Jausovec 1997a,b; Jausovec 1998). In these studies, the degree of mental workload and effectiveness of problem solving seemed to be represented by the α-amplitude. An increase marked less mental workload in appropriate brain areas whereas a decrease would represent increased workload. Present results give reason to conclude that music seems to be processed more easily with cannabis than without. The rise of average α-amplitudes about 4 μV might be a neurophysiological indicator for the so-called state of "being high" (Solomon 1966). That auditory information seems to be processed more easily would be another argument for using cannabis as a supportive hearing aid. Alpha-results and changes in audiological tests reported above, user reports (Grinspoon and Bakalar 1994; Mezzrow 1946; Shapiro 1988; Webster 2001) and suggestions (Boyd 1992; Tart 1971) offer evidence of possible benefits that should be researched.

A possible mechanism of this increase of α and decrease of other frequencies might be explained through CB receptor findings. Animal research has shown a cannabis-induced decrease of somatosensory evoked potential (SEP) amplitudes (Campbell et al. 1986). A decrease of amplitudes has been observed in other EEG studies as reported above. The EEG represents postsynaptic dendritic potential summation of cortical cells (Niedermeyer and Lopes de Silva 1993). Postsynaptic cannabinoid receptors are known to imitate GABA-inhibition to reduce cell-firing rates (Joy, Watson, and Benson 1999). Decreased amplitudes in this EEG study might represent a decreased cell-firing mode caused by cannabinoid receptor mechanisms. Further research is needed to prove this speculation of the cannabis-induced decrease of EEG amplitudes. We have observed decreased amplitudes on δ-, θ- and β-frequencies over most parts of the brain, but α-amplitudes also decreased in frontal areas.

Struve has proposed an alpha hyperfrontality as a residual effect of heavy cannabis consumers (Struve, Straumanis, and Patrick 1994). In comparison to a normed-database alpha-rest activity seemed to exhibit more frontal alpha-power in heavy consumers. Rest-EEG here was not compared to a normative database, but more alpha power could not be observed in this study during musical perception or at rest.

Only in parietal parts of the brain did we observe an increase of α-power. This might be due to the intentional listening process, which might be enhanced by cannabis effects, but this reverse relationship of increased amplitudes in parietal areas during stoned music listening and decreases in most other areas of the brain seems to be a typical action mechanism that represents this cannabis-specific state of perception and aesthetic cognition. It reduces energy and permits a more effective processing of the intentionally perceived content. This might be reflected by increased parietal α-power and represent cannabis-induced increased cell firing mediated by CB receptor activity.

Time perception seems to work in this reverse manner, as well. The inner clock seems to speed up while time sense seems to expand. For musicians, this might work like a real-time time-lens, allowing more space between the notes during improvisation or sound design during mixing.

Cannabis as a Hearing Aid?

If one can perceive music, much "better" than before, why should not the hearing impaired also improve? Results reported in the literature and shown in this EEG experiment suggest that cannabis could be used as a hearing aid. It seems that acoustic properties of sound may be enhanced by cannabis. It permits a more effective spatial distinction between sound sources, which is of importance in hearing loss. Significant changes in temporal and occipital areas support this assumption. These changes represent an altered auditory perspective on musical acoustics, and should be taken into account for further research on cannabis-induced enhanced acoustic perception.

Furthermore, the increased α-percentages over the parietal cortex, which might indicate an intensified perceptual strategy with less mental workload, could be used for training programs with hearing-impaired persons. Acquired hearing loss in high frequency ranges could be compensated throughout reactivating and relearning acoustic memory shapes. In certain training courses cannabis could be used to intensify the cerebral hearing strategy of the hearing impaired person. This cannabis effect might help hearing-impaired persons to compensate lost abilities and enhance brain plasticity. However, by discussing possible benefits of cannabis-induced alpha enhancing during attention processes, we have to bear in mind that there are individuals, which show much less or even no alpha in their EEG (Niedermeyer and Lopes de Silva 1993).

Thaler's study showed highly significant improvement for a hearing impaired person on an audiological Word-Test. Others report that prosodic differentiation seems to be enhanced. In view of the fact that spoken language is based on nonverbal musical elements, and that supra-segmental and prosodic features constitute the sound of the human voice (Aldridge 1996), it is possible that it is easier for a hearing-impaired person to catch the meaning of a sentence after having smoked cannabis. Speech perception enhancement might be of interest for aphasia research. Further research is needed to explore possible benefits of cannabis for the hearing impaired.

CONCLUSION

This study gives promising insights into quantified EEG changes of pre/post-THC music listening as provided by amplitude and significance Mapping over averaged EEG epochs of music. Results are not based on a high number of subjects but on ethnographic EEG correlation of "stoned" listening to music. Accompanying this process in the life world provides naturalistic authenticity of tendencies occurring during those processes. Further laboratory research could compare several issues reported and discussed in this ethnographic intervention.

Changes in temporal and occipital areas and increasing α-signal strength in parietal association cortex seem to represent an inter-individual constant EEG correlate of altered music perception and hyperfocusing on the musical time-space.

Post-THC increase in parietal α-percentage showed a marked similarity to reverse α-findings in studies with gifted individuals and might represent a more effective strategy in task-specific information processing.

Cerebral change of perception seemed to be initially indicated throughout the significant spectrum change on the right parietal-occipital electrode, as well as all over changes of temporal and occipital areas, both involved in auditory perceptual changes.

Changes in occipital areas might indicate an enhanced acoustic "insight into the space between the notes" mediated throughout desynchronization in the visual association cortex. Together with the right parietal cortex, this area should be further examined in investigations with combined PET scan and EEG. Theta changes in temporal areas might indicate altered metric intensity scaling during hippocampal censorship of sensory data sets.

Basic research on cannabis-induced auditory changes seems to be indicated to estimate possible benefits for the hearing impaired. Enhanced perception of musical acoustics as perceived in prosodic and suprasegmental properties of speech might be of interest for aphasia research.

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