Stability of motor programs during a state of meditation: electrocortical activity in a pianist playing 'Vexations' by Erik Satie continuously for 28 hours

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ABSTRACT Electroencephalogram (EEG) recordings of an expert pianist playing Erik Satie's 'Vexations' for a continuous period of 28 hours were used to explore the changes in electrocortical activity during a state of trance and the subsequent influence on executive motor function. According to the event protocol, the pianist experienced different states of consciousness throughout the performance ranging from alertness to trance and drowsiness. We then compared the stability of motor performance for those three states by measuring the length of one played sequence as well as the power of the spectrum of the pianist's cerebral activity recorded over posterior regions of the brain. The results revealed no significant difference between the mean duration of a played sequence in the alert as compared to the trance state. A Fast Fourier Transformation of cerebral activity showed a significant increase in power of the alpha 1 spectrum (8.0–10.0 Hz) for the trance state of mind only. This effect occurred more markedly over the left hemisphere and is often referred to as equivalent to a meditative state of consciousness. In summary, one main finding was that in trance the performance of a demanding sensorimotor integration task remained constant. Hence, these results demonstrate the high degree of stability of executive function, even in changing levels of consciousness in expert pianists.

KEYWORDS: *consciousness, electrocortical activity, expert pianist, meditation, music and trance, stability of motor performance*

When Erik Satie composed the short piece for piano entitled 'Vexations' in 1893, he gave the following instructions to the performer: 'In order to play this motif 840 times in succession, it would be advisable to prepare oneself beforehand, in the deepest silence, through serious immobility.' In retrospect, one can only speculate what the composer intended by these instructions and if he was aware of the effect his work might have on a pianist, especially with regard to his or her consciousness and motor function. William James stated in 1890: 'The study of the distribution of consciousness shows to be exactly as we might expect in an organ added for the sake of steering a nervous system grown too complex to regulate itself.' Even today our understanding of the term 'consciousness' and its influences on executive function is deficient. Hebb (1980) refers to consciousness as 'equivalent to complex thought processes'. Eccles (1980) describes it as the process of 'knowing that one knows'. Desmedt and Tomberg (1995) consider consciousness to be an intrinsic feature of biological processes in the brain that has a self-preserving function from the Darwinian perspective of natural selection. From neurophysiological experiments using event-related brain potentials, they draw the conclusion that functional binding between parietal and pre-frontal cortices revealed by transient synchronic brain activation (namely 40 Hz oscillations), plays an essential role for conscious brain mechanisms. However, one of the main problems of research focusing on consciousness is the fact that consciousness itself is a subjective experience and hence difficult to measure objectively. Apart from a clinical assessment, the distribution of spectral activity in the electroencephalogram (EEG) has proven to be a way of quantifying the level of consciousness. Thus, the EEG pattern of an alert subject will differ from that of a person who is drowsy, asleep or in a coma (Niedermeyer, 1999; Niedermeyer and Lopez da Silva, 1999). Besides physiological states of consciousness, human beings can also experience modified states of consciousness, for example trance (Tassi and Muzet, 2001). Trance is often referred to as a distinct level of consciousness, characterized by a restful yet fully alert state of mind with a heightened perception. Thus, in trance one may experience conflicting perceptions and time shortening (Travis and Pearson, 1999). The characteristic features of a meditative state, that is the loss of the external frameworks (time, space and bodily sensation) and mental content (inner and outer perception), are often interpreted as the result of a dominant right hemisphere. In practitioners of transcendental meditation, EEG recordings showed a distinct pattern of electrocortical activity (Dunn et al., 1999; West, 1980) including synchronization of the alpha spectrum (Jevning et al., 1992) and an increase in the relative power of theta 2 (6.0–7.5 Hz) and alpha 1 (8.0–10.0 Hz) activity (Alexander et al., 1990; Maharishi, 1994; Mason et al., 1997). Throughout the duration of a subject's meditative state an increase of left hemispheric activity could be observed, expanding to the right hemisphere during advanced meditation, 'no thought' (Delmonte, 1984). Recently, Positron Emission Tomography

(PET) of subjects with 24-hour sleep deprivation (Thomas et al., 2000) and functional Magnetic Resonance Imaging (fMRI) during a simple form of meditation (Lazar et al., 2000) were used to identify and characterize the involved neural networks. All these experiments have aimed to contribute to our understanding of distinct states of consciousness on a solely descriptive level. However, up until now little effort has been made to specify the interdependence of different levels of consciousness on executive function. Even though it is known that, for instance, agricultural field workers may experience different levels of consciousness from alertness to trance during their work and still keep on reaping the grain (Tolstoi, 1955), no effort has been made to objectively measure the influence of different states of consciousness, for example of trance or drowsiness on executive function. However, one study investigating physiological responses during the performance of fine and gross motor tasks revealed no difference in the performance of meditators and non-meditators during relaxation (Wood, 1986).

We recorded behavioural and EEG data of a pianist during his 28-hour continuous performance of Erik Satie's 'Vexations' in order to provide further evidence for the effects of different states of consciousness on cerebral activity, and most importantly on a highly elaborate executive function such as piano playing.

Method

The EEG recordings took place during the uninterrupted performance of Erik Satie's 'Vexations' in a concert hall in Dresden (Germany) by a professional pianist (AF). 'Vexations' comprises one theme and two variations which are to be repeated 840 times (tempo: *très lent*, see Figure 1); total recording time: 27.50 hr. A light-emitting metronome was present throughout the whole performance. During this time a spectator recorded a protocol of events. Additionally, the pianist recorded a retrospective protocol of events after the performance (Table 1, see pp. 182–3). There is no other possibility in a 28-hour performance of relating EEG data and performers memories in a relatively global way. In this experiment, dynamic online monitoring of state of consciousness, for instance by means of filling in questionnaires at multiple time instances or tracing emotions with a 'joystick' (continuous measurement device as used by Schubert, 1999), is obviously not possible, since the pianist was required to give an uninterrupted performance. By correlating the protocol of the pianist with the protocol of the spectator we intend to increase the validity of the data.

According to this protocol we divided sections of the performance into three different states: alertness (0.10–2.10 hr), trance (14.10–19.09 hr) and drowsiness (19.20–21.00 hr). Behavioural and EEG data of all three states were compared. The performance was played on a grand piano (Yamaha DC 3) with a built-in Midi interface. MIDI data and an acoustical recording were

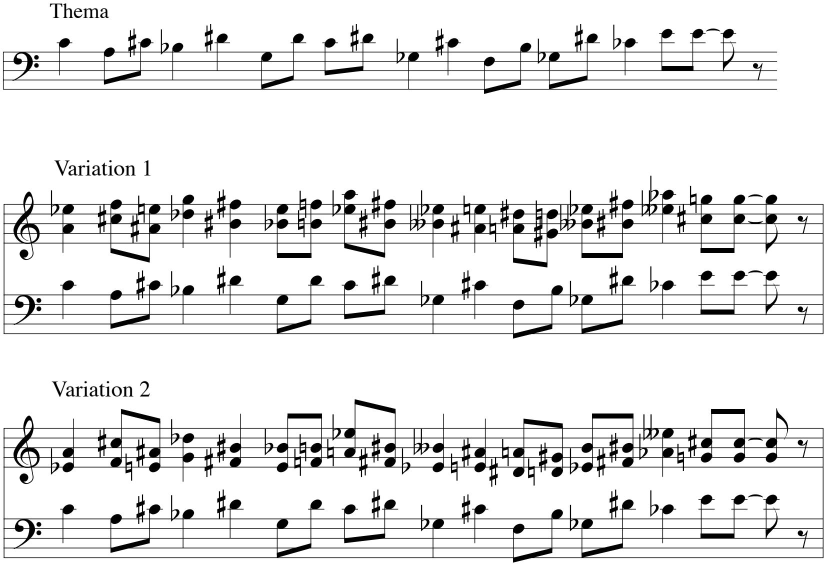



FIGURE 1 *Erik Satie's composition 'Vexations' comprises one theme and two variations and has to be repeated 840 times. Tempo:* très lent.

stored on hard disc. For data reduction, as a reliable behavioural equivalent for the stability of motor performance, the length of one played sequence, e.g. one theme, was measured. For each state (alertness, trance and drowsiness) 40 sequences were included.

The EEG was recorded from two tin electrodes that were placed on parietal bilateral positions (P3 and P4 according to the 10/20 system of Jasper, 1958). A reference electrode was placed on the left mastoid process and an electro-oculogram was recorded. Placement of frontal electrodes was not possible due to restrictions of cable length and the resulting immobilization of the pianist. The time constant was set to 0.3 sec and a high pass filter of 50 Hz was used. Fast Fourier Transformation (FFT) was done on the data (software Prism/Persyst Insight, version 2001.01.08 © 1996–8, Persyst Development Corporation) at a sampling rate of 128 Hz, and a power spectrum was obtained for the frequency range of 0.5–32.0 Hz. For each state, 10 time windows were evaluated, each of 5 minutes duration. Statistical testing was done on the data according to the *Friedman-Test* for non-parametric dependent samples.

Results

Figure 2 shows the median length of one played sequence for each condition. Most impressively, the pianist managed to keep a constant tempo during the beginning of the performance as well as during a trance state. The *Friedman-*

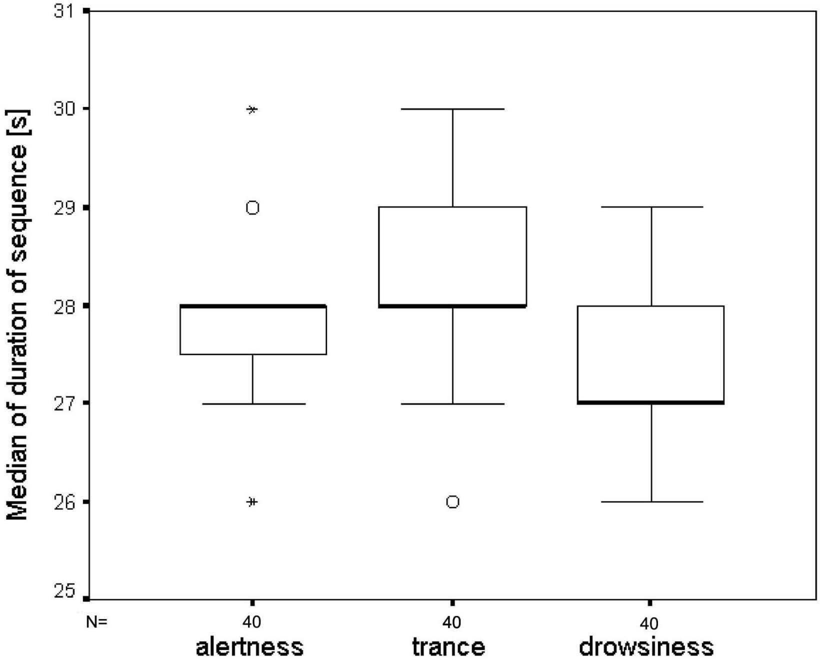


FIGURE 2 *Boxplot of median length in seconds [s] of one played sequence (N = 40) for each state (* = extreme value; o = outlier).*

Test revealed no significant differences between the first two performance sections ($\chi^2(1, N = 40) = 2.462$; $p = .117$), whereas in the drowsy state the tempo increased significantly as compared to alertness ($\chi^2(1, N = 40) = 9.846$; $p = .002$) and trance ($\chi^2(1, N = 40) = 16.133$; $p < .001$). In summary, the data confirm the high degree of stability of the motor performance, even in a trance state.

In Figure 3, the power of the spectra (0.5–32.0 Hz; 95% confidence interval, $N = 10$) of cerebral activity for all three states and both hemispheres is depicted – left hemispheric P3 electrode on the left and right hemispheric P4 electrode on the right-hand side. At the beginning of the performance (alert state) the power spectrum shows a broad distribution of activity over the whole spectrum. Throughout the performance, whilst experiencing different levels of consciousness, from alertness to trance, the composition of spectral activity also changes. For example, a synchronization could be found in the delta (0.5–3.5 Hz) and alpha 1 (8.0–10.0 Hz) range of the spectrum. This effect evolves bilaterally, but is more distinct over the left hemisphere with an additional peak in the beta 1 range (13.0–15.0 Hz). The difference spectrogram (trance–alert) as depicted at the top of Figure 4 confirms these observations. During drowsiness the spectrogram shows a prominent peak in the delta spectrum, whereas the synchronization of alpha 1 activity is no longer

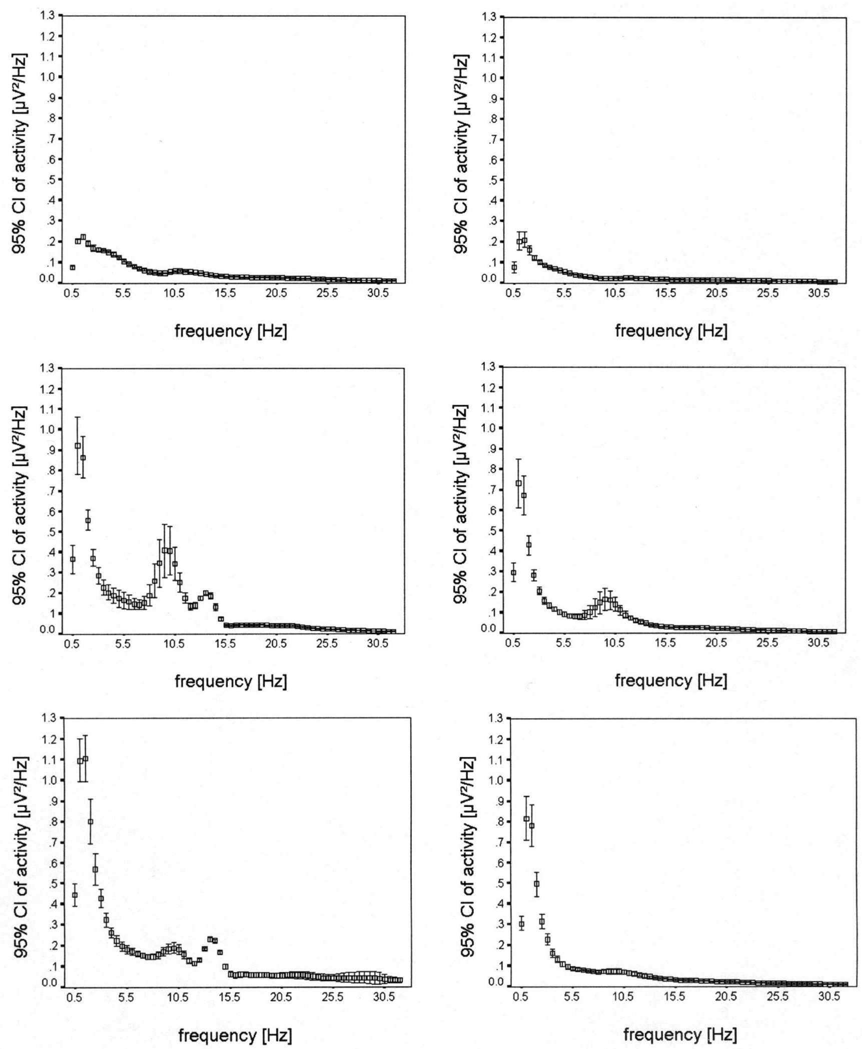


FIGURE 3 *Power of spectra shown for each state (*top: *alertness;* middle: *trance;* bottom: *drowsiness).* Left side: *left hemispheric P3 electrode;* right side: *right hemispheric P4 electrode.* Delta: *0.5–3.5 Hz;* theta: *4.0–7.5 Hz;* alpha 1: *8.0–10.0 Hz;* alpha 2: *10.5–12.5 Hz;* beta 1: *13.0–15.0 Hz;* beta 2: > *15 Hz.*

(P4 electrode) or only marginally (P3 electrode) present. Accordingly, the difference spectrogram shows an increase of delta activity as the main difference between the states of drowsiness and alertness (Figure 4, middle). In summary, the main effect of drowsiness seems to comprise an increase in delta activity, whereas in trance an additional synchronization in the alpha 1 range can be observed (see difference spectrogram trance–drowsiness, Figure 4). Figure 5 illustrates the ratio between the activity of a given bandwidth

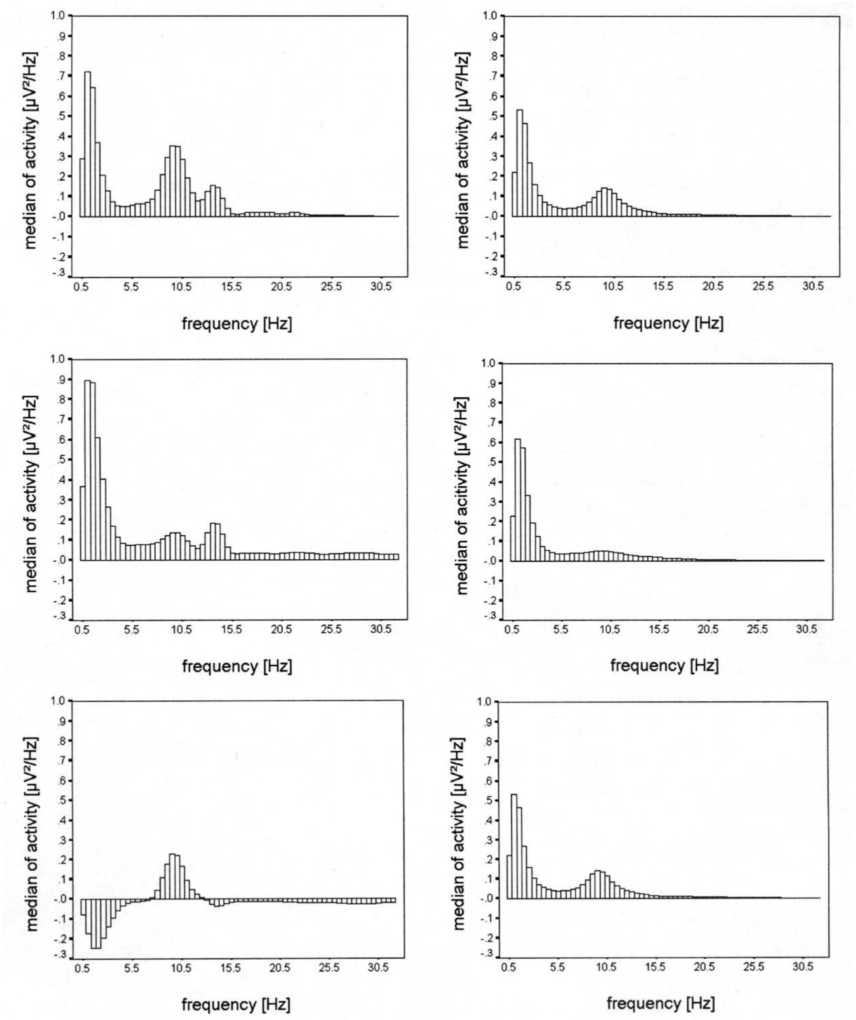
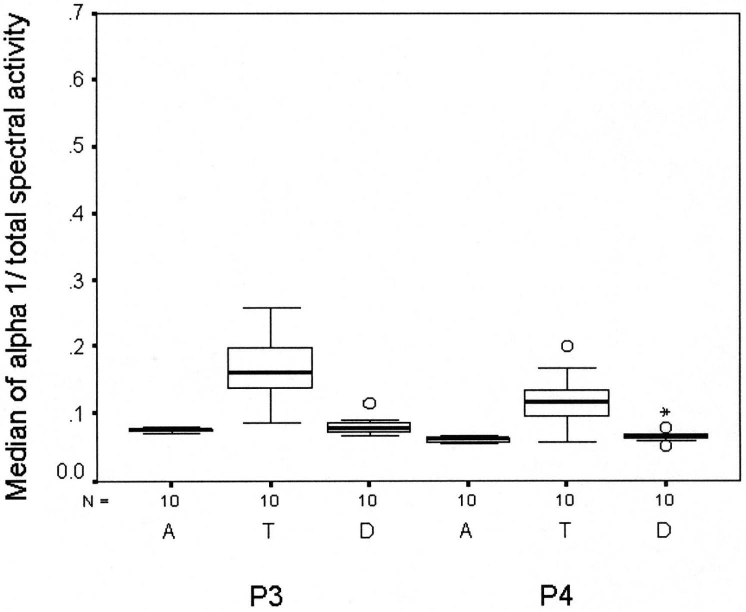


FIGURE 4 *Difference-spectrograms [µV^2/Hz] for trance–alertness (top), drowsiness–alertness (middle) and trance–drowsiness (bottom); P3 electrode on the left, P4 electrode on the right side.* Delta: *0.5–3.5 Hz;* theta: *4.0–7.5 Hz;* alpha 1: *8.0–10.0 Hz;* alpha 2: *10.5–12.5 Hz;* beta 1: *13.0–15.0 Hz;* beta 2: > *15 Hz.*

(e.g. alpha 1) and the sum of total spectral activity for each state (alertness/trance/drowsiness). Besides the effects already detailed, statistical testing (*Friedman-Test*) done on these data shows a significant increase of alpha 1 activity during trance as compared to alertness (P3 electrode: $\chi^2(1, N = 10) = 10.00$; $p = .002$; P4 electrode: $\chi^2(1, N = 10) = 10.00$; $p = .002$) and drowsiness (P3 electrode: $\chi^2(1, N = 10) = 6.4$; $p = .011$; P4 electrode: $\chi^2(1, N = 10) = 6.4$; $p = .011$), whereas no such difference was found for alertness as compared to drowsiness (P3 electrode: $\chi^2(1, N = 10) = 1.6$; $p = .206$;



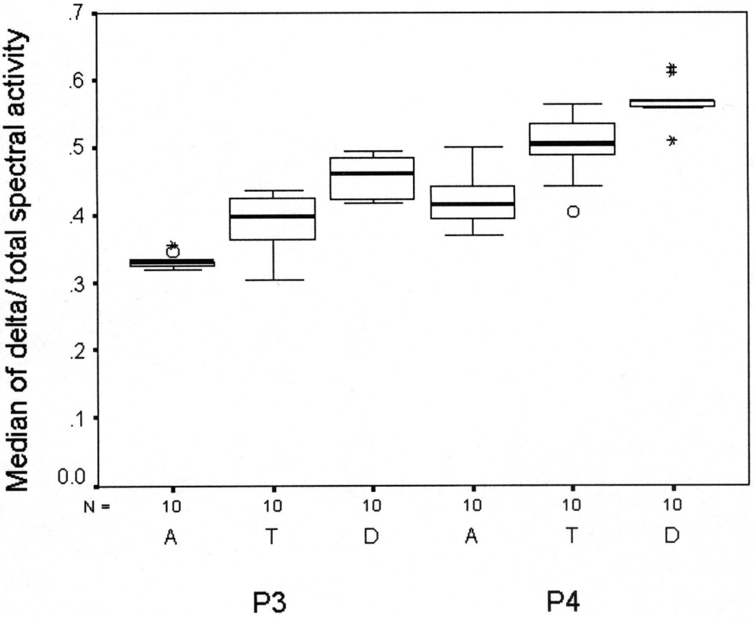


FIGURE 5 *Boxplots of the ratio of the activity of* alpha 1 *(top) and* delta *(bottom) bandwidth to the sum of total spectral activity (* = extreme value; o = outlier). Shown for each state (A = alertness; T = trance; D = drowsiness), P3 electrode on the left, P4 electrode on the right side.*

P4 electrode: $\chi^2(1, N = 10) = 0.4$; $p = .527$). However, the increase of delta activity over the course of the performance became statistically significant during all three states with increasing delta activity from alertness to trance to drowsiness.

In summary, the analysis of behavioural data shows most impressively that the stability of motor performance during alertness as compared to trance remained constant, whereas during drowsiness the sequence duration decreased as a result of increase in tempo. As for the cerebral activity, the main effect of trance seems to be an increase in, and synchronization of, spectral activity in the alpha 1 range. However, in both states of trance and drowsiness, delta activity increased. Both effects could be observed bilaterally with a bias towards the left hemisphere.

Discussion

The aim of this study was to shed some light on the interference of changing levels of consciousness on executive function. During his 28-hour continuous performance of a piano piece comprising 840 repeats, the pianist experienced different states of consciousness from alertness to drowsiness and trance, the latter characterized by time-shortening, extra-corporal experiences and states of altered perception (see Table 1). Despite mistakes occurring during some episodes (e.g. 13.30–14.00 hr; 18.30–18.47 hr; 19.03–19.15 hr; 22.00–23.00 hr; 25.40–26.00 hr), the main body of the performance remained undisturbed and uninterrupted throughout. The behavioural data confirm the immense degree of stability of the player's motor performance. Thus, the length of a given sequence did not significantly differ between him being alert or in trance (see Figure 2). Although maintaining a constant tempo was one of his main goals, in becoming drowsy, he failed to maintain the extraordinarily slow tempo and it finally increased despite the use of a light-emitting metronome throughout the whole performance.

The tempo maintenance during alertness and trance cannot be explained by the use of the light-emitting metronome. As the pianist reported, the metronome's function was only to support the development of a reliable tempo 'feeling' during the first two hours of performance. For the remainder of the performance, tempo was uninfluenced by the metronome due to the pianist's complete ignorance of this external timekeeper. From this it follows that changes in tempo occurring after the second hour of performance can only be attributed to internal processes. Against the background of the current state of research in rhythm perception and production, we favour free-running neural oscillators as the underlying mechanism for reliable timing control in motor execution. The stability of such an ensemble of oscillators seems to be influenced by different states of consciousness. We also assume that internal oscillators interact with circadian rhythms which control,

TABLE 1 *Event protocol of the performance recorded by an observer (left-hand column) and retrospectively by the pianist (right-hand column)*

Time	d [hr]	Protocol of spectator	Protocol of pianist (AF)	State
9 am–5 pm	–8.00		Got up, breakfast, preparation in concert hall, interview, setting electrodes for EEG, kinesiologic exercises	
5 pm	0.00	**Beginning of performance**	No chance to concentrate before the beginning	**Alertness** 0.10–2.10 hr
6 pm	1.00			
7 pm	2.00		Relaxed state of mind	
8 pm	3.00			
9 pm	4.00		First complaints (pain in shoulder, clavicula)	
10 pm–3 am	5.00–10.00			
4 am	11.00	First meal, first cigarette	Extremely tired, hard to concentrate	
	11.25	**Signs of beginning trance**	Better after smoking	
5 am	12.00			
6 am	13.30	2nd cigarette, mixes up passages, stops to measure time	Approx. 6.30 am **beginning of trance**, felt extremely tired, unconnected tone groups in pianissimo	
7 am	14.00		**Confuse reality and dream, lose control of my body, extra-corporal experience,** disassociation of the piece into single tone groups	**Trance** 14.10–19.09 hr
8 am	15.00		Number of mistakes increases; not sure if I should continue; ask the audience if I should, get some water to drink, afterwards I feel better; alert state of mind	
9 am	16.30	Seems to be extremely tired, outside churchbell rings	**Trance**	
10 am	17.00			

11 am	18.30	Mix-up of form sections, improvising		**Trance** 14.10–19.09 hr
	18.47	**Seems to be in deep trance**		
12 am	19.03	Increased dynamic, motoric loop, eats Something – **end of trance ?**	**End of trance** Now I know that I will succeed, feel well	
	19.15	Plays two octaves lower in both hands (Startled reaction due to film cameras)		
1 pm	20.07	Plays two octaves lower in both hands	**Feel** tired	**Drowsiness** 19.20–21 hr
2 pm	21.00			
3 pm	22.00	Churchbell rings, minor changes of musical form		
4 pm	23.00		Feel tired, **beginning of trance**	
5 pm	24.00			
6 pm	25.00	Churchbell rings, eats something	**Permanent light trance**, time seems to pass very slowly, free variations of of the theme (octave transposition) and change of sequence, I forget what I play, feeling that I have no time	
	25.40	Plays theme only with left hand		
7 pm	26.00			
8 pm	27.00		**Loss of time structure, experience performance as part of a buddhist rite** (I will receive my new name after the performance), **trance, time stops,** continue to play as long as I am able to do so	
8:47.15 pm	27.47	End of performance	**I stop after eight more repeats (in fact it was only 1), ‘something’ stops silence.**	

for example, periodic changes of cortisol or blood sugar. Forthcoming analyses of the performance's expressive timing data will enable more insight into the basic mechanisms of large-scale control of timing in music performance. In summary, the behavioural data demonstrate the different influences of distinct states of consciousness on executive motor function.

The power spectra of the three different states show a broad distribution of activity across the whole spectrum in the alert state, changing to a more synchronized spectrum in the trance and drowsy states. The two latter conditions show an increase of delta activity, corroborating findings of a PET study from Thomas et al. (2000) who reported a decreased metabolism in thalamic, pre-frontal and posterior parietal brain regions after one night of sleep deprivation. Furthermore, in trance a strong synchronization in the alpha 1 spectrum could be detected (see Figures 3 and 4). Statistical testing confirmed the significance of this effect (see Figure 5) with a bias towards a left hemispheric location. These results confirm earlier studies on EEG changes in meditative states (Alexander et al., 1990; Delmonte, 1984; Maharishi, 1994; Mason et al., 1997) in showing a synchronization in the alpha 1 spectrum. Furthermore, Delmonte (1984) showed that the initiation of synchronization begins in a left hemispheric location, spreading to the right hemisphere during ongoing meditation.

As is widely believed, increased alpha band power is thought to reflect a decrease in the corresponding region of the underlying cerebral cortex (Benca et al., 1999); however, our data support the hypothesis that meditation facilitates right hemispheric function (Delmonte, 1984; Pagano and Frumkin, 1977; Persinger, 1992) due to a more intense inhibition of left hemispheric activity. Most importantly, whilst in deep trance, which included effects such as time-shortening, altered perception and characteristic changes in the EEG, the pianist managed not only to keep on playing but also to maintain a constant tempo, hence executing complex motor schemes at a high level of performance. Thus, our results can be taken as an argument in opposition to Damasio (1999) who argues that motor execution leads via sensory input to consciousness because, even when in a state of trance, motor performance remained constant but consciousness shifted to a state of trance. In fact, we do not believe that Damasio's theory holds for all motor actions. In terms of human evolution, automated motor actions were very important, for example when walking long distances in order to find food and so on. One could speculate that trance in these circumstances might have been a means of overcoming fatigue and releasing powerful self-reward hormones.

In summary, these findings demonstrate most impressively the high degree of stability of complex motor programs even during changing levels of consciousness ranging from a fully alert state to deep trance.

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