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Correlation Between Fluctuations in Human Ultra-weak Photon Emission and EEG Alpha Rhythm

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Abstract

“Ultra-weak photon emission” (UPE) recording is a technique that registers, non-invasively and on-line, reactive oxygen species (ROS) fluctuations. The objective of the present study was to perform simultaneous recordings in human subjects of UPE and EEG and to study a possible correlation between UPE and EEG fluctuations. Thirty-six EEG recordings of 1 h each were performed at P3 and P4 with simultaneous registration of UPE of the right dorsum hand utilizing a newly designed tabletop photomultiplier device. Both spectral, statistical and correlation analyses were performed. The data suggest significant correlations between fluctuations in photon emission and fluctuations in strength of alpha wave production in the 7-13 Hz frequency band and its 1-Hz sub-bands. Correlations between UPE and the whole alpha region were clarified when correlations were addressed UPE and specific 1-Hz sub-bands. Further clarification was observed with smaller fragments of time series data which suggested that the correlations were temporary. When one data row was shifted over defined lag periods compared to the other, different data emerged. The synchronization exhibits characteristics of a weak phase and frequency coupling, indicating that the systems are neither completely independent nor in a fixed mutual relationship. The synchronization also highlights that the weak coupling may involve slowly drifting and sliding phases. The data are discussed in relationship to mind – body interactions and the role of consciousness in health.

Key Words: Alpha suppression, EEG, human, ultra-weak photon emission, biophotons

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Please see supplementary files for Tables.

Introduction

“Ultra-weak photon emission” (UPE) recording is a technique that registers, non-invasively, non-destructively and on-line, free radical processes within living systems (even in intact organisms)

without the use of light-amplifying substances (photosensitizers). It has received increasing attention because of its connection to the hypothesized central role of the Reactive Oxygen Species (ROS) – antioxidant system both in health physiology and the development of chronic disease.

The recording system that is most utilized for humans is a photomultiplier system (PMS) that is sensitive to wavelengths in the UV and visible range and not to wavelengths higher than 650 nm. This form of registration excludes

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heat as a cause of photon emission (Cohen & Popp, 1997; Van Wijk & Van Wijk, 2004; Van Wijk & Van Wijk, 2005a; Slawinsky, 2005). The data captured by this technology enables one to perform spectral analyses and statistical analyses of UPE (Van Wijk & Van Wijk, 2005b; Van Wijk et al., 2005c; Van Wijk et al., 2006a).

Analysis of spectral color distributions (human UPE is 420-560 nm) has led to the conclusion that the majority of spontaneous emissions from living systems is a form of luminescence due to recombination of free radicals (Van Wijk et al., 2008a). The intensity of UPE differs among humans. However, a common percentage distribution pattern exists over different anatomic locations (Van Wijk et al., 2006b; Van Wijk et al., 2006c). Fluctuations may occur in a 24-hour cycle as well as a yearly cycle (Van Wijk et al., 2007a).

Human UPE is significant for monitoring the human oxidative status. The oxidative status plays an important role in development of chronic diseases. Convincing evidence supports the role of reactive oxygen species in development of chronic diseases such as cancer, atherosclerosis and a number of brain pathologies (e.g. Cross et al., 1987; Van Wijk et al., 2008a). The role of meditation in ROS processes has also received increased attention both biochemically (Yadav et al., 2005; Kim et al., 2005; Schneider et al., 1998) and by utilizing UPE recording of subjects (Van Wijk et al., 2006d; Van Wijk et al., 2008b). Meditation has been scientifically established as a self-regulation technique to help restore disturbances caused by stress (Shapiro, 1982).

Many studies have focused on the brain's physiologic patterns during and after the use of meditation, particularly with Transcendental Meditation (TM) (Cahn, 2006; Travis & Wallace, 1997; Travis, 2001). The electroencephalogram (EEG) has been utilized in a number of studies documenting the emergence of specific EEG patterns during TM. In particular, suppression of electro-cortical arousal in the alpha wave region (7-13 Hz) has been observed.

Such data have led to the hypothesis that there may be some correspondence between electro-cortical brain activities and ultra-weak photon emission in humans. Since both activities demonstrate fluctuations in time,

it can be hypothesized that fluctuations in UPE may correspond with fluctuations in the intensity of alpha activity. The present study examined such possible coupling between electro-cortical activity (alpha of the EEG) and the strength of UPE, when subjects were awake with eyes closed.

Materials and Methods

Setting and experimental design

The study focused on the correlation analysis between fluctuations in UPE and simultaneously recorded fluctuations in alpha wave activity. Eighteen healthy subjects, research colleagues, participated in the testing of the procedure and protocol. The average age was 58.7 years; SD was 11.8 years.

The experiments were performed in a darkened room maintained at a temperature of 18°C. Subjects prior to the registration were dark-adapted for 45 minutes. To register parietal EEG, Ag/AgCl electrodes were affixed to P3 (left) and P4 (right). Both earlobes were grounded and referenced to the EEG recording. Electrical potential was measured between a parietal point on the head and the opposite earlobe.

The subjects sat in front of a newly designed table-top model photomultiplier system (PMS). The table top model consisted of two dark chambers specially designed for both hands of a subject. Two Hamamatsu photomultiplier tubes were housed in this device. The photosensitive area of each detector had a diameter of 5 cm. Spectral sensitivity of both PMT's was limited to 300-650nm range. The photomultiplier system counted single photons continuously. They were then summed for each 50 milliseconds. The amplifiers and discriminators converted the output signals from the PMT's to 5V pulses fed to an IBM-PC utilizing two synchronized interface cards to count the photons. A constant temperature of 18°C was maintained in the hand compartment of the table top PMS. That temperature facilitated stable background noise at approximately 7 cps.

In the present study, only the UPE of the right hand dorsum was recorded. To register UPE, the subject placed the right hand in the appropriate compartment of the PMS. EEG and UPE registration began synchronously. The UPE and EEG data were sent to the same computer

enabling synchronization of the two different recordings.

A single continuous registration of one subject lasted 3600 s. For each participant, two such registrations were completed.

Data collection and handling

Both the EEG and UPE data were first examined for artifacts. Each experiment of 3600 continuous seconds was divided into groups of data of 5 s epochs each. For each subject, 720 data sets were collected in each experiment.

In each 5s epoch, 100 photon count data were available since these were counted in 50 ms dwell times. This set of 100 data was utilized to calculate strength of signal (mean and standard error).

For each 5s epoch, EEG spectra were computed using a Fast Fourier Transformation (FFT) algorithm with spectral resolution of 0.125 Hz. The resulting spectra had a frequency range of 1.0 to 21.4 Hz. All peaks in the alpha rhythm occurred in the 7-13 Hz range. This part of the spectrum was utilized for the calculation of amplitudes of each 1 Hz band width, resulting in amplitudes for each 5 s period of the 7-8 Hz, 8-9 Hz, 9-10 Hz, 10-11 Hz, 11-12 Hz and 12-13 Hz bands from both left and right brain. Amplitudes were calculated as surface area under the spectral curve for each (sub-) band of the alpha range.

Correlation analysis

Data sets of all experiments with the above-mentioned protocols were collected for analysis. Data were tested for stationary in each series. Correlation analysis addressed a. surface area under the spectral curve of each alpha EEG (sub-) band from left brain with mean UPE and b. surface area under the spectral curve of each alpha EEG (sub-) band from right brain with mean UPE. In order to test whether significant correlations found were not based on coincidence, each series of original (not-normalized) photon and EEG data was analyzed for correlation. Each series was then shuffled by linking it to a series of random numbers (sorted from low to high). After shuffling the data, the exact same correlation analysis was performed as accomplished with the previously non-shuffled data. To study stability of cross-system synchrony, the dynamics of the correlation was

estimated when one data row was shifted over defined time lag periods compared to the other.

Results

Fluctuations in UPE and alpha wave activity

Subjects, when they closed their eyes, exhibited an alpha peak with different sub-bands of the EEG frequency spectrum. During an experimental session, the intensity of the typical alpha region (7-13 Hz) fluctuated; in most sessions the major activity was in the 9-11 Hz range. A typical example of the intensity of the 7-13 Hz region is presented in Figure 1. Data demonstrate a high degree of synchronization between the fluctuations of the left and right side of the brain. A corresponding example time course of the 1-Hz (sub-) bands is shown in Figure 2A for the left and Figure 2B right.

During an experimental session, UPE also fluctuated continuously. A typical example is presented in Figure 3. The mean level differed from one person to the other. Mean levels of the same subject could also be different from one registration to the next when these registrations were performed with some time in between. The average photon strength in the different experiments was between 4 cps and 38 cps; the mean value, taking all experiments together, was 8.7 (with a standard deviation of 7.8).

The first correlation analysis was performed utilizing Y-axis fluctuation data of UPE and the 7-13 Hz alpha region of every individual participant in each recording session. This correlation analysis is acceptable only when it is assumed that neither the alpha band nor the UPE exhibit upward or downward trends. Regression analysis then demonstrated that data actually did fluctuate around a constant mean value. Upward or downward trends were not observed in any of the UPE or EEG time courses.

Of the 36 one-hour registrations, 4 exhibited a small, but significant negative correlation between UPE and 7-13 Hz alpha wave activity both left and right (see Suppl. files, Table 1, left panel). A decrease in alpha activity typically corresponds with an increase in UPE. However, in this study, another 4 experiments exhibited a significant positive correlation between UPE and 7-13 Hz alpha wave activity of which 3 were on the left side. This indicates that alpha activity increased when the UPE increased. Of the 8 cases that exhibited significant

correlation, 5 occurred between UPE and both the EEG of the left and the EEG of the right regions of the brain.

Stronger correlations were found in certain 1 Hz sub-bands. The correlating sub-bands did not always correspond to those of the major alpha peak and were, at times, just in sub-bands of frequencies above and below that peak (Suppl files, Table 1, right panel). In a further analysis, it was assumed that any correlations between UPE and the 7 - 13 Hz alpha wave activity were present, but not all the time.

The strength of correlations varied. This was the subject of further investigations. To this end, the data rows were split, specifically, for the purpose of working with a smaller number of epochs. It was expected that in the event a constant correlation existed, such splitting would demonstrate almost similar correlation strengths in the two remaining data groups. On the other hand, correlations might temporarily occur with different strengths. In that case, the two remaining data groups might exhibit two different correlations.

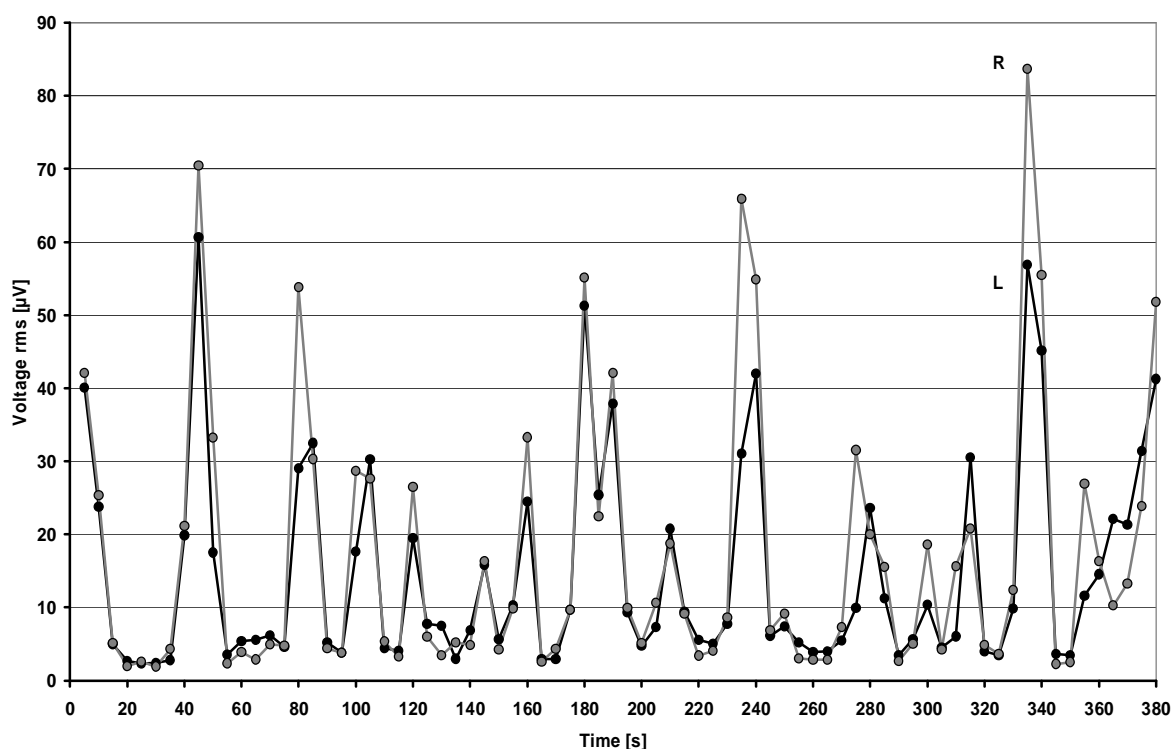


Figure 1. A typical example of fluctuations in 7-13 Hz at P3 (closed circle) and P4 (open circle) during 380 s of recording. Data are expressed in microvolt (μV) root mean squared (rms).

This was tested by splitting the data groups of 720 epochs of 5 s each (total duration of 3600 s) into 20 fragments. Each fragment, then, included 36 epochs of 5 s. The length of a single fragment (36 epochs) was insufficient for reliable correlation analysis. To establish validity of the correlation analysis, fragments were combined as illustrated in Figure 4. Two correlation coefficients were then calculated: one based on the combination of all A fragments and the other based on the combination of all B fragments.

Tables 2 A and 2B (see Suppl. files) demonstrate the significant correlations between mean UPE and alpha wave activity in the 7-13 Hz range (left panels) and its 1 Hz subbands (right panels) for P3 and P4, respectively. These data suggest that correlations are of different strength. It is possible by dividing the data row, that combinations arise without any significant correlation while the other combination exhibits enhanced correlation strength compared to the original data set. In certain situations, without

significant correlation in the 7-13 Hz band, bands.
significant correlations may arise in the 1 Hz sub-

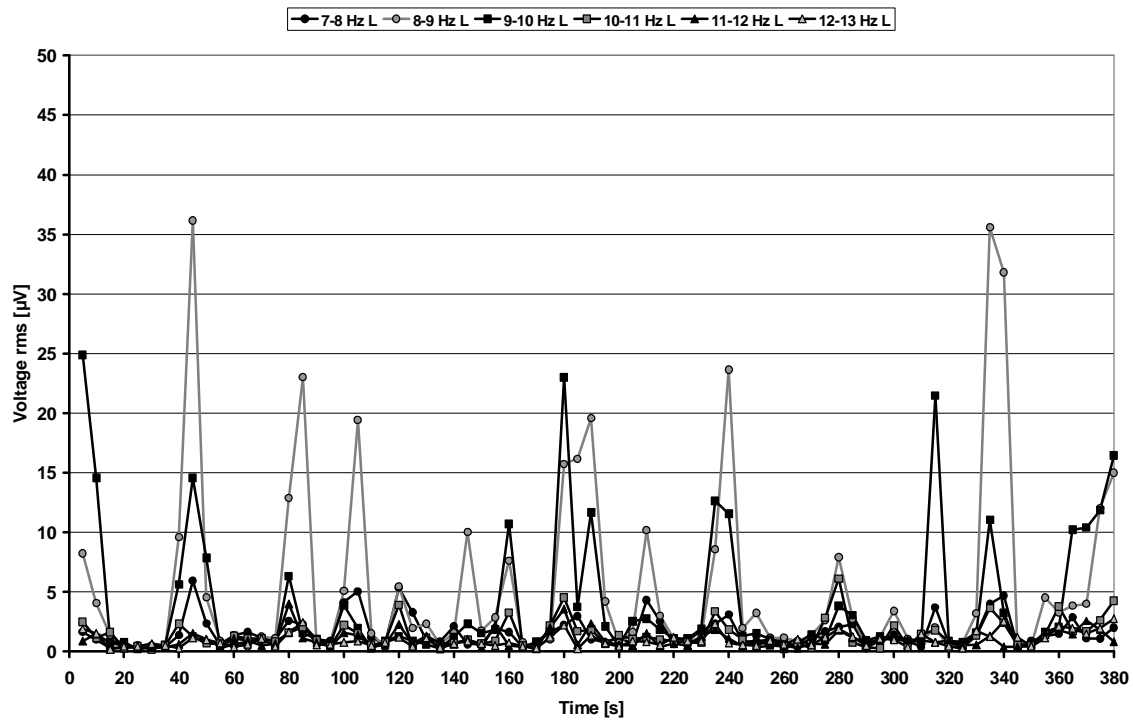


Figure 2A. Typical example of fluctuations in 1 Hz alpha sub-bands at P3 during 380 s of recording. Fluctuations in alpha 1 Hz sub-bands at P3 (left side).

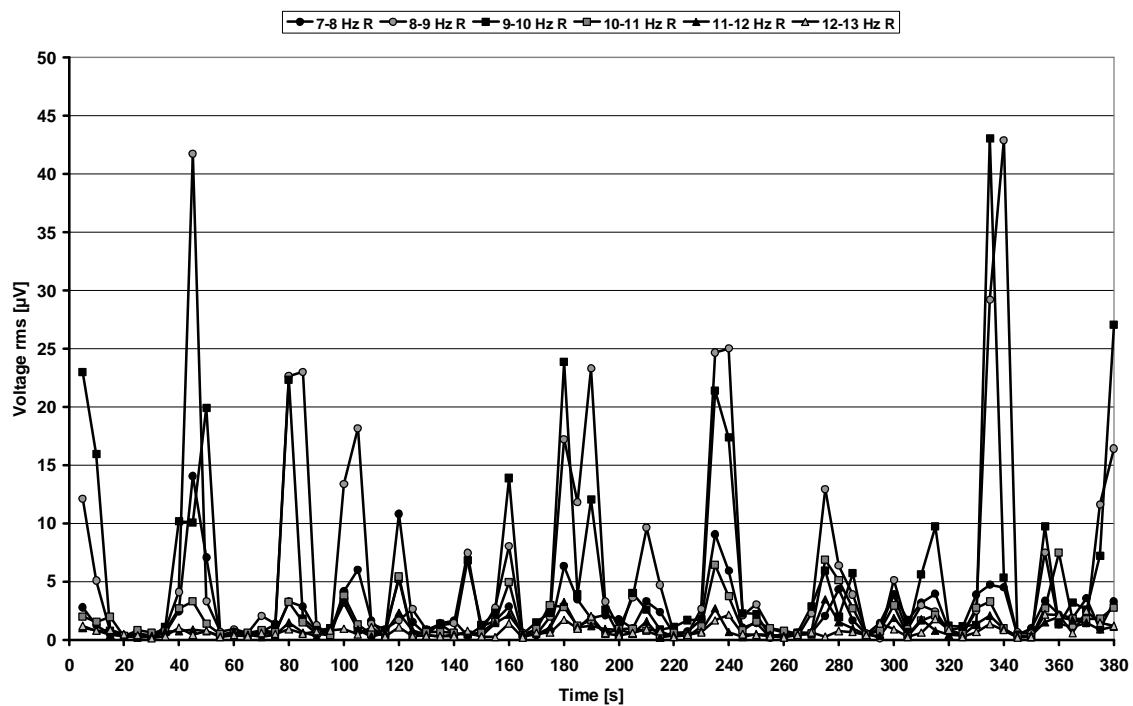


Figure 2B. Fluctuations in alpha 1 Hz sub-bands at P4 (right side). Symbols: 7-8 Hz (closed circle), 8-9 Hz (open circle), 9-10 Hz (closed square), 10-11 Hz (open square), 11-12 Hz (closed triangle) and 12-13 Hz (open triangle). Data are expressed in microvolt (μV) root mean squared (rms).

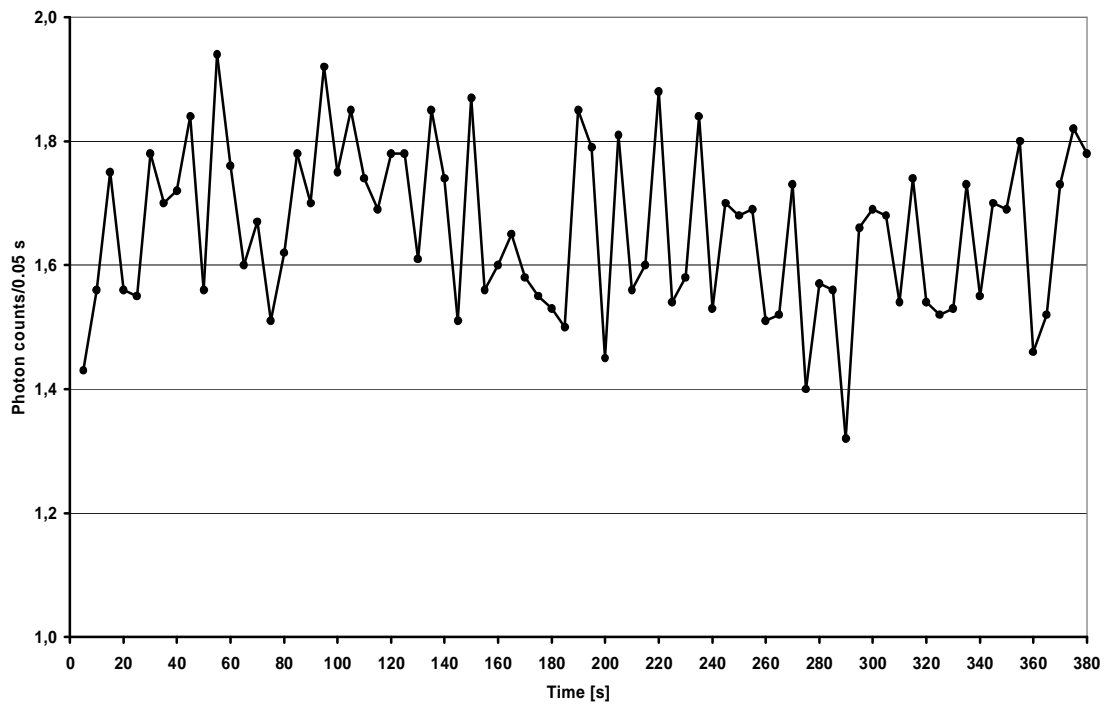


Figure 3. Typical example of continuous fluctuations in UPE during 380 s of recording. Number of photons was summed for 50 millisecond periods. One hundred of these periods were utilized to calculate the mean photon emission of a 5 s period. Mean UPE is expressed as photon counts per 50 ms.

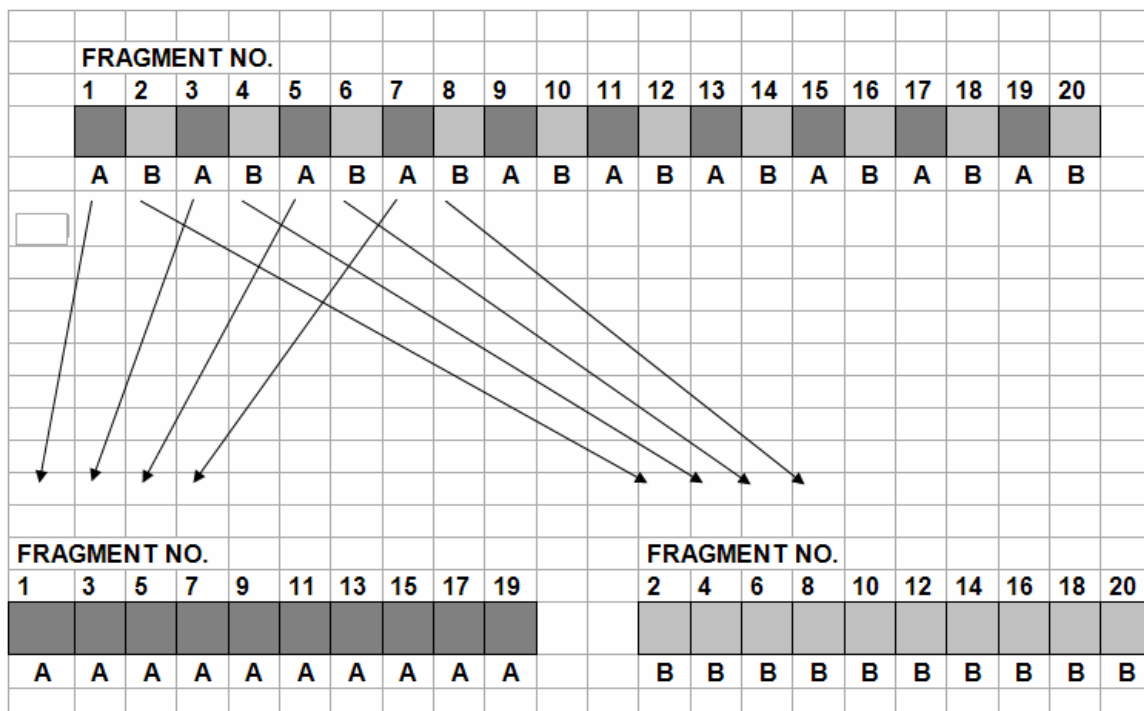


Figure 4. Illustration of splitting data groups. Data groups of 720 epoch of 5 s each were split into 20 fragments. Fragments were combined as illustrated by A and B.

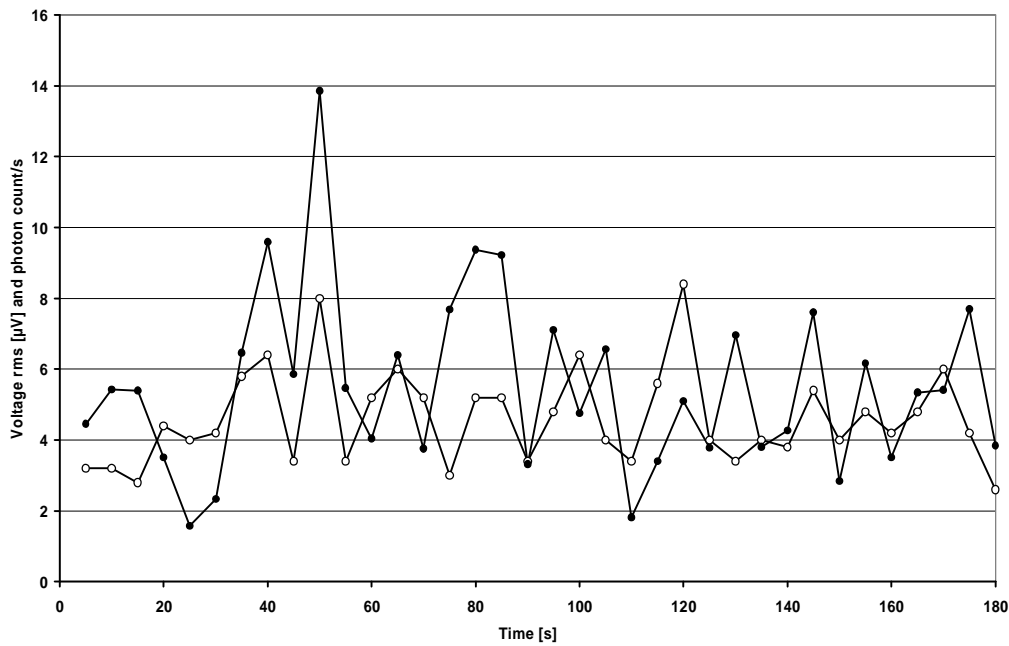


Figure 5. Example of a 3 min fragment with positive correlation between UPE and 8-9 Hz EEG. The fluctuations in UPE (-○-) and 8-9 HZ sub-band (-●-) demonstrate a high degree of synchronicity.

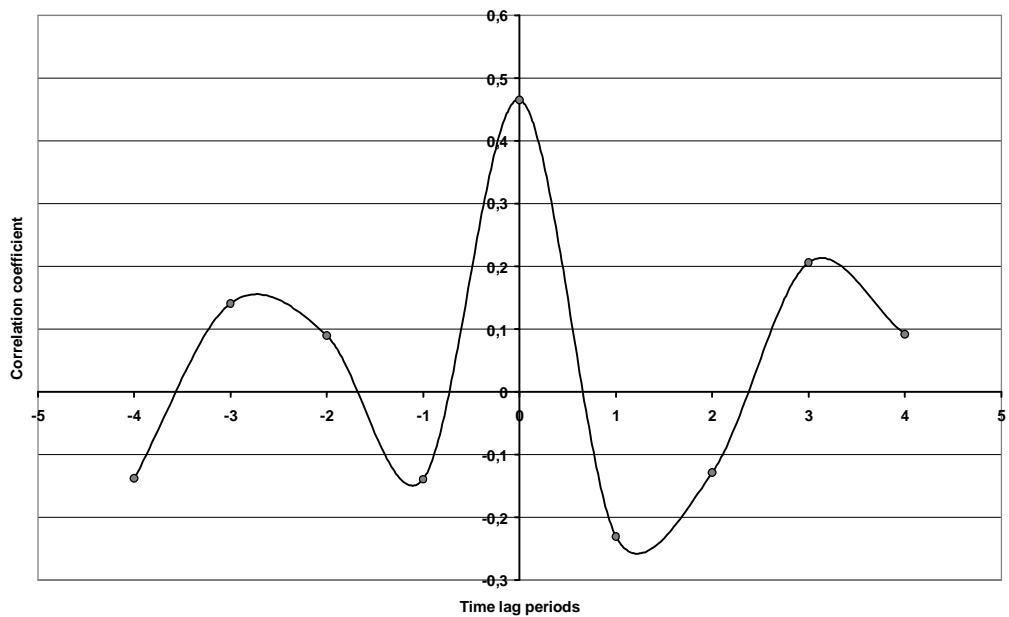


Figure 6. Dynamics of correlation coefficient based on shifting one data row over defined lag periods compared to the other. Shifting occurs over 1 to 4 lag periods back and forth and is given at the X-axis. The corresponding correlation coefficients are at the Y-axis.

Robustness of statistical conclusions

The robustness of the statistical conclusions was studied in several directions:

1. There is a high bilateral correlation between fluctuations of alpha intensities of the left and right sides of the brain. However, this correlation is not absolute because symmetry is never perfect (Figure 2). If fluctuations of EEG, bilaterally, are highly correlated, it can then be expected that any correlation between UPE and

EEG sub-bands on one side of the brain may be paralleled by a correlation with the corresponding EEG sub-band at the other side of the brain. The data illustrated in Table 2 are utilized to estimate the number of bilateral correlations which is summarized in Table 3 (see Suppl files).

2. The sub-division of the alpha peak is somewhat artificial. The sub-band frequencies are characterized by whole numbers: 7, 8, 9, 10,

11, 12 and 13. However, in practice, upward and downward fluctuations will not be limited to these strict boundaries. Instead, it is expected that a fluctuation observed in one sub-band may extend to an adjacent sub-band. This has been evaluated by comparing, for each side of the brain, the number of correlations in adjacent sub-bands as summarized in Table 3.

3. Whether the correlations are real and truly reflect correlations was evaluated by constructing surrogate, randomized data sets. For this purpose, random numbers were assigned to the photon counts in the original time series and then the random numbers were sorted by size. In the experimental situation, the correlations based on surrogate data were found to be 4.4 % of all pairs of data sets, close to the 5 % error probability ($p=0.05$) used in the analysis. In the original pairs of data sets, 10 % (see Suppl. files, Table 2) and 12 % (Table 1) demonstrated a significant correlation between mean UPE and 1-Hz alpha sub-band activity. This is well above the 5 % error probability ($p=0.05$).

Is the number of correlations dependent on signal strength (Y-axis) of UPE and the intensity (Y-axis) of an alpha band?

Participating subjects may be different both in mean UPE strength and intensity of the alpha peak. In particular, for UPE data, it must be understood that the (electronic) background is approximately 7 cps compared to the observed range of mean UPE strength values (9-30 cps). Also, since electronic background fluctuates to some extent, the fluctuations of hand emissions will be disturbed and even overshadowed by the background fluctuations. In principle, a similar situation may arise for the EEG alpha band. However, as shown in Figure 2, the alpha peak band is relatively high compared to background (due to influences of adjacent frequencies).

These considerations were the reasons to further study whether the number of correlations may be related to the absolute UPE values or absolute EEG intensities. For this reason, for each experiment, the number of correlations occurring between UPE and any of the sub-bands of the alpha region was included. This number varied between 0 and 13 (Table 2). The number of correlations was then compared to both the mean UPE and the alpha band

intensity in each experiment. Correlation analysis demonstrated that the number of correlations observed between UPE and EEG subbands was significantly influenced by the UPE strength ($r=0,3444$; $p=0.003$). However, the number of correlations was not influenced by alpha intensity.

What does it mean when we measure correlations?

The data suggest that correlations between UPE and EEG sub-band intensities are present, but vary in strength and even in direction. They are not likely to be attributed to some "spurious event". Such will be further validated when it is possible to characterize these correlations in more detail utilizing two further approaches:

1. Searching high correlation data rows for increased correlation is accomplished by utilization of 3-min data rows in parallel with the calculation of the correlation. An example of a high correlation ($r=0.44$) fragment is illustrated in Figure 5. Visual detection shows the correlation between UPE and 8-9 Hz.

2. Evaluate for causal ordering. The existence of a causal relationship implies a statistical causal ordering (or a predictive relationship between two time series variables). Although a test for true causality does not exist, it is nevertheless possible to obtain information in terms of one variable predicting the other. Testing for causal ordering is based on the dynamics of the correlation when one data row is shifted over defined time lag periods compared to the other. The causal ordering has been validated by shifting UPE strength (Y-axis) values (Figure 6)

Discussion

The results (especially those of the shuffle test) suggest that significant correlations between UPE and EEG sub-band intensities are present, not based on coincidence. This correlation varied both in strength and even direction. The significant correlations are randomly distributed among the frequency sub-bands. One explanation regarding the fact that not all subjects exhibited significant correlations might be that such correlations are only detectable in subjects with a relatively high UPE (the individuals tested in the summer). Correlation was not dependent on the alpha wave activity.

The analysis for a predictive relationship between the two time series variables has indicated that shifting one data row over defined lag periods compared to the other did decrease the correlation coefficients independent of the direction of shifting. This conclusion was obtained both from data rows that have low and relatively high degrees of correlation. This means that there was no indication regarding a causal relationship. However, one must be very careful. A test for true causality does not exist. Furthermore, data were collected over time periods of 5 s which implies that any causal relationship based on predicting one variable by the other still may be within this time period. When one time series follows the other (predictive) within less than a few seconds, it will not appear with this test.

The direction of the correlation could be different. In 4 recordings, 7-13 Hz alpha wave activity (cortical arousal) decreased when UPE increased. In 4 recordings, alpha activity increased with the increase in UPE. Utilizing smaller fragments of data, the conclusion was close to similar.

Although a small number of positive correlations were observed in overall negatively correlating experiments, this number seems not to exceed the 5% (error) probability level. However, in the few overall positively correlating experiments, the majority of correlations that were observed, even with smaller fragment lengths, were found to be positive (the few negative correlations in these experiments could be easily explained by chance). This indicates that for the duration of an experiment, at least a subject could be either characterized by positive correlations or negative ones. Whether this is a characteristic of the subject, to date, has not been clarified.

Neurophysiologic research has demonstrated that in most individuals, an increase in alpha activity is associated with a feeling of relaxation. However, in some people, underlying tensions may be experienced as soon as relaxation begins (Knox, 1982). Thus, a dual, opposite regulation may exist. More data will be needed to study whether this is related to the observed positive or negative correlations between UPE and alpha wave activity.

The small fragments of relatively high correlations between UPE and alpha wave activity were found over the whole alpha region, not always in the major alpha peak of the subjects. The correlations were also observed in alpha frequency bands above and below the alpha peak. This may indicate that electrical activity in other cortical locations or in higher frequency bands not stored in our spectral data may play a role. However, the focus of this study was on the UPE measurements and included a limited analysis of the EEG.

The two electrodes were placed over strategic (parietal) positions on the scalp. Subjects were awake with eyes closed. An alpha rhythm dominated the posterior where the visual cortex is located. The intention regarding future studies is to measure the EEG over additional scalp positions with hardware and software that stores spectral data with a broader frequency range.

Low level luminescence reflects the production of electronically-excited states in biologic systems. Human UPE, therefore, is a significant biomarker that can facilitate monitoring of human oxidative status. Convincing evidence supports the role of reactive oxygen species due to interactions with DNA, lipids and the misassembly and aggregation of proteins. These physiologic lesions may, ultimately, result in development of chronic diseases such as cancer, atherosclerosis and a number of brain pathologies (see for review: Van Wijk et al., 2008a).

Considering the literature regarding the role of free radicals in disease, much has emphasized "antioxidant" systems that "check and balance" the production of these substances. The repertoire of antioxidant protection constitutes antioxidant, protective enzymes, coenzymes and regenerating metabolic pathways that involve many essential nutrients.

Epidemiological studies have led to increased understanding of negative and positive life style factors (Lesgard et al., 2002; Chalmers et al., 2003). Examples of negative life style factors include smoking, alcohol consumption and exposure to toxic substances such as cadmium and arsenide. All result in high ROS productions. Positive life style factors

including fruits, vegetables or antioxidants have a protective effect regarding a number of pathologies. Meditation as another life habit has also been shown to result in a decrease in the oxidative stress of an organism. Such has been recently documented in humans recording the lower lipid peroxide levels in the plasma of practitioners of TM (Schneider et al., 1998), Zen meditation (Kim et al., 2005) and yoga (Yadav et al., 2005). The data correspond with recordings of UPE in humans utilizing different forms of meditation (Van Wijk et al., 2005c; Van Wijk et al., 2006d; Van Wijk et al., 2008b).

The present study highlights the association between cortical arousal and UPE. Relatively low UPE documented in long-term TM practitioners corresponds to a decreased sympathetic arousal and may facilitate protection from the negative effects of ROS. This may correlate with evidence suggesting that an array of mind-body therapies can be used as effective adjuncts to conventional medical treatments for a number of common clinical conditions (i.e., arthritis, cardiovascular disease, hypertension, asthma, diabetes and psoriasis).

Data in this study also indicate changes in the synchronization of activities between two major systems, electro-cortical activity of the brain (EEG) and ROS (recorded by UPE). They jointly facilitate the connection of mind – body function or dysfunction in health and disease.

To understand the temporary and varying degree of synchronization and coherence, it is necessary to distinguish between two principles governing coordination: absolute and relative (Von Holst, 1939). A tendency of an oscillator maintaining a steady rhythm evolves into totally synchronized movements. This can be understood as states of absolute coordination. In contrast, a weak phase and frequency coupling (“relative coordination”) occurs when systems are neither completely independent nor in a fixed mutual relation. This can evoke into sliding coordination with slowly drifting or sliding phases. This study documents the latter property. It will be interesting to study this phenomenon in more detail utilizing additional correlation fragments.

The data suggest that the human organism can be viewed as a highly complex resonating system of pulsating matter and

oscillating fields coupled to each other by constantly changing synchronizations. The phenomenon of synchronization has been researched addressing various physiologic systems and supports the impression that synchronization is an important organizing principle in biology. The phenomenon has also been labeled coherence, which, then, is understood as synchronized interaction between rhythmically oscillating expressions of systems. Two different types of synchronization / coherence can be distinguished: auto-coherence and cross-coherence.

Auto-coherence refers to synchronization within one physiologic system. Such coherence has been well described for various systems. Thus, the integration of neural processing across spatially separate neural networks has been ascribed to the synchronization of neuronal oscillations (Van der Malsburg, 1981; Varela et al., 1981; Gray & Singer, 1989; Crick & Koch, 1990). Similarly, sympathetic synchronization is the synchronization of the activity of sympathetic nerves leading to different muscles (Wallin et al., 1992; Chang et al., 1999). Furthermore, muscular coherence is the synchronization between motor units in muscles and between different muscles (Kilner et al., 2002; Semmler et al., 2002; Santello & Fuglevand, 2004; Schnitzler et al., 2006).

Cross-coherence considers synchronization between different physiologic systems within one biological subject. Examples of cross-coherence are: cortico-muscular coherence, cardio-respiratory synchronization, visual-motor coherence. Cortico-muscular coherence is the synchronization between motor cortex and musculature (Mima & Hallett, 1999; Mima et al., 2000; Gross et al., 2000; Marsden et al., 2000; Grosse, 2004; Pohja, 2005; Andrykiewics et al., 2007). Somato-sympathetic synchronization is the synchronization of the activity of sympathetic nerves leading to end organs of different physiologic systems (Kocsis et al., 1999; Kamiya et al., 2006). Cardio-respiratory coherence is the synchronization between heart / circulation and breathing (Cysarz et al., 2004; Cysarz & Bussing, 2005). Visual-motor coherence is the synchronization between the visual and

motor systems (Childers & Perry 1971; Classen et al., 1998).

The present data demonstrate a high degree of neuronal auto-coherence across spatially separate neural oscillating networks (P3 and P4). More interesting is the cross-correlation between an oscillating light-producing system and the neuronal field. In fact, the light field is one of the innumerable partial fields that superimpose in a complex way and determine the overall state of the human biofield vis-à-vis their interaction. Within the overall field of the organism, the light field can be relatively independent. In general, in a coherent field, partial fields can dominate different regional states. These partial fields are relatively uncoupled from the state of the overall field. However, the total field does not lose its ability to resume overall control at any time and without delay, if necessary.

Previous studies have demonstrated that long-term meditation has influence over the biophoton field (Van Wijk et al., 2006d; Van Wijk et al., 2008b). This indicates that different states of consciousness may always be coupled to the functional aspect of correlated physiologic states. Thus, states of the human biofields are simultaneously connected both to consciousness and the physiologic states of the body. Using cross-coherence, one should, perhaps in the future, be able to evaluate if all physiologic functions are working with optimal balance.

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