We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

6,900
Open access books available

185,000
International authors and editors

200M
Downloads

154
Countries delivered to

Our authors are among the

TOP 1%
most cited scientists

12.2%
Contributors from top 500 universities

CLARIVATE ANALYTICS
BOOK CITATION INDEX
INDEXED

WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com

The Utility of Electromagnetic Activity Measures in Obsessive Compulsive Disorder and Schizophrenia

Elana Harris and Milena Korostenskaja

Additional information is available at the end of the chapter

1. Introduction

A young adult presents to a psychiatrist and describes the need to "unwind" himself around pieces of furniture if he has passed them in a clockwise direction. When he is weighed, he expresses the concern that pieces of rubber will come off the office scale and that will be considered stealing. He hesitates before he sits down on a chair in the office because he is afraid that he will catch the emotional problems of the person who sat in the chair before him. Are these psychotic delusions or obsessions and compulsions?

A delusion is a fixed, false, unshakable belief. An obsession is a worried thought or image that is experienced as disturbing. The distinction is important to make as the treatment paths for obsessive compulsive disorder (OCD) and schizophrenia (SCZ) diverge.

The aim of this chapter is to review electromagnetic measures that may be used to help with diagnostic clarification and may predict treatment response in these two psychiatric disorders. At present, electroencephalograms (EEGs) or other neurophysiological measures are not routinely ordered for psychiatric patients. They have not yet become the standard of care. The Food and Drug Administration (FDA) recently approved the Neuropsychiatric EEG-Based Assessment Aid (NEBA) System to assist in the diagnosis of attention deficit hyperactivity disorder (ADHD) based on the ratio of theta to beta frequency bandwidths. Electrophysiological tests to aid in the diagnosis and management of patients with OCD and SCZ may develop in the near future.

2. Similarities and differences between OCD and SCZ: Epidemiology and clinical signs

2.1. Epidemiology

The prevalence of both OCD and SCZ is high, with estimates across the globe ranging from 1-2% of the population [1-4]. There is significant morbidity associated with both of these conditions [5]. Symptoms of these diseases may impact the individual's family, and ability to work and contribute to society. The quality of life of patients with OCD is impaired primarily during the symptomatic state but less so when patients are treated or in remission [6, 7]. Close to 76% of patients with SCZ are unable to engage in basic social roles, even when psychotic symptoms are in remission; few marry, and less than one third are in regular employment [8]. Nine to thirteen percent of patients with schizophrenia commit suicide [9].

The prevalence of obsessive compulsive symptoms in patients with SCZ ranges from 7.8% [10] to 25% [11]. Whereas less than 2% of patients with OCD develop psychotic symptoms [12]. The age of onset of OCD is bimodal with peaks both in children and young adults [13]; the typical age of onset of SCZ is in the third decade of life with childhood onset being extremely rare [14].

2.2. Clinical characteristics

The clinical presentation of OCD and SCZ is currently what is used to diagnose and distinguish these conditions. OCD is characterized by the presence of obsessions and/or compulsions [15]. Obsessions are unwanted thoughts or images that recur. Compulsions are repetitive behaviors or mental acts that an individual feels driven to perform. Patients with OCD often describe either a sense of incompleteness if a ritual is not done just right or a sense that something bad will happen if they don't perform the ritual. SCZ, on the other hand, is characterized by positive and negative symptoms [15]. Positive symptoms refer to additional symptoms that are not present in a healthy individual such as hallucinations, delusions, and thought disorder. Negative symptoms refer to deficits, such as, lack of facial expressions and emotional variability, decreased energy and diminished verbal output. Cognitive dysfunction [16] and disorganized behavior may be present as well and include disorganized speech, bizarre behavior and poor attention [17].

While OCD and SCZ are described as distinct psychiatric disorders [18], some authors argue that a "schizo-obsessive disorder" exists as well [19-21]. Indeed, a subset of individuals with SCZ present with obsessive compulsive symptoms and a subset of patients with OCD lack insight. Some have concluded from this overlap, that there is a spectrum of disorders that ranges from: [1] OCD, [2] OCD with poor insight, [3] OCD with schizotypal personality disorder, [4] schizophrenia with obsessive compulsive symptoms, [5] SCZ with OCD and [6] SCZ [22].

3. Electromagnetic measures of neural activity

3.1. Transcranial magnetic stimulation (TMS)

TMS is a versatile tool in the hands of a neurophysiologist as it can be used to measure and modulate cortical excitation and inhibition. The TMS unit consists of a strong (1 to 2 Tesla) electromagnetic generator and a handheld magnet or adjustable coil. When stimulating, the coil is positioned manually over the scalp. Some systems also include a means by which the investigator may navigate and visualize the location of stimulations by co-registering the head position with a 3-dimensional reconstruction of the subject's own MRI. The magnet can be set to deliver single or repetitive pulses generating focal electrical currents.

With the magnet held over the contralateral primary motor cortex, a single magnetic pulse excites the underlying brain tissue and leads to an evoked potential and movement in the corresponding muscle. The amplitude of the motor evoked potential (MEP) and the motor threshold (or level at which 50% of the stimuli lead to movement) reflects the degree of excitability of the brain, spinal cord neurons and muscles in that individual. A period of inhibition, typically lasting for a few hundred milliseconds, follows the MEP. This cortical silent period (CSP) is obtained by asking the subject to maintain muscle contraction while a single suprathreshold TMS pulse is applied to the motor cortex [23-25].

Neuroplasticity is a feature of the nervous system that helps the brain learn, develop or reorganize in response to intrinsic or environmental stimuli. In broad terms, though such reorganization can be associated with the development of a healthy skill or recovery after a functional loss such as a stroke, maladaptive changes may lead to problematic patterns of thoughts and behaviors. The underlying mechanism behind the strengthening or weakening of neuronal connections is supported by in vivo and in vitro animal experimentation and is thought to be based upon long term potentiation (LTP) or long-term depression respectively (LTD) [26, 27]. More recently, several TMS protocols have been developed to study the inhibition and facilitation of MEPs which may reflect the underlying influences of inhibitory and excitatory cortico-cortial and subcortico-cortical circuits which modulate cortical excitability.

Paired-pulse TMS is a method of applying stimuli below the MEP threshold to change the size of subsequent MEP. A single "conditioning" pulse is followed by a "test" pulse. The interstimulus interval (ISI) affects the size of the resultant MEP. In short interval intracortical inhibition (SICI) protocols, a subthreshold stimulus is followed by a suprathreshold stimulus. Interstimulus intervals of 1-5ms lead to suppression of the MEP. With long interval intracortical inhibition (LICI) both pulses are suprathreshold, and the interstimulus interval is 50-200ms. MEPs can be facilitated when a subthreshold pulse is given 10-25ms before a suprathreshold pulse. Research suggests that intracortical inhibition and facilitation reflect the influences of inhibitory and excitatory cortio-cortical and subcortical–cortical circuits modulating activity in motor cortex output neurons without the involvement of spinal neurons [28-30].

More durable changes to cortical excitability which persist past the stimulation period can be induced utilizing various repetitive TMS (rTMS) protocols. Already in wide use for the treatment of depression, 1 Hz rTMS can also be used experimentally to temporarily disrupt cortical activity and thus establish structure-function relationships when used in tandem with behavioral experiments and functional imaging. Higher frequency rTMS (5 to 20 Hz) tends to increase cortical excitability. Although 1-Hz rTMS (applied at 90% of resting motor threshold) to the contralateral motor cortex for 10 minutes results in approximately 10 minutes of MEP size depression following stimulation, recent protocols that utilize more complicated patterns of stimulation can result in effects that last longer than 30 minutes. Theta-burst stimulation, for example, consists of ultra-rapid trains of three TMS pulses (50 Hz) with variable interval between bursts for a total stimulation time of 40 to 190 seconds. Remarkably, this brief stimulation can result in relatively long-lasting changes in MEP size resembling a human model of LTP and LTD of synaptic efficiency [31].

TMS has an important role in research regarding the nervous system and its role in the treatment of various psychiatric conditions is expanding (for review, see 32). It has been shown to be useful in reducing auditory hallucinations [33, 34] and improving negative symptomatology in SCZ [35]. The jury is still out on whether rTMS will prove useful for improving symptoms in OCD; the three studies to date do not support significant benefit of rTMS [36].

TMS studies in OCD. Just as there are few treatment studies utilizing TMS in OCD, so too, few investigator have employed TMS to examine cortical excitability in OCD. The first study we found in the literature, reported decreased SICI in 12 patients with OCD compared with 12 healthy comparison subjects (HCS) [37]. This group expanded upon their findings using both single-pulse TMS and paired-pulse TMS in 9 medicated and 7 unmedicated patients with OCD compared with 11 HCS [38]. They found a lower motor threshold both when the OCD subject was stimulated at rest or during an active state. They also found diminished SICI in the OCD subjects, with even lower intracortical inhibition in subjects with comorbid OCD and a tic disorder. There were no significant differences between subjects with OCD and HCS with regard to MEP amplitude, intracortical facilitation or length of the silent period. In a larger sample, Richter, de Jesus [39] compared 34 patients with OCD (23 medicated and 11 unmedicated) with 34 HCS. In contrast to the previous study, no difference was found in resting motor threshold between the OCD and HCS, although the resting motor threshold was significantly lower in the OCD subjects on medication. The CSP was shorter in patients with OCD compared with HCS. No differences were found in SICI between the OCD and HCS, but patients with OCD had greater intracortical facilitation. No correlations were found between illness severity and TMS parameters in either the medicated or unmedicated patients. The discrepancies between these studies may reflect the presence of unmedicated subjects or may be attributed to different TMS stimulus parameters. However given the paucity of studies of TMS in subjects with OCD there is a need to continue research to further our understanding of the possible excitation inhibition imbalance in this disorder.

To explore the mechanism of action of rTMS in subjects with OCD, recently Pedapati, DiFranscesco [40] examined the effects of 30 minutes of 1 Hz repetitive TMS (rTMS) of the dorsolateral prefrontal cortex. We compared sham (subthreshold) TMS with rTMS on the blood oxygena-

tion level-dependent (BOLD) signal during symptom provocation and found increased BOLD activity in the right inferior frontal gyrus, right insular cortex, and the left thalamus in the sham subjects suggesting that rTMS may have inhibited the desensitization process experienced by the subjects during provocative image exposure (Figure 1).
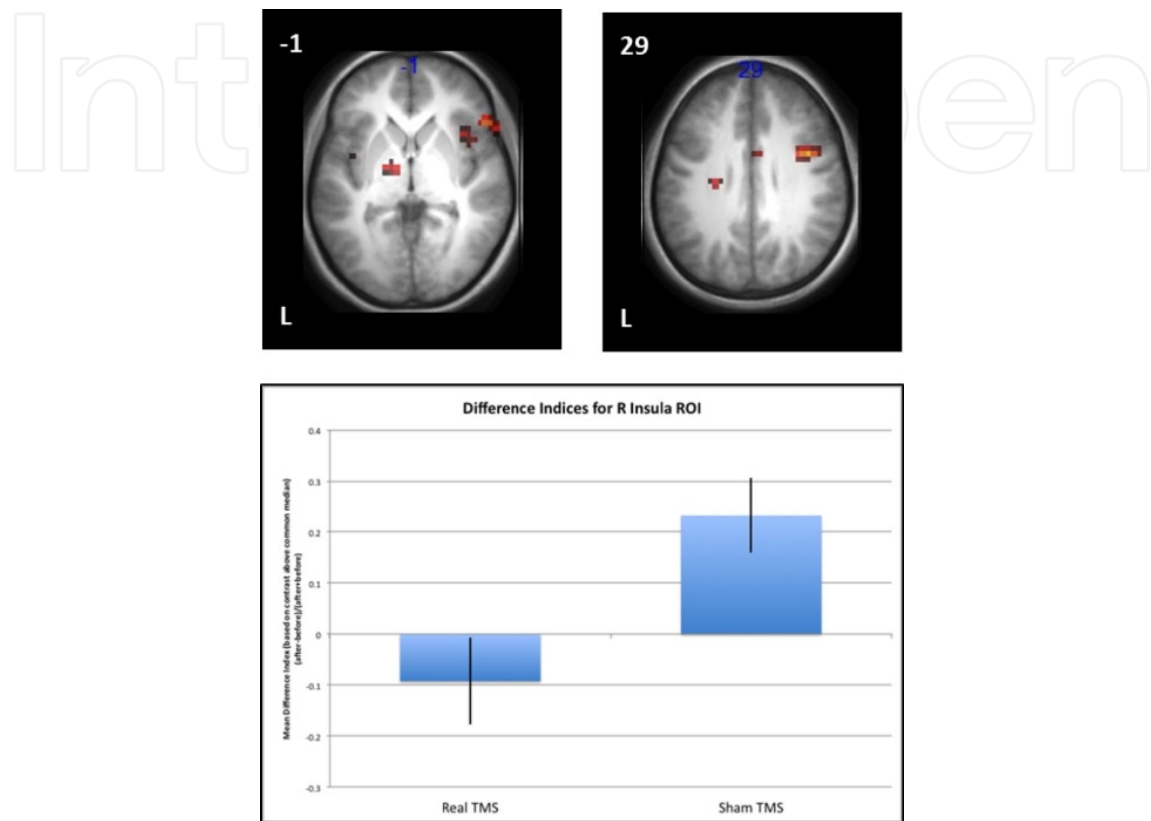
Figure 1. Differences in brain activation for subject-specifc OCD symptom-provocative task comparing 1 Hz rTMS with sham rTMS. Top: Select axial slices show an interaction between the intervention (real or sham rTMS) and time (pre- or post-rTMS). Hot colors indicate (sham/after > sham/before) > (TMS/after > TMS/before) contrasts. Colors indicate activations that passed an uncorrected threshold of p < 0.005. Neurological convention used. Bottom: Results of regional analysis for a region of interest covering the right insula. A difference index comparing activation before and after rTMS is shown for the real and sham rTMS subject groups. The group difference is significant at p<0.05. Black bars indicate the standard error.

TMS studies in SCZ. There is a somewhat larger body of literature examining the effects of TMS in SCZ that is less divergent in its findings than the OCD literature. Abnormalities in cortical inhibition in patients with SCZ have been reported by a number of authors [41-43]. Eichhammer, Wiegand [44] found that treatment naïve patients with SCZ had significantly lower resting motor threshold relative to healthy subjects. Liu, Fitzgerald [45] found that patients with SCZ who were treated with clozapine had longer CSP compared with other patients with SCZ, while Wobrock, Schneider-Axmann [46] found prolonged CSP in patients with new onset SCZ who had limited exposure to medication. Daskalakis, Christensen [47] found deficits in use-dependent plasticity in subjects with SCZ which is measured after subjects have been trained to move in the opposite direction of the movement that is induced by TMS.

Reduced SICI has been recorded in first-episode SCZ and has been found to correlate with positive symptom severity [46, 48]. Some medications have been found to affect TMS measures of cortical inhibition. For instance, Fitzgerald, Brown [49] found that olanzapine and risperidone confer different effects on the resting motor threshold and cortical inhibition. It may take time or a dose effect to notice medication changes as Daskalakis, Christensen [50] have pointed out that single doses of haloperidol and olanzapine did not alter cortical inhibition in healthy subjects.

In summary, relative to HCS, patients with OCD were found, by at least some investigators, to have lower motor threshold, shorter CSP, decreased SICI, and greater intracortical facilitation. Patients with SCZ were also found to have lower motor threshold and decreased SICI, but prolonged CSP and abnormalities in use-dependent plasticity. Thus the only measure to date which may distinguish between these conditions to date, using TMS, is the length of the cortical silent period. For the development of a useful diagnostic measure, head-to-head studies are needed for direct comparison between these and other psychiatric conditions. No studies to our knowledge have used TMS measures to predict treatment outcome, although, as discussed above, TMS measures can detect changes that result from treatment with antipsychotics.

3.2. Electroencephalography (EEG) and magnetoencephalography (MEG)

The neural origins of brain function in psychiatric patients can also be effectively studied with non-invasive neurophysiological techniques such as electroencephalography (EEG) and magnetoencephalography (MEG) [51-53]. Handy (2009) notes that for a time investigators began to consider EEG to be a tool of the past, but functional magnetic resonance imaging helped revive an interest in combining the complimentary anatomical and electrophysiological approaches and there is now an upsurge of interest in EEG and MEG. Both EEG and MEG can be recorded in patients at rest with eyes open or closed (spontaneous EEG or MEG) as well as during cognitive or behavioral tasks. Signal analysis techniques allow for quantitative interpretation of both EEG and MEG waveforms – qEEG/qMEG, respectively. Such analysis can be helpful not only in the diagnosis of psychiatric conditions [54], but also in predicting treatment outcome [55]. Moreover, recent development in functional connectivity analysis, permit investigators to study the activity in disparate brain regions in psychiatric patients at rest with MEG or EEG. This approach has been referred to as the study of "resting state functional connectivity" or the "default mode network." [56]. Indeed, since there is evidence to suggest that the core feature of disorders like OCD and SCZ are a result of altered functional connections between different brain regions [57, 58] this approach is likely to prove to be very valuable.

EEG and MEG add, to the already rich functional imaging literature, the ability to record neural activity with high temporal resolution. EEG uses surface scalp electrodes to monitor cortical electrical potentials. Electrodes distributed across the scalp together with mathematical analyses can estimate the location of the generator of the neural activity within several centimeters. Measurements with MEG permit 3-D localization of current sources studied on a time scale of less than 1 ms [59]. MEG uses magnetometers to record the magnetic fields

produced by extracellular electrical currents. The most common magnetemotors in use are referred to as superconducting quantum interference devices or SQUIDS. Subjects are seated or supine during recordings with a helmet containing the SQUIDS placed over their heads. Cortical activity is on the order of 10 femtotesla (fT) and the alpha rhythm runs on the order of1000 fT. These magnetic fields are much smaller than the background noise, which is on the order of 10^8 fT, thus various strategies are employed to remove the noise, including magnetically shielding the recording room. With three fiducial markers (typically at points on the nose and ears), MEG data can be aligned with the subject's own anatomical magnetic resonance image (MRI). MEG and MRI data can further be transformed to Tailarach space to assist in group comparisons.

One of the principal differences between MEG and EEG is thought to be that MEG mainly records activity from tangentially oriented sources leading to better recordings from sulci where the pyramidal cell dendrites are lined up parallel with the cortex, while EEG can detect sources with both radial and tangential components resulting from intracellular currents [51, 60, 61]. If one uses a perfect sphere to model the brain, there would be no magnetic field detected from an entirely radially oriented current dipole. However, the human brain has a more complex shape and most current dipoles have both radial and tangential components. Therefore, a nearly radial source in the brain may generate a magnetic field that can be detected by MEG [62]. In both mathematical modeling studies and in animal experiments, the strength of the sources has been found to differ based on the location and orientation [63-65]. Sensitivity to tangential sources makes MEG highly relevant for studies of auditory processing. For example, MEG can be particularly sensitive to studying auditory hallucinations in SCZ or auditory sensory information processing in OCD, as temporal brain regions are thought to be involved in pathophysiology of both of these disorders [66-68]. A further difference between EEG and MEG recordings is that magnetic fields are less distorted than electric fields by the skull and scalp, leading to better spatial resolution for MEG. Thus, although EEG is sensitive to activity both at the tops of the gyri and in the sulci, activity that is recorded with MEG can be localized better.

Since frontal regions play a prominent role in the pathophysiology of both OCD and SCZ, one might wonder how effective MEG is at detecting neuronal activity in the orbitofrontal cortex (OFC), for instance. Hillebrand et al. [69] addressed this issue with detailed computations of MRI modeled brain gyral surfaces, realistic strength cortical sources, and realistic background noise. As a result of the study, the authors found limitations for MEG sensitivity only for the most posterior aspect of the OFC. A careful study comparing MEG and fMRI localization of responses to emotionally laden pictures showed co-localization of MEG and fMRI activation of orbitofrontal cortex within 7-9 mm [70]. More recently, others [71, 72] have confirmed MEG sensitivity to source activity in the OFC.

In quantitative electroencephalography (QEEG), multichannel recordings, usually from the standard 19 electrode positions, are obtained while the subject has his or her eyes-closed and is in a relaxed, awake state. One to two minutes of artifact-free data is analyzed using the Fast Fourier Transform to quantify the power at each frequency of the EEG averaged across the recording time. This is referred to as the power spectrum. There is very good test-retest

reliability of power spectra computed in this manner. Power spectra are typically examined in the range of 1 to 20 Hz frequency band. This frequency range is further divided into frequency bands and assigned names from the Greek alphabet: delta (δ, 1.5—3.5 Hz), theta (θ, 3.5—7.5 Hz), alpha (α, 7.5—12.5 Hz), and beta (β, 12.5—20 Hz). Results of the analyses describe absolute power in each frequency band, the relative power or percentage of total power in each channel, coherence which measures synchronization between two channels, or symmetry which is the ratio of power in each band between a symmetrical pair of electrodes [73].

EEG/MEG in OCD. The first known EEG study regarding patients with OCD patients reported seizure like patterns with slow waves of 2–4 Hz [74]. Similarly, nonspecific theta activity was found in the EEG of patients with OCD [75]. To date, the δ, θ, α and β frequency bandwidths have been examined in patients with OCD in the awake, resting state and during the performance of cognitive tasks. Table 1 illustrates the large variability in findings between different investigators. Both increased α and β [76-79], as well as, decreased α and β have been found in patients with OCD [80-85]. There are also reports of lateralized left [86] and right hemispheric differences in patients with OCD [87, 88]. What the majority of the studies have in common is a deviation from the healthy comparison group in frontal and frontotemporal regions [78, 79, 81, 83, 84, 87, 89].

Method	Population	Results for OCD patients (pts)	Authors, year
Resting EEG intracortical exact low resolution electromagnetic tomography software	30 drug-free pts with OCD and 30 HCS	↓ lagged non-linear coherencee β2 frequency between frontal brain areas but not within the default mode network. High vigilance stages had yielded ↓ frontal phase synchronisation for β and θ	Olbrich, Olbrich [90]
Resting EEG with standardized low-resolution electromagnetic tomography software	50 OCD (8 drug-free; 42 on SSRIs), 50 HCS	↑ δ in the cingulate gyrus, did not correlate with symptom severity or illness duration. δ power in the right orbitofrontal cortex positively correlated with age of OCD onset	Koprivova, Horacek [91]
Resting EEG with low-resolution electromagnetic tomography and coherence analysis	37 drug naïve pts with OCD and 37 HCS	↑ δ in the insula ↑ β in frontal, parietal and limbic regions. Decreased interhemisphereic coherence Reduced coupling between δ and β	Velikova et al. [79]
Quantitative EEG	20 adults (10 M, 10 F) with OCD and 19 HC	↑ in θ coherence in the fronto-occipital region	Desarkar et al. [92]
Resting EEG with variable resolution electromagnetic	20 adults with OCD treated with paroxetine	↑ α in the striatum, orbito-frontal and temporo-frontal regions pre-treatment. This abnormality decreased following successful treatment with paroxetine.	Bolwig et al. [76]

Method	Population	Results for OCD patients (pts)	Authors, year
tomography			
Quantitative EEG	18 unmedicated adults with OCD and 18 HC	Lower average background frequency in frontal regions. ↑ δ - and ↓ α / β power.	Pogarell et al. [81]
Multilead QEEG while subjects performed executive function tasks	32 drug-free pts with OCD and 32 HC	↓ α power	Bucci et al. [80]
Rey-Osterrieth Complex Figure Test	23 pts with OCD	Score correlated with the α power with regression coefficients that had different directions by hemisphere	Shin et al. [93]
neurometric QEEG	20 nondepressed pts with OCD all treated with paroxetine	↑ α at baseline in medication responders.	Hansen et al. [77]
19-channel QEEG recorded at rest in supine subjects	32 drug-free patients (8 males) with OCD and 31 HCS (9 males)	↓ absolute β power and an ↑ relative θ power in frontotemporal regions There were also differences by OCD subtype	Karadag et al. [84]
QEEG during resting state and during hyperventilation	22 unmedicated nondepressed pts with OCD and 20 HC	At rest: ↑ δ & θ; ↓ α in left frontotemporal regions During hyperventilation: ↓ β in left frontal regions	Tot et al. [82]
self-paced movement of the right thumb; 29-channel EEG	10 untreated OCD patients and 10 HC	Delayed onset of mu event-related desynchronization with movement preparation and less postmovement β synchronization	Leocani et al. [94]
QEEG during live and imaginal exposure to feared contaminants	6 pts with OCD	significant change in the anterior-to-posterior scalp distribution of α power during live exposure	Simpson et al. [96]
rest and during a temporal lobe activating procedure, i.e., olfactory stimulation	37 drug-free patients with OCD and 30 HCS	At rest: ↑ delta-1 and ↓ α -2 power. During olfactory stimulation: HCS had a power increase in β, whereas OCD patients showed no change (right) or slight decrease (left)	Locatelli et al. [83]
EEG spectral analysis	50 pts with OCD, 50 pts with anxious neurosis, 25 HC	↑ mean α power in occipital regions. ↓ frontal β activity found in both patient groups	Serra et al. [85]
QEEG	27 adult patients with OCD in a drug-free state at baseline	Found 2 groups: Cluster 1 - ↑ relative power θ in the frontal and frontotemporal regions; 80% of these patients did not respond to medication. Cluster 2 - ↑relative power α, 82.4% of these patients were treatment responders.	Prichep et al. [78]

Table 1. Summary of EEG findings in OCD

Spontaneous MEG in OCD. In the first documented MEG study with OCD subjects, the findings of Amo, Quesney [71] are reminiscent of the early EEG studies in OCD (for example, 74) with fronto-temporal paroxysmal rhythmic activity with low-amplitude spikes and intermittent isolated spikes and sharp waves. Amo, Quesney [71] expanded their findings with the addition of two selective serotonin specific reuptake inhibitor-naïve subjects [97] and they found similar paroxysmal activity in fronto-temporal regions. Maihofner, Sperling [98] observed the spontaneous MEG activity in 10 subjects with OCD and 10 healthy subjects. These authors parsed the frequency bandwidths examined into "slow" (2-6 Hz) and "fast" (12.5-30 Hz). They found dipole maxima concentrated in the left superior temporal gyrus with no difference in the number of dipoles between subject groups for slow MEG activity. However, the OCD group had a clustering of slow MEG activity over the left dorsolateral prefrontal cortex.
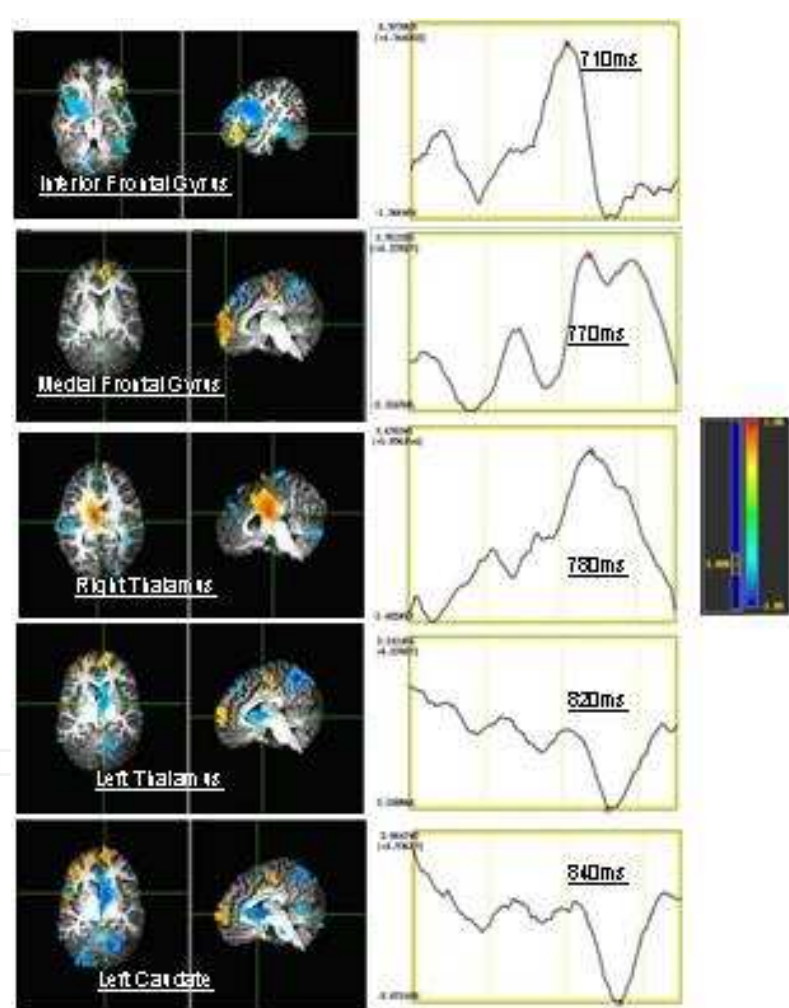
Figure 2. Example of MEG data in an Adolescent with OCD following the presentation of Symptom Provocative Images. Event-related beta synchronization (warm colors) and de-synchronization (cool colors) are shown in frontal corti-cal regions, thalamus and caudate in an adolescent subject with OCD who was presented with contamination related stimuli. Left to right, Axial, parasagittal views (Left=Right), and graph of time course of activity following stimulus presentation. The red circle in the graph indicates the time at which the peak activity occurs within the green cross-hairs in the corresponding MRI.

*Task-related MEG in OCD.*To explore the network and compensatory mechanisms, Ciesielski, Hamalainen [99] examined the MEG pattern of activation during a working memory task in subjects with OCD. They found that during the encoding phase, there was enhanced activity in OCD subjects in the anterior insula and decreased activity in the posterior inferior parietal cortex. During the retention phase, activity was lower in the occipital, parietal, superior temporal sulcus and dorsolateral prefrontal cortex. During the retrieval phase there was a significant increase in activation from the right anterior insula extending toward the orbital region and the right superior temporal sulcus. There was reduced activity in the left parietal cortex. Ciesielski et al. [100] examined event-related synchronization (ERS) and desynchronization (ERD) in the alpha band associated with a working memory task in subjects with OCD and healthy subjects. In subjects with OCD, these authors found lower baseline alpha and a task phase-specific ERD.

In a small sample of adolescents with OCD, we have begun to look at the power of oscillations at rest and during a symptom provocative task [101, 102]. The majority of images for the visual task were the neutral and contamination sets of images previously used by Gilbert, Akkal [103] The spatiotemporal structure of beta band event-related changes were analyzed with synthetic aperture magnetometry together with a Stockwell transform to provide power as a function of time for each voxel. Results from one individual are illustrated in Figure 2 demonstrating the ability of MEG to show the precise timing of activity of elements within the circuit.

With regards to functional connectivity analysis of electromagnetic data, to our knowledge, only one study in OCD has been conducted to date [90]. When recording resting state EEG, these authors demonstrated altered functional connectivity within the frontal brain region (decreased non-linear coherence within the beta-2 frequency band) in OCD group compared with HCS.

Overall, although the electrophysiological literature is sparse, both EEG and MEG data support other functional imaging modalities (Beucke et al. 2013; [104] in their implication of elements of a frontocortical, striatal, thalamic circuit with involvement of limbic regions, in line with current neural model of OCD [105].

Spontaneous EEG/MEG in SCZ. A large number of studies have demonstrated that EEG abnormalities occur more frequently in patients with SCZ than in healthy subjects. As early as 1936, Lemere [106] wrote "... the apathy and affective deficiency of the schizophrenic was the feature of the illness most clearly related to an absent or 'poor' alpha rhythm." Berger, too, in 1937 [107], noted alpha and beta frequency abnormalities in a patient with schizophrenia. Early reports also suggested that there were statistically significant resting EEG differences between healthy individuals and patients with SCZ [108-116]. Abnormalities include general slowing, dysrhythmia, nonspecific diffuse patterns, atypical sharp waves and epileptiform discharges. A discussion in the literature ensued regarding the relationship between schizophrenia and epilepsy. In support of this connection were the slow waves and spikes that were recorded during catatonic episodes [112, 117, 118]. Still in all, a number of early studies failed to find any EEG abnormalities in patients with SCZ, e.g., Colony and Willis [119] did not find EEG differences between their 1000 patients with SCZ and HCS. Abnormal EEG activity was thought of by some to be the result of a premorbid head injury or the consequence of treatment

with electric, insulin or chemical shock [120-122]. Sponheim et al. [123, 124] looked for correlations to explain the variance in central EEG slow wave prevalence. Patterns found include a relationship that favored winter birth over diagnosis. Patients with more negative symptoms and larger ventricles had an increased likelihood of slow wave abnormalities. In a landmark study, Shagass et al. [125] compared the EEGs of patients with SCZ with patients with other psychiatric conditions and HCS. They reported a sensitivity of 50% and specificity of 90% when patients with SCZ were compared to patients with Major Depression. Their work was replicated by Gerez and Tello [126] who used a battery of 10 neurophysiological assessments and found 78% sensitivity and 85% specificity in classifying subjects. However, Sponheim et al. [127] were unable to differentiate patients with SCZ from patients with affective disorders using low frequency and alpha band EEG power, but they succeeded in using these measures to differentiate SCZ from healthy subjects.

The intrinsic EEG of SCZ show augmented theta/delta and reduced alpha power (for example, 128, 129, 130). These abnormalities correlate with psychotic symptoms [131, 132], candidate risk genotypes [129] and perithalamic ventricular volume [123]. Stimulus elicited low frequency (delta-alpha) phase locking and single trial power is also consistently reduced in SCZ [133, 134], an effect that is highly heritable [135]. Importantly, thalamic aberrations have been theorized to be relevant both for SCZ neuropathology and the expression of psychotic symptoms [136, 137]. Klimesch, Sauseng [138] suggest that the heritability and consistency across paradigms with regard to alpha/theta/delta oscillations should be a considered an EEG marker of thalamocortical disconnectivity in SCZ.

Siekmeier and Stufflebeam [139] reviewed the resting state MEG literature for patients with SCZ from 1993 to 2009 and found that there was overwhelming support (11/12 studies) for increased theta (4-8 Hz) and delta (1-4 Hz) band oscillations in the temporal lobes of patients. Of the studies that correlated oscillations with symptoms, there was a positive correlation (in 8/10 studies) between temporal lobe theta activity and positive symptoms.

As Boutros, Arfken [140] point out in their meta analysis that included 15 studies of spontaneous EEG comparing subjects with SCZ to healthy subjects or non-schizophrenic psychotic patients, a large number of statistically significant differences have been found. However, they go on to note, no systematic effort using a large multicenter population has been made to standardize an assessment battery. Further research in this area is warranted.

Task-related EEG in SCZ. In addition to resting state analyses, EEG oscillations can be examined during specific phases of cognitive tasks. For example, Dias, Bickel [141] compared the responses of patients with SCZ and HCS during the "AX" continuous performance task. In this task, subjects are asked to attend to a sequence of individually presented letters and must respond whenever they view a letter "A" followed by a letter "X," and ignore all other sequences. They found task-related event-related desynchronization that was reduced in the beta band in the parieto-occipital cortex for sensory encoding in and reduced beta ERD in the motor cortex during response preparation in patients with SCZ.

Gamma EEG oscillations in humans can be stimulated by a task, induced by a stimulus, or evoked by repetitive inputs. In almost all cases, the amplitude of gamma is reduced in SCZ

[142]. Gamma oscillations are thought to support the cognitive processes (e.g., attention, memory, and learning) that are disrupted in SCZ, and these oscillations are thought to facilitate communication between brain regions involved in SCZ. This has given rise to the hypothesis that abnormalities in gamma oscillations may be one of the principal underlying problem in patients with SCZ [143]. In support of this notion, many studies have found that patients with SCZ to have decreased power or synchrony of gamma oscillations during responses to sensory stimulation or cognitive tasks [144-149]. In some cases, these abnormalities correlate with the severity of cognitive dysfunction or other symptoms [145, 148]. Despite the decreased power or synchrony of gamma oscillations evoked by sensory stimuli or cognitive tasks, surprisingly, auditory hallucinations are apparently linked with increased power or synchrony of beta and gamma oscillations [150-152].

Functional connectivity studies in SCZ. As highlighted above by the opposing valence of the changes in gamma oscillations in SCZ dependent on the task or setting, examination of a single frequency range in a single brain region may yield insufficient information to be a reliable biomarker of disease state. Bassett has suggested that functional connectivity disturbances would make excellent diagnostic biomarkers for the disease [153]. The examination of oscillations across brain regions using network theoretical tools borrowed from the social sciences indeed provides support for "dysconnectivity" in patients with SCZ [153-165]. Allen, Liu [166] demonstrated that cross-frequency interactions are abnormal and increased or decreased in various regions in SCZ, with the strength of these interactions correlating with genetic risk factors for the disease. Hinkley, Vinogradov [58] too performed resting-state functional connectivity analysis of MEG data (alpha frequency band) with eyes closed in SCZ patients and compared it with HCS. In SCZ patients, left prefrontal cortex as well as right superior temporal cortex had decreased connectivity; at the same time functional connectivity in left extrastriate cortex and in the right inferior prefrontal cortex were increased. Importantly, these latter changes in the right inferior prefrontal cortex correlated with cognitive deficits in SCZ patients. Important results were demonstrated by Higashima, Takeda [167], who by using functional connectivity analysis approach of resting state EEG data, showed that there is a functional disconnection between left and right frontal lobes in schizophrenia patients and with normalization following antipsychotic treatment.

Most recently, Siebenhuhner, Weiss [154] examined the functional connectivity in 14 patients with SCZ and 14 HCS using MEG during a working memory N-back task. Their analysis was based on a multiresolution approach [159] which posits that neurophysiological alterations in SCZ manifest as a complex hierarchy of signatures across univariate (individual sensor time series or entropy), bivariate (co-variability between time series or functional connectivity), and multivariate (patterns of co-variability across sensors or network topology) statistical measurements. In addition, they examined functional networks constructed from the interactions between frequency bands. They found an extensive pattern of altered network structure and network dynamics in patients with SCZ with disease-associated changes in brain function at each level of analysis. Patients with SCZ had lower time series entropy and increased strength of co-variability between time series. These findings were suggestive of decreased information content of MEG signals and, perhaps surprisingly, hyperconnectivity between brain regions.

They also found that patients with SCZ had deviant topological organization in binary sensor networks and that network properties of cross-frequency associations between time series in the beta and gamma bands differed between groups.

Overall, there is a strong potential of functional connectivity analysis to contribute to diagnosis and treatment in SCZ since the essential feature of this disorder is thought to be one of functional disconnection between brain regions.

In our review of the literature, we did not find any comparative studies that examined groups of subjects with OCD and directly compared them with subjects with SCZ using spontaneous EEG or MEG recordings or functional connectivity analyses. This work would be valuable to aid in the development of diagnostic tests that differentiate between these conditions.

3.3. Information processing studied with event related potentials and fields (ERPs/ERFs)

Signal averaging helps extract event-related potentials (ERPs, recorded with EEG) and event-related fields (ERFs, recorded with MEG), brain responses specifically related to the external or internal stimuli, from background spontaneous brain activity. ERPs/ERFs studies contributed significantly to understanding neural basis of both OCD and SCZ, and specifically the neural origins of cognitive dysfunction of these disorders [168]. Moreover, some of ERPs are proposed to be used as biomarkers of each of these specific disorders [169, 170]. For a summary of information about ERP studies in OCD – see Table 2). The main ERP/ERF responses studied in OCD and SCZ to date are related to early sensory processing, attention and performance monitoring.

Information processing at the brain stem level. In OCD, it has been possible to demonstrate changes in processing of auditory information stream already at the level of brain stem [85, 171]. For instance, Nolfe et al. [171] by recording brain stem auditory evoked potentials (BAEPs) showed that the interpeak latency of wave I-V was delayed, as well as amplitude of wave III was reduced in OCD patients when compared with HCS.

At the same time, BAEPs results observed in SCZ are variable [172, 173], with some of them including modified BAEPs among patients with positive symptoms [173]. More recently, Kallstrand, Nehlstedt [174] has demonstrated significant interhemispheric differences in wave II of BAEPs in SCZ patients when compares with HCS, which may imply that lateralized abnormalities exist already on the initial level of auditory information processing in the brain.

Overall, information processing alterations at the brain stem level seem to be better documented and more consistent in OCD patients rather than in patients with SCZ. Comparative studies are needed to evaluate differences on the initial stages of auditory information processing in the brain in these two patient groups.

Sustained neuronal entrainment to repetitive stimulation. A remarkable opportunity to study how brain activity is synchronized with the external events is provided by steady-state evoked responses (SSR) (for review, see 175). SSRs can be evoked by the trains of repetitive auditory (ASSR) [176], visual (VSSR) [177] or multi-sensory (audio-visual) [178] stimuli. At certain frequencies, these stimuli entrain electromagnetic brain activity in such a way that an evoked

EEG/MEG response is produced with its frequency components remaining constant in amplitude and phase during the whole duration of sensory processing of presented stimuli. Unlike conventional ERPs/ERFs, which are analyzed primarily in the time domain (by calculating amplitude, latency, evaluating brain topography or estimating source localization at each particular time point), SSRs are evaluated in the frequency domain. The use of such responses may provide important insight into how internal brain activity and external information are synchronized in OCD. However, no ASSR studies in OCD have been conducted to date.

The situation is different for SCZ. A number of authors demonstrated deficits in ASSR generation in patients with SCZ as compared to HCS (for review, see 179]. The main findings related to ASSR abnormality in SCZ are: [1] a reduction of spectral power to 40-Hz clicks, in particular in the gamma-frequency band [180, 181]; [2] diminished inter-trial phase-locking [182]; and [3] delayed phase synchrony [181] when compared with HCS. However, some data points to the fact that under certain circumstances ASSRs may be augmented in SCZ [183] and might be resting state related [184].These findings imply an impaired mechanism of neuronal entrainment and possible alteration of synchronization/desynchronization mechanisms of electromagnetic brain activity in SCZ patients, especially in gamma-frequency band.

3.4. Early sensory processing

Sensory processing is altered in both OCD and SCZ patients. In OCD, it is can often be observed clinically as sensory intolerances or as a neurological soft sign [185]. A case series provide examples of pediatric patients with OCD who were significantly impaired by a chief complaint of a sensory intolerances to external environmental triggers, e.g. the sensation of oil on the skin, the smell of fish, salad dressing or cheese, and the tension of shoelaces and underwear [185-187]. In SCZ, on the other hand, the most frequent complaints of sensory changes are responses to internal visual or auditory experiences [188, 189]. Involvement of primary auditory areas in auditory hallucinations has been demonstrated in a number of studies with SCZ patients [190-192].

Early sensory information processing studied ERPs/ERFs in OCD. Sensory intolerances can be investigated on the neurophysiological level by studying early information processing with auditory, visual, or tactile stimuli. Indeed, a number of ERP studies demonstrated that processing of primary sensory information is altered in OCD patients. In our ERF study, Korostenskaja, Harris [193] demonstrated increased early auditory evoked fields M100 and M150 in the right hemisphere when compared to the right hemisphere in OCD subjects, whereas in no significant asymmetry was found in HCS. This interhemispheric asymmetry deserves detailed attention. This finding of increased auditory evoked response amplitudes over the right hemisphere is supported by other studies. In this way, Oades, Zerbin [194] found that OCD patients had higher N1 response amplitude in the right hemisphere, which was not the case in HCS. Morault et al. [195] showed that in response to verbal auditory stimuli presented in an "odd-ball" paradigm, patients with OCD had auditory evoked responses that are more positive in the left hemisphere while healthy subjects have more positive responses in the right hemisphere, however the opposite tendency was found for words when compared

with HCS [196]. In addition, mismatch negativity (MMN) responses shifted to the right in subjects with OCD in a study by Oades et al. [194]. Gonçalves et al. [197] hypothesized that patients with OCD have an inter-hemispheric functional imbalance that is responsible for their symptoms and improves with treatment. Specifically, Serra et al. [85] suggested that patients with OCD have insufficient fronto-caudal regulation of the left hemisphere.

There is a large literature of support for interhemispheric asymmetry, supposedly reflecting interhemispheric dysfunction, in patients with OCD. Early evidence of such dysfunction in OCD subjects comes from neuropsychological performance results, implicating the dominant (left) hemisphere in the pathophysiology of OCD [86].

Anatomically, both gray matter and white matter interhemispheric differences have been found. There is reduced cortical folding in the left anterior cingulate cortex in subjects with OCD [198]. Using diffusion spectrum imaging, subjects with OCD were shown to have decreased left-lateralized asymmetry of the anterior segment of the cingulum bundles compared with HCS [199]. In pediatric patients with OCD, increased gray matter in the left putamen and right lateral orbitofrontal cortex correlate with OCD symptom severity [200].

Electrophysiologically, left hyperactivity in the frontal region is supported by alpha frequency bandwidth power increase [93]. Quantitative EEG analysis shows higher frequencies of slow-wave bands and lower frequencies of alpha activity predominantly in left frontotemporal regions in patients with OCD [82]. A left predominance of posterior frontal mid-temporal theta-2 was reported by [201].

Interhemispheric neurochemical differences have been found as well. Patients with OCD have higher binding ratios for the dopamine transporter in the left caudate and left putamen compared with healthy subjects and a higher D2 receptor binding potential in the left caudate [202, 203]. Interestingly, the P2 EEG response, which is considered to be an analogue of the M150 magnetic response has been proposed to reflect DA and NA activities [204]. M150 may reflect early stimulus evaluation and correspond to information inhibition processing in cortical and subcortical structures [205-207]. Importantly, deficits in inhibitory control were reported by a large number of studies on subjects with OCD [208, 209].

The data points to forward toward dissociation of early sensory processing deficits in auditory and visual modalities. Thus, early (before 200 ms) processing alterations in OCD patients are observed in the auditory, but not the visual, modality. For example, Savage, Weilburg [210] found shorter latencies for N1 and P2 responses of the auditory evoked potential to binaural clicks in adult OCD population. Importantly, the authors did not observe similar changes in the visual modality, suggesting particular involvement of auditory system in the pathophysiology of OCD. Moreover, the study by Ciesielski et al. [211] demonstrated that processing visual stimuli is altered in OCD subjects, only for the later but not the early stages of processing. In this way, the early visual component (P130) did not differ between HCS and OCD patients, but a later N220 component was reduced in amplitude and had shorter latency during the cognitive task consisting of presented two different picture stimuli in OCD subjects. However, one can expect changes already on the early stages of auditory processing in those OCD subjects, whose sensory intolerances are related to visual stimuli. More studies are needed to

understand diverging results of processing auditory and visual information streams in OCD patients, including those with different types of sensory intolerances.

Early sensory information processing studied with ERPs/ERFs in SCZ. Although several studies reported early sensory auditory processing deficits in SCZ patients, which can start as early as after 15ms after the stimulus onset [212], the deficit at the early stages of visual information processing is more prominent and specific to this particular disorder.

Hypoactivation of the magnocellular pathway in patients with SCZ and schizoaffective disorder is a well documented phenomenon [213, 214]. Patients with SCZ have deficits at the early stages of visual information processing, starting with reduction of P1 amplitude to red light in VEPs [215] and following by reduced P1 during memory encoding and retrieval phases [216]. Notably, only a reduction in visual P1 amplitude but not in the later N1 and P2 components was found in SCZ patients in a study by Koychev et al. [217], although the study by Oribe et al. [218] demonstrated deficits on the late stages on visual information processing in SCZ patients as well.

Abnormalities in the latency and/or amplitude of auditory evoked responses may represent biomarkers of disease state in SCZ patients. Some investigators have shown that P2 component abnormalities represent physiological markers for a positive-symptom subtype [219, 220]. Likewise, Roth et al. [221] demonstrated a negative correlation between P2 latency to frequency tones and the delusion/hallucination score, and Laurent et al. [222] showed a negative correlation between P2 latency and the PANSS positive syndrome score, whereas Shenton et al. [223] found that reduced P2 amplitudes correlated significantly with a negative-symptom subtype.

In regards to functional asymmetry in SCZ, it found to be abnormal (for review, see 224, 225). Patients with SCZ failure to demonstrate functional asymmetry for language function. Although the main alterations in asymmetrical responses are observed at later stages of information processing, first changes can be detected as early as 150 ms [226]. Functional asymmetry in SCZ has been proposed to be utilized as a possible biomarker of SCZ disorder [227].

OCD and SCZ studies investigating early sensory information processing with ERPs/ERFs. No comparative studies investigating early stages of sensory processing in OCD and SCZ patients have been conducted to date. However, from the existing literature the following tendencies emerge: [1] Early auditory information processing is altered more OCD than in SCZ. This might be related to sensory intolerances that predominate in patients with OCD, more so than in patients with in SCZ; In OCD, such changes in auditory information processing can start already at the level of brain stem; [2] Early visual information processing is deficient in SCZ, but not in OCD; this tendency changes during the late stages of the processing, during which both OCD and SCZ show deficits. Comparative studies are needed for developing biomarkers distinguishing OCD and SCZ based on early visual and auditory ERP responses. Functional asymmetry can be a potential biomarker for these two psychiatric conditions.

3.5. Change detection processing

The auditory MMN, which can also be detected magnetically (MMN*m*), was first reported by Näätänen et al. [228] (see also, [229]). It is a negative ERP component elicited by any change in the repetitive auditory stimulus presentation (such as changes in frequency, duration, intensity, location) The MMN peaks at about 100-200 ms from change onset (for review, see [230]). It is suggested that the MMN represents a sensory memory trace formation process related to the evaluation of presented stimuli. The MMN could provide information about the amount of neuronal resources participating in automatic (involuntary) change-detection processes [231].

The change detection mechanism studied with MMN/MMNm in OCD. There are very few studies, to date, that investigate the change-detection mechanism in OCD patients. Most studies do not demonstrate significant differences between OCD patients relatively to HCS. For example, Towey et al. [232] did not find any alterations in MMN responses in OCD patients when compared with HCS. Nevertheless, they demonstrated differences between OCD patients and HCS in the later ERP components. It must be mentioned, though, that MMN in the above mentioned study was not elicited in the passive listening condition – without active partici-pation, which is the most established approach to record this evoked response. Rather, the study participants were asked to pay active attention to deviant stimuli. Therefore, the study was addressing active rather than passive change-detection processes. More relevant infor-mation was obtained in a comparative MMN study between OCD and SCZ groups. This will be discussed below.

Perhaps it is unlikely for there to be abnormalities in the MMN in patients with OCD given its proposed neurochemical basis. The neurochemical dysfunction in OCD is thought by many to involve, deficits in serotonin (5-HT). Some studies confirm 5-HT involvement in MMN generation [233, 234]. However, it seems that NMDA-related changes have more influence on MMN generation than the serotonergic influences [235]. Therefore, one may not expect strong pronounced deficits in MMN generation in OCD patients.

Change detection mechanism studied with MMN/MMNm in SCZ. Unlike studies of MMN in OCD, the literature on MMN research in SCZ is very extensive. Both MMN and MMN*m* have proved to be particularly valuable in SCZ research (for review, see [236], [237]). The first report concerning MMN deficiency in SCZ was made by Shelley et al. [238]. Patients with SCZ show abnormal MMN and MMN*m* responses (for review, see [236], [239]) and the most significant finding is the reduction of the MMN amplitude [239, 240]. This is also shown in the magnetic MMN counterpart [241]. Important interhemispheric differences were also demonstrated in MMN response amplitude. Patients with SCZ seem to have lower MMN responses over the left hemisphere when compared with HCS [241, 242]. This corresponds well with MRI studies showing that SCZ patients have structural brain abnormalities with reduced grey matter density in the left posterior superior temporal gyrus, the medial temporal lobe structures [243], the left inferior parietal lobule, the cingulate gyrus, the left middle frontal gyrus, the left hippocampal gyrus and the right superior frontal cortex [244]. Moreover, the MMN amplitude in patients with SCZ correlates with the volume of primary auditory cortex (Heschl gyrus) [245]. In addition, several studies reported correlations between negative symptoms and the

MMN amplitude [240, 246]. More recently, studies of MMN in schizophrenia, utilize a functional connectivity analysis approach [247]. These authors demonstrated that cortical functional connectivity is impaired during "odd-ball" task eliciting MMN response. Imaginary coherence indexes measured from EEG activity in gamma frequency band between different brain regions correlated with hallucinatory behavior and clinical positive and negative symptom scores.

It is important to mention a relation between MMN generation and dysfunctional neurotransmission in SCZ. Glutamate NMDA receptors, which are thought to be implicated in pathophysiology of SCZ, are crucially involved in MMN generation [248, 249]. Another neurotransmitter system implicated in pathophysiology of SCZ was demonstrated to have significant inhibitory GABA influences on MMN generation as well [250, 251].

Comparative OCD and SCZ studies investigating change detection mechanism with MMN/MMNm. In their comparative study, Oades et al. [194] contrasted MMN findings between paranoid-hallucinatory and non-paranoid schizophrenia patients with OCD and HCS. Main differences were found in MMN scalp distribution. In this way, MMN amplitudes were higher on the right in OCD patients, whereas in a group of paranoid SCZ patients they were distributed bilaterally and in the group of non-paranoid SCZ patients they have shifted posteriorly. Right-hemispheric MMN amplitude asymmetry in OCD group is consistent with our previous findings of increased amplitudes of both M100 and M150 components over the right hemisphere in OCD patients [193]. In their study Oades et al. [252] found MMN reduced at frontal and increased at temporal sites of the brain in patients with SCZ in both passive and active attention conditions. Usually expected increase of MMN amplitude with switch to the active condition was observed only in OCD and HCS groups, but not in the SCZ group. Overall, both studies on neurochemical regulation of MMN and comparative studies between MMN responses in OCD and SCZ suggest the possibility of using the MMN as a marker to differentiate these disorders.

3.6. Attention

A specially designed "distraction" paradigm utilizes novel (distractive) stimuli to elicit P3a response [253, 254], which is considered to reflect reorienting of involuntary attention towards the novel (distracting) event. The P3a in EEG recordings is a positive response, peaking around 250-350 ms after stimulus onset [255]. It follows the processes reflected by it preceding MMN response [254]. The frontal lobes seem to be necessary for P3a generation, as P3a amplitude was significantly diminished in the presence of distracting stimuli in patients with frontal lobe lesions [256]. Similar to MMN, the P3a response can be recorded with MEG (P3a*m*) [257, 258]

The P300 (or P3) first described by Sutton et al. [259] is a positive potential occurring at an approximate latency of 300 ms and is evoked by the presentation of a deviant target (rare) stimulus embedded among irrelevant (frequent) stimuli, while the subject is actively reacting (pressing a button or mentally counting) to the target stimuli [260]. Classical P300 response requires positive response to the infrequent stimulus of an "odd-ball" task, has a parietal scalp maximum, and sometimes is referred to as P3b [261]. P300 is usually interpreted as an electrophysiological correlate of active attention processes and working memory [262]. The

latency of P300 could correspond to the speed of cognitive processing or to that of stimulus classification [263]. It is notable that the P300 latency is negatively correlated with mental function in normal subjects, such that shorter latencies are related to superior cognitive performance [264].

Attention studied with P300 in OCD. There are few studies regarding novelty detection reflected in P3a response in patients with OCD. The only study we were able to find to date showed increased in novelty P3a amplitude in OCD patients compared with HCS [265]. It was interpreted by authors as "indicator of an enhanced cortical orienting response implicating stronger involuntary shifts of attention." Interestingly, the emotional context (neutral or negative) of stimulus presentation did not have any influence on P3a generation. It is worth mentioning here two other studies by Gohle, Juckel [266] and Mavrogiorgou, Juckel [267], who separated P3a and P3b subcomponents from P300 response elicited during classical "odd-ball" paradigm with one standard and one deviant stimuli in OCD patients. Study design did not utilize novel distracting stimuli here to elicit novelty P3a response.

Reports about alteration in P300 response in OCD patients are variable. Reduced P300 amplitude was demonstrated by Beech, Ciesielski [268] as well as by Towey, Tenke [232] in response to attended target stimuli. At the same time an increase in P300 amplitude was reported by other research groups [266, 267]. Interestingly, Towey, Tenke [232] observed differences in P300 amplitudes between two conditions – attended and unattended stimuli. P300 amplitude for unattended non-target stimuli was increased; at the same time it was decreased in response to attended targets. These authors speculated that these findings may imply abnormal allocation of attentional resources from relevant information (decreased P300 amplitude to the attended target stimulus) to irrelevant details (increased P300 amplitude to unattended non-target stimuli). Interestingly, the degree of P300 increase was shown to separate future treatment responders from non-responders [195]. Unlike the variable findings regarding P300 amplitude in OCD, the findings of changes in P300 latency are very consistent among the research groups. All studies show reduced P300 component latency in the OCD group when compared to HCS [195, 211, 267-270] (see also Table 2). This is very important finding demonstrating cortical hyperarousal associated with active attention processes and faster cognitive processes in OCD patients.

Attention studied with P300 in SCZ. Similar to MMN response, most of the published studies demonstrate decrease in P3a amplitude in SCZ patients when compared with HCS [271-273]. Reduction in P3a amplitude is strongly associated with clinical symptomatology, such as negative SCZ symptoms [272]. P3a reduction in SCZ is a well established phenomena and has also been confirmed in nonhuman primate model [274]. Together with MMN response, P3a changes are excellent proposals for biomarkers of SCZ [275, 276].

Patients with SCZ also show reduction of P300 amplitude, particularly in an auditory task [277-279]. Roth and Cannon [280] were the first to report reduced P300 amplitude in SCZ. Since that time, the reduction of P300 amplitude has been demonstrated in various experimental paradigms in acute, remitted, medicated and medication-free patients [277, 281-284]. Patients with SCZ also exhibit a delayed P300 latency [285, 286]. These effects are robust and independent of medication, gender, or clinical state at the time of testing. A positive correlation

between the duration of schizophrenia illness and P300 latency was demonstrated [287]. A parietal P300 amplitude reduction in SCZhas been linkedto poorer performance on neuropsychological tests of memory, whereas frontal P300 amplitude reduction has been linked to impaired selective attention [288]. Notably, the relationship between neural P300 generator and clinical symptomatology was observed. In this way, Kim, Shim [289] demonstrated that the decreased P300 source activation in the middle temporal gyrus, posterior cingulate, precuneus, and superior occipital gyrus negatively correlated with negative symptom scores.

Comparative OCD and SCZ studies investigating attention processes with P300. Several comparative studies were conducted. Kim, Kang [290] compared P300 responses elicited by an auditory "odd-ball" paradigm in OCD, SCZ and a group of HCS; these authors also correlated neurophysiological results with neuropsychological scores. In this study, the P300 amplitude was smaller in both OCD and SCZ groups when compared with HCS. However, the differences in correlation between deficits in P300 generation and cognitive performance scores were observed in OCD and SCZ. Whereas P300-related cognitive deficits in OCD patients were localized and mostly related to controlled attention and self-guided behavior, the P300-associated cognitive deficits in SCZ were generalized, implying wide-range impairment. A more recent study by Pallanti, Castellini [291] explored not only differences in P300 responses between OCD and SCZ groups, but it also looked at SCZ patients exhibiting OCD behavior (Schizo-OCD patients). This group of patients demonstrated a distinct pattern of P300responses: Unlike OCD patients there was no differences in P300 responses between non-target and target conditions; unlike HCS there was elevated P300 amplitudes in the target condition and reduced P300 amplitudes in non-target condition. Thus it was possible to distinguish the SCZ-OCD patients from both the OCD and SCZ groups. These authors argue that using a neurophysiological approach one can separate a distinct clinical entity of Schizo-OCD from OCD and SCZ.

Overall, ERPs reflecting attention-influenced cognitive processes can be potential biomarkers distinguishing OCD and SCZ. Increased P3a amplitude in OCD and decreased P3a amplitude in SCZ, shorter P300 latencies in OCD and longer P300 latencies in SCZ may all be good candidates for making such a distinction. In addition, the, P300 can be used as a potential biomarker to distinguish Schizo-OCD subtype from both OCD and SCZ.

3.7. Action monitoring

Acton monitoring processes can be assessed by error related negativity (ERN, [292]) the negative portion of an event related potential that occurs 50-100 ms after a subject gives an incorrect response. The ERN is usually followed by a positive deflection or error positivity (PE, [293], [294]) and occurs 200-500 ms after an incorrect response.

Action monitoring studied with event-related negativity (ERN) in OCD. Patients with OCD are thought to monitor their actions excessively. Electrophysiological support for this notion comes from ERN measurements. Several studies have looked for error-related deviations in brain activity in subjects with OCD. Multiple studies have found greater ERN amplitude in subjects with OCD compared with healthy controls [292, 295-299]. Interestingly, Santesso et al., [300] expanded this finding to children. However, Nieuwenhuis et al. [301] did not find

enhanced error-related activity in patients with OCD nor did Grundler et al. [296] in a population with subclinical obsessive compulsive symptoms using a probabilistic learning task. Yet, Grundler et al. [296] did find larger ERNs when using a flanker task. This finding of a differential task-dependent response was replicated by Endrass et al. [302].

Action monitoring studied with event-related negativity (ERN) in SCZ. In contradistinction to the results observed in OCD patients, the amplitude of ERN component related to action monitoring in SCZ patients is reduced [303-305]. This reduction was found to be associated with negative symptom severity and poorer real-world functioning (indicated by unemployment and re-hospitalization over 10 years of illness) in a study by Foti, Kotov [306]. Authors hypothesized that their results may represent decreased motivation to pursue goal-directed behavior, which is thought to underlie the exhibition of negative symptoms in SCZ.

Comparative studies on action monitoring with event-related negativity (ERN) between OCD and SCZ. To our knowledge, no comparative OCD-SCZ studies assessing action monitoring behavior with its neurophysiological analogue – ERN have been performed to date. From the individual reports of ERP studies in these two patient groups, it is evident that there are major differences in ERN generation. These differences includeincreased ERN amplitude in OCD and decreased ERN response in SCZ. These differences in ERN may be helpful as further biomarkers of disease.

In conclusion, there are obvious reasons to believe that neurophysiological markers distinguishing OCD and SCZ can be found. The main candidates are P3a and P3b responses as well as ERN. Additional studies are needed to determine whether there are changes in MMN in OCD. Future studies are recommended to dissociate deficits at the early stages of auditory and visual processes in OCD and SCZ. New studies evaluating entraining mechanisms with SSR in OCD are warranted. A special emphasis should be placed on examining developmental differences in the neurophysiological responses in OCD. The use of MEG is highly recommended in OCD group, as it can provide not only time-related information, but also localize the activity of interest in the space domain.

Studied processes	ERP/ERF component (-s) studied/paradigm	Study participants /age of OCD patients/	Observed ERP changes		Authors
Brain stem function					
Brain stem function	BAEPs to clicks	50 OCD; 50 anxiety disorder; 25 HCS /adults; mean 33 ± 8 yo/	wave I–V wave III	interpeak L↑ A↓	Nolfe et al. [171]
Early sensory processing (pre-attentive)					
Early visual processing	VEPs to flash	8 OCD; 8 HCS /adults; mean age 36.5 yo/	P130	-	Ciesielski et al. [211]
Early, auditory, visual and	AEPs to binaural clicks, VEPs to checkerboard flashes, SEPs	14 OCD; 14 neurotics; 14 HCS /adults/	Comparison with HCS:	A↑ A↓ A↓	Shagass et al. [324]

Studied processes	ERP/ERF component (-s) studied/paradigm	Study participants /age of OCD patients/	Observed ERP changes		Authors
somatosensory processing			Somatosensory P60 Visual N75 Auditory P50 Auditory P85	L↑	
Early somatosensory processing	SEPs	14 OCD; 28 neurotics; 99 HCS; 49 chronic SCZ; 27 "other" SCZ; 20 latent SCZ; 42 major depressive /adults; 23-48 yo/	Comparison with HCS: N60 P90 N130	A↑ A↓ A↓	Shagass et al. [325]
Early auditory and visual sensory processing	AEPs to tone bursts and VEPs to flash	50 OCD; 40 HCS /no age-related information was provided by authors/	Auditory and visual P1 N1 P2	-	Khanna et al. [326]
Early auditory and visual sensory processing	AEPs to binaural clicks and VEPs to flash	15 OCD (unmedicated); 30 HCS /adults; 35.6 ± 9.9/	Auditory N1 Auditory P2 Visual N1 Visual P2	L↓ L↓ - -	Savage et al. [210]
	BAEPs to	50 OCD; 50 anxiety disorder; 25 HCS /adults; mean 33 ± 8 yo/	wave I–V wave III		
Early auditory sensory processing	AEFs to binaural clicks	10 OCD; 10 HCS /youth; 8-13 yo/	M70 M100 M150	- L↑ -	Korostensk aja et al. [193]*
Brain activity synchronization with external events (pre-attentive)					
Synchronation of brain activity with external periodic sensory stimulation	ASSR to repetitively presented trains of identical clicks	No studies reported to date in OCD patients; for comparison, see review section of ASSR studies in schizophrenia			
Change detection (automatic attention processes)					
Automatic response to a change in external stimuli	Auditory MMN response to deviant tones interspersed among frequent tones. No task execution required	Only limited number of studies performed - see comparative OCD/SCZ section; for comparison, see also review section of MMN studies in schizophrenia			
Novelty detection (involuntary attention switch)					
Processing of novel	AEPs elicited in response to auditory novelty "odd-ball" task with irrelevant	20 OCD; 20 HCS /adults; 32.8 ± 9.9 yo/	P3a	A↑	Ischebeck et al. [265]

Studied processes	ERP/ERF component (-s) studied/paradigm	Study participants /age of OCD patients/	Observed ERP changes		Authors
(unexpected) stimuli	repeated frequent sounds and rare novel sounds interspersed among them; the paradigm was presented during performance of visual recognition task				
Active attention processes					
Selective attention; complex processing of visual information	VEPs elicited during visuospatial task: discrimination of two similar shapes	8 OCD; 8 HCS /adults; mean age 36.5 yo/	N220 P340	A↓; L↓ Similar trend as for N220, however not statistically significant	Ciesielski et al. [211]
Selective attention; complex processing of visual information	VEPs elicited during visuospatial task of increasing difficulty: discrimination of two similar shapes	8 OCD; 8 HCS /adults; average age 40 yo/	N220 P350	A ↓; L ↓ A ↓; L ↓ Effect was stronger with increasing task complexity	Beech et al. [268]
Active attention	AEPs elicited during auditory "odd-ball" discrimination paradigm of increasing difficulty	10 OCD (drug-free for two weeks); 10 HCS /adults; 18-55 yo/	N200 P300	A↑ L↓ during difficult discrimination task	Towey et al. [269]
Active attention	AEPs elicited during auditory "odd-ball" discrimination paradigm of increasing difficulty	17 OCD (unmedicated); 16 HCS /adults; 18-55 yo/	N200 P300	A↑ A over the left hemisphere "/> than over the right hemisphere -	Towey et al. [327]
Selective attention	AEPs elicited during direct attention task	18 OCD (unmedicated); 15 HCS /adults; mean age 30.0 ± 9.1 yo/	MMN (N2a) N200 (N2b) P300 for attended targets P300 for unattended non-targets	- - A↓ A↑ L↑, A↑ A↑	Towey et al. [232]

Studied processes	ERP/ERF component (-s) studied/paradigm	Study participants /age of OCD patients/	Observed ERP changes		Authors
			PN SW for unattended non-targets		
Active attention and discrimination of verbal stimuli	AEPs elicited to verbal (disyllabic) auditory stimuli (meaningful and meaningless) presented in an "oddball" paradigm; subjects were asked to keep a mental count of target stimuli	13 OCD (unmedicated); 13 HCS /adults; 21-56 yo/	N1 N2 P2 P3	L↑ A↓ L↑ L↓ A over the left hemisphere < than over the right hemisphere	Morault et al. [195]
Active attention and discrimination of auditory stimuli	AEPs elicited during auditory "odd-ball" paradigm with two frequency deviants; subjects were asked to keep a mental count of target stimuli	18 OCD (unmedicated); 18 HCS /adults; 19-59 yo/	N200 P300 SW	A↑ - L↓	de Groot et al. [329]
Active attention and discrimination of auditory stimuli	AEPs elicited during auditory "odd-ball" paradigm with two frequency deviants; subjects were asked to keep a mental count of target stimuli	23 OCD (unmedicated); 12 SP (unmedicated); 18 HCS 21 OCD (medication-free); 21 HCS / mixed: youth and adults; 16-50 yo/	N200 P300	L↓ than SP and HC A↑ than in HC L↓ than SP and HC	Miyata et al. [270]
Active attention	AEPs elicited during auditory "oddball" paradigm; authors do not specify details of the task performed by the subjects	30 OCD (medication-free for 2-4 weeks); 30 HCS /mixed: youth and adults; 16-40 yo/	P200 in response to irrelevant (frequent) stimuli N200	A↑ A↓	Okasha et al. [330]
Active attention	AEPs elicited during "oddball" paradigm with frequent and deviant (target) stimuli; subjects had to press a button in response to target stimuli	21 OCD (medication-free); 21 HCS / mixed: youth and adults; 17-27 yo/	P3a P3b (importantly, separation between P3a and P3b was performed with	- A↑ L ↓ (in the right hemisphere)	Mavrogiorg ou et al. [267]

Studied processes	ERP/ERF component (-s) studied/paradigm	Study participants /age of OCD patients/	Observed ERP changes		Authors
			dipole modeling)		
Active attention	AEPs elicited during "oddball" paradigm with frequent and deviant (target) stimuli; subjects had to press a button in response to target stimuli	63 OCD (acutely ill, unmedicated); 63 HCS /adults; mean age 33.71 ± 10.17 yo/	P3a P3b (separation between P3a and P3b was performed with dipole modeling)	- A↑	Gohle et al. [266]
Learning and memory					
Implicit memory; word repetition effect	Implicit memory (word repetition) task; ERPs to visually presented word/ non-word lexical decision task; subjects were asked to decide whether each item was word or non-word	12 OCD; 13 HCS /adults; 19-29 yo/	Word repetition effect at 300-500 ms post-stimulus Hemispheric functional asymmetry for the new words	OCD: No HCS: Yes OCD: Right-sided asymmetry HCS: Left-sided asymmetry	Kim et al. [331].
Error-related behavior					
Action monitoring	ERPs were elicited during Stroop task, consisting of three visually presented words "red", "green", and "blue"; subjects were instructed to press the right or left mouse button in response to the color of the words	9 OCD; 9 HCS /adults; 19-58 yo/	ERN	A↑	Gehring et al. [292]
Action monitoring and target detection	ERP responses elicited during visual presentation of letters 'H' and 'O'; targets consisted of large letters, non-targets consisted of small letters; subjects were instructed to press a button held in the right hand whenever a	10 OCD; 10 HCS /adults; 22-40 yo/	ERN P3b	A↑, L↓ L↓	Johannes et al. [298]

Studied processes	ERP/ERF component (-s) studied/paradigm	Study participants /age of OCD patients/	Observed ERP changes		Authors
	target H appeared and to press another button in the left hand when a target O appeared				
Action monitoring and error detection	ERPs were elicited during Stroop task, consisting of three visually presented words "red", "green", and "blue"; subjects were instructed to press the right or left mouse button in response to the color of the words	18 high-OCD; 17 low-OCD	Response-locked ERN	A↑ in high-OCD group	[332]
Action monitoring	ERPs were recorded in probabilistic learning task and were associated with errors and negative feedback	16 OCD; 16 HCS /adults; 21-49 yo/	ERN	-	Nieuwenhuis et al. [301]
Error monitoring processes	ERPs were elicited during combined a Go/NoGo task with an Eriksen flanker paradigm	11 OCD; 11 HCS	ERN "early" Pe "late" Pe	A↑ - -	Ruchsow et al. [333]
Performance monitoring	ERPs were elicited during modified version of flanker interference task	20 OCD; 20 HCS /adults; 33.5 ± 8 yo/	ERN CRN Pe	A↑ A↑ -	Endrass et al. [295]
Performance monitoring before and after treatment	ERPs were elicited during modified version of Simon task	Before treatment: 18 OCD; 18 HCS After treatment: 10 OCD; 13 HCS /youth; 8 - 17 yo/	ERN	A↑ (the effect remained after treatment)	Hajcak et al. [297]
Performance monitoring	ERPs were elicited during modified version of flanker interference task	22 OCD; 22 HCS /adults; 31.2 ± 8.4 yo/	Standard condition: ERN CRN Pe	A↑ A↑ -	Endrass et al. [302]
Performance monitoring	ERPs was elicited during modified Erikson flankers task	25 OCD, 27 GAD, 27 HCS /adults; 32.5 ± 10.2 yo/	ERN Ne of difference waveform amplitude at	A↑ in OCD A↑ in OCD subjects, but not in GAD	Xiao et al. [334]

Studied processes	ERP/ERF component (-s) studied/paradigm	Study participants /age of OCD patients/	Observed ERP changes		Authors
			medial frontal electrodes Pe	(compared with HCS) -	
Performance monitoring	ERPs was elicited during modified Erikson flankers task	44 OCD; 44 HCS /youth; 10 - 19 yo/	ERN	A↑	Hanna et al. [335]
Performance monitoring	ERPs was elicited during modified Erikson flankers task	26 OCD; 13 non-OCD anxiety disorder; 27 HCS /youth; 8 - 16 yo/	ERN	A↑	Carrasco et al. [170]
Performance monitoring	ERPs was elicited during modified Erikson flankers task	40 OCD; 19 unaffected siblings of OCD subjects; 40 HCS /youth; 10 - 17 yo/	ERN	A↑ (in both OCD patients and their siblings)	Carrasco et al. [336]

A – amplitude; AEFs – auditory evoked fields; AEPs – auditory evoked potentials; ASSR – auditory steady-state evoked responses; BAEPs - Brainstem auditory evoked potentials; CNV – contingent negative variation; CRN – correct response negativity; ERN/Ne – error-related negativity; ERP – event related potential; GAD - generalized anxiety disorder; HAMA - Hamilton Anxiety Rating Scale; HAMD - Hamilton Depression Rating Scale; HCS – healthy comparison subjects; L – latency; MMN – mismatch negativity; OCD – obsessive-compulsive disorder; Pe – error positivity; PN – processing negativity; SCZ – schizophrenia; SEPs - sometosentory evoked potentials; SP - social phobia; SW – slow wave; T/C – test/conditioning ratio; VEPs – visual evoked potentials; yo – years old; ↓ – decrease; ↑ increase; "- " – no effect; * denotes MEG studies

Table 2. ERP/ERF studies in patients with OCD

4. Neurophysiological markers of treatment response

Neurophysiologically guided clinical decisions is an exciting direction for translational research. We are close to clinically useful predictors of treatment response in both OCD and SCZ. Finding such a biomarker or assessment battery has been a longstanding goal of clinicians and scientists, as the current treatment approach is one of trial-and-error with respect to choice of medication. Since both SCZ and OCD are chronic conditions, patients with life-long, treatment-resistant disorders suffer from complications including medication side effects, poor quality of life, depression, unemployment and stigma. Although the symptoms of OCD typically begin in childhood [307], only about half of youths with OCD respond to the current standard-of-care treatment consisting of a serotonergic medication and cognitive behavior therapy (POTS, [308]).

As early as 1984, Insel, Mueller [309] attempted to find a biomarker to predict treatment response. This group of investigators examined a number of tests, including sleep EEG, the dexamethasone suppression test and platelet 3H-imipramine binding, but they were unsuccessful in finding a marker that predicted clinical response to clomipramine in patients with OCD. More recently, a number of functional imaging studies in adults have described changes functional changes in specific anatomical regions as a response to treatment. Nakao et al. [317]

found that elevated activity in the OFC, dorsolateral PFC and anterior cingulate cortex decreased with fluvoxamine or cognitive behavior therapy. Rauch et al. [318] reported that lower pretreatment regional cerebral blood flow (rCBF) in the OFC and higher rCBF in the posterior cingulate cortex were predictive of treatment response to fluvoxamine in adults with contamination obsessions. Similarly, Saxena et al. [319] reported glucose metabolism decreased in the right anterolateral OFC and right caudate as a result of 8-12 weeks of treatment with paroxetine. Prior to treatment with clomipramine, Rubin et al. (1995) reported that there was increased uptake of HMPAO in the OFC, posterofrontal cortex and dorsal parietal cortex compared with healthy volunteers. Decreased uptake in these regions occurred following treatment.

With regard to electrophysiological studies, a series of three papers by a single team of investigators have identified two groups of patients with OCD; one group had elevated alpha power at baseline and the other group had elevated theta power. These groups predict treatment response: the majority of patients with excess alpha respond to paroxetine and the majority of the patients with excess theta were non-responders. The excess alpha observed in the resting state prior to treatment normalized with treatment [76-78]. Fontenelle et al. [95], on the other hand, found yet another EEG band predictive of treatment response. These investigators obtained the pretreatment EEG in 17 drug-free patients with OCD and analysed the EEG with low-resolution electromagnetic tomography. Subjects were then treated for 12 weeks with antidepressants; 10 subjects responded and 7 were considered non-responders. There was significantly lower beta band activity in the anterior cingulate and medial frontal gyrus in the pretreatment EEG of responders. In a randomized double-blind study comparing sham feedback with neurofeedback (NFB) for the treatment of OCD, a significant decrease in compulsions was seen in the NFB group. Unlike the findings of Fontanelle, these authors noted than an increase in delta, low alpha and low beta in the baseline EEG were predictive of worse treatment outcome [320].

In an early study of treatment prediction for SCZ, Galderisi et al., (1994) examined baseline QEEG characteristics and their changes following a single test dose of either haloperidol or clopenthixol in 29 patients with SCZ. Those who responded to medication less slow activity and more fast activity than nonresponders. However, the authors go on to note that there was overlap in the baseline activity of responders and non-responders decreasing the utility of this approach. Yet changes in alpha 1, observed 6 hours after the administration of a single test dose of either haloperidol or clopenthixol, did succeed in discriminating between responders and nonresponders. Antipsychotic medications currently used to treat SCZ symptoms In a more recent study of 22 drug-naïve patients with SCZ treated with a variety of medications including conventional dopamine-blocking neuroleptics, serotonin-dopamine antagonists, anticholinergic agents, antihistaminergic agents or benzodiazepine derivatives, no spectral changes were found when comparing EEGs pre and post-treatment. However, using a novel approach for treatment response assessment, this study used an analysis of multiscale entropy and found that subjects with SCZ had greater complexity for lower frequencies than HCS in fronto-centro-temporal regions, but not in parieto-occipital regions. Following treatment, the elevated complexity normalized in fronto-central regions but was not alleviated in temporal

regions [315]. Based on these studies, one wonders whether pretreatment alpha power does not predict response to dopamine antagonists, but what about medications that target the glutamatergic system which can also alleviate psychotic symptoms in SCZ [316]? Clinical trials for such compounds may consider changes in alpha EEG activity as a biomarker of treatment response or an alternate approach to response prediction.

For patients with SCZ, Khodayari-Rostamabad et al. [310] successfully used an alternative analytic approach – that of machine learning-- to extract features in the pre-treatment EEG to predict clinical response to clozapine. As such novel analytic approaches gain popularity in neurophysiological research, there is hope that these will have translational value for treatment prediction in the future. One such illustrative example is the machine learning approach to develop computational models based on the patients' MMNm and clinical data [311]. In the field of epilepsy, investigators use machine learning to predict seizures outcome following neurosurgery with 90% success rate [312] and to predict the likelihood of having a seizure from EEG features [313]. New and important information about the effect of epilepsy on information processing was reported by Ralescu, Lee [311] (Figure 3). The advantage of the computational approach used by these authors is that it allows experimentation with various settings of the parameters to generate possible scenarios for different models [314]. This computational approach for psychophysiological data analysis may reveal individual patterns of activity within the group. This innovative solution may have a strong potential to provide new insights into predicting treatment response for other conditions using the neurophysiological parameters of EEG/MEG or ERP/ERF responses in both OCD and SCZ.
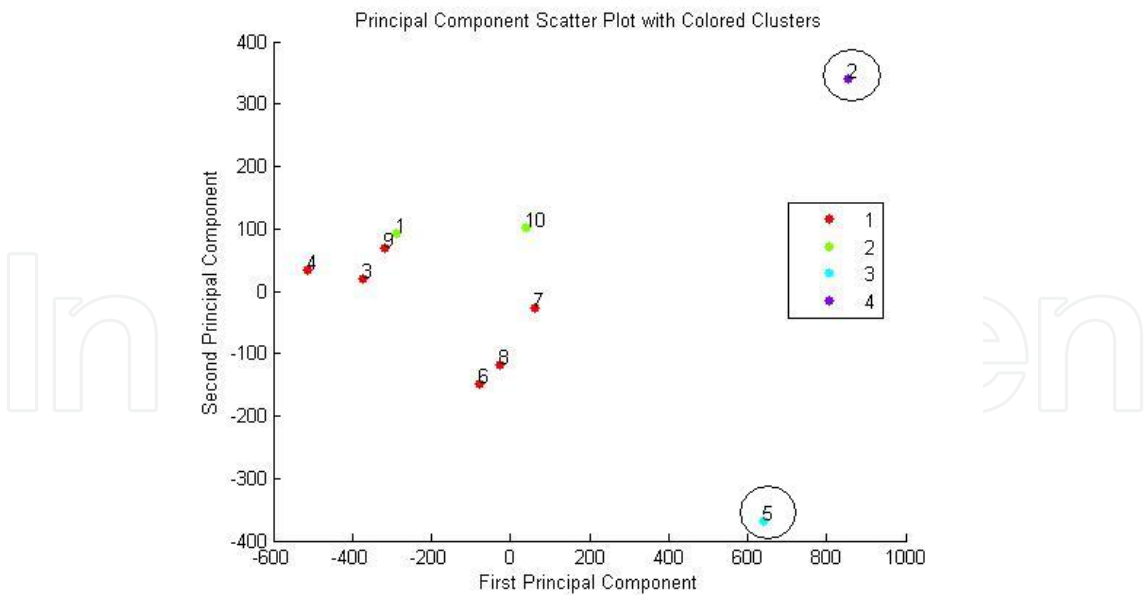
Figure 3. Clustering the MMNm response data of the ten patients with epilepsy in a two dimensional space of principal components. Patient P2 was farthest away from the rest of the data. Inspection of the P2 individual characteristics revealed that her age at onset of epilepsy (0.5 years) was the earliest among the rest of the patients. Utilized approach allowed differentiation of unique patients' characteristics through the parameters of neurophysiological MMNm responses.

5. Future directions

On the basis of clinical history and mental status examination, the young adult with unwinding, stealing and contamination would be given the diagnosis of OCD. The authors are hopeful that in the near future it will be possible to order an electrophysiological battery to confirm the diagnosis in challenging cases and to guide individually tailored treatment.

The hope that a biomarker for psychiatric conditions will emerge is already becoming a reality for some conditions. Basar's [321] proposal that brain functions are a result of simultaneous oscillations in various frequency bands has yielded fruit. Patients with ADHD can now be diagnosed based on the ratio of theta to beta frequency bandwidths. Robinson [322] found an inverse relationship between alpha and delta waves that correlated with personality type, with lower magnitude in extraverted and neurotic subjects. Changes in the cross-frequency coupling can be seen following treatment with psychotherapy [323]. Further examination of the interactions between different frequency bandwidths for patients with schizophrenia and OCD may be the logical next step.

Acknowledgements

Author details

Elana Harris[1*] and Milena Korostenskaja[2,3]

*Address all correspondence to: elana.harris@cchmc.org

1 Division of Child and Adolescent Psychiatry, Cincinnati Children's Hospital Medical Center, Cincinnati, Ohio, USA

2 MEG Lab, Florida Hospital for Children, Orlando, FL, United States, USA

3 Functional Brain Mapping and Brain Computer Interface Lab, Florida Hospital for Children, Orlando, FL, USA

The authors have no financial or personal relationships to disclose.

References

[1] Weissman MM, Bland RC, Canino GJ, Greenwald S, Hwu HG, Lee CK, et al. The cross national epidemiology of obsessive compulsive disorder. The Cross National Collaborative Group. J Clin Psychiatry. 1994;55 Suppl:5-10. Epub 1994/03/01.

[2] Saha S, Chant D, McGrath J. Meta-analyses of the incidence and prevalence of schizophrenia: conceptual and methodological issues. International journal of methods in psychiatric research. 2008;17(1):55-61. Epub 2008/02/21.

[3] Saha S, Chant D, Welham J, McGrath J. A systematic review of the prevalence of schizophrenia. PLoS medicine. 2005;2(5):e141. Epub 2005/05/27.

[4] Sasson Y, Zohar J, Chopra M, Lustig M, Iancu I, Hendler T. Epidemiology of obsessive-compulsive disorder: a world view. J Clin Psychiatry. 1997;58 Suppl 12:7-10. Epub 1997/01/01.

[5] Whiteford HA, Degenhardt L, Rehm J, Baxter AJ, Ferrari AJ, Erskine HE, et al. Global burden of disease attributable to mental and substance use disorders: findings from the Global Burden of Disease Study 2010. Lancet. 2013. Epub 2013/09/03.

[6] Bobes J, Gonzalez MP, Bascaran MT, Arango C, Saiz PA, Bousono M. Quality of life and disability in patients with obsessive-compulsive disorder. Eur Psychiatry. 2001;16(4):239-45. Epub 2001/06/22.

[7] Huppert JD, Simpson HB, Nissenson KJ, Liebowitz MR, Foa EB. Quality of life and functional impairment in obsessive-compulsive disorder: a comparison of patients with and without comorbidity, patients in remission, and healthy controls. Depress Anxiety. 2009;26(1):39-45. Epub 2008/09/19.

[8] Bellack AS, Green MF, Cook JA, Fenton W, Harvey PD, Heaton RK, et al. Assessment of community functioning in people with schizophrenia and other severe mental illnesses: a white paper based on an NIMH-sponsored workshop. Schizophr Bull. 2007;33(3):805-22. Epub 2006/08/26.

[9] Caldwell CB, Gottesman, II. Schizophrenics kill themselves too: a review of risk factors for suicide. Schizophr Bull. 1990;16(4):571-89. Epub 1990/01/01.

[10] Eisen JL, Beer DA, Pato MT, Venditto TA, Rasmussen SA. Obsessive-compulsive disorder in patients with schizophrenia or schizoaffective disorder. Am J Psychiatry. 1997;154(2):271-3. Epub 1997/02/01.

[11] Berman I, Kalinowski A, Berman SM, Lengua J, Green AI. Obsessive and compulsive symptoms in chronic schizophrenia. Comprehensive psychiatry. 1995;36(1):6-10. Epub 1995/01/01.

[12] de Haan L, Dudek-Hodge C, Verhoeven Y, Denys D. Prevalence of psychotic disorders in patients with obsessive-compulsive disorder. CNS Spectr. 2009;14(8):415-7. Epub 2009/11/06.

[13] Anholt GE, Aderka IM, van Balkom AJ, Smit JH, Schruers K, van der Wee NJ, et al. Age of onset in obsessive-compulsive disorder: admixture analysis with a large sample. Psychol Med. 2013:1-10. Epub 2013/03/23.

[14] Hafner H, Maurer K, Loffler W, Fatkenheuer B, an der Heiden W, Riecher-Rossler A, et al. The epidemiology of early schizophrenia. Influence of age and gender on onset and early course. The British journal of psychiatry Supplement. 1994(23):29-38. Epub 1994/04/01.

[15] APA. Diagnostic and statistical manual of mental disorders, DSM-IV-tr (IV ed.). Washington, DC: American Psychiatric Pub Inc; 2000.

[16] Bora E, Murray RM. Meta-analysis of Cognitive Deficits in Ultra-high Risk to Psychosis and First-Episode Psychosis: Do the Cognitive Deficits Progress Over, or After, the Onset of Psychosis? Schizophr Bull. 2013. Epub 2013/06/19.

[17] Kerns JG, Berenbaum H. Cognitive impairments associated with formal thought disorder in people with schizophrenia. J Abnorm Psychol. 2002;111(2):211-24. Epub 2002/05/11.

[18] APA. Diagnostic and Statistical Manual of Mental Disorders, 5th Edition: DSM-5: American Psychiatric Publishing; 2013.

[19] Faragian S, Fuchs C, Pashinian A, Weizman R, Weizman A, Poyurovsky M. Age-of-onset of schizophrenic and obsessive-compulsive symptoms in patients with schizo-obsessive disorder. Psychiatry Res. 2012;197(1-2):19-22. Epub 2012/03/23.

[20] Bottas A, Cooke RG, Richter MA. Comorbidity and pathophysiology of obsessive-compulsive disorder in schizophrenia: is there evidence for a schizo-obsessive subtype of schizophrenia? J Psychiatry Neurosci. 2005;30(3):187-93. Epub 2005/06/10.

[21] Gross-Isseroff R, Hermesh H, Zohar J, Weizman A. Neuroimaging communality between schizophrenia and obsessive compulsive disorder: a putative basis for schizo-obsessive disorder? World J Biol Psychiatry. 2003;4(3):129-34. Epub 2003/07/23.

[22] Poyurovsky M, Weizman A, Weizman R. Obsessive-compulsive disorder in schizophrenia: clinical characteristics and treatment. CNS Drugs. 2004;18(14):989-1010. Epub 2004/12/09.

[23] Fuhr P, Agostino R, Hallett M. Spinal motor neuron excitability during the silent period after cortical stimulation. Electroencephalography and clinical neurophysiology. 1991;81(4):257-62. Epub 1991/08/01.

[24] Ziemann U, Netz J, Szelenyi A, Homberg V. Spinal and supraspinal mechanisms contribute to the silent period in the contracting soleus muscle after transcranial

magnetic stimulation of human motor cortex. Neuroscience letters. 1993;156(1-2): 167-71. Epub 1993/06/25.

[25] Kobayashi M, Pascual-Leone A. Transcranial magnetic stimulation in neurology. Lancet Neurol. 2003;2(3):145-56. Epub 2003/07/10.

[26] Bliss TV, Lomo T. Long-lasting potentiation of synaptic transmission in the dentate area of the anaesthetized rabbit following stimulation of the perforant path. J Physiol. 1973;232(2):331-56. Epub 1973/07/01.

[27] Pascual-Leone A, Amedi A, Fregni F, Merabet LB. The plastic human brain cortex. Annu Rev Neurosci. 2005;28:377-401. Epub 2005/07/19.

[28] Kujirai T, Caramia MD, Rothwell JC, Day BL, Thompson PD, Ferbert A, et al. Corticocortical inhibition in human motor cortex. J Physiol. 1993;471:501-19. Epub 1993/11/01.

[29] Ziemann U, Rothwell JC, Ridding MC. Interaction between intracortical inhibition and facilitation in human motor cortex. J Physiol. 1996;496 (Pt 3):873-81. Epub 1996/11/01.

[30] Di Lazzaro V, Restuccia D, Oliviero A, Profice P, Ferrara L, Insola A, et al. Magnetic transcranial stimulation at intensities below active motor threshold activates intracortical inhibitory circuits. Experimental brain research Experimentelle Hirnforschung. 1998;119(2):265-8. Epub 1998/04/16.

[31] Huang YZ, Edwards MJ, Rounis E, Bhatia KP, Rothwell JC. Theta burst stimulation of the human motor cortex. Neuron. 2005;45(2):201-6. Epub 2005/01/25.

[32] Bersani FS, Minichino A, Enticott PG, Mazzarini L, Khan N, Antonacci G, et al. Deep transcranial magnetic stimulation as a treatment for psychiatric disorders: a comprehensive review. Eur Psychiatry. 2013;28(1):30-9. Epub 2012/05/09.

[33] Kindler J, Homan P, Flury R, Strik W, Dierks T, Hubl D. Theta burst transcranial magnetic stimulation for the treatment of auditory verbal hallucinations: Results of a randomized controlled study. Psychiatry Res. 2013;209(1):114-7. Epub 2013/05/08.

[34] Kindler J, Homan P, Jann K, Federspiel A, Flury R, Hauf M, et al. Reduced neuronal activity in language-related regions after transcranial magnetic stimulation therapy for auditory verbal hallucinations. Biol Psychiatry. 2013;73(6):518-24. Epub 2012/07/31.

[35] Poulet E, Haesebaert F, Saoud M, Suaud-Chagny MF, Brunelin J. Treatment of shizophrenic patients and rTMS. Psychiatria Danubina. 2010;22 Suppl 1:S143-6. Epub 2011/02/08.

[36] Slotema CW, Blom JD, Hoek HW, Sommer IE. Should we expand the toolbox of psychiatric treatment methods to include Repetitive Transcranial Magnetic Stimulation

(rTMS)? A meta-analysis of the efficacy of rTMS in psychiatric disorders. J Clin Psychiatry. 2010;71(7):873-84. Epub 2010/04/07.

[37] Greenberg BD, Ziemann U, Harmon A, Murphy DL, Wassermann EM. Decreased neuronal inhibition in cerebral cortex in obsessive-compulsive disorder on transcranial magnetic stimulation. Lancet. 1998;352(9131):881-2. Epub 1998/09/22.

[38] Greenberg BD, Murphy DL, Rasmussen SA. Neuroanatomically based approaches to obsessive-compulsive disorder. Neurosurgery and transcranial magnetic stimulation. Psychiatr Clin North Am. 2000;23(3):671-86, xii. Epub 2000/09/15.

[39] Richter MA, de Jesus DR, Hoppenbrouwers S, Daigle M, Deluce J, Ravindran LN, et al. Evidence for cortical inhibitory and excitatory dysfunction in obsessive compulsive disorder. Neuropsychopharmacology. 2012;37(5):1144-51. Epub 2011/12/16.

[40] Pedapati EV, DiFranscesco M, Wu S, Giovanetti C, Nash T, Harris E. Functional Magnetic Imaging Reveals Neural Changes Associated With Transcranial Magnetic Stimulation In Adolescents With Obsessive Compulsive Disorder. American Academy of Child and Adolescent Psychaitry 60th Annual Meeting; October 22-27; Orlando, Florida, USA2013.

[41] Daskalakis ZJ, Christensen BK, Chen R, Fitzgerald PB, Zipursky RB, Kapur S. Evidence for impaired cortical inhibition in schizophrenia using transcranial magnetic stimulation. Arch Gen Psychiatry. 2002;59(4):347-54. Epub 2002/04/03.

[42] Fitzgerald PB, Brown TL, Daskalakis ZJ, Kulkarni J. A transcranial magnetic stimulation study of inhibitory deficits in the motor cortex in patients with schizophrenia. Psychiatry Res. 2002;114(1):11-22. Epub 2002/02/28.

[43] Fitzgerald PB, Brown TL, Marston NA, Oxley TJ, de Castella A, Daskalakis ZJ, et al. A transcranial magnetic stimulation study of abnormal cortical inhibition in schizophrenia. Psychiatry Res. 2003;118(3):197-207. Epub 2003/07/02.

[44] Eichhammer P, Wiegand R, Kharraz A, Langguth B, Binder H, Hajak G. Cortical excitability in neuroleptic-naive first-episode schizophrenic patients. Schizophr Res. 2004;67(2-3):253-9. Epub 2004/02/27.

[45] Liu SK, Fitzgerald PB, Daigle M, Chen R, Daskalakis ZJ. The relationship between cortical inhibition, antipsychotic treatment, and the symptoms of schizophrenia. Biol Psychiatry. 2009;65(6):503-9. Epub 2008/10/28.

[46] Wobrock T, Schneider-Axmann T, Retz W, Rosler M, Kadovic D, Falkai P, et al. Motor circuit abnormalities in first-episode schizophrenia assessed with transcranial magnetic stimulation. Pharmacopsychiatry. 2009;42(5):194-201. Epub 2009/09/03.

[47] Daskalakis ZJ, Christensen BK, Fitzgerald PB, Chen R. Dysfunctional neural plasticity in patients with schizophrenia. Arch Gen Psychiatry. 2008;65(4):378-85. Epub 2008/04/09.

[48] Wobrock T, Schneider M, Kadovic D, Schneider-Axmann T, Ecker UK, Retz W, et al. Reduced cortical inhibition in first-episode schizophrenia. Schizophr Res. 2008;105(1-3):252-61. Epub 2008/07/16.

[49] Fitzgerald PB, Brown TL, Daskalakis ZJ, Kulkarni J. A transcranial magnetic stimulation study of the effects of olanzapine and risperidone on motor cortical excitability in patients with schizophrenia. Psychopharmacology. 2002;162(1):74-81. Epub 2002/07/11.

[50] Daskalakis ZJ, Christensen BK, Chen R, Fitzgerald PB, Zipursky RB, Kapur S. Effect of antipsychotics on cortical inhibition using transcranial magnetic stimulation. Psychopharmacology. 2003;170(3):255-62. Epub 2003/08/09.

[51] Hamalainen MS, Hari R, Ilmoniemi RJ, Knuutila J, Lounasmaa OV. Magnetoencephalography - theory, instrumentation, and applications to noninvasive studies of theworking human brain. Rev Mod Phys. 1993;65:413-97.

[52] Cohen D. Magnetoencephalography: detection of the brain's electrical activity with a superconducting magnetometer. Science. 1972;175(4022):664-6. Epub 1972/02/11.

[53] Williams MA, Sachdev PS. Magnetoencephalography in neuropsychiatry: ready for application? Curr Opin Psychiatry. 2010;23(3):273-7. Epub 2010/03/11.

[54] Coburn KL, Lauterbach EC, Boutros NN, Black KJ, Arciniegas DB, Coffey CE. The value of quantitative electroencephalography in clinical psychiatry: a report by the Committee on Research of the American Neuropsychiatric Association. J Neuropsychiatry Clin Neurosci. 2006;18(4):460-500. Epub 2006/12/01.

[55] Hunter AM, Cook IA, Leuchter AF. The promise of the quantitative electroencephalogram as a predictor of antidepressant treatment outcomes in major depressive disorder. Psychiatr Clin North Am. 2007;30(1):105-24. Epub 2007/03/17.

[56] Takahashi T. Complexity of spontaneous brain activity in mental disorders. Progress in neuro-psychopharmacology & biological psychiatry. 2013;45:258-66. Epub 2012/05/15.

[57] Schmitt A, Hasan A, Gruber O, Falkai P. Schizophrenia as a disorder of disconnectivity. Eur Arch Psychiatry Clin Neurosci. 2011;261 Suppl 2:S150-4. Epub 2011/08/26.

[58] Hinkley LB, Vinogradov S, Guggisberg AG, Fisher M, Findlay AM, Nagarajan SS. Clinical symptoms and alpha band resting-state functional connectivity imaging in patients with schizophrenia: implications for novel approaches to treatment. Biol Psychiatry. 2011;70(12):1134-42. Epub 2011/08/25.

[59] Vrba J, Robinson SE. Signal processing in magnetoencephalography. Methods. 2001;25(2):249-71. Epub 2002/01/29.

[60] Baillet S, Friston K, Oostenveld R. Academic software applications for electromagnetic brain mapping using MEG and EEG. Computational intelligence and neuroscience. 2011;2011:972050. Epub 2011/08/09.

[61] Cohen D, Cuffin BN. EEG versus MEG localization accuracy: theory and experiment. Brain Topogr. 1991;4(2):95-103. Epub 1991/01/01.

[62] Cuffin BN. Effects of head shape on EEG's and MEG's. IEEE Trans Biomed Eng. 1990;37(1):44-52. Epub 1990/01/01.

[63] Ahlfors SP, Han J, Belliveau JW, Hamalainen MS. Sensitivity of MEG and EEG to source orientation. Brain Topogr. 2010;23(3):227-32. Epub 2010/07/20.

[64] Melcher JR, Cohen D. Dependence of the MEG on dipole orientation in the rabbit head. Electroencephalography and clinical neurophysiology. 1988;70(5):460-72. Epub 1988/11/01.

[65] Haueisen J, Ramon C, Czapski P, Eiselt M. On the influence of volume currents and extended sources on neuromagnetic fields: a simulation study. Annals of biomedical engineering. 1995;23(6):728-39. Epub 1995/11/01.

[66] Silverman JS, Loychik SG. Brain-mapping abnormalities in a family with three obsessive compulsive children. J Neuropsychiatry Clin Neurosci. 1990;2(3):319-22. Epub 1990/01/01.

[67] Alonso P, Orbegozo A, Pujol J, Lopez-Sola C, Fullana MA, Segalas C, et al. Neural correlates of obsessive-compulsive related dysfunctional beliefs. Progress in neuropsychopharmacology & biological psychiatry. 2013. Epub 2013/08/06.

[68] Cottraux J, Gerard D, Cinotti L, Froment JC, Deiber MP, Le Bars D, et al. A controlled positron emission tomography study of obsessive and neutral auditory stimulation in obsessive-compulsive disorder with checking rituals. Psychiatry Res. 1996;60(2-3): 101-12. Epub 1996/03/29.

[69] Hillebrand A, Barnes GR. A quantitative assessment of the sensitivity of whole-head MEG to activity in the adult human cortex. NeuroImage. 2002;16(3 Pt 1):638-50. Epub 2002/08/10.

[70] Northoff G, Richter A, Gessner M, Schlagenhauf F, Fell J, Baumgart F, et al. Functional dissociation between medial and lateral prefrontal cortical spatiotemporal activation in negative and positive emotions: a combined fMRI/MEG study. Cereb Cortex. 2000;10(1):93-107. Epub 2000/01/20.

[71] Amo C, Quesney LF, Ortiz T, Maestu F, Fernandez A, Lopez-Ibor MI, et al. Limbic paroxysmal magnetoencephalographic activity in 12 obsessive-compulsive disorder patients: a new diagnostic finding. J Clin Psychiatry. 2004;65(2):156-62. Epub 2004/03/09.

[72] Kringelbach ML, Lehtonen A, Squire S, Harvey AG, Craske MG, Holliday IE, et al. A specific and rapid neural signature for parental instinct. PLoS ONE. 2008;3(2):e1664. Epub 2008/02/28.

[73] Hughes JR, John ER. Conventional and quantitative electroencephalography in psychiatry. J Neuropsychiatry Clin Neurosci. 1999;11(2):190-208. Epub 1999/05/20.

[74] Pacella B, Polation P, Nagle S. Clinical and EEG studies in obsessive compulsive states. American Journal of Psychiatry. 1944;100:830-8.

[75] Insel TR, Donnelly EF, Lalakea ML, Alterman IS, Murphy DL. Neurological and neuropsychological studies of patients with obsessive-compulsive disorder. Biol Psychiatry. 1983;18(7):741-51. Epub 1983/07/01.

[76] Bolwig TG, Hansen ES, Hansen A, Merkin H, Prichep LS. Toward a better understanding of the pathophysiology of OCD SSRI responders: QEEG source localization. Acta Psychiatr Scand. 2007;115(3):237-42. Epub 2007/02/17.

[77] Hansen ES, Prichep LS, Bolwig TG, John ER. Quantitative electroencephalography in OCD patients treated with paroxetine. Clin Electroencephalogr. 2003;34(2):70-4. Epub 2003/06/06.

[78] Prichep LS, Mas F, Hollander E, Liebowitz M, John ER, Almas M, et al. Quantitative electroencephalographic subtyping of obsessive-compulsive disorder. Psychiatry Res. 1993;50(1):25-32. Epub 1993/04/01.

[79] Velikova S, Locatelli M, Insacco C, Smeraldi E, Comi G, Leocani L. Dysfunctional brain circuitry in obsessive-compulsive disorder: source and coherence analysis of EEG rhythms. NeuroImage. 2010;49(1):977-83. Epub 2009/08/18.

[80] Bucci P, Mucci A, Volpe U, Merlotti E, Galderisi S, Maj M. Executive hypercontrol in obsessive-compulsive disorder: electrophysiological and neuropsychological indices. Clin Neurophysiol. 2004;115(6):1340-8. Epub 2004/05/12.

[81] Pogarell O, Juckel G, Mavrogiorgou P, Mulert C, Folkerts M, Hauke W, et al. Symptom-specific EEG power correlations in patients with obsessive-compulsive disorder. Int J Psychophysiol. 2006;62(1):87-92. Epub 2006/03/24.

[82] Tot S, Ozge A, Comelekoglu U, Yazici K, Bal N. Association of QEEG findings with clinical characteristics of OCD: evidence of left frontotemporal dysfunction. Can J Psychiatry. 2002;47(6):538-45. Epub 2002/09/06.

[83] Locatelli M, Bellodi L, Grassi B, Scarone S. EEG power modifications in obsessive-compulsive disorder during olfactory stimulation. Biol Psychiatry. 1996;39(5):326-31. Epub 1996/03/01.

[84] Karadag F, Oguzhanoglu NK, Kurt T, Oguzhanoglu A, Atesci F, Ozdel O. Quantitative EEG analysis in obsessive compulsive disorder. The International journal of neuroscience. 2003;113(6):833-47. Epub 2003/05/31.

[85] Serra FP, Palma V, Nolfe G, Buscaino GA. An electrophysiological study in obsessional compulsive disorders. Acta neurologica. 1994;16(5-6):240-8. Epub 1994/12/01.

[86] Flor-Henry P, Yeudall LT, Koles ZJ, Howarth BG. Neuropsychological and power spectral EEG investigations of the obsessive-compulsive syndrome. Biol Psychiatry. 1979;14(1):119-30. Epub 1979/02/01.

[87] Kuskowski MA, Malone SM, Kim SW, Dysken MW, Okaya AJ, Christensen KJ. Quantitative EEG in obsessive-compulsive disorder. Biol Psychiatry. 1993;33(6): 423-30. Epub 1993/03/15.

[88] Khanna S. Obsessive-compulsive disorder: is there a frontal lobe dysfunction? Biol Psychiatry. 1988;24(5):602-13. Epub 1988/09/01.

[89] Jenike MA, Brotman AW. The EEG in obsessive-compulsive disorder. J Clin Psychiatry. 1984;45(3):122-4. Epub 1984/03/01.

[90] Olbrich S, Olbrich H, Adamaszek M, Jahn I, Hegerl U, Stengler K. Altered EEG lagged coherence during rest in obsessive-compulsive disorder. Clin Neurophysiol. 2013. Epub 2013/08/24.

[91] Koprivova J, Horacek J, Raszka M, Brunovsky M, Prasko J. Standardized low-resolution electromagnetic tomography in obsessive-compulsive disorder--a replication study. Neuroscience letters. 2013;548:185-9. Epub 2013/05/25.

[92] Desarkar P, Sinha VK, Jagadheesan K, Nizamie SH. Subcortical functioning in obsessive-compulsive disorder: an exploratory EEG coherence study. World J Biol Psychiatry. 2007;8(3):196-200. Epub 2007/07/27.

[93] Shin YW, Ha TH, Kim SY, Kwon JS. Association between EEG alpha power and visuospatial function in obsessive-compulsive disorder. Psychiatry Clin Neurosci. 2004;58(1):16-20. Epub 2003/12/18.

[94] Leocani L, Toro C, Zhuang P, Gerloff C, Hallett M. Event-related desynchronization in reaction time paradigms: a comparison with event-related potentials and corticospinal excitability. Clin Neurophysiol. 2001;112(5):923-30. Epub 2001/05/05.

[95] Fontenelle L, Piedade RA, Marques C, de Menezes GB, Versiani M. [Quantitative electroencephalography in obsessive-compulsive disorder: preliminary results]. Arquivos de neuro-psiquiatria. 2000;58(3A):677-82. Epub 2000/09/06. Eletrencefalografia quantitativa no transtorno obsessivo-compulsivo: resultados preliminares.

[96] Simpson HB, Tenke CE, Towey JB, Liebowitz MR, Bruder GE. Symptom provocation alters behavioral ratings and brain electrical activity in obsessive-compulsive disorder: a preliminary study. Psychiatry Res. 2000;95(2):149-55. Epub 2000/08/30.

[97] Amo C, Fernandez A, Leon JM, Ortiz T, Maestu F, Ferre F, et al. Paroxysmal MEG activity in obsessive compulsive patients without SSRIs therapy. Eur Psychiatry. 2006;21(2):139-41. Epub 2006/03/07.

[98]   Maihofner C, Sperling W, Kaltenhauser M, Bleich S, de Zwaan M, Wiltfang J, et al. Spontaneous magnetoencephalographic activity in patients with obsessive-compulsive disorder. Brain Res. 2007;1129(1):200-5. Epub 2006/12/13.

[99]   Ciesielski KT, Hamalainen MS, Lesnik PG, Geller DA, Ahlfors SP. Increased MEG activation in OCD reflects a compensatory mechanism specific to the phase of a visual working memory task. NeuroImage. 2005;24(4):1180-91. Epub 2005/01/27.

[100]   Ciesielski KT, Hamalainen MS, Geller DA, Wilhelm S, Goldsmith TE, Ahlfors SP. Dissociation between MEG alpha modulation and performance accuracy on visual working memory task in obsessive compulsive disorder. Human brain mapping. 2007;28(12):1401-14. Epub 2007/03/21.

[101]   Harris E, Robinson S, Holroyd T, Xiang J, Rose D, Horn P, et al. Timing of prefrontal cortical activation in the beta frequency bandwidth in adolescents with obsessive compulsive disorder. The 19th Annual International OCD (Obsessive-Compulsive Disorder) Foundation Conference (ICODF) July 27–29, 2012; Chicago, IL, USA2012.

[102]   Harris E, Robinson S, Holroyd T, Rose D, Xiang J, Korostenskaja M, et al. A magnetoencephalographic study of symptom provocation in youth with obsessive compulsive disorder. Society for Neuroscience, 2012; October 13-17, 2012; New Orleans, LA, USA2012. p. 168.07.

[103]   Gilbert AR, Akkal D, Almeida JR, Mataix-Cols D, Kalas C, Devlin B, et al. Neural correlates of symptom dimensions in pediatric obsessive-compulsive disorder: a functional magnetic resonance imaging study. J Am Acad Child Adolesc Psychiatry. 2009;48(9):936-44. Epub 2009/07/25.

[104]   Hirosawa R, Narumoto J, Sakai Y, Nishida S, Ishida T, Nakamae T, et al. Reduced dorsolateral prefrontal cortical hemodynamic response in adult obsessive-compulsive disorder as measured by near-infrared spectroscopy during the verbal fluency task. Neuropsychiatric disease and treatment. 2013;9:955-62. Epub 2013/07/23.

[105]   Menzies L, Chamberlain SR, Laird AR, Thelen SM, Sahakian BJ, Bullmore ET. Integrating evidence from neuroimaging and neuropsychological studies of obsessive-compulsive disorder: the orbitofronto-striatal model revisited. Neurosci Biobehav Rev. 2008;32(3):525-49. Epub 2007/12/07.

[106]   Lemere F. The significance of individual differences in the Berger rhythm. Brain. 1936;59:366-75.

[107]   Berger H. On the electroencephalogram of man. Twelfth report. Archiv fur Psychiatrie und Nervenkrankheiten. 1937;106:165-87.

[108]   Ellingson RJ. The incidence of EEG abnormality among patients with mental disorders of apparently nonorganic origin: a critical review. Am J Psychiatry. 1954;111(4): 263-75. Epub 1954/10/01.

[109] Hill D. Clinical applications of EEG in psychiatry. The Journal of mental science. 1956;102(427):264-71. Epub 1956/04/01.

[110] Itil TM, Saletu B, Davis S. EEG findings in chronic schizophrenics based on digital computer period analysis and analog power spectra. Biol Psychiatry. 1972;5(1):1-13. Epub 1972/08/01.

[111] Gibbs FA, Gibbs EL, Lennox WG. The likeness of the cortical dysrhythmias of schizophrenia and psychomotor epilepsy. American Journal of Psychiatry. 1938;95:255-69.

[112] Davis PA, Davis H. The electroencephalograms of psychotic patients. American Journal of Psychiatry. 1939;95:1007-25.

[113] Jasper HH, Fitzpatrick CP, Solomon P. Analogies and opposites in schizophrenia and epilepsy. American Journal of Psychiatry. 1939;95:835-51.

[114] Finley KH, Campbell CM. Electroencephalography in schizophrenia. American Journal of Psychiatry. 1941;98:374-81.

[115] Greenblatt M. Age and electroencephalographic abnormality in neuropsychiatric patients: A study of 1,593 cases. American Journal of Psychiatry. 1944;101:82-90.

[116] Ostow M, Ostow M. Bilaterally synchronous paroxysmal slow activity in the encephalograms of non-epileptics. Journal of Nervous and Mental Disease. 1946;103:346-58.

[117] Bonkalo A, Doust JW, Stokes AB. Physiological concomitants of the phasic disturbances seen in periodic catatonia. Am J Psychiatry. 1955;112(2):114-22. Epub 1955/08/01.

[118] MacMahon JF, Walter WG. The electroencephalogram in schizophrenia. Journal of Mental Science. 1938;84:781-7.

[119] Colony HS, Willis SE. Electroencephalographic studies of 1,000 schizophrenic patients. Am J Psychiatry. 1956;113(2):163-9. Epub 1956/08/01.

[120] Hurst LA. Electroencephalographic support for a genetically oriented organic concept of schizophrenia. The Journal of nervous and mental disease. 1952;115(2):95-120. Epub 1952/02/01.

[121] Kennard MA, Levy S. The meaning of the abnormal electro-encephalogram in schizophrenia. The Journal of nervous and mental disease. 1952;116(5):413-25. Epub 1952/11/01.

[122] Kammerer T, Rohmer F, Wackerheim A. L'EEG des Schizophrenes. Strasbourg Medical. 1955;10 (Suppl.):20.

[123] Sponheim SR, Clementz BA, Iacono WG, Beiser M. Clinical and biological concomitants of resting state EEG power abnormalities in schizophrenia. Biol Psychiatry. 2000;48(11):1088-97. Epub 2000/11/30.

[124] Sponheim SR, Iacono WG, Clementz BA, Beiser M. Season of birth and electroence-phalogram power abnormalities in schizophrenia. Biol Psychiatry. 1997;41(10): 1020-7. Epub 1997/05/15.

[125] Shagass C, Roemer RA, Straumanis JJ, Josiassen RC. Psychiatric diagnostic discriminations with combinations of quantitative EEG variables. Br J Psychiatry. 1984;144:581-92. Epub 1984/06/01.

[126] Gerez M, Tello A. Selected quantitative EEG (QEEG) and event-related potential (ERP) variables as discriminators for positive and negative schizophrenia. Biol Psychiatry. 1995;38(1):34-49. Epub 1995/07/01.

[127] Sponheim SR, Iacono WG, Thuras PD, Nugent SM, Beiser M. Sensitivity and specificity of select biological indices in characterizing psychotic patients and their relatives. Schizophr Res. 2003;63(1-2):27-38. Epub 2003/08/02.

[128] Clementz BA, Sponheim SR, Iacono WG, Beiser M. Resting EEG in first-episode schizophrenia patients, bipolar psychosis patients, and their first-degree relatives. Psychophysiology. 1994;31(5):486-94. Epub 1994/09/01.

[129] Venables NC, Bernat EM, Sponheim SR. Genetic and disorder-specific aspects of resting state EEG abnormalities in schizophrenia. Schizophr Bull. 2009;35(4):826-39. Epub 2008/04/03.

[130] Karson CN, Coppola R, Daniel DG, Weinberger DR. Computerized EEG in schizophrenia. Schizophr Bull. 1988;14(2):193-7. Epub 1988/01/01.

[131] Omori M, Koshino Y, Murata T, Murata I, Nishio M, Sakamoto K, et al. Quantitative EEG in never-treated schizophrenic patients. Biol Psychiatry. 1995;38(5):305-9. Epub 1995/09/01.

[132] Merrin EL, Floyd TC. Negative symptoms and EEG alpha in schizophrenia: a replication. Schizophr Res. 1996;19(2-3):151-61. Epub 1996/05/01.

[133] Hamm JP, Gilmore CS, Picchetti NA, Sponheim SR, Clementz BA. Abnormalities of neuronal oscillations and temporal integration to low- and high-frequency auditory stimulation in schizophrenia. Biol Psychiatry. 2011;69(10):989-96. Epub 2011/01/11.

[134] Clementz BA, Keil A, Kissler J. Aberrant brain dynamics in schizophrenia: delayed buildup and prolonged decay of the visual steady-state response. Brain Res Cogn Brain Res. 2004;18(2):121-9. Epub 2004/01/23.

[135] Hong LE, Summerfelt A, Mitchell BD, O'Donnell P, Thaker GK. A shared low-frequency oscillatory rhythm abnormality in resting and sensory gating in schizophrenia. Clin Neurophysiol. 2012;123(2):285-92. Epub 2011/08/25.

[136] Ferrarelli F, Tononi G. The thalamic reticular nucleus and schizophrenia. Schizophr Bull. 2011;37(2):306-15. Epub 2010/12/07.

[137] Llinas RR, Ribary U, Jeanmonod D, Kronberg E, Mitra PP. Thalamocortical dysrhythmia: A neurological and neuropsychiatric syndrome characterized by magnetoencephalography. Proc Natl Acad Sci U S A. 1999;96(26):15222-7. Epub 1999/12/28.

[138] Klimesch W, Sauseng P, Hanslmayr S. EEG alpha oscillations: the inhibition-timing hypothesis. Brain Res Rev. 2007;53(1):63-88. Epub 2006/08/05.

[139] Siekmeier PJ, Stufflebeam SM. Patterns of spontaneous magnetoencephalographic activity in patients with schizophrenia. J Clin Neurophysiol. 2010;27(3):179-90. Epub 2010/05/13.

[140] Boutros NN, Arfken C, Galderisi S, Warrick J, Pratt G, Iacono W. The status of spectral EEG abnormality as a diagnostic test for schizophrenia. Schizophr Res. 2008;99(1-3):225-37. Epub 2007/12/28.

[141] Dias EC, Bickel S, Epstein ML, Sehatpour P, Javitt DC. Abnormal task modulation of oscillatory neural activity in schizophrenia. Frontiers in psychology. 2013;4:540. Epub 2013/08/30.

[142] Uhlhaas PJ, Singer W. Abnormal neural oscillations and synchrony in schizophrenia. Nature reviews Neuroscience. 2010;11(2):100-13. Epub 2010/01/21.

[143] Lewis DA, Hashimoto T, Volk DW. Cortical inhibitory neurons and schizophrenia. Nature reviews Neuroscience. 2005;6(4):312-24. Epub 2005/04/02.

[144] Spencer KM, Nestor PG, Perlmutter R, Niznikiewicz MA, Klump MC, Frumin M, et al. Neural synchrony indexes disordered perception and cognition in schizophrenia. Proc Natl Acad Sci U S A. 2004;101(49):17288-93. Epub 2004/11/18.

[145] Gallinat J, Winterer G, Herrmann CS, Senkowski D. Reduced oscillatory gamma-band responses in unmedicated schizophrenic patients indicate impaired frontal network processing. Clin Neurophysiol. 2004;115(8):1863-74. Epub 2004/07/21.

[146] Symond MP, Harris AW, Gordon E, Williams LM. "Gamma synchrony" in first-episode schizophrenia: a disorder of temporal connectivity? Am J Psychiatry. 2005;162(3):459-65. Epub 2005/03/03.

[147] Wynn JK, Light GA, Breitmeyer B, Nuechterlein KH, Green MF. Event-related gamma activity in schizophrenia patients during a visual backward-masking task. Am J Psychiatry. 2005;162(12):2330-6. Epub 2005/12/07.

[148] Ford JM, Roach BJ, Faustman WO, Mathalon DH. Out-of-synch and out-of-sorts: dysfunction of motor-sensory communication in schizophrenia. Biol Psychiatry. 2008;63(8):736-43. Epub 2007/11/06.

[149] Cho RY, Konecky RO, Carter CS. Impairments in frontal cortical gamma synchrony and cognitive control in schizophrenia. Proc Natl Acad Sci U S A. 2006;103(52):19878-83. Epub 2006/12/16.

[150] Lee SH, Wynn JK, Green MF, Kim H, Lee KJ, Nam M, et al. Quantitative EEG and low resolution electromagnetic tomography (LORETA) imaging of patients with persistent auditory hallucinations. Schizophr Res. 2006;83(2-3):111-9. Epub 2006/03/10.

[151] Spencer KM, Niznikiewicz MA, Nestor PG, Shenton ME, McCarley RW. Left auditory cortex gamma synchronization and auditory hallucination symptoms in schizophrenia. BMC Neurosci. 2009;10:85. Epub 2009/07/22.

[152] Mulert C, Kirsch V, Pascual-Marqui R, McCarley RW, Spencer KM. Long-range synchrony of gamma oscillations and auditory hallucination symptoms in schizophrenia. Int J Psychophysiol. 2011;79(1):55-63. Epub 2010/08/18.

[153] Bassett DS, Bullmore ET. Human brain networks in health and disease. Curr Opin Neurol. 2009;22(4):340-7. Epub 2009/06/06.

[154] Siebenhuhner F, Weiss SA, Coppola R, Weinberger DR, Bassett DS. Intra- and inter-frequency brain network structure in health and schizophrenia. PLoS ONE. 2013;8(8):e72351. Epub 2013/08/31.

[155] Stephan KE, Friston KJ, Frith CD. Dysconnection in schizophrenia: from abnormal synaptic plasticity to failures of self-monitoring. Schizophr Bull. 2009;35(3):509-27. Epub 2009/01/22.

[156] Wang XJ. Neurophysiological and computational principles of cortical rhythms in cognition. Physiological reviews. 2010;90(3):1195-268. Epub 2010/07/29.

[157] Bassett DS, Bullmore E, Verchinski BA, Mattay VS, Weinberger DR, Meyer-Lindenberg A. Hierarchical organization of human cortical networks in health and schizophrenia. J Neurosci. 2008;28(37):9239-48. Epub 2008/09/12.

[158] Bassett DS, Bullmore ET, Meyer-Lindenberg A, Apud JA, Weinberger DR, Coppola R. Cognitive fitness of cost-efficient brain functional networks. Proc Natl Acad Sci U S A. 2009;106(28):11747-52. Epub 2009/07/01.

[159] Bassett DS, Nelson BG, Mueller BA, Camchong J, Lim KO. Altered resting state complexity in schizophrenia. NeuroImage. 2012;59(3):2196-207. Epub 2011/10/20.

[160] Liu Y, Liang M, Zhou Y, He Y, Hao Y, Song M, et al. Disrupted small-world networks in schizophrenia. Brain. 2008;131(Pt 4):945-61. Epub 2008/02/27.

[161] Lynall ME, Bassett DS, Kerwin R, McKenna PJ, Kitzbichler M, Muller U, et al. Functional connectivity and brain networks in schizophrenia. J Neurosci. 2010;30(28): 9477-87. Epub 2010/07/16.

[162] Weiss SA, Bassett DS, Rubinstein D, Holroyd T, Apud J, Dickinson D, et al. Functional Brain Network Characterization and Adaptivity during Task Practice in Healthy Volunteers and People with Schizophrenia. Front Hum Neurosci. 2011;5:81. Epub 2011/09/03.

[163] Rubinov M, Sporns O. Complex network measures of brain connectivity: uses and interpretations. NeuroImage. 2010;52(3):1059-69. Epub 2009/10/13.

[164] Fornito A, Zalesky A, Pantelis C, Bullmore ET. Schizophrenia, neuroimaging and connectomics. NeuroImage. 2012;62(4):2296-314. Epub 2012/03/06.

[165] Zalesky A, Fornito A, Egan GF, Pantelis C, Bullmore ET. The relationship between regional and inter-regional functional connectivity deficits in schizophrenia. Human brain mapping. 2012;33(11):2535-49. Epub 2011/09/17.

[166] Allen EA, Liu J, Kiehl KA, Gelernter J, Pearlson GD, Perrone-Bizzozero NI, et al. Components of cross-frequency modulation in health and disease. Frontiers in systems neuroscience. 2011;5:59. Epub 2011/08/03.

[167] Higashima M, Takeda T, Kikuchi M, Nagasawa T, Koshino Y. Functional connectivity between hemispheres and schizophrenic symptoms: a longitudinal study of inter-hemispheric EEG coherence in patients with acute exacerbations of schizophrenia. Clin EEG Neurosci. 2006;37(1):10-5. Epub 2006/02/16.

[168] Korostenskaja M, Kahkonen S. What do ERPs and ERFs reveal about the effect of antipsychotic treatment on cognition in schizophrenia? Current Pharmaceutical Design. 2009;15:(In press).

[169] Turetsky BI, Calkins ME, Light GA, Olincy A, Radant AD, Swerdlow NR. Neurophysiological endophenotypes of schizophrenia: the viability of selected candidate measures. Schizophr Bull. 2007;33(1):69-94. Epub 2006/12/01.

[170] Carrasco M, Harbin SM, Nienhuis JK, Fitzgerald KD, Gehring WJ, Hanna GL. Increased error-related brain activity in youth with obsessive-compulsive disorder and unaffected siblings. Depress Anxiety. 2013;30(1):39-46. Epub 2012/12/12.

[171] Nolfe G, Serra FP, Palma V, Buscaino GA. Brainstem involvement in obsessive-compulsive disorder. Biological psychology. 1998;48(1):69-77. Epub 1998/07/24.

[172] Sommer W. Selective attention differentially affects brainstem auditory evoked potentials of electrodermal responders and nonresponders. Psychiatry Res. 1985;16(3):227-32. Epub 1985/11/01.

[173] Mubarak A, Badawy A. The effect of smoking on brainstem auditory evoked potentials in positive- and negative-symptom schizophrenia. CNS Spectr. 2001;6(6):514-6, 9-22. Epub 2005/03/04.

[174] Kallstrand J, Nehlstedt SF, Skold ML, Nielzen S. Lateral asymmetry and reduced forward masking effect in early brainstem auditory evoked responses in schizophrenia. Psychiatry Res. 2012;196(2-3):188-93. Epub 2012/02/14.

[175] Picton TW, John MS, Dimitrijevic A, Purcell D. Human auditory steady-state responses. Int J Audiol. 2003;42(4):177-219. Epub 2003/06/07.

[176] Plourde G. Auditory evoked potentials. Best practice & research Clinical anaesthesiology. 2006;20(1):129-39. Epub 2006/04/26.

[177] Heinrichs-Graham E, Wilson TW. Presence of strong harmonics during visual entrainment: a magnetoencephalography study. Biological psychology. 2012;91(1):59-64. Epub 2012/05/10.

[178] Jenkins J, 3rd, Rhone AE, Idsardi WJ, Simon JZ, Poeppel D. The elicitation of audiovisual steady-state responses: multi-sensory signal congruity and phase effects. Brain Topogr. 2011;24(2):134-48. Epub 2011/03/08.

[179] Brenner CA, Krishnan GP, Vohs JL, Ahn WY, Hetrick WP, Morzorati SL, et al. Steady state responses: electrophysiological assessment of sensory function in schizophrenia. Schizophr Bull. 2009;35(6):1065-77. Epub 2009/09/04.

[180] Ferrarelli F, Massimini M, Peterson MJ, Riedner BA, Lazar M, Murphy MJ, et al. Reduced evoked gamma oscillations in the frontal cortex in schizophrenia patients: a TMS/EEG study. Am J Psychiatry. 2008;165(8):996-1005. Epub 2008/05/17.

[181] Kwon JS, O'Donnell BF, Wallenstein GV, Greene RW, Hirayasu Y, Nestor PG, et al. Gamma frequency-range abnormalities to auditory stimulation in schizophrenia. Arch Gen Psychiatry. 1999;56(11):1001-5. Epub 1999/11/24.

[182] Light GA, Hsu JL, Hsieh MH, Meyer-Gomes K, Sprock J, Swerdlow NR, et al. Gamma band oscillations reveal neural network cortical coherence dysfunction in schizophrenia patients. Biol Psychiatry. 2006;60(11):1231-40. Epub 2006/08/09.

[183] Hamm JP, Gilmore CS, Clementz BA. Augmented gamma band auditory steady-state responses: support for NMDA hypofunction in schizophrenia. Schizophr Res. 2012;138(1):1-7. Epub 2012/05/01.

[184] Griskova-Bulanova I, Dapsys K, Maciulis V, Arnfred SM. Closed eyes condition increases auditory brain responses in schizophrenia. Psychiatry Res. 2013;211(2):183-5. Epub 2012/11/15.

[185] Bolton D, Gibb W, Lees A, Raven P, Gray JA, Chen E, et al. Neurological soft signs in obsessive compulsive disorder: standardised assessment and comparison with schizophrenia. Behav Neurol. 1998;11(4):197-204. Epub 2001/09/25.

[186] Hazen EP, Reichert EL, Piacentini JC, Miguel EC, do Rosario MC, Pauls D, et al. Case series: Sensory intolerance as a primary symptom of pediatric OCD. Ann Clin Psychiatry. 2008;20(4):199-203. Epub 2008/11/27.

[187] Miguel EC, do Rosario-Campos MC, Prado HS, do Valle R, Rauch SL, Coffey BJ, et al. Sensory phenomena in obsessive-compulsive disorder and Tourette's disorder. J Clin Psychiatry. 2000;61(2):150-6; quiz 7. Epub 2000/03/25.

[188] Heckers S. Neural models of schizophrenia. Dialogues in clinical neuroscience. 2000;2(3):267-79. Epub 2000/09/01.

[189] Gauntlett-Gilbert J, Kuipers E. Visual hallucinations in psychiatric conditions: appraisals and their relationship to distress. Br J Clin Psychol. 2005;44(Pt 1):77-87. Epub 2005/04/14.

[190] Dierks T, Linden DE, Jandl M, Formisano E, Goebel R, Lanfermann H, et al. Activation of Heschl's gyrus during auditory hallucinations. Neuron. 1999;22(3):615-21. Epub 1999/04/10.

[191] Raij TT, Valkonen-Korhonen M, Holi M, Therman S, Lehtonen J, Hari R. Reality of auditory verbal hallucinations. Brain. 2009;132(Pt 11):2994-3001. Epub 2009/07/22.

[192] Kompus K, Falkenberg LE, Bless JJ, Johnsen E, Kroken RA, Krakvik B, et al. The role of the primary auditory cortex in the neural mechanism of auditory verbal hallucinations. Front Hum Neurosci. 2013;7:144. Epub 2013/05/01.

[193] Korostenskaja M, Harris E, Giovanetti C, Horn P, Wang Y, Rose D, et al. Magnetoencephalography reveals altered auditory information processing in youth with obsessive-compulsive disorder. Psychiatry Res. 2013;212(2):132-40. Epub 2013/04/03.

[194] Oades RD, Zerbin D, Dittmann-Balcar A, Eggers C. Auditory event-related potential (ERP) and difference-wave topography in schizophrenic patients with/without active hallucinations and delusions: a comparison with young obsessive-compulsive disorder (OCD) and healthy subjects. Int J Psychophysiol. 1996;22(3):185-214. Epub 1996/06/01.

[195] Morault PM, Bourgeois M, Laville J, Bensch C, Paty J. Psychophysiological and clinical value of event-related potentials in obsessive-compulsive disorder. Biol Psychiatry. 1997;42(1):46-56. Epub 1997/07/01.

[196] Kim YY, Roh AY, Yoo SY, Kang DH, Kwon JS. Impairment of source memory in patients with obsessive-compulsive disorder: equivalent current dipole analysis. Psychiatry Res. 2009;165(1-2):47-59. Epub 2008/11/26.

[197] Goncalves OF, Carvalho S, Leite J, Pocinho F, Relvas J, Fregni F. Obsessive Compulsive Disorder as a functional interhemispheric imbalance at the thalamic level. Med Hypotheses. 2011;77(3):445-7. Epub 2011/07/09.

[198] Shim G, Jung WH, Choi JS, Jung MH, Jang JH, Park JY, et al. Reduced cortical folding of the anterior cingulate cortex in obsessive-compulsive disorder. J Psychiatry Neurosci. 2009;34(6):443-9. Epub 2009/12/02.

[199] Chiu CH, Lo YC, Tang HS, Liu IC, Chiang WY, Yeh FC, et al. White matter abnormalities of fronto-striato-thalamic circuitry in obsessive-compulsive disorder: A study using diffusion spectrum imaging tractography. Psychiatry Res. 2011;192(3): 176-82. Epub 2011/05/07.

[200] Szeszko PR, Christian C, Macmaster F, Lencz T, Mirza Y, Taormina SP, et al. Gray matter structural alterations in psychotropic drug-naive pediatric obsessive-compul-

sive disorder: an optimized voxel-based morphometry study. Am J Psychiatry. 2008;165(10):1299-307. Epub 2008/04/17.

[201] Perros P, Young ES, Ritson JJ, Price GW, Mann P. Power spectral EEG analysis and EEG variability in obsessive-compulsive disorder. Brain Topogr. 1992;4(3):187-92. Epub 1992/01/01.

[202] Denys D, Zohar J, Westenberg HG. The role of dopamine in obsessive-compulsive disorder: preclinical and clinical evidence. J Clin Psychiatry. 2004;65 Suppl 14:11-7. Epub 2004/11/24.

[203] van der Wee NJ, Stevens H, Hardeman JA, Mandl RC, Denys DA, van Megen HJ, et al. Enhanced dopamine transporter density in psychotropic-naive patients with obsessive-compulsive disorder shown by [123I]{beta}-CIT SPECT. Am J Psychiatry. 2004;161(12):2201-6. Epub 2004/12/01.

[204] Korostenskaja M, Kicic D, Kahkonen S. The effect of methylphenidate on auditory information processing in healthy volunteers: a combined EEG/MEG study. Psychopharmacology. 2008;197(3):475-86. Epub 2008/02/12.

[205] Catts SV, Armstrong MS, Ward PB, McConaghy N. Reduced P200 latency and allusive thinking: an auditory evoked potential index of a cognitive predisposition to schizophrenia? The International journal of neuroscience. 1986;30(3):173-9. Epub 1986/09/01.

[206] Chiarenza GA, Papakostopoulos D, Dini M, Cazzullo CL. Neurophysiological correlates of psychomotor activity in chronic schizophrenics. Electroencephalography and clinical neurophysiology. 1985;61(4):218-28. Epub 1985/10/01.

[207] Oades RD, Dittmann-Balcar A, Schepker R, Eggers C, Zerbin D. Auditory event-related potentials (ERPs) and mismatch negativity (MMN) in healthy children and those with attention-deficit or tourette/tic symptoms. Biological psychology. 1996;43(2): 163-85. Epub 1996/04/12.

[208] Herrmann MJ, Jacob C, Unterecker S, Fallgatter AJ. Reduced response-inhibition in obsessive-compulsive disorder measured with topographic evoked potential mapping. Psychiatry Res. 2003;120(3):265-71. Epub 2003/10/17.

[209] Kim MS, Kim YY, Yoo SY, Kwon JS. Electrophysiological correlates of behavioral response inhibition in patients with obsessive-compulsive disorder. Depress Anxiety. 2007;24(1):22-31. Epub 2006/08/26.

[210] Savage CR, Weilburg JB, Duffy FH, Baer L, Shera DM, Jenike MA. Low-level sensory processing in obsessive-compulsive disorder: an evoked potential study. Biol Psychiatry. 1994;35(4):247-52. Epub 1994/02/15.

[211] Ciesielski KT, Beech HR, Gordon PK. Some electrophysiological observations in obsessional states. Br J Psychiatry. 1981;138:479-84. Epub 1981/06/01.

[212] Leavitt VM, Molholm S, Ritter W, Shpaner M, Foxe JJ. Auditory processing in schizophrenia during the middle latency period (10-50 ms): high-density electrical mapping and source analysis reveal subcortical antecedents to early cortical deficits. J Psychiatry Neurosci. 2007;32(5):339-53. Epub 2007/09/08.

[213] Lalor EC, De Sanctis P, Krakowski MI, Foxe JJ. Visual sensory processing deficits in schizophrenia: is there anything to the magnocellular account? Schizophr Res. 2012;139(1-3):246-52. Epub 2012/06/19.

[214] Lalor EC, Yeap S, Reilly RB, Pearlmutter BA, Foxe JJ. Dissecting the cellular contributions to early visual sensory processing deficits in schizophrenia using the VESPA evoked response. Schizophr Res. 2008;98(1-3):256-64. Epub 2007/11/13.

[215] Bedwell JS, Chan CC, Trachik BJ, Rassovsky Y. Changes in the visual-evoked P1 potential as a function of schizotypy and background color in healthy young adults. J Psychiatr Res. 2013;47(4):542-7. Epub 2013/02/02.

[216] Haenschel C, Bittner RA, Haertling F, Rotarska-Jagiela A, Maurer K, Singer W, et al. Contribution of impaired early-stage visual processing to working memory dysfunction in adolescents with schizophrenia: a study with event-related potentials and functional magnetic resonance imaging. Arch Gen Psychiatry. 2007;64(11):1229-40. Epub 2007/11/07.

[217] Koychev I, El-Deredy W, Haenschel C, Deakin JF. Visual information processing deficits as biomarkers of vulnerability to schizophrenia: an event-related potential study in schizotypy. Neuropsychologia. 2010;48(7):2205-14. Epub 2010/04/24.

[218] Oribe N, Hirano Y, Kanba S, del Re EC, Seidman LJ, Mesholam-Gately R, et al. Early and late stages of visual processing in individuals in prodromal state and first episode schizophrenia: an ERP study. Schizophr Res. 2013;146(1-3):95-102. Epub 2013/02/26.

[219] Hegerl U, Gaebel W, Ulrich G. Relationship between residual symptomatology and auditory evoked potentials in schizophrenic outpatients. Pharmacopsychiatry. 1988;21(6):329-30. Epub 1988/11/01.

[220] Schwarzkopf SB, Lamberti JS, Jiminez M, Kane CF, Henricks M, Nasrallah HA. Visual evoked potential correlates of positive/negative symptoms in schizophrenia. Biol Psychiatry. 1990;27(4):400-10. Epub 1990/02/15.

[221] Roth WT, Pfefferbaum A, Kelly AF, Berger PA, Kopell BS. Auditory event-related potentials in schizophrenia and depression. Psychiatry Res. 1981;4(2):199-212. Epub 1981/04/01.

[222] Laurent A, Garcia-Larrea L, d'Amato T, Bosson JL, Saoud M, Marie-Cardine M, et al. Auditory event-related potentials and clinical scores in unmedicated schizophrenic patients. Psychiatry Res. 1999;86(3):229-38. Epub 1999/09/11.

[223] Shenton ME, Faux SF, McCarley RW, Ballinger R, Coleman M, Torello M, et al. Correlations between abnormal auditory P300 topography and positive symptoms in

schizophrenia: a preliminary report. Biol Psychiatry. 1989;25(6):710-6. Epub 1989/03/15.

[224] Oertel-Knochel V, Linden DE. Cerebral asymmetry in schizophrenia. Neuroscientist. 2011;17(5):456-67. Epub 2011/04/27.

[225] Ribolsi M, Koch G, Magni V, Di Lorenzo G, Rubino IA, Siracusano A, et al. Abnormal brain lateralization and connectivity in schizophrenia. Rev Neurosci. 2009;20(1): 61-70. Epub 2009/06/17.

[226] Spironelli C, Angrilli A, Stegagno L. Failure of language lateralization in schizophrenia patients: an ERP study on early linguistic components. J Psychiatry Neurosci. 2008;33(3):235-43. Epub 2008/07/02.

[227] Oertel-Knochel V, Knochel C, Stablein M, Linden DE. Abnormal functional and structural asymmetry as biomarker for schizophrenia. Current topics in medicinal chemistry. 2012;12(21):2434-51. Epub 2013/01/03.

[228] Naatanen R, Gaillard AW, Mantysalo S. Early selective-attention effect on evoked potential reinterpreted. Acta psychologica. 1978;42(4):313-29.

[229] Naatanen R, Michie PT. Early selective-attention effects on the evoked potential: a critical review and reinterpretation. Biological psychology. 1979;8(2):81-136.

[230] Kujala T, Tervaniemi M, Schroger E. The mismatch negativity in cognitive and clinical neuroscience: theoretical and methodological considerations. Biol Psychol. 2007;74(1):1-19.

[231] Haenschel C, Vernon DJ, Dwivedi P, Gruzelier JH, Baldeweg T. Event-related brain potential correlates of human auditory sensory memory-trace formation. J Neurosci. 2005;25(45):10494-501.

[232] Towey JP, Tenke CE, Bruder GE, Leite P, Friedman D, Liebowitz M, et al. Brain event-related potential correlates of overfocused attention in obsessive-compulsive disorder. Psychophysiology. 1994;31(6):535-43. Epub 1994/11/01.

[233] Kahkonen S, Makinen V, Jaaskelainen IP, Pennanen S, Liesivuori J, Ahveninen J. Serotonergic modulation of mismatch negativity. Psychiatry Res. 2005;138(1):61-74.

[234] Ahveninen J, Kahkonen S, Pennanen S, Liesivuori J, Ilmoniemi RJ, Jaaskelainen IP. Tryptophan depletion effects on EEG and MEG responses suggest serotonergic modulation of auditory involuntary attention in humans. NeuroImage. 2002;16(4): 1052-61. Epub 2002/08/31.

[235] Heekeren K, Daumann J, Neukirch A, Stock C, Kawohl W, Norra C, et al. Mismatch negativity generation in the human 5HT2A agonist and NMDA antagonist model of psychosis. Psychopharmacology. 2008;199(1):77-88. Epub 2008/05/20.

[236] Umbricht D, Krljes S. Mismatch negativity in schizophrenia: a meta-analysis. Schizophr Res. 2005;76(1):1-23.

[237] Umbricht DS, Bates JA, Lieberman JA, Kane JM, Javitt DC. Electrophysiological indices of automatic and controlled auditory information processing in first-episode, recent-onset and chronic schizophrenia. Biol Psychiatry. 2006;59(8):762-72.

[238] Shelley AM, Ward PB, Catts SV, Michie PT, Andrews S, McConaghy N. Mismatch negativity: an index of a preattentive processing deficit in schizophrenia. Biol Psychiatry. 1991;30(10):1059-62.

[239] Michie PT. What has MMN revealed about the auditory system in schizophrenia? Int J Psychophysiol. 2001;42(2):177-94.

[240] Javitt DC. Intracortical mechanisms of mismatch negativity dysfunction in schizophrenia. Audiol Neurootol. 2000;5(3-4):207-15.

[241] Kreitschmann-Andermahr I, Rosburg T, Meier T, Volz HP, Nowak H, Sauer H. Impaired sensory processing in male patients with schizophrenia: a magnetoencephalographic study of auditory mismatch detection. Schizophr Res. 1999;35(2):121-9.

[242] Hirayasu Y, Potts GF, O'Donnell BF, Kwon JS, Arakaki H, Akdag SJ, et al. Auditory mismatch negativity in schizophrenia: topographic evaluation with a high-density recording montage. Am J Psychiatry. 1998;155(9):1281-4.

[243] Hirayasu Y, Shenton ME, Salisbury DF, Dickey CC, Fischer IA, Mazzoni P, et al. Lower left temporal lobe MRI volumes in patients with first-episode schizophrenia compared with psychotic patients with first-episode affective disorder and normal subjects. Am J Psychiatry. 1998;155(10):1384-91.

[244] Wolf RC, Hose A, Frasch K, Walter H, Vasic N. Volumetric abnormalities associated with cognitive deficits in patients with schizophrenia. Eur Psychiatry. 2008. Epub 2008/04/25.

[245] Salisbury DF, Kuroki N, Kasai K, Shenton ME, McCarley RW. Progressive and interrelated functional and structural evidence of post-onset brain reduction in schizophrenia. Arch Gen Psychiatry. 2007;64(5):521-9.

[246] Catts SV, Shelley AM, Ward PB, Liebert B, McConaghy N, Andrews S, et al. Brain potential evidence for an auditory sensory memory deficit in schizophrenia. Am J Psychiatry. 1995;152(2):213-9.

[247] Fujimoto T, Okumura E, Takeuchi K, Kodabashi A, Otsubo T, Nakamura K, et al. Dysfunctional cortical connectivity during the auditory oddball task in patients with schizophrenia. The open neuroimaging journal. 2013;7:15-26. Epub 2013/06/12.

[248] Korostenskaja M, Nikulin VV, Kicic D, Nikulina AV, Kahkonen S. Effects of NMDA receptor antagonist memantine on mismatch negativity. Brain research bulletin. 2007;72(4-6):275-83.

[249]   Kreitschmann-Andermahr I, Rosburg T, Demme U, Gaser E, Nowak H, Sauer H. Effect of ketamine on the neuromagnetic mismatch field in healthy humans. Brain Res Cogn Brain Res. 2001;12(1):109-16.

[250]   Rosburg T, Marinou V, Haueisen J, Smesny S, Sauer H. Effects of lorazepam on the neuromagnetic mismatch negativity (MMNm) and auditory evoked field component N100m. Neuropsychopharmacology. 2004;29(9):1723-33. Epub 2004/05/06.

[251]   Korostenskaja M, Pekkonen E, Horn P, Huttunen J, Kivisaari R, Kahkonen S. Mismatch negativity (MMN) reflects changes in GABA system: combined EEG/MEG study. EPIC XV 15th International Congress on Event-Related Potentials of the Brain; APRIL 22 – 25, 2009; Bloomington, Indiana, USA2009. p. 50.

[252]   Oades RD, Dittmann-Balcar A, Zerbin D, Grzella I. Impaired attention-dependent augmentation of MMN in nonparanoid vs paranoid schizophrenic patients: a comparison with obsessive-compulsive disorder and healthy subjects. Biol Psychiatry. 1997;41(12):1196-210. Epub 1997/06/15.

[253]   Schroger E, Wolff C. Behavioral and electrophysiological effects of task-irrelevant sound change: a new distraction paradigm. Brain Res Cogn Brain Res. 1998;7(1): 71-87.

[254]   Escera C, Yago E, Alho K. Electrical responses reveal the temporal dynamics of brain events during involuntary attention switching. Eur J Neurosci. 2001;14(5):877-83.

[255]   Friedman D, Cycowicz YM, Gaeta H. The novelty P3: an event-related brain potential (ERP) sign of the brain's evaluation of novelty. Neurosci Biobehav Rev. 2001;25(4): 355-73. Epub 2001/07/11.

[256]   Knight RT. Decreased response to novel stimuli after prefrontal lesions in man. Electroencephalography and clinical neurophysiology. 1984;59(1):9-20. Epub 1984/02/01.

[257]   Alho K, Winkler I, Escera C, Huotilainen M, Virtanen J, Jaaskelainen IP, et al. Processing of novel sounds and frequency changes in the human auditory cortex: magnetoencephalographic recordings. Psychophysiology. 1998;35(2):211-24. Epub 1998/04/08.

[258]   Kahkonen S, Marttinen Rossi E, Yamashita H. Alcohol impairs auditory processing of frequency changes and novel sounds: a combined MEG and EEG study. Psychopharmacology. 2005;177(4):366-72. Epub 2004/08/04.

[259]   Sutton S, Braren M, Zubin J, John ER. Evoked-potential correlates of stimulus uncertainty. Science. 1965;150(700):1187-8.

[260]   Polich J. Clinical application of the P300 event-related brain potential. Phys Med Rehabil Clin N Am. 2004;15(1):133-61.

[261] Squires NK, Squires KC, Hillyard SA. Two varieties of long-latency positive waves evoked by unpredictable auditory stimuli in man. Electroencephalography and clinical neurophysiology. 1975;38(4):387-401.

[262] Karakas S, Basar E. Models and theories of brain function in cognition within a framework of behavioral cognitive psychology. Int J Psychophysiol. 2006;60(2): 186-93.

[263] Magliero A, Bashore TR, Coles MG, Donchin E. On the dependence of P300 latency on stimulus evaluation processes. Psychophysiology. 1984;21(2):171-86.

[264] Polich J, Howard L, Starr A. Effects of age on the P300 component of the event-related potential from auditory stimuli: peak definition, variation, and measurement. J Gerontol. 1985;40(6):721-6.

[265] Ischebeck M, Endrass T, Simon D, Kathmann N. Auditory novelty processing is enhanced in obsessive-compulsive disorder. Depress Anxiety. 2011;28(10):915-23. Epub 2011/09/08.

[266] Gohle D, Juckel G, Mavrogiorgou P, Pogarell O, Mulert C, Rujescu D, et al. Electrophysiological evidence for cortical abnormalities in obsessive-compulsive disorder - a replication study using auditory event-related P300 subcomponents. J Psychiatr Res. 2008;42(4):297-303. Epub 2007/03/03.

[267] Mavrogiorgou P, Juckel G, Frodl T, Gallinat J, Hauke W, Zaudig M, et al. P300 subcomponents in obsessive-compulsive disorder. J Psychiatr Res. 2002;36(6):399-406. Epub 2002/10/24.

[268] Beech HR, Ciesielski KT, Gordon PK. Further observations of evoked potentials in obsessional patients. Br J Psychiatry. 1983;142:605-9. Epub 1983/06/01.

[269] Towey J, Bruder G, Hollander E, Friedman D, Erhan H, Liebowitz M, et al. Endogenous event-related potentials in obsessive-compulsive disorder. Biol Psychiatry. 1990;28(2):92-8. Epub 1990/07/15.

[270] Miyata A, Matsunaga H, Kiriike N, Iwasaki Y, Takei Y, Yamagami S. Event-related potentials in patients with obsessive-compulsive disorder. Psychiatry Clin Neurosci. 1998;52(5):513-8. Epub 1999/04/24.

[271] Atkinson RJ, Michie PT, Schall U. Duration mismatch negativity and p3a in first-episode psychosis and individuals at ultra-high risk of psychosis. Biol Psychiatry. 2012;71(2):98-104. Epub 2011/10/18.

[272] Jahshan C, Cadenhead KS, Rissling AJ, Kirihara K, Braff DL, Light GA. Automatic sensory information processing abnormalities across the illness course of schizophrenia. Psychol Med. 2012;42(1):85-97. Epub 2011/07/12.

[273] Kaur M, Battisti RA, Ward PB, Ahmed A, Hickie IB, Hermens DF. MMN/P3a deficits in first episode psychosis: comparing schizophrenia-spectrum and affective-spectrum subgroups. Schizophr Res. 2011;130(1-3):203-9. Epub 2011/05/10.

[274] Gil-da-Costa R, Stoner GR, Fung R, Albright TD. Nonhuman primate model of schizophrenia using a noninvasive EEG method. Proc Natl Acad Sci U S A. 2013. Epub 2013/08/21.

[275] Jahshan C, Wynn JK, Mathis KI, Altshuler LL, Glahn DC, Green MF. Cross-diagnostic comparison of duration mismatch negativity and P3a in bipolar disorder and schizophrenia. Bipolar Disord. 2012;14(3):239-48. Epub 2012/05/03.

[276] van der Stelt O, Belger A. Application of electroencephalography to the study of cognitive and brain functions in schizophrenia. Schizophr Bull. 2007;33(4):955-70. Epub 2007/03/17.

[277] Ford JM, Sullivan EV, Marsh L, White PM, Lim KO, Pfefferbaum A. The relationship between P300 amplitude and regional gray matter volumes depends upon the attentional system engaged. Electroencephalography and clinical neurophysiology. 1994;90(3):214-28.

[278] Juckel G, Muller-Schubert A, Gaebel W, Hegerl U. Residual symptoms and P300 in schizophrenic outpatients. Psychiatry Res. 1996;65(1):23-32.

[279] Molina V, Sanz J, Munoz F, Casado P, Hinojosa JA, Sarramea F, et al. Dorsolateral prefrontal cortex contribution to abnormalities of the P300 component of the event-related potential in schizophrenia. Psychiatry Res. 2005;140(1):17-26.

[280] Roth WT, Cannon EH. Some features of the auditory evoked response in schizophrenics. Arch Gen Psychiatry. 1972;27(4):466-71.

[281] Hirayasu Y. Brain imaging in schizophrenia. Neuropathology. 2007;27(6):601-3.

[282] Ford JM, Pfefferbaum A, Roth W. P3 and schizophrenia. Ann N Y Acad Sci. 1992;658:146-62.

[283] Sumich A, Kumari V, Dodd P, Ettinger U, Hughes C, Zachariah E, et al. N100 and P300 amplitude to Go and No-Go variants of the auditory oddball in siblings discordant for schizophrenia. Schizophr Res. 2008;98(1-3):265-77.

[284] Kawasaki Y, Sumiyoshi T, Higuchi Y, Ito T, Takeuchi M, Kurachi M. Voxel-based analysis of P300 electrophysiological topography associated with positive and negative symptoms of schizophrenia. Schizophr Res. 2007;94(1-3):164-71.

[285] Pfefferbaum A, Wenegrat BG, Ford JM, Roth WT, Kopell BS. Clinical application of the P3 component of event-related potentials. II. Dementia, depression and schizophrenia. Electroencephalography and clinical neurophysiology. 1984;59(2):104-24.

[286] Araki T, Kasai K, Kirihara K, Yamasue H, Kato N, Kudo N, et al. Auditory P300 latency prolongation with age in schizophrenia: gender and subcomponent effects. Schizophr Res. 2006;88(1-3):217-21.

[287] Mori Y, Kurosu S, Hiroyama Y, Niwa S. Prolongation of P300 latency is associated with the duration of illness in male schizophrenia patients. Psychiatry Clin Neurosci. 2007;61(5):471-8.

[288] Nieman DH, Koelman JH, Linszen DH, Bour LJ, Dingemans PM, Ongerboer de Visser BW. Clinical and neuropsychological correlates of the P300 in schizophrenia. Schizophr Res. 2002;55(1-2):105-13.

[289] Kim DW, Shim M, Kim JI, Im CH, Lee SH. Source Activation of P300 Correlates with Negative Symptom Severity in Patients with Schizophrenia. Brain Topogr. 2013. Epub 2013/07/31.

[290] Kim MS, Kang SS, Youn T, Kang DH, Kim JJ, Kwon JS. Neuropsychological correlates of P300 abnormalities in patients with schizophrenia and obsessive-compulsive disorder. Psychiatry Res. 2003;123(2):109-23. Epub 2003/07/10.

[291] Pallanti S, Castellini G, Chamberlain SR, Quercioli L, Zaccara G, Fineberg NA. Cognitive event-related potentials differentiate schizophrenia with obsessive-compulsive disorder (schizo-OCD) from OCD and schizophrenia without OC symptoms. Psychiatry Res. 2009;170(1):52-60. Epub 2009/10/06.

[292] Gehring WJ, Himle J, Nisenson LG. Action-monitoring dysfunction in obsessive-compulsive disorder. Psychological science. 2000;11(1):1-6. Epub 2001/03/07.

[293] Falkenstein M, Hohnsbein J, Hoormann J, Blanke L. Effects of crossmodal divided attention on late ERP components. II. Error processing in choice reaction tasks. Electro-encephalography and clinical neurophysiology. 1991;78(6):447-55. Epub 1991/06/01.

[294] Falkenstein M, Hoormann J, Christ S, Hohnsbein J. ERP components on reaction errors and their functional significance: a tutorial. Biological psychology. 2000;51(2-3): 87-107. Epub 2000/02/25.

[295] Endrass T, Klawohn J, Schuster F, Kathmann N. Overactive performance monitoring in obsessive-compulsive disorder: ERP evidence from correct and erroneous reactions. Neuropsychologia. 2008;46(7):1877-87. Epub 2008/06/03.

[296] Grundler TO, Cavanagh JF, Figueroa CM, Frank MJ, Allen JJ. Task-related dissociation in ERN amplitude as a function of obsessive-compulsive symptoms. Neuropsychologia. 2009;47(8-9):1978-87. Epub 2009/05/12.

[297] Hajcak G, Franklin ME, Foa EB, Simons RF. Increased error-related brain activity in pediatric obsessive-compulsive disorder before and after treatment. Am J Psychiatry. 2008;165(1):116-23. Epub 2007/11/08.

[298]   Johannes S, Wieringa BM, Nager W, Rada D, Dengler R, Emrich HM, et al. Discrepant target detection and action monitoring in obsessive-compulsive disorder. Psychiatry Res. 2001;108(2):101-10. Epub 2001/12/12.

[299]   Ruchsow M, Spitzer M, Gron G, Grothe J, Kiefer M. Error processing and impulsiveness in normals: evidence from event-related potentials. Brain Res Cogn Brain Res. 2005;24(2):317-25. Epub 2005/07/05.

[300]   Santesso DL, Segalowitz SJ, Schmidt LA. Error-related electrocortical responses are enhanced in children with obsessive-compulsive behaviors. Dev Neuropsychol. 2006;29(3):431-45. Epub 2006/05/05.

[301]   Nieuwenhuis S, Nielen MM, Mol N, Hajcak G, Veltman DJ. Performance monitoring in obsessive-compulsive disorder. Psychiatry Res. 2005;134(2):111-22. Epub 2005/04/21.

[302]   Endrass T, Schuermann B, Kaufmann C, Spielberg R, Kniesche R, Kathmann N. Performance monitoring and error significance in patients with obsessive-compulsive disorder. Biological psychology. 2010;84(2):257-63. Epub 2010/02/16.

[303]   Bates AT, Kiehl KA, Laurens KR, Liddle PF. Error-related negativity and correct response negativity in schizophrenia. Clin Neurophysiol. 2002;113(9):1454-63. Epub 2002/08/10.

[304]   Kopp B, Rist F. An event-related brain potential substrate of disturbed response monitoring in paranoid schizophrenic patients. J Abnorm Psychol. 1999;108(2): 337-46. Epub 1999/06/16.

[305]   Morris SE, Yee CM, Nuechterlein KH. Electrophysiological analysis of error monitoring in schizophrenia. J Abnorm Psychol. 2006;115(2):239-50. Epub 2006/06/02.

[306]   Foti D, Kotov R, Bromet E, Hajcak G. Beyond the broken error-related negativity: functional and diagnostic correlates of error processing in psychosis. Biol Psychiatry. 2012;71(10):864-72. Epub 2012/02/18.

[307]   Millet B, Kochman F, Gallarda T, Krebs MO, Demonfaucon F, Barrot I, et al. Phenomenological and comorbid features associated in obsessive-compulsive disorder: influence of age of onset. J Affect Disord. 2004;79(1-3):241-6. Epub 2004/03/17.

[308]   JAMA. Cognitive-behavior therapy, sertraline, and their combination for children and adolescents with obsessive-compulsive disorder: the Pediatric OCD Treatment Study (POTS) randomized controlled trial. JAMA. 2004;292(16):1969-76. Epub 2004/10/28.

[309]   Insel TR, Mueller EA, 3rd, Gillin JC, Siever LJ, Murphy DL. Biological markers in obsessive-compulsive and affective disorders. J Psychiatr Res. 1984;18(4):407-23. Epub 1984/01/01.

[310]   Khodayari-Rostamabad A, Hasey GM, Maccrimmon DJ, Reilly JP, de Bruin H. A pilot study to determine whether machine learning methodologies using pre-treatment

electroencephalography can predict the symptomatic response to clozapine therapy. Clin Neurophysiol. 2010;121(12):1998-2006. Epub 2010/11/03.

[311] Ralescu A, Lee KH, Korostenskaja M. Machine learning techniques provide with a new insight into pre-attentive information processing changes in pediatric intractable epilepsy. Society for Psychophysiological Research 51st Annual Meeting 2011; September 14-18, 2011; Boston, MA, USA2011. p. 92.

[312] Armananzas R, Alonso-Nanclares L, Defelipe-Oroquieta J, Kastanauskaite A, de Sola RG, Defelipe J, et al. Machine learning approach for the outcome prediction of temporal lobe epilepsy surgery. PLoS ONE. 2013;8(4):e62819. Epub 2013/05/07.

[313] Chang NF, Chen TC, Chiang CY, Chen LG. Channel selection for epilepsy seizure prediction method based on machine learning. Conf Proc IEEE Eng Med Biol Soc. 2012;2012:5162-5. Epub 2013/02/01.

[314] Visa S, Ralescu A. Data-driven fuzzy sets for classification. International Journal of Advanced Intelligence Paradigms. 2008;1(1):3-30.

[315] Takahashi T, Cho RY, Mizuno T, Kikuchi M, Murata T, Takahashi K, et al. Antipsychotics reverse abnormal EEG complexity in drug-naive schizophrenia: a multiscale entropy analysis. NeuroImage. 2010;51(1):173-82. Epub 2010/02/13.

[316] Javitt DC. Glutamatergic theories of schizophrenia. Isr J Psychiatry Relat Sci. 2010;47(1):4-16. Epub 2010/08/06.

[317] Nakao T, Nakagawa A, Yoshiura T, Nakatani E, Nabeyama M, Yoshizato C, et al. Brain activation of patients with obsessive-compulsive disorder during neuropsychological and symptom provocation tasks before and after symptom improvement: a functional magnetic resonance imaging study. Biol Psychiatry. 2005;57(8):901-10. Epub 2005/04/12.

[318] Rauch SL, Shin LM, Dougherty DD, Alpert NM, Fischman AJ, Jenike MA. Predictors of fluvoxamine response in contamination-related obsessive compulsive disorder: a PET symptom provocation study. Neuropsychopharmacology. 2002;27(5):782-91. Epub 2002/11/15.

[319] Saxena S, Brody AL, Maidment KM, Dunkin JJ, Colgan M, Alborzian S, et al. Localized orbitofrontal and subcortical metabolic changes and predictors of response to paroxetine treatment in obsessive-compulsive disorder. Neuropsychopharmacology. 1999;21(6):683-93. Epub 2000/01/14.

[320] Koprivova J, Congedo M, Raszka M, Prasko J, Brunovsky M, Horacek J. Prediction of treatment response and the effect of independent component neurofeedback in obsessive-compulsive disorder: a randomized, sham-controlled, double-blind study. Neuropsychobiology. 2013;67(4):210-23. Epub 2013/05/03.

[321] Basar E. The theory of the whole-brain-work. Int J Psychophysiol. 2006;60(2):133-8. Epub 2006/03/28.

[322] Robinson DL. How brain arousal systems determine different temperament types and the major dimensions of personality. Personality and Individual Differences. 2001;31:1233–59.

[323] Miskovic V, Moscovitch DA, Santesso DL, McCabe RE, Antony MM, Schmidt LA. Changes in EEG cross-frequency coupling during cognitive behavioral therapy for social anxiety disorder. Psychological science. 2011;22(4):507-16. Epub 2011/03/08.

[324] Shagass C, Roemer RA, Straumanis JJ, Josiassen RC. Distinctive somatosensory evoked potential features in obsessive-compulsive disorder. Biol Psychiatry. 1984;19(11):1507-24. Epub 1984/11/01.

[325] Shagass C, Roemer RA, Straumanis JJ, Josiassen RC. Evoked potentials in obsessive-compulsive disorder. Advances in Biological Psychiatry. 1984:1569-75.

[326] Khanna S, Mukundan CR, Channabasavanna SM. Middle latency evoked potentials in obsessive-compulsive disorder. Biol Psychiatry. 1989;25(7):980-3. Epub 1989/04/01.

[327] Towey J, Bruder G, Tenke C, Leite P, DeCaria C, Friedman D, et al. Event-related potential and clinical correlates of neurodysfunction in obsessive-compulsive disorder. Psychiatry Res. 1993;49(2):167-81. Epub 1993/11/01.

[328] Baribeau-Braun J, Picton TW, Gosselin JY. Schizophrenia: a neurophysiological evaluation of abnormal information processing. Science. 1983;219(4586):874-6. Epub 1983/02/18.

[329] de Groot CM, Torello MW, Boutros NN, Allen R. Auditory event-related potentials and statistical probability mapping in obsessive-compulsive disorder. Clin Electroencephalogr. 1997;28(3):148-54. Epub 1997/07/01.

[330] Okasha A, Rafaat M, Mahallawy N, El Nahas G, El Dawla AS, Sayed M, et al. Cognitive dysfunction in obsessive-compulsive disorder. Acta Psychiatr Scand. 2000;101(4):281-5. Epub 2000/04/27.

[331] Kim YY, Yoo SY, Kim MS, Kwon JS. Equivalent current dipole of word repetition effects in patients with obsessive-compulsive disorder. Brain Topogr. 2006;18(3):201-12. Epub 2006/03/18.

[332] Hajcak G, Simons RF. Error-related brain activity in obsessive-compulsive undergraduates. Psychiatry Res. 2002;110(1):63-72. Epub 2002/05/15.

[333] Ruchsow M, Grön G, Reuter K, Spitzer M, Hermle L, Kiefer M. Error-Related Brain Activity in Patients with Obsessive- Compulsive Disorder and in Healthy Controls. Journal of Psychophysiology 2005;19(4):298-304.

[334] Xiao Z, Wang J, Zhang M, Li H, Tang Y, Wang Y, et al. Error-related negativity abnormalities in generalized anxiety disorder and obsessive-compulsive disorder. Progress in neuro-psychopharmacology & biological psychiatry. 2011;35(1):265-72. Epub 2010/11/30.

[335] Hanna GL, Carrasco M, Harbin SM, Nienhuis JK, LaRosa CE, Chen P, et al. Error-related negativity and tic history in pediatric obsessive-compulsive disorder. J Am Acad Child Adolesc Psychiatry. 2012;51(9):902-10. Epub 2012/08/25.

[336] Carrasco M, Hong C, Nienhuis JK, Harbin SM, Fitzgerald KD, Gehring WJ, et al. Increased error-related brain activity in youth with obsessive-compulsive disorder and other anxiety disorders. Neuroscience letters. 2013;541:214-8. Epub 2013/03/05.