An improvising brain

A neuroscientific investigation within the context of a matriculation project by Paolo Rüegg, 6i

Dedicated to music

I would like to thank most sincerely

Prof. Lutz Jäncke for providing me with equipment and inspiration indispensable to this project

Dr. Jürg Kühnis for having monitored the data collection and for helping me with questions of all sorts

Dipl. Zoologe Marco Lichtsteiner for supervising this project and for helping that everything is the way it should be

My parents for having brought the guitar into my life

Contents

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1. Abstract

Within the context of my matriculation project, I have designed a Single Subject study investigating the neurophysiological correlates of playing musical pieces that are subject to varying practice and hence to varying ability to improvise. Three similar musical pieces in terms of genre and musical complexity have been chosen for examination. They feature different levels of automation of the associated motor functions, ranging from a new, unpracticed piece up to one I have fully mastered. Cortical voltage fluctuations were measured by electroencephalography during musical performance representing the associated neuronal processes. Along the piece I have mastered, I improvised extensively in order to evoke the sought changes. As hypothesized, the inverse solution revealed that musical improvisation leads to a significant increase in the activity of the anterior cingulate cortex. The data imply that improvisation, an acute creative activity, may train the afore-mentioned brain area that is responsible for important creative, emotional and cognitive processes. Likewise, I speculate that improvisation encourages human development on a musical, social and work-related level and should be implemented and promoted in educational systems.

2. Preface

It must have taken me a maximum of a few seconds to realize that I wanted to write a scientific essay involving science and music. Already as a three year old, I developed a special affection towards music. If I recall it correctly, that was about the time I got my first "The Beatles" record. Four years later Id begin playing an instrument; first the acoustic, then the electric guitar. I never let it go ever since – or vice-versa.

Another major part of me that originated way back in my childhood is my scientific vein. My natural curiosity made me accumulate a lot of scientific knowledge via the Internet and the books at home. I liked physics, because it was mind-blowing. I liked chemistry, because it reminded me of the infamous alchemists; but Biology always fascinated the most because I saw it everywhere. Observing the nature from a biological point of view, whether it is its behavior, its development or simply its beauty struck me like few things did beside.

I started this project by simply asking around in my family and friend circles whether somebody knew a neuroscientist or professionals in a related field. Some contacts did not respond, many just declined, but a lot recommended getting in touch with *Prof. Lutz Jäncke*. He is one of the few scientists in Switzerland – well, actually in the world – investigating the relationship between music and our brain.

Upon first contact, he crushed my propositions that I had at the time, which indeed were pretty unrealistic. Nevertheless, he asked me if I played an instrument and why I would not want to conduct an experiment involving me playing. He also recommended the book he wrote '*Macht Musik schlau?'* which I read instantly and inspired me even more. In a short, but very insightful conversation he helped me elaborate my attempts concerning my research and agreed to provide me with the necessary equipment as well as supervision.

It was only three months later that I found out that this opportunity was nothing short of a miracle. First of all, *Prof. Lutz Jäncke* has extremely limited time; in addition to that, the university absorbed all expenses.
I certainly had a lot of luck, but I am also amazed how easy life can be at times. The most banal thing like asking can be the best thing that can happen to you. My mathematics teacher once summed it up beautifully:

"Intelligence doesn't only depend on what you know and can do yourself,
but also on whether you know whom to ask!"

3. Introduction

Everybody knows that practice makes perfect. The more we repeat specific sequences of motions (e.g. speaking) or solve cognitive tasks (e.g. logic problems), the more efficient and accurate we become at doing so. One of the most interesting phenomena in that regard is playing a musical instrument. Every musician has experienced that the practice one devotes to a specific musical piece is positively correlated to the smoothness and ease of the movements (Shadmehr R, Holcomb HH, 1997) and to the quality of the performance in general. By spending more time practicing, which is called motor learning in scientific terms, we gradually play more fluently, with fewer errors and with less cognitive effort. At a very high level of skill we are even able to transcend the boundaries given by the sheet music and improvise along the chord progressions.

It is well known that the processes associated with practicing, playing the instrument and improvising are exclusively directed by the brain. All these activities heavily rely on fine motor memory, also (misleadingly) referred to as muscle memory. The motor functions required when playing an instrument are not simple. In fact, they are complex enough that the brain is forced to structure the sequences hierarchically (Jäncke, L. 2008i). It has to optimize the cognitive effort expended on the coordination of the movements so that the musician is able to reproduce a musical piece flawlessly and without breaks. It does so by us practicing.

The origin of the need for practice lies in the fact that our brain is able to process only a finite amount of information at any given moment. Most people can store seven plus or minus two information 'chunks' in their working memory (Miller G., 1956). For instance, a novice to a musical instrument controls each finger more or less consciously and has to command each one of them separately resulting in a relatively high mental effort. It is clear that practice will increase the novice's abilities, but how?

From a neurobiological point of view, our brain consists of hundreds of billions of neurons that are all interconnected by synapses. Donald Hebb proposed the first and simplest so-called neuronal learning rule[1]:

"When an axon of cell A is near enough to excite a cell B and repeatedly or persistently takes part in firing it, some growth process or metabolic change takes place in one or both cells such that A's efficiency, as one of the cells firing B, is increased." – Donald Hebb

Hebb's rule tells us that repetition of movement sequences (amongst other things) increases the synaptic efficiency in certain brain areas. In other terms: The more skill we acquire regarding a musical piece, the less cognitive effort has to be expended by the brain. By practicing, it consolidates important memories and discards useless knowledge. If our brain saved every bit of information, it would overload utterly, which is true in

[1] Hebb, D.O., 1949

general. The memories for the individual finger movements that existed in early stages of practice are gradually conflated into a superordinate memory. Our brain automates and coheres movements so that they do not overstrain our cognitive capabilities. How these neurobiological processes work is not fully understood yet, but irrelevant for this paper anyway. For the purposes of my research, the salient point is that motor learning is a wiring together of neurons in certain brain areas that is dependent on the amount of practice.

If a musician has mastered a musical piece and hence has minimized the cognitive effort associated, he or she has the possibility to become creative. The unused resources allow the artist to focus on the artistic aspect of the music (Haslinger B. et al., 2004). The most obvious form of immediate artistic activity in that regard is improvisation. Improvisation is a creative activity that combines emotions, technique and spontaneous response to the musical piece resulting in immediate composition (Gorow R., 2002).

Although improvisation is extremely basic to almost every music genre there have only been few studies investigating the phenomenon. Psychologists often couple improvisation to a so-called flow experience, a condition resulting in full immersion, involvement and enjoyment of an activity. From a neuroscientific point of view, however, it is still not clear which brain areas are involved and to what extent improvisation resembles other activities. For my matriculation project I have therefore designed a Single Subject study investigating the relationship of varying practice, and hence varying ability to improvise, to the neurophysiological response of my brain. In essence, the neurophysiological differences between mastered pieces along which I can improvise and new pieces that I have to play note by note were sought. 'Mastering' in this context was defined as a product of the automation accomplished for a specific piece and the abilities that were given in regard to improvisation (ref. to 4.1.2). I represented the only subject having played the guitar for nine years. The neuroscientific data was collected using electroencephalography (EEG) while playing three musical pieces. EEG is a method to measure brain waves during performance of a task. These waves are then correlated to specific behaviors and compared to results of previous studies. Furthermore, using specific algorithms, the neurophysiological origin of a given activity can be approximated (ref. to 4.3.2). The research question for this experiment was posed as follows:

> **What are the neurophysiological correlates of playing musical pieces that are subject to varying practice and hence to varying ability to improvise?**

Current scientific knowledge already covers that improvisation heavily relies on the limbic system (Jäncke, L. 2008ii), which includes a number of cerebral structures that are located towards the middle of the brain. I therefore expected the activation of some of these medial areas to increase the more improvisational abilities were given. The limbic system is mainly responsible for the processing of emotions and should be particularly involved around the cingulate cortex. This region acts as a link between cognitive control centers and the emotional brain areas (Jäncke, L. 2008i), approximately located four centimeters behind the middle of our eyebrows. Also, it has already been established that frontal midline Theta-activity (6-7Hz; ref. to 4.3.1), a specific type of EEG signal, appears in emotionally positive states and states of internalized attention (Aftanas, Golocheikine, 2001); conditions that are often reported by improvising musicians. Incorporating these ideas the following hypothesis was posed:

> *The Theta activity peak induced by playing a musical piece that I have mastered (A) is increased in medial brain areas compared to the ones I have not studied (C) or have not mastered (B).*

3.1 Aims of this study

Since there has been almost no research on the topic up to today, this Single Subject Design experiment is intended as an explorative approach to the field and should lay basis to more extensive Multiple Subject Design studies. Analogous to drilling for oil, on new scientific ground there are always some theoretical estimations and hypotheses involved; however, only an empiric attempt will effectively show whether further effort is worthwhile. In that aspect, this experiment serves as a pilot study. Through my research scientists should be able to construct more specific hypotheses and to investigate whether they are still true for a study with multiple subjects. Please note that this paper does not claim generalizability and the data is only applicable to my brain.

Apart from the purely scientific goals involved here, this study should also be a help to the music community. Improvisation, flow or just the emotional expression of oneself through music is found in all music genres including Blues, Rock, Latin, Indian music, in particular moreover in Jazz. The mere fact that improvisation is met all around the world among music genres that often are not connected in any way tells us that improvisation is innate to music. It allows the musician to immerse in the musical world and to express his or her emotions associated to it. All humans need some sort of emotional expression; otherwise we get frustrated and depressed. Improvisation (or composing for that matter) serves as channel for our emotional self. I want to find out why the shivers run up and down every musician's spine while improvising and where this inspiration and soulfulness originates. Studies like this also have an educational merit by revealing that improvisation enhances the activity of certain brain areas and can result in permanent change of the neurophysiology of our brain. In that regard, this study should again underline the importance of musical improvisation in general.

4. Methods

4.1 Data collection

4.1.1 Electroencephalography

The brain measurements were conducted using electroencephalography (EEG). As already mentioned, our brain consists of hundreds of billions of neurons that are interconnected with each other by an even bigger amount of synapses. A single neuron has a permanent electric resting potential since ionic charges constantly travel in and out of its membrane in closed loops as depicted in *Figure 1*. If this resting potential is substantially changed by an incoming charge through an adjacent synapse, an action potential is initiated. This, however, only occurs when a certain threshold of charge is attained at the trigger zone (also known as axon hillock). If this is the case, the action potential then reaches the dendritic synapses of yet another neuron and triggers the release of a so-called neurotransmitter. Depending on the function of our neuron and the kind of neurotransmitter released, an increase (excitation) or a decrease (inhibition) of the postsynaptic membrane potential is achieved. In simpler terms this means that the firing of the subsequent neuron is either inhibited or excited. Today it is assumed that EEG corresponds to these postsynaptic membrane potentials of all neurons as well as to the dendritic signals of pyramidal cells, a special kind of neuron. It is furthermore important to state that EEG can only measure activity produced by relatively big populations of neurons with the same spatial direction, because they would not reach the electrodes on the scalp otherwise. Please note that this is a very simplified explanation of the origin of the EEG signal. The reader should consult Speckmanns and Elgers excellent overview for more information[2].

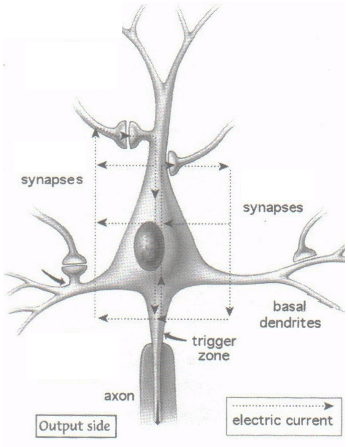

Figure 1: A (pyramidal) neuron is schematized. An action potential is driven in at the synapses and is then transmitted to the trigger zone along the 'charge loops'. It may then send another action potential along its axon.

For my research 32 electrodes were installed on my scalp to measure the cortical voltage fluctuations, which represent the *dependent variable* in my experiment, at a frequency of 5000Hz. The electrode positions are shown in *Figure 2* covering frontal, parietal, temporal and occipital scalp sites, which are the four main subdivisions of the human cerebrum. Their approximate borders should also follow the afore-mentioned figure. Tp9 and Tp10 are two reference electrodes placed on the ear lobes. The EEG measurements are prone to so-called artifacts, which are distortions of the data due to electrical jam sources, but also due to blinking and other muscle contractions. Since the fluctuations occur within the range of microvolts and hence are very fragile a number of variables were controlled to minimize these artifacts:

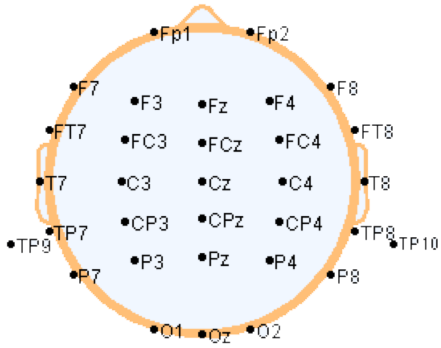

Figure 2: Positions of the 32 electrodes according to the International 10-20 system. Regarding the nomenclature: F = Frontal, P = Parietal, T = Temporal, O = Occipital, C = Central, Even numbers = Right hemisphere, Odd numbers = Left hemisphere, z = Midline of the scalp

Conductance of the scalp

On the day of the measurements I washed my hair with glycerin soap only, because it is a non-oily substance. Usual shampoo and especially conditioner restrain the conductance of the scalp and make it impossible to collect useful data. The conductance was measured and optimized multiple times before starting the experiment using a conducting semi-liquid.

Minimizing of muscle contractions

Preliminary tests allowed me to estimate the distortions arising from muscle contractions. Movements due to playing the instrument are not problematic since manual muscles are quite distant to the head. Cephalic movements on the other hand had to be omitted.

Magnetic fields

All measurements were performed in a Faraday cage. One might object and say that the pickups of the electric guitar produce a magnetic field. This is true; however, it is a static magnetic field and therefore poses no problem. Loudspeakers as from an amplifier on the contrary would severely distort the data due to the dynamic magnetic field created and were replaced by a transistor headphone amplifier.

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[2] Speckmann E., Elger C., 1999

4.1.2 Musical pieces under observation

To ensure maximal comparability of the three musical piece played, I chose similar pieces in respect of genre and structure. All songs best fit the Jazz genre. Although some are accounted to a different musical category in their original performance, the arrangements under observation were very similar. This means that general complexity of the chords, the melody and the difficulty were equalized. However, there were no explicitly identical passages that would have allowed for distortion of the results. I knew all the songs equally well with regard to how they sound on the record. They are listed below while their most important aspects are compiled in *Table 1*. Please note that the musical pieces represent the *independent variable* in the experiment.

A Misty (Erroll Garner) as a representative of a mastered song

I was first confronted with Misty eight months prior to the experiment. I memorized the chord progression in the meantime and learned to improvise extensively along the latter. The highest grade has been given to my performance of Misty at my final music examinations, where I was improvising and accompanying a singer.

In neuroscientific terms:

The automation of the neuronal processes involved with playing the musical piece Misty is very advanced; the chord progression is completely memorized and automated. Hence the subject is able to devote its cognitive resources to improvisation.

B Moon River (Henry Mancini) as a representative of a practiced song

I started to practice Moon River two months before the experiment. By now I know the song more or less by heart, but do not yet reproduce it flawlessly. Improvising along the chord progression is only possible in rudimentary forms.

In neuroscientific terms:

Some neuronal processes have already been automated, but still a lot of cognitive effort is involved in reproducing the piece flawlessly. Mistakes are common i.e. the automation process is still in progress. Improvising is hardly possible as the cognitive resources are highly in use.

C Here, There and Everywhere (The Beatles) as a representative of a 'new' song

I only decided to play this song three days prior to the experiment, not least because the temptation to take a glance at such a nice song is very strong. I have no practice at all, but I know the song well from having heard the record as with the two other songs.

In neuroscientific terms:

The subject has had no previous contact with the musical piece, which in turn means that there are no automated neuronal processes. The ability to improvise along the chord progression is not given at all.

Table 1: Compilation of the most important features of the musical pieces

Musical piece	First contact	Automation	Improvisation	As a representative of a
Misty (Erroll Garner); A	8 months prior to the experiment	Very advanced	Extensive	Mastered song
Moon River (Henry Mancini); B	2 months prior to the experiment	In progress	Rudimentary	Practiced song
Here, There and Everywhere (The Beatles); C	At the day of the experiment	None	None	'New' song

All musical pieces were played on my Gibson CS-365 that was connected to a headphone amplifier. The acoustic feedback was crucial, because neurophysiological changes can only be evoked, when a subject hears what he or she is playing. The guitar part was also recorded in an additional audio channel to enable me to spot discontinuities of the data, which was not necessary fortunately. The guitar produced a clean, non-distorted sound, which is probably best compared to the sound of a bass intensive Jazz guitar. Needless to say, the instrument was tuned and showed no defects that could have inhibited the performance.

4.1.3 Measurements

The measurements took place on the 18th (Preliminary tests) and 19th of July 2013 (Target date). The data was collected in an isolated, fairly small room. As a consequence, no external stimuli were present. This means that there were no distractions or disturbances such as noises or rapidly changing lighting conditions. It goes without saying that there were no interruptions during the measurements.

I did not take any drugs as late as 48 hours prior to the experiment. Furthermore, I avoided consume of caffeine that acts as an antagonist of the adenosine receptors in the brain and could have distorted the data. I consumed a balanced diet and felt well on the target date. My general health is excellent: I am lucky not to suffer from any noteworthy physical or psychical impairment. The procedure of the measurements was set as listed in *Table 2* and was digitally logged using markers in the recording software.

Table 2: Order, type and duration of measurements

Name of measurement	Type of measurement	Activity	Duration / minutes
Pre	Control	Eyes open (EO)	5
		Eyes closed (EC)	5
		Cognitive task (Cog)	5
C	Baseline	Eyes open (EO)	5
	Playing	Play	30
B	Baseline	Eyes open (EO)	5
	Playing	Play	30
A	Baseline	Eyes open (EO)	5
	Playing	Play	30
Post	Control	Eyes open (EO)	5
		Eyes closed (EC)	5
		Cognitive task (Cog)	5

The measurements during performance were set to 30 minutes per musical piece. This decision arose due to the fact that neurophysiological changes need some time to take effect. Still, undergoing longer measurements would have increased the danger of making me drowsy and distracted, which in turn would have falsified the data.

In addition to the measurements while playing, control experiments previous to and after the playing the musical pieces were performed. In this way potential differences in the resting state before and after the experiment due to an ongoing impact of the playing could be spotted. The three different conditions (EO, EC, Cog) should ensure that no changes in different activities have taken place over the course of the experiment. Since it was not possible to eliminate this danger, I furthermore performed baseline measurements before playing any song to ensure a reference. If the resting conditions however did not differ significantly before and after the experiment, they would not be used for further analysis.

In total, 3 gigabytes (3'000'000'000 data points) of raw EEG data were collected, which is a lot to process computationally. There were no problems during the measurements and also the conductance of the electrodes remained stable. An impression of the procedure is given in *Figure 3*.

Figure 3: Playing the guitar while measuring cortical voltage fluctuations using the EEG-system. The guitar was connected to a headphone amplifier and the sheet music has been attached to the wall.

4.2 Data preprocessing

The original EEG-signal is quite useless. There are a lot of artifacts due to blinking and eye saccades that simply cannot be prevented as depicted in *Figure 4*. Therefore all serious EEG studies begin with an intense preprocessing of the data. The steps are compiled on the next page.

1.) *Filtering*

The data was first filtered from 1 to 30 Hz, since neuronal activity for the purposes of this experiment did not exceed these values. In this way, activity due to electrical jam sources was removed for instance.

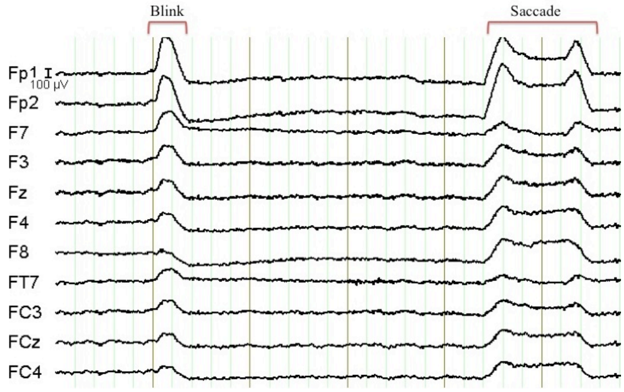


Figure 4: An excerpt of the filtered (1-30Hz) data for the musical piece B showing artifacts due to blinking and saccades. We can observe that eye movements have an impact on both near (Fp1) and far (e.g. FC3) electrodes

2.) *ICA (Independent Component Analysis) and invICA*

To eliminate the blinking and the saccades a so-called ICA (Jung et al., 2000) was run over all the datasets. This is a multivariate statistics method that relies on extremely complicated algorithms, which will not be explained here. ICA basically works out what we do everyday; it recovers a distinct source from a mix of data. The principle is equivalent to when we have to focus on a person that is speaking although others may be talking at equal volume. Similarly, we want to recover the eye movements from the data. ICA does so by computing all EEG-signals into factors. These factors represent sources of which some are linked to blinking and saccades, which are then discarded. Finally, the inverse solution of the reduced number of factors is recomputed onto the 32 electrodes (invICA). The big merit of this step is depicted in *Figure 5*.

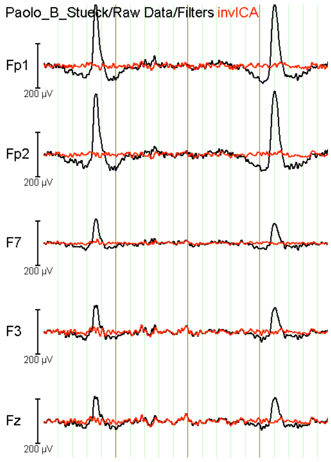


Figure 5: An excerpt of an EO session showing the signal before (black) and after (red) ICA.

3.) *Sorting of the data*

This rather simple step consisted of cutting the data in sections by means of markers that were set during the measurements.

4.) *Segmentation and artifact rejection*

The data was segmented into observations of four seconds length. This step was of use for the following artifact rejection, where the software filtered the data for certain anomalies. Three conditions were checked, the first one being the maximal allowed voltage steps per millisecond (50µV) i.e. the gradient of the wave. Secondly, differences of values after an interval of 200ms that exceed relative ±200µV were detected. At last, the amplitude of the signal was checked and must not lie out of the absolute ±200µV spectrum. Two percent of the data did not pass these conditions; the corresponding segments were excluded. The important EEG signals were now crystallized.

4.3 Data processing

Fast Fourier Transformation (FFT) and averaging

Fourier transformation is the basis to all modern EEG studies. It is hard, basically impossible, to get a deep understanding of the significance of a raw EEG-wave. Mr. Fourier, a phenomenal French mathematician, has fortunately worked out a number of mathematical formulae to 'twist' such functions. As every student should know, a wave is determined by its frequency, phase and amplitude. Instead of plotting the time on the x-axis as in the previous two figures, we now plot the frequency there. The mechanism is visualized in *Figure 6*; its practical application can be observed in *Figure 8*. By doing so, we admittedly lose the time information provided by EEG, however we have a more neatly arranged figure. Since discrete Fourier transformation, the mathematically elegant and exact way, is computationally very demanding for big amounts of data, a much faster algorithm was programmed. Fast Fourier Transformation (FFT) (Cooley and Tukey, 1965) is over 50'000 times faster for a million data points (Freeman, Quiroga, 2013). After FFT has been performed on all segments for all electrodes, they were averaged so that we end up with one figure for each electrode per measurement.

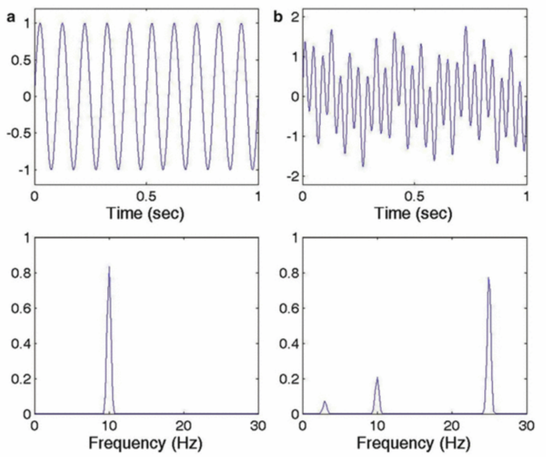


Figure 6: Two examples of Fourier transformation are shown for a sinusoidal signal (a) and in for a more complex wave (b). The upper figure shows the amplitude over time, the lower its frequency components.

4.3.1 Frequency analysis[3]

Before proceeding to the results section, an introduction to frequency analysis is necessary. The Theta-band, which is of special interest to this study, has already been mentioned in the hypothesis. It is a specific domain in the frequency range covered by EEG. Already early in the history of EEG, scientists have realized that certain frequencies of waves are correlated to certain stimuli. They have divided the frequency spectrum of approximately 1 to 60Hz mainly due to their functions and localization. Frequency analysis looks at the distribution of these so-called frequency bands and is by far the most used method to quantify EEG signals. The data from the FFT is commonly also projected onto scalp maps showing the cortical distribution of a certain frequency in a process called band mapping (*Figure 11)*. A rough overview of the frequency bands and their characteristics in healthy humans is given as follows:

Delta band (0.5 – 3.5Hz)

Delta activity is typically found during deep sleep stages and shows high amplitudes. Depending on where they occur and how they behave, they can either be normal or pathological as in brain tumors.

Theta band (3.5 – 7.5Hz)

Theta activity also occurs during deep sleep. In children, it is an indicator for pleasurable stimuli. As an example, a study with a 9-month-old girl revealed that the Theta activity spiked when she was kissed by her mother (Maulsby, 1971). In adults, high Theta activity throughout the brain is considered abnormal. Interestingly, Theta activity over the frontal midline region at 6 to 7 Hz has often been correlated with mental activities such as problem solving. It has also been associated with emotionally positive states and internalized attention (with simultaneous decline of Alpha activity) (Aftanas, Golocheikine, 2001) and creative, meditative states in general.

Alpha band (7.5 – 12.5Hz)

Alpha rhythms are enhanced upon relaxation and mental inactivity. They are best evoked by closing the eyes and are most pronounced in occipital regions. Alpha activity is also correlated with the menstrual cycle for instance.

Beta activity (12.5 – 30Hz)

Beta activity appears during mental calculations and active concentration. The rhythms are most pronounced in central and frontal locations and show lower amplitudes than alpha waves.

Gamma activity (>30Hz)

Fast frequencies are very low in amplitude, which makes them hard to analyze properly. Gamma waves are thought to represent the amount of connections between neuronal populations and hence reflect the formation of neuronal networks (Kaiser, J., Lutzenberger, W., 2003).

4.3.2 The inverse problem

Further cognitive resources shall now be expended on a problem surrounding electroencephalography. Since EEG only provides information about voltage fluctuations on the scalp, we gain no direct implications on what brain areas are activated. This dilemma arises due to the fact that two EEG waves can annihilate their signals without ever reaching the scalp. This microscopic example demonstrates that certain activity physically cannot be recorded by EEG. This makes determining the source of the signal somewhat problematic and has been titled 'the inverse problem'. However, given that a sufficient quantity of data is provided, we are able to approximate the areas that are involved nowadays. The most efficient and accurate mechanism is called LORETA (Pascual-Marqui, R.D., 1994). Its accuracy in comparison to fMRI is depicted in *Figure 7*. We can observe the strong similarities between the glucose metabolism as measured by fMRI and the source of the electrical signals approximated by LORETA. This mechanism has been developed at the University of Zürich and is a standard method today. The concrete usage for my experiment is to identify the brain area(s) responsible for improvisation and hence to lay basis for the discussion of the results.

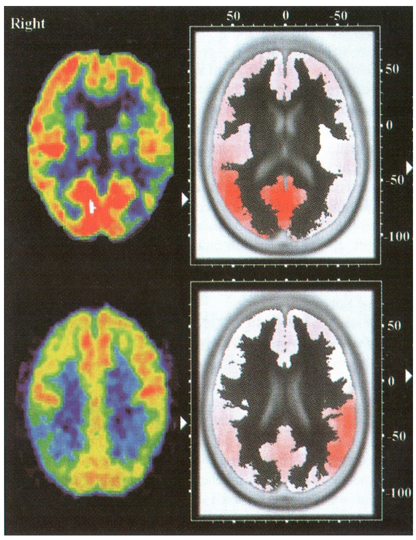


Figure 7: A comparison between LORETA (right) and the glucose metabolism of the brain provided by fMRI (left).

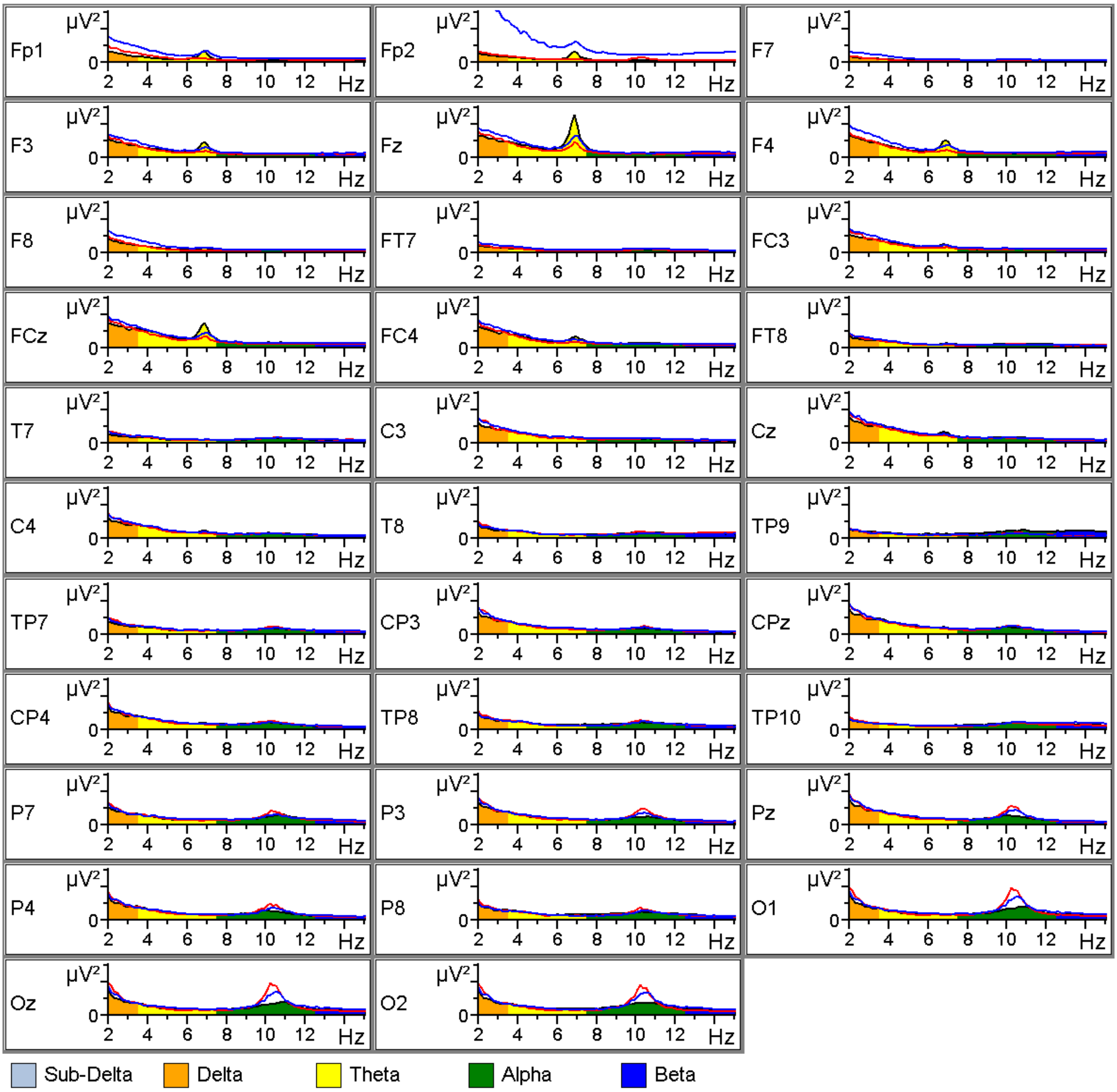
[3] Freeman W., Quiroga R., 2013 and Niedermeyer E., 1993

5. Results

5.1 Setting of focus

In regard to my hypothesis and to the amount of data collected, it is vital to set a clear focus on a target area as early as possible in the process of analysis; namely already in the process of showing the results. The rest of the preprocessed and visualized data can be retrieved in the *8. Appendix* section. As stated in the hypothesis, the behavior of Theta activity in medial brain regions during improvisation (A) is in the spotlight. Thus, the averaged FFT of the three datasets A (460 segments), B (448 segments) and C (472 segments) were compared as depicted in *Figure 8*. The figure clearly implies that the Fz electrode is best suited for further examination. First of all, its position (ref. to *Figure 2*) is in agreement with the sought brain areas. Secondly, we see that the Theta peak at the Fz electrode and its surrounding (F3, F4, FCz) is of most significance. Anomalies include the behavior of Fp2 in dataset C that is most likely due to an error in data collection. The otherwise so similar behavior of B and C makes a cerebral origin of the Fp2 electrode (of C) too disproportionate. The varying alpha band peaks at Oz, O1 and O2 are addressed in *6. Discussion.*

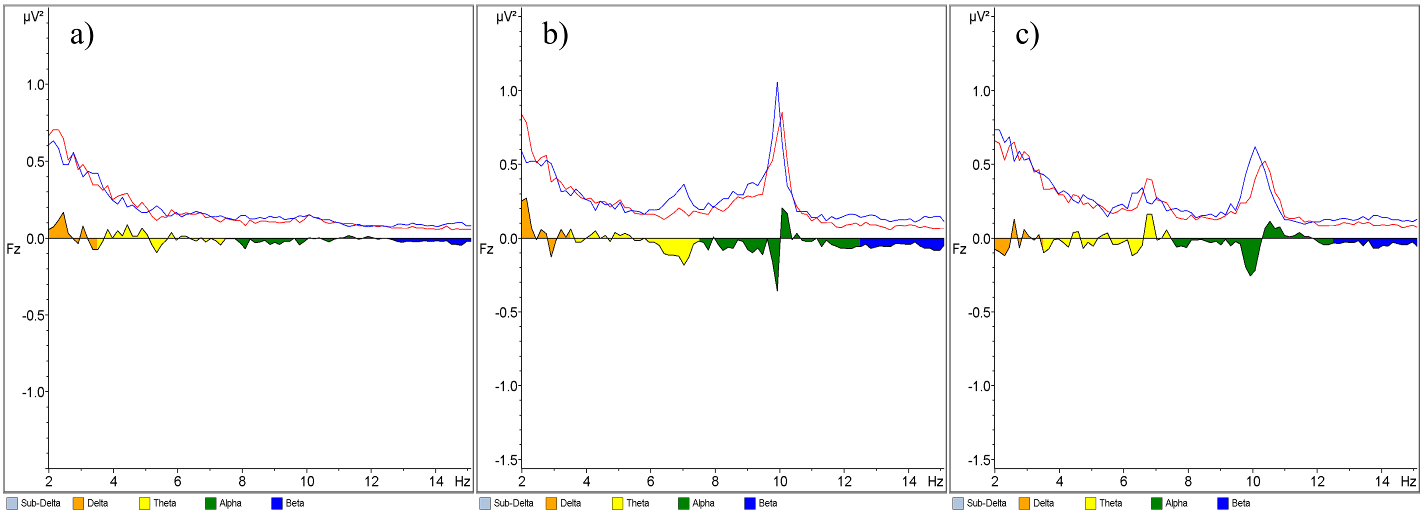
Figure 8: Averaged FFT performed over data sets A (black and colored below; 460 segments), B (red; 448 segments) and C (blue; 472 segments) showing the frequency distribution of the EEG signals on the x-axis and the squared voltage fluctuations on the y-axis. Each vertical tick mark corresponds to 0.5 μV^2



5.2 Control experiments regarding the Fz electrode

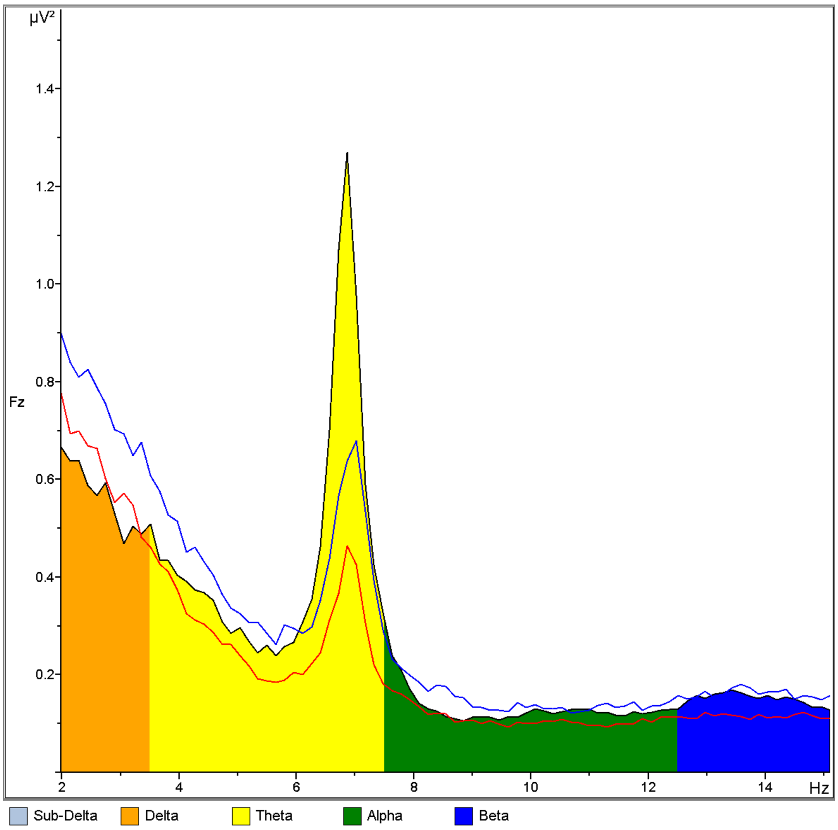
Previous to closer analysis of the frontocentral scalp site, the reliability of the data had to be verified. The results of the Pre and Post measurements in the target area were visualized in *Figure 9.* As we can observe, all curves behave clearly alike making the data reliable and resilient. A minor exception may be found in b), where a slightly higher Theta activity in the target area occurred after the experiment. Since this difference, however, is in no way severe or even significant, I decided not to analyze the baseline measurements. Their analysis would be redundant knowing that a constant reference is present. Please note that minimally varying peaks as seen for instance in b) or c) at 10Hz result in a somewhat misleading graphical representation of the differences. Although the peaks of the two datasets are almost alike, their slight difference in position on the x-axis creates a disproportionate impression of the overall similarity. This phenomenon is also to be seen in the Appendix and is not a sign of unreliability, but rather of the limitations of the representation.

Figure 9: Differences in activity between the Pre (red) and Post (blue) measurements at the Fz-electrode. a) shows eyes open, b) shows eyes closed and c) shows the cognitive task. The y-axis shows the activity in μV^2 while the x-axis shows the frequency bands.



5.3 Comparison of the three datasets in the target area

Figure 10: Averaged FFT for musical pieces A (black and dyed below), B (red) and C (blue) showing distinct differences in the height of the Theta-peak at the Fz-electrode.

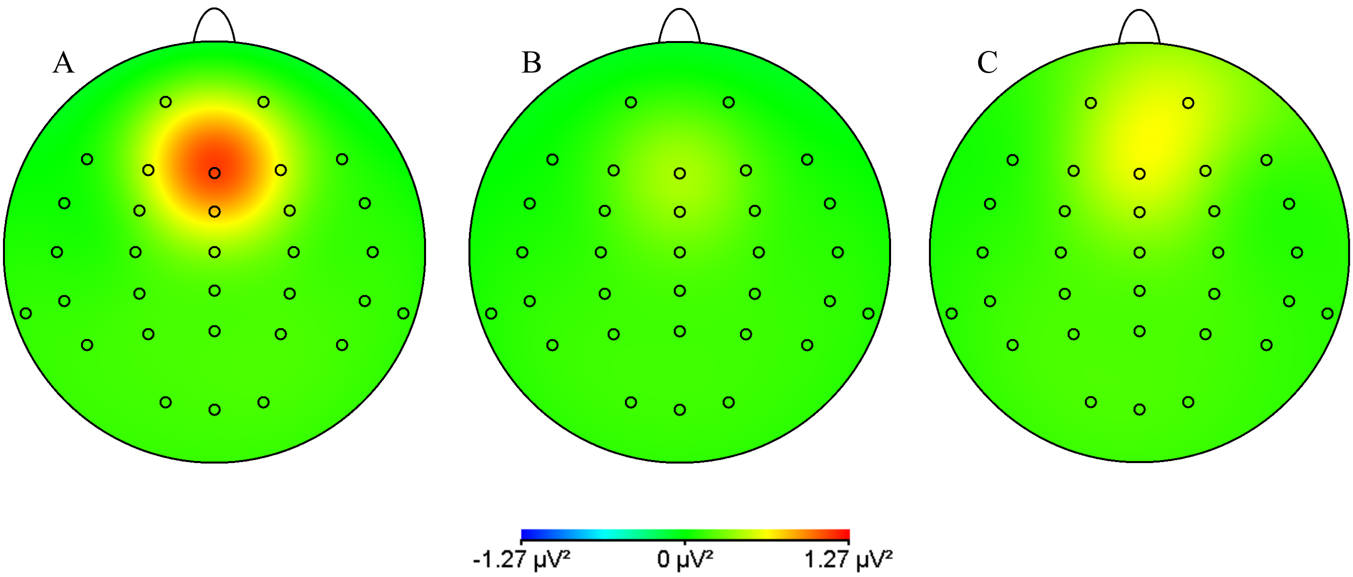


Having established that the control experiments were successful, the focus will now lie on the relationship of the three pieces to each other. I plotted the averaged FFT (of the Fz electrode) for all three musical pieces in *Figure 10.* We can clearly observe that the Theta activity generated by improvising along a mastered piece is much higher than when playing note for note (B) or learning a new piece (C). Interestingly, the unpracticed, 'new' musical piece induced more Theta-activity than B. Still, we observe that all three pieces induced the same peak at the frequency of 6.866 Hz.

Two-tailed t-tests for the difference between A and C and between B and C have been performed at the peak frequency of 6.866Hz. Equal variance and thus standard deviation was assumed, which is done by default since the spread of EEG data usually does not vary significantly. Since I tested three musical pieces against one another the general significance level of $\alpha = 0.05$ had to be multiplied by $1 \,/\, (n\_1 + n\_2\,)$ according to the Bonferroni method, where n_1 and n_2 represent the number of segments (or observations) per data set. This resulted in $\alpha = 0.000055$ (rounded) for both t-tests. There are exactly $n\_1 + n\_2 - 2$ degrees of freedom per test which adds up to 908 degrees of freedom for A vs. C and 894 degrees of freedom for B vs. C. It has been found that the peak of A is significant ($p < 0.000055$) in comparison to the peaks induced by the other two songs showing a t-value of 6.93. On the other hand, a statistically insignificant difference ($p > 0.000055$) between the peaks of B and C was established showing a corresponding t-value of 2.88.

To better illustrate and further analyze the differences in activity produced by the musical pieces, topographical maps of the scalp were computed for all three musical pieces as depicted in *Figure 11*. First of all, we see once again that A has clearly induced the most Theta-activity compared to the other two songs. It becomes apparent that the distribution of the target frequency regarding A is of a concentrated and local nature and not result of widely dispersed activity across the scalp. These data strongly suggest that the source of the signal is coming from one brain area. C on the other hand shows only rudiments of this phenomenon, while B created no considerable activity. In addition, we observe that in C the activation is smeared towards the electrode Fp2 that has collected erroneous data (ref. *Figure 8*).

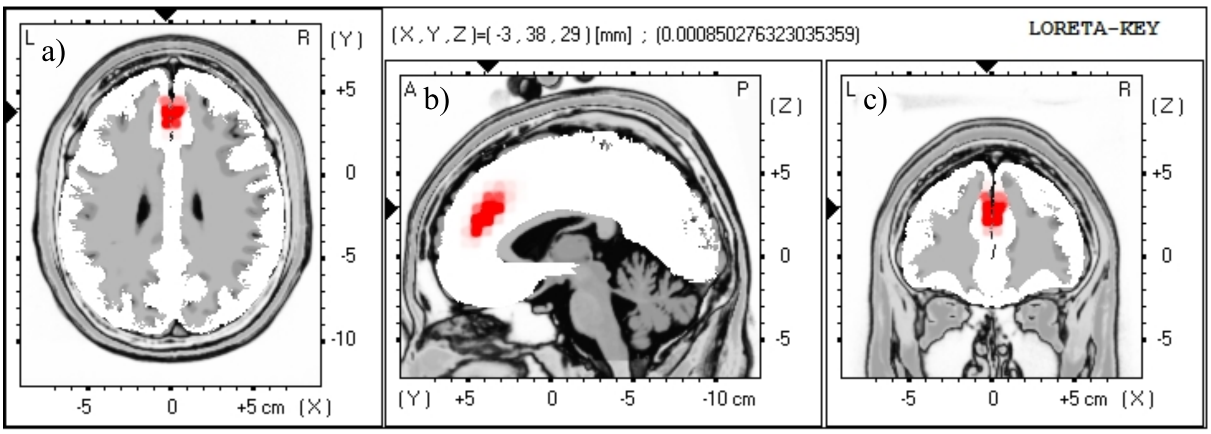
Figure 11: Topographical maps based on *Figure 10* showing the cortical distribution of activity at the peak frequency of 6.866 Hz for the musical pieces A, B and C. The colors indicate the absolute activity induced in μV^2.



5.4 The inverse solution

Using LORETA, an inverse solution (*Figure 12)* was computed for data set A in order to localize the cerebral structure that has generated the concentrated Theta-activity. The software identified the responsible brain area as the anterior cingulate cortex (ACC) that has already been mentioned in the introduction. a) and c) show well that the ACC is a medial structure that covers both left and right hemispheres.

Figure 12: The inverse solution of Figure 10 approximating the origin of the Theta-activity (6.886Hz). The responsible brain area has been projected onto transversal (a), sagittal (b) and coronal (c) sectional planes and has been identified as the anterior cingulate cortex (ACC).



6. Discussion

6.1 Conclusions

Due to the phenomenal results acquired, a number of conclusions in agreement to the hypothesis and beyond can be drawn. First of all the hypothesis as posed in the introduction is recapitulated below:

> *The Theta activity peak induced by playing a musical piece that I have mastered (A) is increased in medial brain areas compared to the ones I have not studied (C) or have not mastered (B).*

Both the figures as well as statistical computations have shown that a significant difference in the Theta activity exists; namely between mastered pieces along which I can improvise and pieces I have not studied (A vs. C) and pieces along which I cannot improvise (A vs. B), respectively. Also by means of the location of the sought activity, pleasurable conclusions can be drawn. The data have revealed that the Theta activity during improvisation occurs clustered at the frontocentral scalp site (Fz electrode), suggesting a medial origin of the targeted activity. The low spread of the distribution of the Theta activity or, in other terms, its concentrated nature indicates a single source of the EEG. By computing the inverse solution of the data, the responsible brain area was identified as the anterior cingulate cortex (ACC). In that regard, the hypothesis can be fully accepted.

At this point it makes sense to incorporate previous findings about the function of the ACC that will help me explain anomalies and underline my hypothesis. As highlighted in *Figure 13* we see that the frontal part of the Cingulate gyrus wraps around the Corpus callosum like a collar. The whole Cingulate gyrus is accounted to the limbic system that has already been mentioned in the introduction. In general, this system is involved in functions including processing of emotions, maintaining the sex drive, long-term memory and others. Still, it is crucial to state in that aspect that the structures constituting the limbic system are independent on one another; they only share similar functional characteristics, as they are all responsible for instinctive behaviors and emotions.

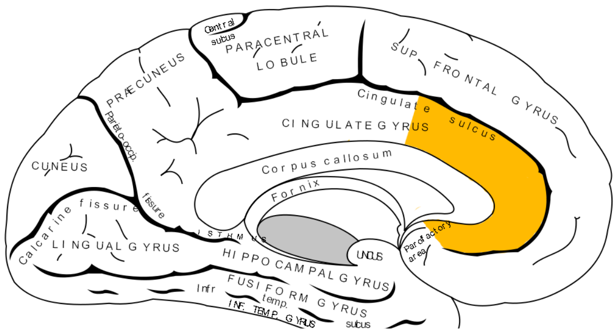


Figure 13: A schematic depiction of the brain showing various brain areas the anterior cingulate cortex (ACC) is highlighted.

The ACC has some very interesting properties. On a cellular level for instance, it is the only cerebral structure that contains spindle cells, a specialized form of neurons that only occur in humans and great apes. They are widely connected to diverse areas of the brain and are thought to coordinate these areas in order to achieve self-control and the ability to focus on difficult problems (Allman J. et al., 2001). Furthermore, the ACC shows one of the richest dopaminergic innervations (density of nerves) of all brain structures (Gaspar P. et al., 1989). Dopamine is an important neurotransmitter and is called 'happiness hormone' in common parlance, which should be a self-explanatory term. In monkeys, it has been proven that the dopaminergic pathways are activated when the animal receives a reward or a signal associated with it (Schultz, W., 1998). In humans there is also strong evidence that the dopamine levels in the ACC are reward-related (Kuenig G. et al., 1999) and drop immediately when a reward is not received. It is hence indicated that the ACC monitors performance and reward to optimize payoff (Allman J. et al., 2001). In regard to my research it is thus strongly implied that improvisation can be seen as a form of reward in that it extends and completes the musical performance. If it is not maintained, the activity should cease immediately. Likewise, the dopamine levels to be found in the ACC during improvisation would be a very interesting research topic.

Already previous to my experiment the ACC has been identified as the source of a 4 to 7 Hz EEG signal during a task requiring focused concentration (Gevins, A. et al., 1997), which increased with task difficulty. The latter has also been proven by functional imagining studies. It has been found that the activation of the ACC is linked to focused mental effort. In regard to improvisation these findings again make complete sense. The task difficulty during improvisation is constantly high as it is not subject to practice; hence focused effort is necessary to maintain the performance. As soon as the test persons however have automated the task, the activation vanished. In that regard, the lower Theta activity induced by B makes sense.

The ACC is furthermore activated when one feels well and untroubled. It has been found that when the subject is anxious or restless the ACC was inactivated (Suetsugi, M. et al., 2000). Also, there is strong evidence that its activation occurs during meditative and creative stages (Gruzelier, J., 2009). The subsequent conclusion paired with my findings is that improvisation lowers anxiety and acts as a source of creativity.

Lastly, I would like to shed light on an interesting aspect of my data. The previous study has also coupled the afore-mentioned states with decline in Alpha activity. If we take a look again at *Figure 8* we clearly see the decline in Alpha activity in occipital regions. This ratio between Theta and Alpha activity may be a useful tool to evaluate the amount of creativity or focused attention that is involved with a certain task. In conclusion, we see that my hypothesis can be accepted and that my data fully harmonizes with previous findings.

6.2 Implications of this study

Improvisation is crucial. We have seen that improvising along a certain musical piece induces activity that could have never been attained had I just reproduced the piece. In a world we live in today, where the youth in particular is utterly overloaded by stimuli from TV or video games, the act of being creative slowly vanishes. However, this does not mean that creativity is not demanded anymore. In fact, it is more valuable than ever before. In the work world, during social interactions or in any other life situation: Immediate adaption to a situation and producing something oneself is key to human intelligence.

This study should encourage young people in particular to be creative and to insist on this right. Likewise, educators and music teachers must more intensely incorporate improvisation in school. It is not surprising that a lot of children stop playing an instrument when their own creativity is fully oppressed. Continuous practice of the same piece for months resembles a Sisyphean task and is not healthy for both the child's musical and human development. Only by allowing the youth to express itself through an instrument rather than impairing their abilities, the motivation and musical knowledge will augment. I do not want to get personal here, but were it not for improvisation, I had stopped playing the guitar years ago.

The life of young persons is shaped by a lot of momentous experiences such as love, problems at home, identity crises et cetera. Improvisation and composition for that matter does not only advance our creative abilities, but also our personal strengths. We learn to express our emotions and cope with severe experiences rather than hiding them. For more people than one thinks, interpersonal emotional expression represents a difficult topic. As an example, people who stammer during speech sing beautifully and self-confidently all the same. It becomes apparent that musical communication facilitates the expression of emotions. Likewise, improvisation can act as an emotional channel in good times as in bad.

Of course, musical activity in general is also encouraged by this study. From a neurophysiological point of view, I speculate that professional musicians will achieve a significantly higher activation of the ACC. With increasing ability to improvise, we hence also strengthen our creativity and problem solving skills. The art of improvising is not only applicable to music, but also to the work world and other fields.

Prof. Lutz Jäncke uses a fitting example in his book '*Macht Musik schlau?*' to describe the value of creativity. Suppose a new professor is sought to enhance the reputation of whichever faculty. Amongst the candidates one shows particular social abilities, the other one has a perfect memory, while the third is creative and known to strike new paths. Exactly in situations like the described one, which are not solvable with routine methods but require innovative approaches, the ones who are able to think freely and act creatively have a huge advantage. Likewise, the third candidate probably has the best chances of getting the job. Be it Isaac Newton, Ludwig van Beethoven or Miles Davis: It was the ones thinking outside the box that revolutionized the world.

6.3 Reflection and evaluation

In all honesty, this matriculation project restored my hopes in the Swiss educational system. As with improvisation, the most effective and momentous learning processes are accomplished by giving the student freedom. Similarly, this was without doubt the best educational experience I have made during my six years of gymnasium. Finally, I find that crucial abilities were demanded that are insufficiently encouraged in normal class. Students could combine their creativity, motivation and academic knowledge in order to create a product transcending the usual requirements. My impression of this particular project is that it turned out very well. I even feel a spark of pride as I have learned far more than just academic matter.

Of course, there are still some improvements that could be made such as a more scientific determination of the degree of automation and improvisational abilities involved with a musical piece. This should have included learning all pieces under observation solely for the purpose of this study in order to effectively monitor the progress and the associated abilities. If it had not been for the limitations regarding the time available for measurements, moreover, more musical pieces should have been investigated to reinforce the significance of the findings. Also, some sort of post-rating after each performance by means of self-evaluating mental states during improvisation would have been beneficial. In this way I could have linked neurophysiological data to psychological findings regarding the flow experience in particular. Furthermore, It would have been interesting to play a mastered piece without improvising and then compare it to the improvised performance. Last but not least, repeating the measurements over a long period is key to all scientific investigations and would have hugely strengthened the results. In total, however, I find that I made a lot of the time and means I was given.

For a future Multiple Subject Study, I suggest taking into account the afore-mentioned weaknesses and suggestions. Evidence from EEG studies should naturally be backed up and expanded by fMRI studies, given that some technical problems surrounding musical performance in the scanner can be overcome. Other interesting findings could arise from lesion studies investigating potential improvisational impairments that the affected people suffer. Finally, crucial factors such as dopamine levels during improvisation could be investigated using positron emission tomography. The accomplishment of this research has been an unparalleled pleasure from start to finish. If this paper delivers any message, which can be doubted, it would go as follows.

“Life is a lot like Jazz… It’s best when you improvise”
– George Gershwin

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7.2 Pictures and software

Figure 1 and 6 taken from:

Freeman W., Quiroga R. (2013). Imaging Brain Function With EEG: Advanced Temporal and Spatial Analysis of Electroencephalographic Signals. New York: Springer Science+Business Media

Figure 2 was produced using:

MATLAB and Statistics Toolbox Release 2012b, The MathWorks, Inc., Natick, Massachusetts, United States.

Figure 7 taken from:

Dierks T. (2005). Funktionelle Bildgebung in Psychiatrie und Psychotherapie. Stuttgart: Schattauer GmbH

Figure 8 taken from:

"Anterior cingulate cortex" Wikipedia: The Free Encyclopedia. Wikimedia foundation, Inc. Retrieved on 06.10. 2013, http://en.wikipedia.org/wiki/Anterior_cingulate_cortex

All figures except for Figure 12 as well as all data preprocessing and processing was performed using:

Brain vision Analyzer 2, Brain Products GmbH, Gilching, Germany.

Figure 12 was produced using LORETA:

Pascual-Marqui RD, Michel CM, Lehmann D. Low resolution electromagnetic tomography: a new method for localizing electrical activity in the brain. International Journal of Psychophysiology 1994, 18:49-65.

The whole document was written and designed using Microsoft © Word for Mac 2011

8. Appendix

8.1 Preprocessed and visualized data

8.1.1 Control experiments

Figure 14: Differences in the averaged FFT between the Pre (red) and Post (blue) measurements of all electrodes for the eyes open (EO) condition. Each vertical tickmark corresponds to one squared microvolt.

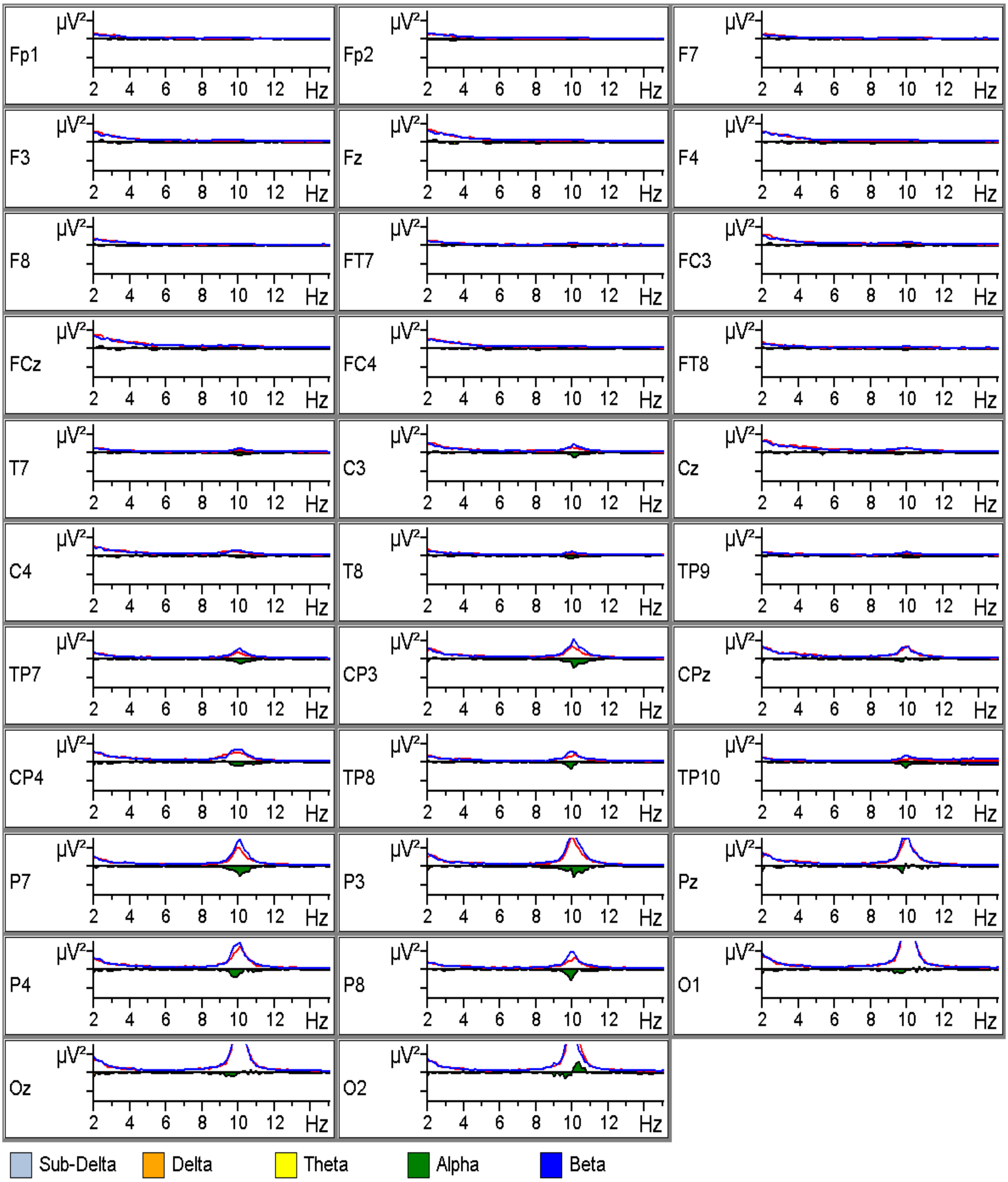


Figure 15: Differences in the averaged FFT between the Pre (red) and Post (blue) measurements of all electrodes for the eyes closed (EC) condition. Each vertical tickmark corresponds to one squared microvolt.

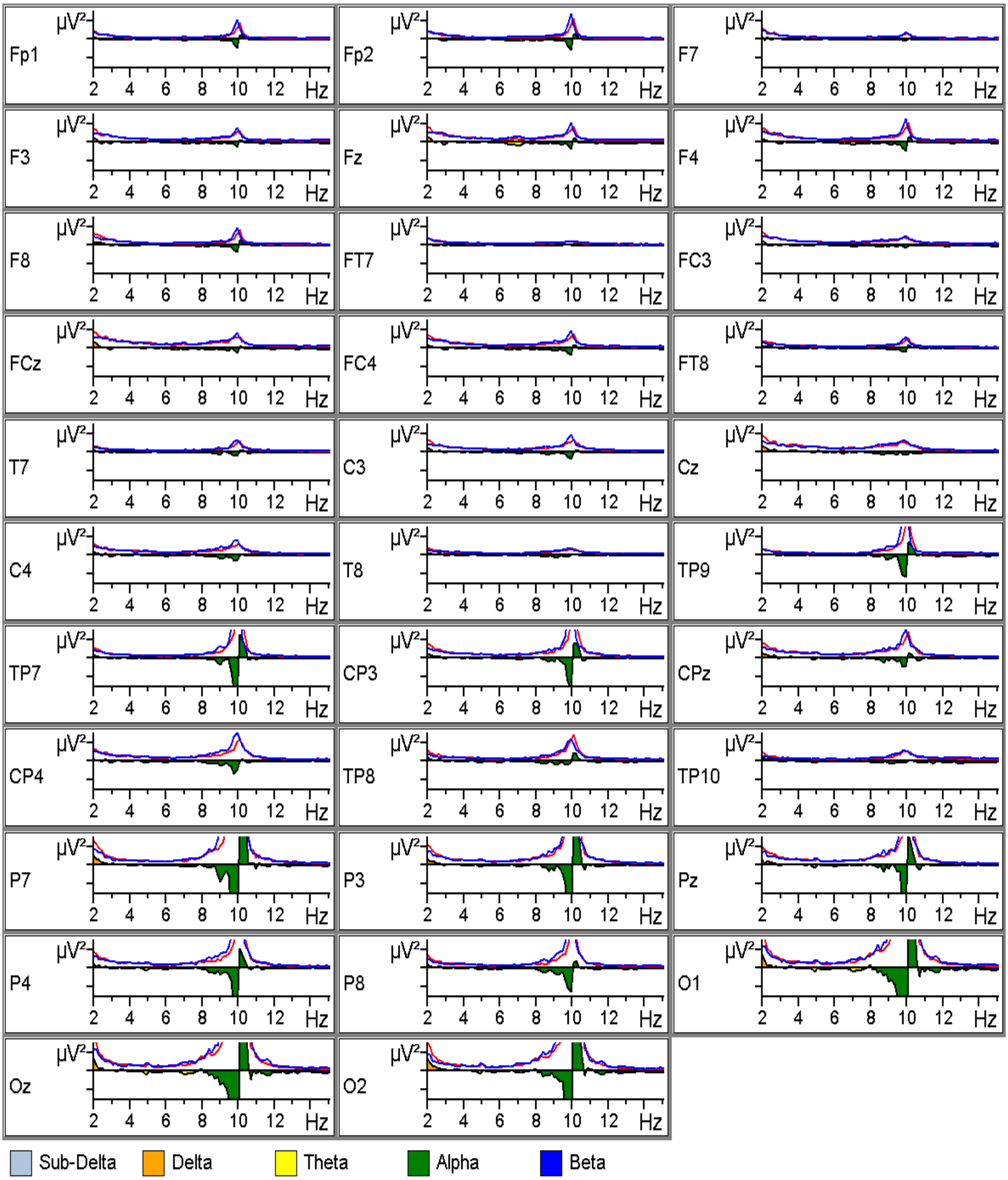
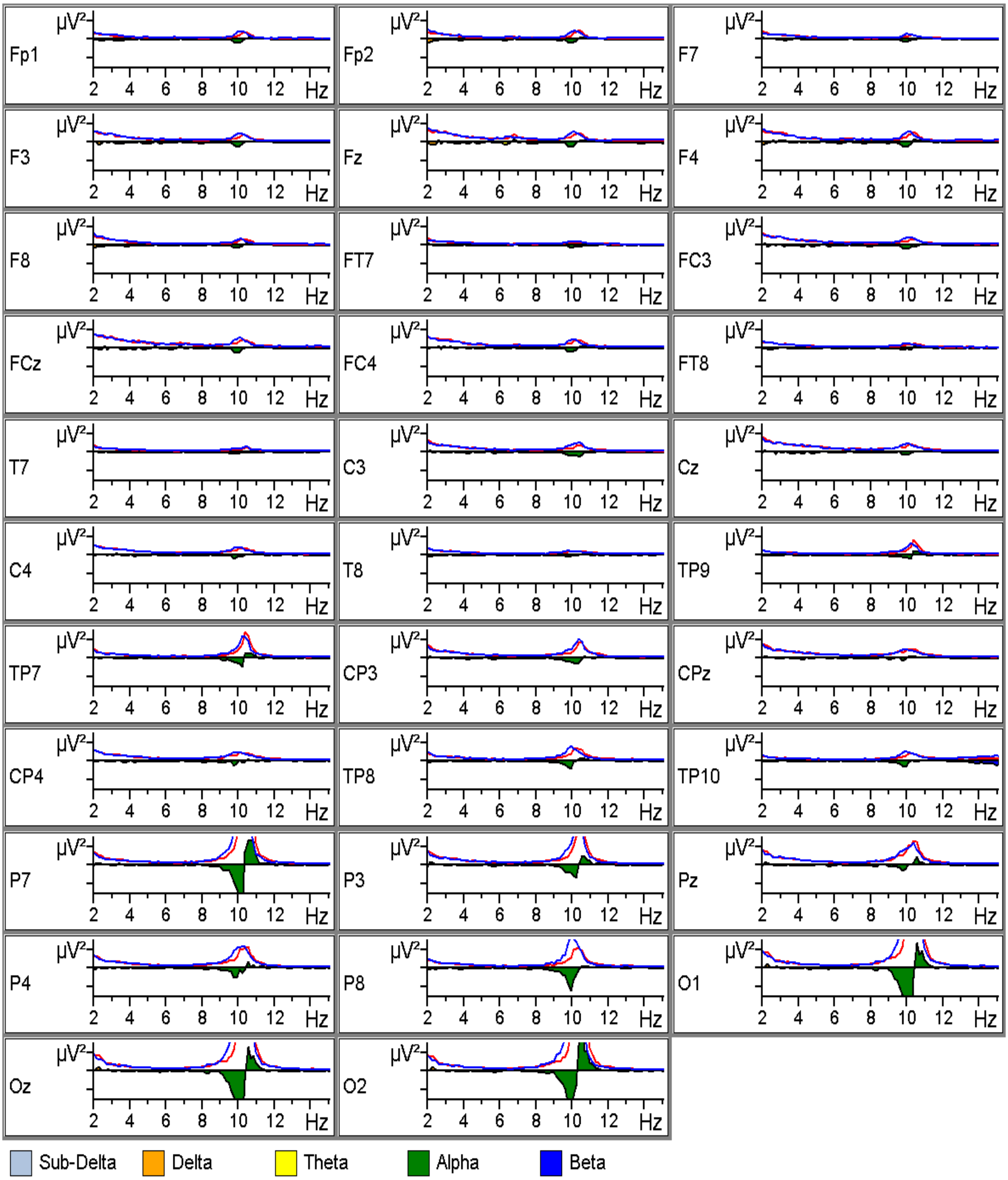


Figure 16: Differences in the averaged FFT between the Pre (red) and Post (blue) measurements of all electrodes for the cognitive task (Cog) condition. Each vertical tickmark corresponds to one squared microvolt.



8.1.2 Measurements during performance

Figure 17: Averaged FFT performed over data set A showing the frequency distribution of the EEG-waves on the x-axis and the squared voltage fluctuations on the y-axis. Each vertical tick mark corresponds to 0.5 μV^2

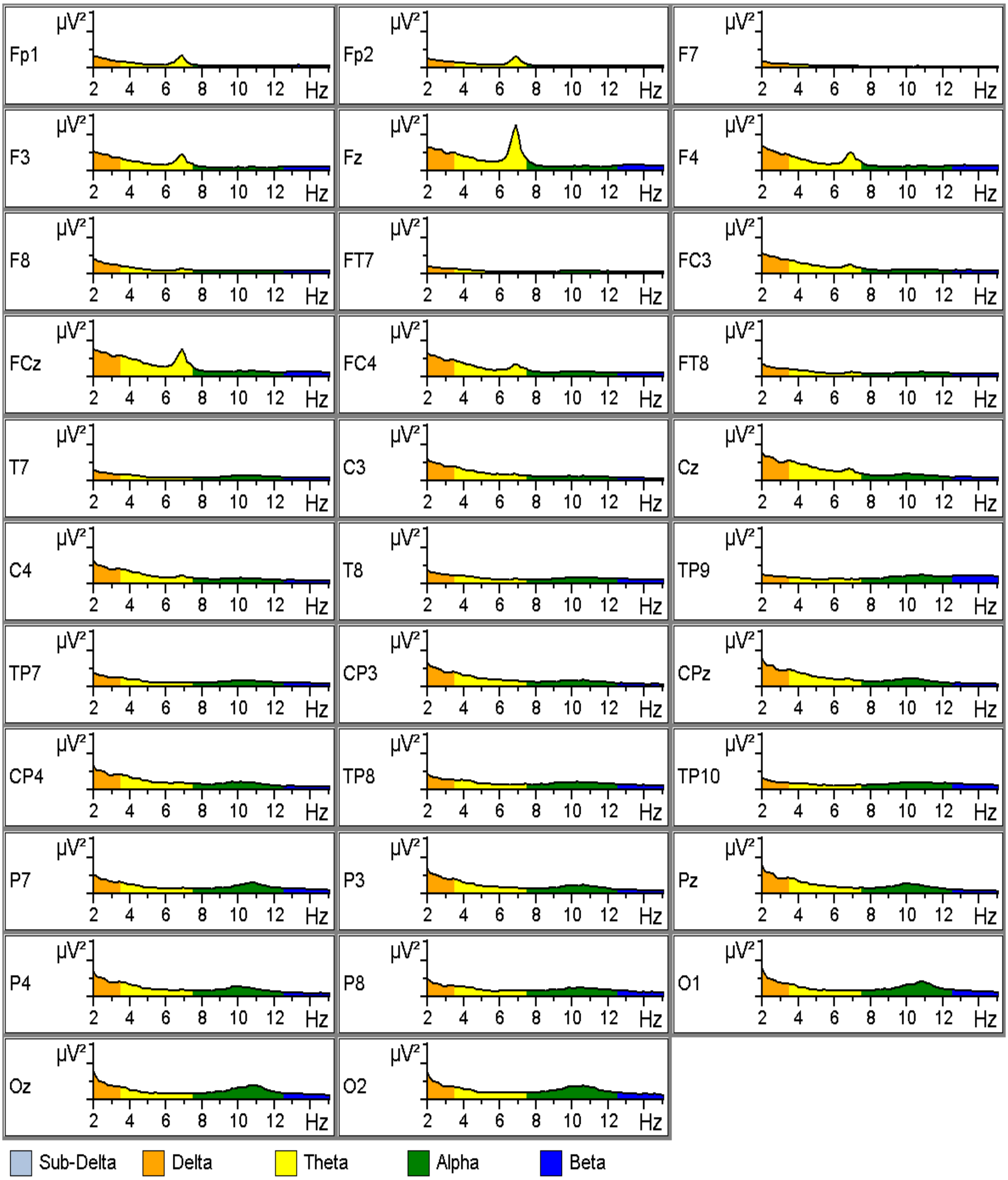


Figure 18: Averaged FFT performed over data set B showing the frequency distribution of the EEG-waves on the x-axis and the squared voltage fluctuations on the y-axis. Each vertical tick mark corresponds to 0.5 μV^2

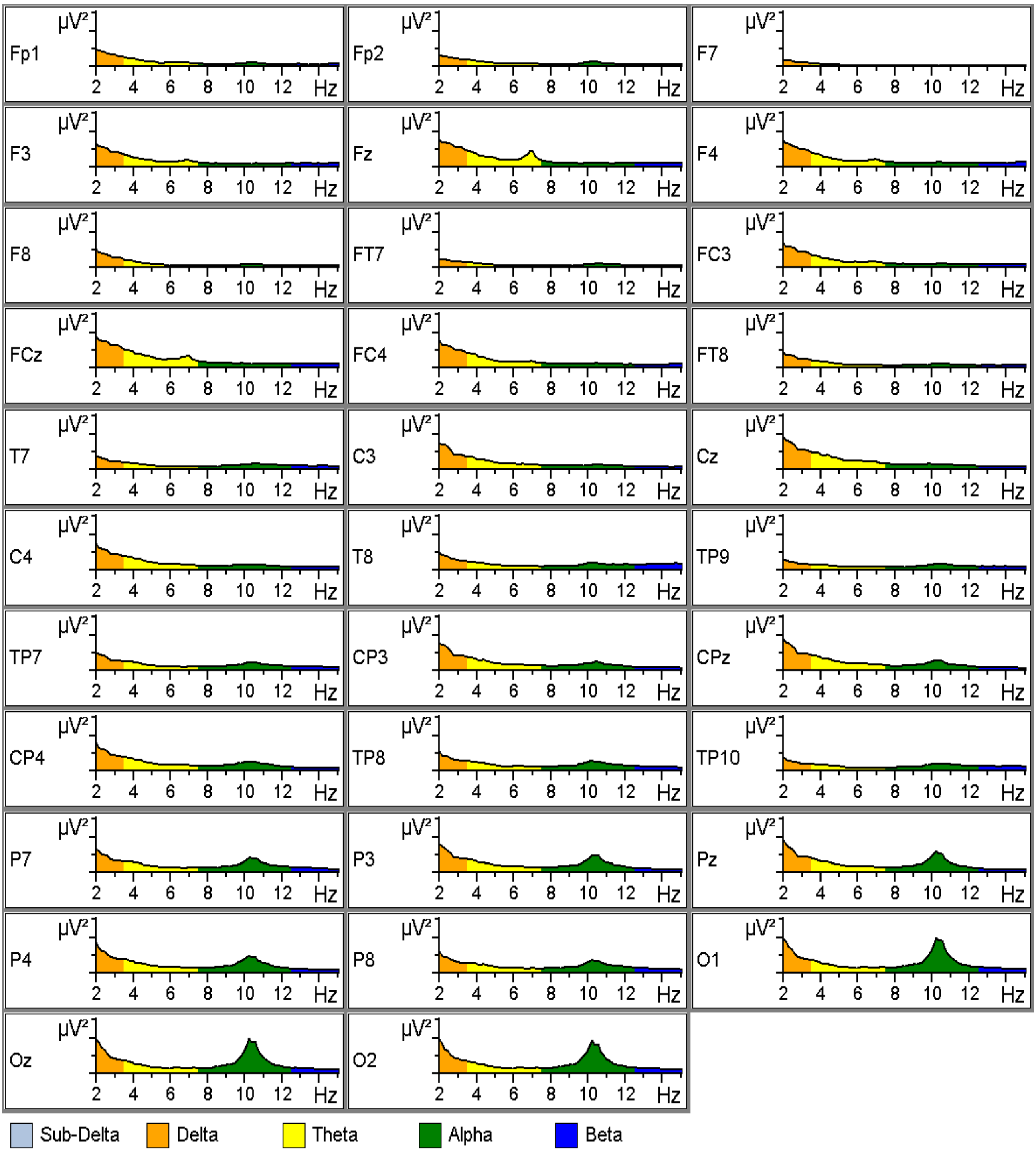


Figure 19: Averaged FFT performed over data set C showing the frequency distribution of the EEG-waves on the x-axis and the squared voltage fluctuations on the y-axis. Each vertical tick mark corresponds to 0.5 μV^2