POLITECNICO DI TORINO

Corso di Laurea Magistrale

in Ingegneria Gestionale

Tesi di Laurea Magistrale

A New Approach to Investigate the Design Process:

Contrasting Divergent and Convergent Thinking by Means of Electroencephalography and Eye Tracking

Relatore:

Prof. Francesca Montagna

Candidato:

Alessandro Laspia

Aprile 2018

Abstract

Science of design approaches Design scientifically, in order to collect the basic knowledge necessary to develop scientific methods and tools that can support design activity. Traditional protocol analysis employed in science of design focuses on the designer overt behaviours; such research method has provided valuable results, but it is not able to capture the designer cognitive representations. Further research techniques such as content analysis have been introduced to complement protocol analysis, but these approaches rely on specific encoding strategies selected by the researchers who are performing the analysis. Today, physiological recording devices allow to objectively assess the internal cognitive processes of the designer and exploratory studies are needed to evaluate the possibilities and the limitations of these new research instruments. The present study explores the adoption of electroencephalography (EEG) and eye tracking in order to assess cognitive representations of the design thought. The study in particular is grounded on the concepts of divergent and convergent thinking as proposed by Guilford (1950).

The first part of the present work provides a detailed review of neuroscientific literature on creative cognition, then it merges the main evidences with two oculometric studies which shed new light on the functional interpretation of brain activity during divergent thinking. The second part of the study describes the experiment that was conducted. Fourteen male engineering students performed an adaptation of the well-established Alternative Uses task (Jauk, Benedek, & Neubauer, 2012). While performing the task, electrical activity was collected by way of electroencephalography from the scalp of participants and ocular activity was recorded by an infrared eye tracker. The novelty of the experiment consists in the combined employment of these two physiological recording devices.

From the literature review it emerges that evidences in neuroscientific approach to creativity are fragmented because of the variegated experimental designs and analysis procedures. However, it seems that alpha power synchronization in the right parietal lobe would be characteristic of specific cognitive processes occurring during divergent thinking. Such cortical activity has been interpreted as top-down inhibition of task-irrelevant cognitive processes in neuroscience, but findings in oculomteric studies seem to suggest button-up task shielding operated by active visual-gating of the eyes. Unfortunately, experimental results did not reach statistical significance both for brain activity and for ocular behaviour measures. Experimental setting and analysis method employed were identified as possible reasons of such results. The study presents valuable expedients to overcome such limitations in future research. Indeed, artifacts affecting the brainwave signal were identified and corrected only by means of algorithms, whilst employing electrooculogram in the experiment would have been useful to further clean the signal from ocular artifacts. Furthermore, visual inspection would have helped to clean EEG data from muscular artifacts. Also, the employment of an eye tracker with higher sampling rate would have allowed to adopt noise-corrections in order to avoid possible distortions of ocular data. Finally, placement of the reference electrode seems to heavily condition the EEG results. In future studies it would be very important to further delve into the influences of the experimental settings and of the analysis methods on the results of physiological studies.

Therefore, even if the present study does not confirm the evidences described by other authors, it provides useful insights and a framework to position the different research questions for setting future experiments.

Acknowledgments

I wish to thank Professor Peter Törlind and all ETS department for having hosted me at Luleå University of Technology. They didn't just make my research possible, but they also welcomed me in a very friendly environment. I would like to thank my thesis supervisor, Professor Francesca Montagna, for her continuing support and for her trust. I wish to thank the volunteers who took part to the experiment and to Joel and Lisa for helping me with the tests, without them my experiment wouldn't have taken place.

I would especially like to express my gratitude to my uncle Giuseppe, my aunt Daniela and my cousins not just for the beautiful Sundays spent together, but for having been a second family for me in Turin. I would also like to thank my aunt Palma, as she has always supported me during these university years. I wish to thank my friends, and particularly Giovanni, for their support and their friendship.

Finally, I am grateful to my mother, my father and my sister for their unconditional love and their unfailing support. Thank you for inspiring me.

Table of Contents

1. Introduction

1.1. Thesis Statement

Our society is shaped by design actions. Science of design approaches Design as a phenomenon to be studied scientifically (Cantamessa & Montagna, 2016), in order to provide basic knowledge to improve the scientific methods and tools which can support design activity. Traditional protocol analysis employed in design process research focuses on the time sequence of designers' overt behaviours, by collecting verbalization, sketches, audio and visual recordings. Such research method has provided valuable results in the last years, but it is not able to capture the designers' internal cognitive representations. Further techniques such as content analysis and process tracking have been introduced to complement protocol analysis (Hürsen, Kaplan, & Özdal, 2014), but these approaches rely on specific encoding strategies selected by the researchers who are performing the analysis. It is thus necessary to bypass these limits, in order to objectively analyse the designer internal cognitive processes. Today, physiological recording devices have the potential to help researchers to delve further into science of design research questions. Physiological studies in science of design research field are still in their infancy (Nguyen & Zeng, 2010; Steinert & Jablokow, 2013) and more exploratory studies are needed. The purpose of the present work is to evaluate the potentiality and the actual limitations of these new research instruments.

1.2. The Present Study Contribution

The present study explores the adoption of electroencephalography (EEG) and eye tracking for the investigation of cognitive representations of the design thought. In doing this, the thesis examines the creativity construct proposed by Guilford (1950) on which neuro-cognitive literature focused in recent years. The employment of electroencephalography jointly with eye tracking is an element of novelty characterising the present study.

The work provides an updated review of the last findings on divergent thinking in neuroscientific research by reporting the last evidences on the specific role of the right-parietal lobe in such cognitive process (Benedek et al., 2014). Furthermore, the study highlights the contribution that the conjoint use of oculometric and EEG data could provide to the functional interpretation of the right-parietal lobe activity during divergent thinking.

The presentation of the experiment conducted in the present study, which involved fourteen participants, provides a useful insight into the elements to take in account when designing an experiment involving physiological recording devices such as EEG and eye tracking. The main aim of the experiment was to assess if findings from the previous studies could be replicated. Furthermore, the specific experimental design adopted would have contributed to verify if findings of the reference study (Walcher, Körner, & Benedek, 2017) on eye behaviour were task-dependent. More in detail, by employing an adaptation of the Alternate Uses task (Jauk et al., 2012) it was expected to observe cortical reinforcement of power in the alpha frequency band during the uncommon response condition, which simulated divergent thinking, as compared to the common response condition, which simulated convergent thinking. On the oculometric side, higher fixation rate was expected under divergent thinking condition as compared to the convergent thinking condition (Walcher et al., 2017). Unfortunately, despite results from behavioural analysis were in accordance with the previous studies (Benedek, Schickel, Jauk, Fink, & Neubauer, 2014; Fink et al., 2009; Jauk et al., 2012), factorial analysis of variance between convergent and divergent thinking failed to reach statistical significance for both the EEG and the oculometric measures, unlike the other studies. However, even if not confirming the evidences described by other authors, the experiment description is useful to show how small changes in the experimental design and in the analysis method can affect the final results of this kind of studies.

The present work provides a framework to position the next research questions that will ultimately contribute to adopt these new research tools in science of design.

1.3. Science of Design

Design activity is a complex cognitive process which cannot be completely understood merely by a technological perspective. The aim of design is to elaborate a solution that can handle a specific situation well, whilst the ideal would be designing solutions able to tackle a wide range of circumstances (Cantamessa & Montagna, 2016). Science of design scientifically approaches design, in order to eventually provide the basic knowledge to improve the design activity.

In the present paragraph, first science of design will be defined by describing its history, then the main contributions to science of design will be briefly presented. In the end of the paragraph, creativity construct proposed by Guilford in 1950 will be explained. The present work will focus on such construct in order to explore the application of new investigating tools in science of design.

1.3.1. History of Science of Design

As early as the fourth century B.C. Aristotele was one the first to recognize design as the distinguishing human activity and he also declared the dualism between science and technology. It was only in 1969 that Nobel Prize-winner Herbert Simon, in his book “The Sciences of the Artificial”, advocated for scientific dignity of the study of technology, which characterizes the artificial world dominating modern life. In accordance to Simons, in order to understand the artificial world, one should investigate the phenomenon that heavily shapes it, that is the design activity. Simon recognised design as a cognitive phenomenon characterised by typical traits independent from the technical domain. In 2001 it was Nigel Cross to classify this research field as science of design. Such branch of knowledge investigates the designer and the design process scientifically and with an interdisciplinary approach. The final goal of science of design is to provide to design science the basic knowledge to develop new methods and tools to improve the performance of design activity (Cantamessa & Montagna, 2016).

1.3.2. Science of Design Contributions

Research in science of design provided some useful insights into how the design process actually works at an individual level and how it influences social relations among designers.

Through protocol studies Donald Schön found that at an individual level the design process is not a rational predefined sequence of steps, instead it consists of several feedback loops in which the solution gradually emerges from the interaction between the designer and the design problem. The loop alternates design actions and evaluation of the results. Schön showed that the first part of the design process consists in the identification of the elements and of the boundaries which define the design problem. Then the problem is decomposed in simpler parts which are tackled with the aforementioned interactive approach until a satisfactory solution is reached. Then the focus shifts to the next part of the problem. Furthermore, Smith and Browne showed the importance in design of the translation from the level of reality to the level of abstraction in which the designer cognitively operates, by synthesising the goals and the design constraints in order to generate alternative solutions which have to be transferred in the real world. From an organizational level, design activity is a social process involving multiple players. The link between the product architecture and the groups dynamics is so strong that the organizational relationships are often shaped on the base of the product architecture (Cantamessa & Montagna, 2016).

1.3.3. Convergent and Divergent Thinking

Creativity is a fundamental part of the design process, since it is heavily involved in the generation of multiple possible solutions to the design problem through the so-called divergent thinking. However, creativity to be effective needs convergent thinking, during which the designer selects and refines the final solution. Creativity is commonly defined as the ability to produce novel and useful work within a social context (Fink & Benedek, 2012).

Divergent thinking was an attempt by Joy Paul Guilford (1950) in distinguishing creative from non-creative information processing. The name takes origin from the activity of the brain during creativity, because, when mind faces open problems, it "goes off in different directions" (J. Guilford, 1959) in order to create an amount of different original ideas. This cognitive process has been conceptualized as the simultaneous retrieval of exiting knowledge from memory and the combination of various aspects of that knowledge into novel ideas (Fink & Benedek, 2012). A good knowledge is essential, indeed, to combine ideas, to make unexpected associations or to synthetize facts that apparently seem unrelated. However, the many ideas generated during divergent thinking significantly differ in terms of quality. So, in order to generate novelty that is useful, the other feature of creativity, the brain needs to evaluate the ideas generated and to select the best solution. This last process is known as convergent thinking and often researchers tend to wrongly associate the entire creativity process to divergent thinking, whereas the convergent phase is essential to generate effective novelty. Summing up, convergent thinking is oriented toward finding a single answer, by logic and by using previous knowledge: the result is a single answer and increased knowledge. Whilst divergent thinking generates not always effective novelty and variability, by generating multiple and alternative ideas from available information (Cropley, 2006).

1.4. The Science of Design's Tools and Their Limitations

For many years protocol analysis contributed to research, but today science of design needs new methods of investigation to generate new knowledge and to explain further phenomena. In the present paragraph a brief description of protocol analysis and its limitations will be provided as well as a pair of examples of emerging approaches in this research field which brought electroencephalography (EEG) methodology into protocol analysis.

Protocol Analysis and Its Limitations

Protocol analysis is an empirical and observational research method which collect the time path of overt behaviours. Pioneer works employing protocol analysis as research method started in the 60s, but such technique gained more attention after the late 80s. Since then, protocol analysis has been adopted by almost all major design disciplines as a valid research tool (industrial design, architecture, engineering design, etc.). In the last years protocol analysis has been widely used to investigate the cognitive abilities of designers and has provided valuable results (Jiang & Yen, 2009).

Protocol analysis mainly relies on verbalization, with designers verbally reporting the cognitive process they follow when tackling a design problem. However, such research method is subject to issues regarding the validity of verbal reports and the effects that such reporting have on the design process investigated. Furthermore, not all the elements of the design process can be verbalized, because verbal-conceptual elements coexist with visual-graphic elements during the design activity. So, protocol studies also rely upon sketches created by the designers and audio-visual recordings collected during the design process. Protocol studies can involve individual designers, in these cases verbal or think-aloud protocols are employed, or groups of subjects, in these cases the studies employ discussion protocols. The collection of data most of the times is concurrent but it can also be retrospective. In concurrent collection verbal protocols are recorded while the designer performs the design task, whilst in retrospective collection the designer recalls the design process he followed after the completion of the task. Retrospective collection does not influence the performance of the task, but issues about the completeness of the reporting are greater than in concurrent recording. Some retrospective protocols also involve introspection, that is the post-rationalization of behaviours performed by participants. By its own nature introspection cannot be considered properly protocol analysis (Jiang & Yen, 2009).

In order to detect the presence of meaningful patterns in verbal protocols, some studies resort to content analysis (Hürsen et al., 2014). Content analysis allows researchers to spot trends in large amounts of textual information by, for example, detecting the frequency of keywords in the text. However, contend analysis relies on the categorization of the textual information and such classification, even if based on specific coding frames, can be influenced by the specific decisions taken by the researchers who perform the analysis.

Thus, protocol analysis approaches are affected by subjectivity either of the researcher, in content analysis, or the subject, in introspective “protocol analysis”. Furthermore, none of these techniques is able to assess the subconscious internal cognitive processes of the designer. Considering these intrinsic limitations, new research techniques able to reveal the designer cognitive processes by assessing the subconscious physiological responses could help to improve research in design of science.

Emerging Approaches

Although studies in science of design investigating new research approaches are still few, below are reported a pair of examples. These new research approaches are still influenced by traditional protocol analysis, nevertheless adoption of EEG methodology helps to assess the cognitive activity directly.

One of the first studies in science of design exploring the application of EEG (Nguyen & Zeng, 2010) investigated the designer’s cognitive operations during conceptual design. The researchers adopted a sort of protocol analysis by dividing EEG data through the identification of the different phases of the designing process (problem analysis, solution evaluation, solution generation and solution expression) by looking at video recordings of the experimental session. Such approach enabled researchers to assess directly the brain activity, although the research technique was still dependent on the encoding strategy adopted when segmenting the EEG data. However, the study revealed new insights into mental effort during design activity, indeed the researchers delved into this subject in the subsequent years.

Another study (Steinert & Jablokow, 2013) investigated how the underlying cognitive processes of the designer correlate with psychological preferences in order to track and model the interactions between preference, behaviour and cognition. The study did not reach statistically significant results, however it adopted the same technique in segmenting the data of the other study here presented, by identifying convergent and divergent thinking phases on the base of video recordings of the experiment.

1.5. Other Instruments Available

Internal cognitive processes can be analysed by looking at the subconscious physiological responses of the designer. Physiological instruments can help to bypass subjectivity of protocol analysis in order to validate or not the design activities theories in science of design.

In the following pages some basic concepts about the brain will be presented as well as how the brain works and how cognitive activity can be assessed trough different neuroimaging techniques. The present study will focus on electroencephalography (EEG) which enables to assess directly neuronal activity by capturing electric potential generated by synapses during cognitive processes. Then the main ocular behaviours will be presented such as an explanation of how eye activity can be captured by means of eye tracking devices. Finally, other physiological recording devices that could be employed in research will be briefly presented. In the experiment performed in the present study EEG, eye tracking, galvanic skin response and facial expression recording devices were employed, but the analysis was performed only on EEG and ocular data.

1.5.1. The Brain

In the following pages an explanation will be provided about the brain and how it is possible to assess directly the cognitive activity. The available neuroimaging techniques will be briefly reviewed and then electroencephalography technique and its measures will be presented more in detail.

Basic Concepts about the Brain

Human brain is part of the central nervous system (CNS) and it is its main organ. The brain can be divided in cerebrum, cerebellum, limbic system and brainstem. The brain stem regulates the autonomic body processes, such as breathing and heartbeat; the limbic system includes thalamus, hypothalamus and amygdala and is one of the evolutionary oldest parts of the human brain; the cerebellum controls posture, balance and fine movements; the cerebrum, also known as cortex, is responsible for higher brain processes such as conscious thought, decision making and control.

The cortex is composed by two hemispheres, right and left, which are not directly connected, but rely on long-range connections to communicate with each other. The cerebrum is characterized by ridges, named gyri, surrounded by depressions, called sulci. The cerebral cortex is divided in four lobes (Figure 1): frontal lobe, parietal lobe, occipital lobe and temporal lobe. Each lobe has a left and right counterpart that often does not significantly differ from the other. The frontal lobe is associated to decision making and conscious thoughts and is involved in cognitive processes associated to short-term memory, motivation, reward and attention. Furthermore, the frontal lobe controls voluntary movements of the limbs and the eyes. The parietal lobe merges information from external and internal sources, and it processes how human body and environment are related with each other. The occipital lobe is meanly responsible for visual processing of the brain. The temporal lobe transforms the sensory inputs in higher meanings, through visual memories, emotional associations and language. The temporal lobe is also responsible for long-term memory (iMotions, 2016).

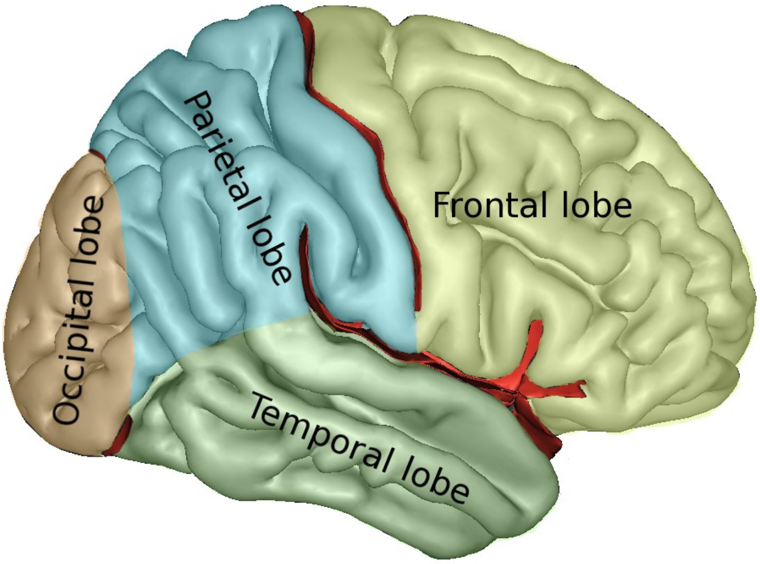


Figure 1: Lobes, lateral view of the cerebrum (Sebastian023)

Human brain is composed by about one-hundred billion neurons. Neurons are cells heavily interconnected with each other through their terminations, named synapses. Synapses control the excitatory and inhibitory activity between neurons, respectively by allowing or preventing the propagation of information from one neuron to the next. The release of neurotransmitters triggers the synaptic transmission; this causes a variation in voltage across the cell membrane. The generated electrical field, also known as postsynaptic potential, last tens or hundreds of milliseconds and it is very subtle. When the postsynaptic potential involves groups of neurons the electrical field becomes stronger and therefore detectable by specific instruments such as the electroencephalography (EEG). This is possible because of the pyramidal neurons in the cortex: their orientation, perpendicular to the cortical surface, allows the propagation of the electrical field up to the scalp. Otherwise the electrical field, spreading in different directions, would fade out before reaching the brain's surface (iMotions, 2016).

The brain is functionally and anatomically specialized. Nevertheless, it is able to unify the distribution of neural processes across the brain in single cognitive moments, adopting large-scale integration. Every cognitive act taking place in the brain is associated to the emergence of specific neuronal assemblies. Neural assemblies are distributed local networks of neurons transiently linked by reciprocal dynamic connections (Varela, Lachaux, Rodriguez, & Martinerie, 2001). Neurons belonging to a given assembly have preferential interactions with a sub-ensemble of other interconnected neurons. These connections can happen within the same cortical area or they can link different brain regions. Connections of this type can be bottom-up (also known as feedforward) or top-down (also known as feedback) connections. Bottom-up connections start from a stimulus and its perception goes from hierarchy lower to higher stages of processing. In top-down connections the starting point is an endogenous activity, such as states of preparation or of attention, for example. Bottom-up and top-down connections are heuristic terms, but in reality, the brain is organized on the principle of reciprocity: if one area connects to another area, there are also reciprocal connections from the last area to the first.

Brain Electrical Signals

Electrical signals generated by the brain are the result of excitatory and inhibitory postsynaptic potentials of neurons, and they are associated with cortical activity. When neural postsynaptic potentials occur in synchrony and at the same time, the signals generate a detectable electric field.

The electrical signal that reaches the scalp is a mixture of several underlying base frequencies, typically included in a range between 1 Hz and 80 Hz. Specific frequency bands are thought to reflect internal cognitive states. Frequencies vary depending on several factors, such as individual characteristics (Da Silva & Pfurtscheller, 1999), proprieties of the stimulus and internal states. For this reason, researchers classified five significant frequency ranges: delta band (1-4 Hz), theta band (4-8 Hz), alpha band (8-12 Hz), beta band (13-25 Hz) and gamma band (>25 Hz).

By bandpass filtering the electrical signal in single frequency bands, it is evident that higher frequencies are characterized by lower amplitude. That is because amplitude of fluctuations decreases with increasing frequency . Since amplitude of brain oscillations is proportional to the number of synchronously active neuron assemblies of slowly oscillating cells generating low frequency signal comprise more neurons than fast oscillating cells generating higher frequency signal. In light of this, changes in the bands' power can be considered due to changes in synchrony of the underlying neural populations. Variations in synchrony are generated by changes in the parameters controlling the oscillations in neural networks, such as the dynamic of synaptic processes or the strength of the interconnections between the network elements. That is, such variations are generated by changes in the activity of local interactions between main neurons and interneurons that control the frequency components of the ongoing electrical field (Pfurtscheller & Da Silva, 1999).

Neuroimaging Techniques

Several neuroimaging techniques are available to investigate how brain elaborates cognitive processes at neurological level. The most used in research are electroencephalography (EEG) and functional magnetic resonance imaging (fMRI). In fMRI neuro-cognitive studies participant perform the tasks lying supine inside a magnetic resonance imaging (MRI) scanner, which detects the blood oxygen level-dependent signal (BOLD). Such MRI scanners are bulky and noisy, and the subject is constricted in a very small area. BOLD responses occur slowly, and this is the reason why fMRI is not the best instrument for the analysis of time-related brain activity changes. But fMRI has a good spatial resolution, in the order of millimeters, and this characteristic allows to detect the increases in blood flows accompanying neural activity in local cerebral areas. Anyway, the exact correlation between BOLD and neural activity is still object of research. While fMRI measures neural activity indirectly, by looking at the oxygen recruited by the brain, electroencephalography (EEG) directly detects neuroelectric activity through electrodes placed on the scalp. Time resolution of EEG is excellent to capture the cognitive processes, occurring within tens to hundreds of milliseconds. But EEG's spatial resolution is low, in the order of centimeters: while the spatial resolution on the scalp can be increased adding more electrodes, EEG cannot distinguish between the signal from the brain areas closer to the scalp and the signal generated by deeper areas of the brain. Comparted to fMRI, EEG experimental conditions replicate better the real-life environment, because EEG does not need any noisy scanner such as the MRI and participants can perform the task just wearing an electrodes cap.

Other instruments such as positron emission tomography (PET), single photon emission computed tomography (SPECT) and near infrared spectroscopy (NIRS) are very rarely used in neuroscientific research because of their invasive nature. In positron emission tomography (PET), an isotope, called tracer, is injected into the bloodstream of the subject. When the tracer reaches the brain, it shows the brain's metabolic processes thanks to its beta radioactive decay, detected by a PET scanner. Usually PET tracers measure the amount of regional glucose absorption; in this way researchers can infer which are the most active brain areas. Single photon emission computed tomography (SPECT) relies on a tracer too. Brain tissues absorb a quantity of tracer proportional to the blood flow and this allows to infer about the most active areas of the brain by scanning gamma decay of the isotope. Both methods are invasive and lack high time resolution. Gamma rays allow the functioning of near infrared spectroscopy (NIRS) too, whereas this technique is not very sensitive. This technique assesses the activity of specific regions of the brain by monitoring the blood hemoglobin levels through optical imaging. Unlike PET and SPECT, NIRS does not need a bulky scanner to detect the radiations, but it employs several optical sensors contained in a cap. In this way, subjects can perform their tasks seated and not lying still on a table like for PET and SPECT.

For all the reasons above electroencephalography (EEG) is widely adopted in neuroscientific research and this thesis is focused on the use of this research instrument.

Electroencephalography (EEG)

Electroencephalography (EEG) is able to directly measure the brain's neural activity, by detecting the electrical field generated by the synapses. EEG's time resolution is excellent for recording cognitive processes, which occur within tens to hundreds of milliseconds. Furthermore, it is inexpensive compared to other neuroimaging instruments, and it can be used in different contexts thanks to its lightness and because it is portable. Also, EEG is completely passive in collecting data and it is non-invasive for the subjects. Above all, like others neuroimaging instruments, EEG is able to detect internal cognitive processes that otherwise would not be observable from the overt behaviors.

EEG consists of several electrodes and one amplifier. Electrodes are metal disk or pellet sensors and they are placed on the scalp, often by means of a cap or strips in order to guarantee faster setups. The electrodes capture the electrical field generated by the neural activity and they contrast it to the electrical signal captured by a reference electrode, in order to compute the electrical potential. The reference electrode is typically placed on the mastoids, on the cheek or on the tip of the nose. The number of electrodes, reference electrode included, corresponds to the number of the channels supported by the EEG device. Impedance is the resistance opposed to the electrical connection between scalp and electrode due to dead skin cells, sebum and sweat which are naturally present on the scalp. This is the reason why most EEG devices typically work with wet electrodes: saline-based conductive gel, paste or cream is applied between the electrode and the scalp and this facilitate the signal transmission. EEG also consists of an amplifier, which emphasizes the weak signal detected from the scalp, in order to collect also the subtlest voltage variations. The continuous signal is digitally sampled at about 250-500 Hz, depending on the specific device. The transmission of the sample to the recording device can be wired or wireless.

Data collected by EEG can be affected by artifacts. Artifacts are electrical signals picked up by the electrodes and they are exogenous respect to the investigated cognitive phenomenon. Such signals can be generated by the body itself with muscles contractions, eye movements or blinks. But artifacts can also be generated by external sources such as the noise from the power line, movements of the electrodes themselves or the swinging of the subjects. The signal can be post-processed and in this way artifacts can be removed, also by means of automatic algorithms.

The most common system to define the location of the electrodes on the scalp is the 10-20 system (Figure 2). Such system refers to two midlines: one vertical line between the nasion and inion and one horizontal line between the left and right preauricular points. The name of the positions in the system starts with one or two letters: they indicate the brain regions below the position of the electrodes (Fp = frontopolar; F = frontal; C = central; P = parietal; T = temporal; O = occipital). The letters are followed by a number. If the number is odd the position is located on the left hemisphere, on the right hemisphere if it is even. The numbers increase with the increasing distance from the vertical midline. Electrodes on the vertical midline are not labeled with a number, but with "z" which stands for zero (iMotions, 2016).

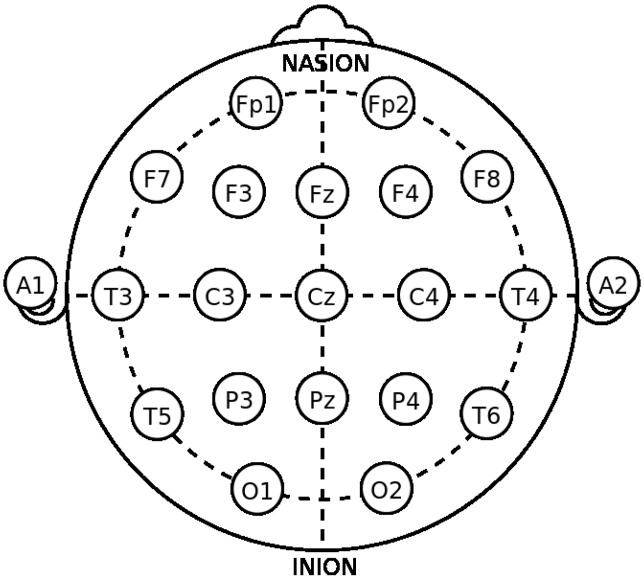


Figure 2: 10-20 system

EEG Measures

The thousands of time series of electrical voltages recorded by EEG in several sites on the scalp can be assessed in several ways. Methods employed in past studies range from the study of local changes in potential, with event-related potentials (ERP) measures or spectral power analysis, to the analysis of functional connectivity between different areas of the cortex, with coherence or phase measures.

Local Changes in Potential Neurons display repeated variations in their electrical voltage level across membrane cells, according to a fast action potential process (also known as spike) and a slower-varying post-synaptic potential process (Ward, 2003). While event-related potential looks directly to the potential time-locked to the stimulus, spectral power analysis manipulates the signal and focuses on specific frequency bands. Both the measures are assessed specifically for each single electrode.

Event-Related Potentials This kind of measure has been rarely used in the previous studies. The ratio at the base of this measure is that external stimuli generate a stimulus-related EEG activity. Such variation in potential is buried in random noise completely unrelated from the stimulus; such noise reflects the inner default activity of the brain. By repeating the stimulus presentations several tens of times and averaging the EEG signal between the trials, one should detect only the EEG response related to that stimulus and the background noise should be attenuated. The result of this analysis is the Event-Related Potential (ERP). Such measure consists of the time-course potential (usually expressed in µV) and is time-locked to the stimulus. ERP is measured for the short segment of EEG data, called epoch, next to the stimulus; the typical length of an ERP epoch is in the order of hundreds of second.

However, it has been proved that a stimulus can generate a reorganization of the phases of the ongoing EEG signals. In light of this, it is evident that considering the stimulus-evoked signal change as additive noise to an uncorrelated pre-stimulus averaged base level of noise is an approximation that does not hold in every situation. Additionally, the commonly used linear methods, such as averaging techniques, are not enough to study these changes and frequency analysis is needed. The reason is that these types of changes are time-locked to the stimulus (with a time delay), but not phase-locked (Pfurtscheller & Da Silva, 1999). It is therefore necessary to analyse the increments or decrements in power of EEG activity in the single frequency bands.

Power Spectral Analysis Power variations can be assessed by looking at the power of the signal during the stimulus by means of power spectral analysis for specific frequencies. Power spectral analysis measures how much the neurons oscillate synchronously at various frequencies during the stimulus. Any repeating series of oscillations in the potential can be represented in simpler sine and cosine oscillations of various frequencies and amplitudes, according to Fourier's theorem. The square of the wave's amplitude at a specific frequency (the Fourier coefficient) is called spectral power (μV^2). Such measure brings EEG signal from the time domain to the frequency domain (Appendix F for further details). In this way, spectral power fluctuations can reveal relationships between cognitive processes and underlying activity of groups of neurons.

Variations in power during the stimulus can be generally categorized as increases or decreases in power compared to another cognitive state or can be contrasted to a reference period recorded just before the stimulus:

Event-Related De/synchronization Increase in synchrony of the underlying neural population in response to an event, called event-related synchronization (ERS), generates an increase in power; while a decrease in synchrony in the neural population, called event-related desynchronization (ERD), generates a decrease in power. Both ERS and ERD are short lasting, band specific and localized amplitude variation of rhythmic activity. So, in order to spot ERD, that is an amplitude decrease in rhythmic activity, a pre-stimulus rhythmicity is needed, i.e. one should find a clear peak in the frequency power spectrum previously to the stimulus. Vice versa, in the case of ERS, after the stimulus a rhythmic component should appear, noticeable through a spectral peak previously not detectable (Da Silva & Pfurtscheller, 1999). Both ERS and ERD are measured as the percentage variation in band power after the stimulus, compared to the power level recorded few seconds before the stimulus.

Functional Connectivity Whereas the brain is functionally and anatomically specialized, it adopts a large-scale neural integration by unifying single cognitive moments, in order to accomplish the cognitive acts. This generates the existence of transient neural assemblies, within or between different cortical areas, that last just a fraction of a second, i.e. the time required to accomplish an elementary cognitive act. This time is sufficient to propagate the neural activity through the single assemblies with transmission delays of tens of milliseconds. Functional connectivity, in neuroscientific literature also named as synchrony (a broader concept compared to the synchronization previously described, because it is not limited to the area below a single electrode), is assessed by looking at the amount of synchrony in the signals detected between pairs of electrodes. Functional connectivity is independent of spectral power and amplitude. There are two possible synchrony measures:

Coherence and Phase When two signals are correlated, variations of one can be predicted as function of the other. The variations can manifest with a time lag. The correlation can also be analyzed for specific frequency, by band-passing the signals and estimating their coherence. But synchrony measurement is more focused than a common correlation: it measures the relation between the rhythms of the signals, regardless their amplitude. There is perfect synchrony when the signals have the same phase in their dominant oscillatory modes; but when the phase difference is nearly constant over a limited time window, defined as a period of phase locking, it is enough to consider that a phenomenon of interest (Varela et al., 2001). EEG is a very good instrument for studying integration through synchronization, due to its high temporal resolution, suitable for the study of temporal dynamics of neural networks in the milliseconds range.

1.5.2. The Eye

The eye is another potential source of information about the ongoing cognitive processes in design. In the present paragraph the main eye activities will be presented such as how they can be captured by means of eye tracking devices.

Ocular Behaviours

Human eye is characterized by limited temporal and spatial sampling of the surrounding environment. Human visual acuity rapidly decreases moving away from the center of the visual field. For this reason, the eye adopts a series of movements to extract information form specific visual locations of interest. Saccades are the biggest type of movement that the eye employ to rapidly align the fovea, the part of the retina with the higher concentrations of cones and providing the sharpest vision, from one point of interest to another. During saccades the image on the retina is poor in quality and as a consequence the brain is not able to extract detailed information. Whilst, during fixations the eye is kept aligned with the target point for a certain amount of time and this allows the brain to process the visual information. Several alternations of saccades and fixations, occasionally interrupted by blinks, enable the brain to create a visual perception of the environment in front of the subject. The saccade latency depends on the task and takes between 100 and 1000 ms. Whereas the duration of a saccade is 20-40 ms on average. Fixations usually last between 50 and 600 ms. During fixations the eye is not perfectly still, but it employs fixational eye movement: the eye moves with minimal movements to avoid perceptual fading and to align with the target point through microsaccades, tremor and drift (Tobii, 2018). In the present study the minimum duration of a blink was considered 6 ms (Walcher, Körner, & Benedek, 2017).

Eye Tracking

Eye tracking devices are able to capture eye positions and movements by tracking reflection of pupil centre. The device illuminates the eye with near-infrared rays, which are not perceived by human eye, and reflections are captured by a high-resolution camera. The data are then processed in order to elaborate gaze positions of the subject. Eye trackers work remotely and then are not intrusive. Furthermore, they are easy to use and require a just a short calibration before starting the experimental recording. Screen-based eye trackers are useful for assessing screen-based stimuli, they are usually mounted near the monitor and record eye movements at a distance, so nothing is attached to the subject. Screen-based eye trackers allow a limited range of head movement. Glasses eye trackers are worn like eye glasses and they record the eye activity from a short range. Glasses enable to capture eye activity when interacting in the real world and not just with stimuli coming from a screen. Accuracy of eye trackers can be influenced by glasses worn by participants or by medical conditions affecting vision such as strabismus.

Figure 3: Heatmap generated by eye tracking

1.5.3. Other Instruments

Neuroimaging and eye tracking are not the only physiological sensors which can contribute to the study of the designer behaviours. Here other recording devices available in the market will be briefly presented (iMotions, 2017).

Galvanic Skin Response

Galvanic skin response (GSR), also known as electrodermal activity, is the subconscious reaction to emotional stimulation which manifest through sweat secretion from glands in human skin. GSR recording devices detect the sweat gland activity through the conductivity of the skin which is influenced by the amount of sweat present on it. Such devices are lightweight, wireless and very easy to setup in experimental procedures.

Heart Rate

The implementation of electrocardiography (ECG) devices allow to assess how anxiety and stress levels of subjects change in relation with their actions by monitoring the heart rate. Another way to assess heart activity is by means of pulse oximeters, which are able to detect blood oxygen saturation and pulse frequency.

Muscular Contraction

Electromyographic (EMG) sensors, by detecting the electric potential generated by muscular contraction, enable to detect the subtlest patterns in muscular activation in response to experimental activities. EMG sensor can be used to detect muscular contraction of the face of the participants or other specific parts of the body.

Facial Expressions

Facial expressions can help understanding the designer behaviour too. Advanced algorithms are able to detect engagement, workload and drowsiness from facial expressions and head orientation through non-intrusive video recordings of the subjects.

1.6. The Thesis Structure

The introduction provided an overview of science of design today, of the need of new research methodologies and of the physiological tools which could bring new knowledge by capturing the internal representations of the designers.

The second part of the dissertation will consist in a detailed literature review of neuroscientific research on creative cognition. Fragmentated evidences will emerge from the review. In order to find some overlapping in findings, the chapter will focus on the creativity construct grounded on the concepts of divergent and convergent thinking as proposed by Guilford (1950). In the last part of the review findings of two oculometric studies will be presented. Such studies will shed new light on the mainstream functional interpretation in neuroscience of brain activity during divergent thinking.

The experiment conducted in the present study will be presented in the third chapter as well as the rationale of the design choices made. The novelty of the experiment consists in the combined employment of two physiological recording devices, the electroencephalogram and the eye tracker. The experiment tried to replicate findings from the reviewed EEG studies and to verify evidences emerged from one specific oculometric study (Walcher, Körner, & Benedek, 2017). The ending part of the third chapter will contrast the present study with the previous ones characterised by the most similar experimental design and then the differences in experimental setting and in the analysis method employed will be discussed. Finally, one last consideration will be shortly presented about an intrinsic limitation apparently common to all the EEG studies reviewed.

The conclusion chapter will summarize the main elements of the work, it will present its limitations and what we should expect from this research field in the years to come.

In the appendices many details about the analytical choices and procedures adopted in the work will be reported in order to lighten the exposition of the present study.

2. Literature Review

After heaving expressed in the previous chapter the valuable contribution that new physiological instruments can make to science of design research, the present chapter will present a deep review of neuroscientific papers regarding the study of creativity. The review will also involve two oculometric studies that will shed new light on the mainstream functional interpretation in neuroscience of brain activity during divergent thinking. The aim of the review was to identify a construct to be investigated by an exploratory study involving electroencephalography and eye tracking related to the design process. Such construct was identified in creativity construct as proposed by Guilford (1950). The review allowed to assess the state of this research field and to subsequently design the exploratory experiment that will be presented in the next chapter.

2.1. Creativity Literature in Neuroscience

In the following pages, after reporting the most common definition adopted for creativity in neurosciences, it will be exposed the complexity in finding common evidence in this research field. To find some evidence, the review will focus on divergent thinking investigations through electroencephalography (EEG) and particularly on findings regarding the alpha frequency band. In the end, possible explanations about alpha activity patterns during divergent thinking tasks will be presented.

2.1.1. Creativity in Neuroscience

Creativity is commonly defined as the ability to produce work that is both original and unique, namely novel, and useful within a social context (Fink & Benedek, 2012). Creativity is a fundamental characteristic of human progress, it makes possible building something new breaking with the present. Despite that, experimental studies of creativity, at least laboratory-based researches, did not develop like other areas of psychological sciences in the last 50 years (Dietrich & Kanso, 2010). In recent years the interest in this issue has raised because of its manifest importance in many areas such as culture, science, economics and industry. For this reason, this subject became popular in several scientific disciplines; among them are cognitive sciences and neurosciences.

2.1.2. Complexity in Comparing Findings

In neuroscience a widely used instrument to study creative thought on cortex level is human electroencephalography (EEG). The present review was mainly focused on studies employing such research tool. Many studies have been conducted, but the evidence of overlap in results is limited (Arden, Chavez, Grazioplene, & Jung, 2010). The reasons for that are several: there are different ways of defining creativity, there are several ways of measuring it, experimental procedures are highly variegated and a broad variety of neurophysiological measures is employed. Such aspects are presented more in detail below.

Construct under investigation

Creativity, characterized by novelty and usefulness, can be seen either as a cognitive state, a cognitive event, a cognitive potential or a personality disposition. Furthermore, creativity may refer to different definitions, such as divergent thinking, insight, cognitive flexibility and imagination, and it may be contextualized in different domains (Fink & Benedek, 2012). All of this led to highly differentiated experimental tasks and methods. Moreover, in the past researchers were not specific enough on the definition under investigation and this contributed to the little clarity on the subject.

Task employed and evaluation parameters

Several studies in the field led to different and not comparable results also because of the creativity tasks employed. Many different types of task have been used in order to estimate the creativity level. Such tasks can be divided in three categories: remote associate tasks, insight tasks and creative ideation tasks.

In remote association problems, examinees can be asked to produce creative artworks, such as stories, melodies or paintings. But the most popular remote associate problem is Remote Associate Test (RAT), in which participants have to find non-obvious semantic relations by mean of loose associations. Remote associate tasks rely on the theory according to which the most original ideas are also the most remote and far down the associative pathway (Runco & Yoruk, 2014).

Insight tasks involve misleading problems that require cognitive restructuring and that may lead to very few or just one sudden “ah-ha!” solution, preceded typically by an incubation period (Runco & Yoruk, 2014).

In creative ideation tasks, also known as divergent thinking tasks, subjects are asked to come up with original ideas for open, and sometimes ill-defined, problems. The most used divergent thinking test is the Alternate Uses Task (AUT), in which participants have to think to many different creative uses for everyday objects. Compared to insight problems, in divergent thinking problems respondents generate many ideas and explore original alternatives. Examinees performing creative ideation tasks are more likely to generate original ideas when they are told that the task is not a test, but a game. In this way they do not tend, ironically, to give more common ideas in order to earn higher scores. It should be kept in mind that results of these types of test are not equivalent to the creativity level. But in the years divergent thinking tests proved to be a reliable instrument to provide estimates of creativity (Runco & Yoruk, 2014).

In addition, there are many ways in which creative tasks can be evaluated when researchers want to psychometrically assess the participants’ creativity level. Creative ideation tasks are often scored for originality, as well as ideational fluency and flexibility. Ideational fluency is computed as the total number of ideas, and some researchers has used exclusively this score to evaluate divergent thinking performance, because it correlates with originality and flexibility. In fact, originality is the number of unique or uncommon ideas generated and flexibility is the number of different conceptual categories to which the produced ideas belong. But ignoring originality and flexibility is not correct, both because originality is more important than fluency for creativity and because the standard definition of creativity does not include fluency, but originality, that, however, is not sufficient alone for having creativity (Runco & Yoruk, 2014).

Different experimental procedures

Variety of experimental procedures is also an obstacle to comparing the different findings. The stimuli, for instance, can differ in duration: in some studies stimuli are shown for the whole duration of the task, in others only for few seconds. Timing plays also a role in tasks’ duration, ranging from few seconds to several minutes. Also, duration of the reference phases, control conditions necessary to contrast brain activity during the tasks, differs among studies. Furthermore, control conditions can be rest periods, that could be recorded either before or after the task or both, but they can also be other tasks. In addition, response modes differ among studies. Responses can be written or verbal. And while in some experiments participants have to press a button when they want to express their solution, in others they have to withhold the response until the end of the task. Regarding how tasks are executed, in some experiments examinees have to keep their eyes open during the tasks, in others close. In some studies, performing the tasks requires to write or draw the solution down, in others participants have just to think about it.

Different neurophysiological measures

Finally, even if only EEG studies are considered, researchers employ many different measures of brain activity. In quantifying brain activation through power levels, some studies merely measure raw power changes, while others measure event-related potentials. Furthermore, some studies try to assess the functional connectivity between different areas of the cortex by looking either at coherence measures or at phase measures.

In addition, brain activity can be assessed either in specific bands (or even sub-bands), by filtering the recorded signal for particular frequency ranges, or in the broad frequency range of the brain.

Such different definitions of creativity, different ways to measure it, different experimental procedures and different neurophysiological measures adopted affect the comparability of results. Usually, the variation of experimental methods is useful to test the robustness of findings, but this is not possible when so many factors vary among studies. Because of this high and unstructured variability, results of researches cannot be compared and integrated reasonably (Fink & Benedek, 2012).

2.1.3. Divergent Thinking Studies

To find some evidence in neuroscience research on creativity, the review will focus on divergent thinking. In the following pages, after having presented how divergent thinking tasks have been adapted to neuroscientific studies, the general design of the studies will be presented and finally the exposition will focus on findings regarding alpha frequency band, the band with less ambiguous evidence.

Divergent Thinking in Neuroscience

Divergent thinking tasks have been adapted to restrictions of neuroscientific methods. For instance, creativity task should not be timed, because timing can influence creativity level of the subjects. But tasks are often limited to few seconds or minutes, because of the big amount of data generated by EEG recording. Moreover, time periods are necessary to separate the process of thinking about the ideas from the expression of the solutions. Furthermore, in many studies participants have to come up with only one idea during the tasks, whereas divergent thinking should be characterized by the generation of several ideas. This adaptation is aimed to assess brain activity only during idea generation, excluding from the analysis other possible cognitive processes, such as memory retention.

The Studies' Design

In Table 1 the reviewed papers on divergent thinking that employ EEG are reported. All the studies analyse local power changes in alpha frequency band and part of the investigations also examine other bands. Most of the studies further divide bands in sub-bands, for example lower (~ 8-10 Hz) and upper alpha (~ 10-12 Hz) band. Only few studies try to assess functional connectivity through coherence or phase measures, but there is not clear evidence of any pattern during divergent thinking for this kind of measures. Some studies also assess potential correlations with other factors, such as intelligence, gender or creativity predicted by psychological tests.

Table 1: Reviewed studies

Study	Bands	Sub-Bands	Fun. Con.	Design	Covariate
Bazanova & Aftanas, 2008	α; β; γ; θ	YES	NA	TR; WTC	NA
Benedek et al., 2014	α; β; θ	NA	NA	TR; WTC	NA
Danko et al., 2009	α; β; γ	YES	NA	TR; BTC	NA
Fink & Neubauer, 2006	α	YES	NA	TR	Verbal IQ; Gender
Fink & Neubauer, 2008	α	YES	NA	TR; BTC	Intro/Extro-version
Fink et al., 2006	α	YES	NA	TR; BTC	DTTT
Fink et al., 2009	α	YES	NA	TR; BTC	NA
Fink, Schwab, Papousek, 2011	α	YES	NA	TR; WTC	NA
Grabner et al., 2007	α	YES	PHASE	TR; WTC	NA
Jauk et al., 2012	α	YES	NA	TR; BTC	NA
Jaušovec, 2000	α	YES	CO	TR	IQ; TTCT
Martindale & Hasenfus, 1978*	α; -	-	-	WTC; BTC	AUT; RAT
Martindale & Mines, 1975*	α; -	-	-	WTC; BTC	NA
Martindale et al., 1984*	α; -	-	-	WTC; BTC	AUT; RAT
Mölle et al., 1999	α; β; δ; θ	NA	NA	TR; BTC	NA
Razumnikova et al., 2009	α; β; θ	YES	CO	TR; BTC	NA
Razumnikova, 2005	α; β; θ	YES	CO	TR; WTC	Gender
Razumnikova, 2007	α; β; θ	YES	CO	TR; WTC	NA
Shemyakina & Danko, 2007	α; β; δ; θ	YES	CO	TR; WTC	NA

Note: AUT = Alternate Uses Task; BTC = Between Task Comparison; CO = Coherence; DTTT = Divergent Thinking Task Training; FUN. CON. = Functional Connectivity measure; IQ = Intelligence Quotient; NA = Not Available; RAT = Remote Associates Test; TR = Task-Rest Comparison; TTCT= Torrance Test of Creative Thinking; WTC = Within Task Comparison; * = Indirect review; α = Alpha Band; β = Beta Band; γ = Gamma Band; δ = Delta Band; θ = Theta Band.

The Main Evidences

Among the studies, only few do not report a significant variation in alpha signal during creativity tasks execution (Danko, Shemyakina, Nagornova, & Starchenko, 2009; Martindale & Hasenfus, 1978; Shemyakina & Danko, 2007). While, among the other bands, beta is the only one with some sort of evidence during creativity tasks: some studies report increases in power in some lobes (Danko et al., 2009; Mölle, Marshall, Wolf, Fehm, & Born, 1999; Razumnikova, 2005; Razumnikova, 2007) and one study reports decreases (Shemyakina & Danko, 2007).

Alpha band is the frequency band with more evidence about differences in activity during divergent thinking when compared to control tasks. Whereas studies divide into some reporting synchronization or increase in alpha power and some reporting desynchronization (Table 2). Concerning differences in brain hemispheres activity, only half of the studies report statistically significant evidence; all of these studies report stronger alpha activity in right hemisphere compared to left hemisphere, with one exception (Razumnikova, 2007) reporting stronger activity in the left hemisphere.

Table 2: Evidence in alpha band

Study	Frontal	Temporal	Parietal	Occipital	Hemisphere
	Power Changes In Lobes				
Bazanova & Aftanas, 2008	INC	NA	ERS	ERS	NA
Benedek et al., 2014	ERS	ERS	ERS	ERS	RIGHT
Danko et al., 2009	NS	NS	NS	NS	NA
Fink & Neubauer, 2006	ERS	ERS	ERS	ERS	NS
Fink & Neubauer, 2008	INC	INC	INC	INC	RIGHT
Fink et al., 2006	ERS	ERS	ERS	ERS	NS
Fink et al., 2009	ERS	ERS/ERD	ERS/ERD	ERS/ERD	RIGHT
Fink, Schwab, Papousek, 2011	ERS	ERS	NS	NS	RIGHT
Grabner et al., 2007	ERS	ERS	ERS	ERS	RIGHT
Jauk et al., 2012	ERS	ERD	ERD	ERD	RIGHT
Jaušovec, 2000	ERS	ERS/ERD	ERD	ERS	NS
Martindale & Hasenfus, 1978*	NS	-	-	-	NS
Martindale & Mines, 1975*	INC	-	-	-	RIGHT
Martindale et al., 1984*	INC	-	-	-	RIGHT
Mölle et al., 1999	NS	NS	INC	NS	NS
Razumnikova et al., 2009	ERD	ERD	ERD	ERD	NS
Razumnikova, 2005	NS	NS	NS	NS	NS
Razumnikova, 2007	NS	ERD	ERD	ERD	LEFT
Shemyakina & Danko, 2007	NS	NS	NS	NS	NA

Note: ERD = Event Related Desynchronization; ERS = Event Related Synchronization; HEMISPHERE = Hemisphere with stronger power/synchronization; INC = Increase in power; NA = Not Available; NS = Non-Significant difference; * = Indirect review.

2.1.4. Evidences on Alpha Power during Divergent Thinking

Many studies report alpha oscillation patterns during creativity-related tasks and for this reason the following review will focus on findings for this specific frequency band.

Research concerning the relation between alpha band and divergent thinking can be clustered in four categories (Fink & Benedek, 2012): consequences of creative tasks demands, differences related to the originality of ideas generated, individual differences and influences of creativity enhancing factors.

Consequences of creative tasks demands

Creativity-related tasks have been proven to influence alpha waves activity in most of the studies reviewed (Table 2). But in general, power changes associated to creativity-related tasks are not always uniform. Almost all the studies reporting significant changes in alpha activity also report increases in power or event-related synchronization in the frontal cortex, except for few (Mölle et al., 1999; Razumnikova, Volf, & Tarasova, 2009; Razumnikova, 2007). In posterior lobes the evidence is not so sharp, with some studies reporting both ERS and ERD for sites belonging to the same lobes (Fink et al., 2009; Jaušovec, 2000), and others reporting widespread alpha desynchronization (Razumnikova et al., 2009; Razumnikova, 2007).

One study (Mölle et al., 1999) specifically contrast brain activity during divergent thinking and during convergent thinking task demands, and stronger alpha power is reported during the performance of the divergent thinking tasks. In this study, through spectral power analysis, researchers pointed out the elicitation of more alpha power in parietal sites when the subjects performed the alternate uses task and the consequences task, which are typical divergent thinking tasks, compared to when they performed the arithmetic task and the intelligence test tasks, that are instead convergent thinking tasks.

In another study (Fink, Benedek, Grabner, Staudt, & Neubauer, 2007) the subjects performed alternate uses tasks, utopian situation tasks (in which participants had to think on consequences of specific situations), insight tasks and word end tasks (in which participants had to complete some words). The first three of the tasks appear to rely on divergent and free-associative demands, while the word end task seems to involve more convergent and intelligence-related demands. From the study the following evidence emerge: the more creative-related a task is, the stronger is the alpha synchronization during that task (Fink & Benedek, 2012).

A third study (Jauk, Benedek, & Neubauer, 2012), differently from the other studies, employs the same alternate uses task under two different conditions in order to contrast divergent and convergent thinking. Divergent thinking is replicated under the condition requiring original responses and convergent thinking is replicated under the condition requiring common responses. While alpha synchronization in frontal lobe persisted, in posterior lobes participants exhibited alpha desynchronization while performing the divergent thinking condition.

Other studies (Razumnikova et al., 2009; Razumnikova, 2007) report alpha desynchronization. The reason for such evidence could be dependent on the relatively long reference period adopted by these studies: five minutes of rest with eyes closed, while in other studies reference period do not exceed two minutes. Since the beginning of EEG technique in 1930s by Hans Berger, it was evident that alpha waves increase in amplitude when individuals have their eyes closed compared to when they have them open. In light of that, it is possible that alpha power was high during the divergent thinking tasks, but not enough to exceed the high average level reached during the five minutes long rest period. Moreover, these two studies employed a type of association task that enhance alpha power less compared to more demanding creative tasks (Fink & Benedek, 2012).

Differences related to the originality of ideas generated

Some studies go beyond assessing alpha activation during creativity-related task demands and they also analyse how alpha activity is related to the originality level of the generated solutions to the tasks. In one study (Fink & Neubauer, 2006) participants had to find as many original solutions as possible to two verbal tasks. Originality of the solutions was scored within each participant through external rating by 3 female and 3 male raters according to Consensual Assessment Technique proposed by Amabile (1982). In centroparietal recording sites researchers reported stronger alpha synchronization for more original solutions then for less original ones.

In another study (Grabner, Fink, & Neubauer, 2007) originality was rated by the respondents themselves after the recording session. In this study too, the most original ideas show stronger alpha synchronization than the less original ideas, particularly in the right hemisphere.

Individual differences

Other studies assess inter-individual differences by means of between subjects comparison. In one study (Jaušovec, 2000) participants were clustered in highly creative and lowly creative people, on the base of their scores in Torrance psychological test of creative thinking. Highly creative people manifested higher alpha power than lowly creative people in all the lobes. Also other two studies (Razumnikova et al., 2009; Razumnikova, 2007) clustered participants in highly and lowly creative people on the base of a psychological test similar to remote associations test. Both studies report higher alpha amplitude in more original individuals. In another study (Fink et al., 2009) participants were clustered, by means of Consensual Assessment Technique, on the base of originality of the ideas generated during the execution of Alternate Uses tasks. The most creative people presented larger hemispheric asymmetry than the less creative individuals, with the right hemisphere exhibiting stronger synchronization than the left hemisphere in posterior lobes.

One study focuses on gender differences (Fink & Neubauer, 2006) in the alpha band. Researchers detected stronger increases in alpha power for females with higher verbal IQ compared to females with average verbal IQ. For males the findings were opposite. In another study (Fink & Neubauer, 2008) the same researchers focused on introverted/extroverted individuals and found that more original extroverted individuals exhibited the strongest alpha power level, while less original introverted people exhibited the weakest alpha power.

Creativity enhancing factors

Finally, a pair of the studies reviewed investigate how creativity enhancing stimuli or training could influence cortical activity. In one study (Fink, Grabner, Benedek, & Neubauer, 2006) participants took two creativity tests, one before and one after an overall two-weeks long divergent thinking training. After the training participants manifested higher task-related frontal alpha synchronization compared to the control group who did not take any training. Another study (Fink, Schwab, & Papousek, 2011) assesses how cognitive and affective stimuli can influence creative cognition and EEG alpha activity. Researchers found that cognitive stimuli such as exposition to others' ideas enhanced alpha activity in prefrontal cortex and in right hemisphere.

Summing up, most of the reviewed papers report increases in alpha power during divergent thinking or at least absence of desynchronization. The evidence of alpha synchronization is stronger for the frontal lobe and the right posterior parietal sites.

Some studies reported alpha desynchronization, but the reason could lie in the different duration of the experimental reference phase and in the different tasks employed. Several studies reported the influence on alpha power of the type of creativity task employed, indeed. More in detail, it has been shown that the more creative a task is, the higher the alpha power recorded is (Fink & Benedek, 2012).

Also, there is evidence that originality of generated solutions affects the levels of alpha power recorded during EEG sessions (Fink & Neubauer, 2006; Grabner et al., 2007).

Some studies exhibited how individual factors can influence alpha activity during creativity tasks, such as gender (Fink & Neubauer, 2006) and introversion or extroversion (Fink & Neubauer, 2008). But, about individual differences, it is particularly interesting to notice that the more creative is a person the more alpha power is elicited during creativity-related task demands. There is also evidence of the influence of creativity enhancing stimuli or training on alpha band in cortical activity (Fink et al., 2006; Fink et al., 2011).

Upper and lower alpha band

Finally, most studies analysed separately upper and lower alpha frequency band, but any clear evidence emerged from such distinction. In some studies (Fink et al., 2006; Grabner et al., 2007; Razumnikova, 2007) lower alpha band was the one influenced by divergent thinking tasks, in others

(Fink et al., 2009; Fink et al., 2011) it was the upper alpha band and in others (Fink & Neubauer, 2008; Jauk et al., 2012; Jaušovec, 2000) no significant difference emerged between the two sub-bands.

2.1.5. Alpha Power during Divergent Thinking, Possible Explanations

Past studies usually associated alpha synchronization to reduced information processing. However recent studies associate increases in alpha power both to cognitive load for the frontal lobe and task shielding for the right parietal lobe. In the present paragraph such functional interpretations will be explained in detail.

Obsolete and New Interpretations of Alpha Event-Related Synchronization

In past studies event-related synchronization of alpha band power was associated to cortical idling or to reduced information processing, because cognitive tasks are usually associated to event-related desynchronization and also because of the well-known event-related synchronization pattern in alpha band when subjects keep their eyes closed. Indeed, this latter phenomenon has been interpreted as the effect of reduced information processing because of the suspension of the visual information stream. However, findings in creative studies increasingly report the eliciting of alpha power (event-related synchronization) in a broad range of creativity tasks. In light of that, the common interpretation of cortical idling or reduced information processing associated to higher alpha power levels does not hold anymore. This seems to be confirmed by studies which employed both EEG and fMRI: the same creativity-related tasks which showed alpha synchronization with EEG showed also increase of BOLD response in frontal lobe with fMRI. In light of these findings, alpha synchronization during creative ideation appears to be the effect of an active cognitive process and not of cortical idling, as previously supposed (Fink & Benedek, 2012).

According to several neuroscientific studies interpreting alpha synchronization as a functional correlate of inhibition or of top-down control, Fink and Benedek (2012) suggest that increments of alpha during creative-related cognitive processes could be interpreted as the consequence of inhibition of cognitive processes not relevant for the demanding task. And this kind of alpha activity can be observed in sites probably exerting top-down control or being subject to it.

Cognitive Demand and Alpha Activity in Frontal Lobe

According to several studies, the reason of increased alpha activity in frontal lobe during creativity-related tasks does not lie in creativity itself, but in higher cognitive demand typical of these tasks.

One of the most interesting studies (Benedek, Bergner, Knen, Fink, & Neubauer, 2011) investigated if alpha activity is actually related to creativity demands or if it is the effect of a more general internal processing demand. Researchers applied two conditions to two different tasks, one divergent thinking task and one convergent thinking task. The conditions aimed to reproduce high and low internal processing demand: in low internal processing demand the items of the task were displayed for all the time needed to complete the task, while in high internal processing demand the items were displayed only for a short time before being masked. Only during high internal processing condition alpha band showed synchronization in the frontal lobe and this happened both during the convergent and during the divergent task. According to the researchers, in light of these findings and in line with other neurocognitive studies, frontal alpha synchronization could be explained as the effect of high internal processing demand, that is predominant in divergent thinking-related tasks. Also, evidence about creative ideation points to the suppression by top down control of not relevant sensory processing, of irrelevant information retrieving and of task-irrelevant activities (Fink & Benedek, 2012).

Thus, internal processing and top-down control appear to be necessary during divergent thinking, but they are not the only characteristic of creative ideation and they do not manifest only during this specific kind of task demands.

Alpha Activity in Right Parietal Lobe

Alpha synchronization in right parietal lobe, and somehow also in right occipital lobe, seems to be specifically representative of divergent thinking cognitive processes. Such activity in alpha band could reflect both suppression of distracting sensory stimuli, memory retrieval and visual manipulation of previous knowledge; all of these are typical processes involved in divergent thinking tasks.

Indeed, in Benedek et al. (2011) there is evidence of alpha synchronization in posterior parietal sites of the right hemisphere exclusively for the divergent thinking task. Other studies report similar evidences in posterior parietal and occipital sites (Fink et al., 2009; Mölle et al., 1999) and the same finding are reported also for more generic creativity tasks. So, parietal alpha synchronization in right hemisphere seems to be typical of divergent thinking tasks. Some old studies suggested a special functional role of right hemisphere during creative cognitive processes, but the evidence does not support this hypothesis (Dietrich & Kanso, 2010).

The frame becomes more complex if fMRI studies are taken in account: in such studies there is evidence of low cortical activation or even deactivation in the right parietal cortex. In other neurocognitive studies, this pattern has been associated to goal-oriented attention and to suppression of irrelevant stimuli, especially in creativity tasks demanding strongly original solution. Considering that, alpha desynchronization in this region could be interpreted, again, as a state of internal attention and of suppression of irrelevant information. Other neurocognitive studies suggest the role of parietal lobe in efficient attentional allocation during memory search and goal-oriented retrieval. Increases in alpha power over parietal and occipital sites could, then, reflect suppression of distracting visual information, but also memory processing occurring for retrieval and recombination of knowledge necessary to generate creative ideas (Fink & Benedek, 2012).

This hypothesis seems to be confirmed by a more recent study (Benedek, Schickel, Jauk, Fink, & Neubauer, 2014) that investigated alpha power increases in right parietal cortex. Researchers compared two divergent thinking tasks, a four-word sentences task and an alternate uses task, under two different conditions aiming to reproduce high and low internal processing demand respectively (by modulating the exposition duration to the items). Researchers conclude that alpha level reflects the suppression of irrelevant sensory stimulation and, thus, the strength of task-focused internal attention. This "task shielding" is particularly strong for Alternate Uses task, because it heavily involves memory retrieval and demanding processes such as generation and manipulation of mental images, which could be easily interfered by external irrelevant stimuli.

Summing up, increases in alpha power observed in several studies seem to denote typical, but not exclusive, cognitive processes related to creativity, that are internally oriented attention, associated with suppression of irrelevant cognitive processes and external stimuli, memory retrieval and knowledge re-combination.

2.2. Oculometric Studies

In the present paragraph a pair of oculometric studies will be presented. The two studies investigate internally-directed cognition. Such cognition characterizes one of the most employed divergent thinking tasks in neuroscience research, namely the Alternate Uses task. The findings at oculomotor level will be then analysed in light of the neuroscientific evidence.

2.2.1. Active Visual Attenuation and Internal Coupling

Walcher, Körner, & Benedek (2017) investigate eye behaviour during goal-directed internally focused cognition. The researchers contrasted an idea generation task, namely an Alternate Uses task, to a reading task. Both tasks are goal-directed, but the first one is characterized by internally directed focus and the latter by externally directed focus. During the idea generation task, the subjects manifested longer and more frequent blinks and fewer microsaccades. Since blinks shout-out the visual information and microsaccades may be associated to fading visual perception, such evidence was associated to an active attenuation of the visual input. Furthermore, the researchers suggested that this phenomenon could be a mechanism to reduce the processing of irrelevant external visual information during the task. Such interpretation seems to suggest bottom up task shielding. Furthermore, the idea generation task was associated with more and shorted fixations, and with wider and more frequent saccades. This eye behaviour resembles searching for the ideas generated by the subjects in the real environment. This last evidence was interpreted as the manifestation of a possible coupling between the internal ongoing cognitive processes and the eye behaviour. Researchers could not say for certain if this last evidence is intrinsic to internally focused attention, because it could depend on the specific task employed.

2.2.2. The Top-Down or Bottom-Up Issue

In another study (Mathias Benedek, Robert Stoiser, Sonja Walcher, & Christof Körner, 2017) regarding the same experiment aforementioned, the oculometric findings are compared to the neuroscientific research involving internally directed cognition tasks. Since internally directed cognition has been repeatedly associated to increases in alpha power levels, particularly in the posterior regions of the brain, and tacking also in account other neuroimaging studies reporting the deactivation of areas of the brain related to the processing of sensory stimuli (occipital lobe), internally directed cognition tasks seem to involve reduced processing of visual information, just as findings in the oculometric study suggest.

There are two possible interpretation about the direction of such visual information suppression. Neuroscientific literature often interpreted increases in alpha level as top-down inhibition of task-irrelevant cognitive processes. There is evidence of increased functional connectivity from the parietal and the frontal lobe to the occipital lobe, the lobe associated to visual processing; in light of that, alpha band activity could be interpreted as a top-down mechanism to suppresses the visual information processing during demanding internal cognition tasks. Otherwise, the deactivation in visual network could be due to bottom-up task shielding, generated by the active visual-gating of the eyes reported in the study (Mathias Benedek, Robert Stoiser, Sonja Walcher, & Christof Körner, 2017).

3. The Experiment

In light of the main findings emerged from the previous studies, an experiment was designed in order to replicate and validate some of the results reported in literature. In the present chapter first an overview of the present study will be presented such as the theoretical objectives and the experimental choices, then all the details about the experiment will be provided, from the task employed to the apparatus and the procedure. Then, after the statistical analysis, a discussion will follow contrasting the results and the experimental choices of the present study and of the previous studies.

A considerable part of the analytical choices will be reported in the appendices in order not to interrupt the presentation of the study. Such appendices will be reported during the exposition and can easily be reached in the end of the document.

3.1. The Present Study

The experiment conducted consisted in one well-established divergent thinking task in neuroscientific research field of creativity, the Alternate Used task. Such task was performed under two different conditions, one simulating convergent thinking and one simulating divergent thinking. The main aim of the study was to assess the employment of physiological analysis in science of design by addressing the creativity construct proposed by Guilford (1950). The experimental hypotheses were elaborated on the base of previous EEG and ocular behaviour studies on divergent thinking and internally directed cognition.

3.1.1. The Main Evidences from the Past Studies

The variegated results of EEG creativity studies seem to point to alpha synchronization in the frontal and right parietal lobe during divergent thinking tasks. Divergent thinking tasks require internally focused cognition and results of an eye behaviour study about this type of cognition could help to shed light on the functional interpretation of such increases of alpha power.

EEG Studies

Most of the reviewed papers reported power increases in the alpha band during divergent thinking or at least absence of desynchronization (Table 2). The evidence of alpha synchronization is stronger for the frontal and the right posterior parietal lobes.

One study (Benedek, Bergner, Knen, Fink, & Neubauer, 2011) showes that alpha power increases in the frontal lobe are not exclusively distinctive of divergent thinking but they represent high internal processing demands; indeed, such increases can also be reproduced for convergent thinking. Thus, alpha synchronization in the frontal lobe seems to merely reflect top-down information processing. On the other hand, another study employing the Alternate Uses task (Benedek, Schickel, Jauk, Fink, & Neubauer, 2014) shows that alpha synchronization in the right parietal lobe is distinctive of internally directed cognition, which is characteristic of divergent thinking tasks. Such evidence has been interpreted as task-focused attention or task shielding from bottom-up processing demands during internally directed cognition.

Eye Behaviour Studies

One study on eye behaviour (Walcher, Körner, & Benedek, 2017) reportes more and longer blinks, less micro-saccades, higher rate of fixations and higher rate of saccades during goal-directed internally focused attention compared to externally focused attention. The internally focused attention task employed in the study was an Alternate Uses task.

During the task researchers report active visual attenuation, because more and longer blinks and less micro-saccades contribute to perceptual fading. This has been interpreted as task shielding from external task-irrelevant inputs, suggesting bottom-up task shielding (Mathias Benedek, Robert Stoiser, Sonja Walcher, & Christof Körner, 2017). Furthermore, in the same study, the higher rate of fixations and saccades during cognitive visual elaboration of the ideas evoked by the task suggests the possible coupling between ocular activity and internal ongoing cognitive processes. However, researchers declare that such patterns in the ocular activity could not be peculiar of internally focused attention, but they could depend on the specific task employed.

3.1.2. Objectives

The more interesting research questions emerged from the literature review are presented below. Two questions could be assessed by means of the apparatus employed in the present study, whilst another question required superior hardware specifications of the eye tracker and it is presented as a suggestion for future studies.

Objectives of the Present Study

The first research question is: can the main findings of the previous EEG studies about alpha power activation during divergent thinking tasks be replicated, particularly in the frontal and in the right parietal lobes? Indeed, the literature review revealed highly variegated findings in EEG studies about creativity. By employing the most used divergent thinking task, the Alternate Uses task, and by replicating the main characteristic of the most used study designs one should expect similar findings.

The second research question is: is the enhanced ocular activity distinctive of internally focused attention (Walcher et al., 2017), and then distinctive of divergent thinking tasks (Benedek et al., 2014), or does it depend on the specific task employed? One could expect more ocular activity during divergent thinking task, compared to convergent thinking task, because of the complex visual manipulation characterizing the first one (Benedek et al., 2014). By employing the same task under to different response conditions to simulate convergent and divergent thinking (Jauk, Benedek, & Neubauer, 2012) one should eliminate the task-dependency of the results. In the present study only ocular fixations were analysed, because the time resolution of eye tracker employed was suited for this kind of analysis. Fixations are one of the two significant factors associated to the hypothesis of coupling between the ongoing internal cognitive process and the ocular behaviour in the previous study (Walcher, Körner, & Benedek, 2017).

An Objective for Future Research

Another very interesting research question could not be investigated because of limitations of the apparatus employed: is the task shielding, which occurs during internally directed cognition and then during divergent thinking tasks (Benedek et al., 2014), a top-down or a bottom-up process? By synchronously employing EEG and eye tracking in the same study, it could have been investigated if the decrease of micro-saccades rate was subsequent or antecedent to the alpha power increase in the right parietal lobe. In light of the findings one could have assessed if task shielding was respectively a bottom-up or top down process (Mathias Benedek et al., 2017). Indeed, increase of alpha power in the right parietal lobe was the only distinctive characteristic (Benedek et al., 2014) of brain activity during divergent thinking tasks, such as the Alternate Uses task, which require internally directed cognition. Micro-saccades are the most time-sensitive factor contributing to visual attenuation (Walcher et al., 2017) and for this reason they could have been compared to the fast-changing alpha power.

Unfortunately, the eye tracker employed in the present study did not have a sampling rate high enough to investigate micro-saccades. However, answering to this research question in future studies would shed light to the functional meaning of alpha power synchronization during divergent thinking tasks.

3.1.3. Experimental Hypotheses

In the present study it was expected to observe a reinforcement in alpha power during the uncommon response condition of the Alternate Uses task, which simulated divergent thinking, as compared to the common response condition, which simulated convergent thinking. Furthermore, higher fixation rate was expected under the divergent thinking condition as compared to the convergent condition (Walcher et al., 2017).

3.1.4. The Design of the Experiment

In the present paragraph the motivations of the main experimental choices will be presented. Such decisions were taken in light of the results of the previous studies, of the objectives of the present study and of the limited dimension of the sample employed.

One Task, Two Experimental Conditions

Several studies report the influence on alpha power of the type of creativity task employed in the past. More in detail, it has been shown that the more creative a task is, the higher the elicitation of alpha power is (Fink & Benedek, 2012). For this reason, in order to obtain findings independent from the task performed, the same task was adopted under two different experimental conditions, one simulating convergent thinking and one simulating divergent thinking. This type of design was employed in a previous study (Jauk et al., 2012) for the first time.

Such experimental design was also employed to verify if the enhanced ocular activity distinctive of internally focused attention (Walcher et al., 2017) is independent from the specific task employed. The complex visual manipulation characterizing the divergent thinking condition (Benedek et al., 2014) should elicit more active ocular activity as compared to the convergent thinking condition.

The experimental task selected for the present study was the Alternate Uses task, which has been widely employed in the EEG past studies and also in the study (Walcher et al., 2017) about ocular behaviour during internally focused cognition.

Specific Sample

The sample was restrictively defined in order to control the variability of the results. In fact, many studies reported individual differences in brain activity during cognitive cognition. Several studies reported individual differences related to the creativity level of the subjects (Fink et al., 2009; Jaušovec, 2000; Razumnikova, Volf, & Tarasova, 2009; Razumnikova, 2007) and other studies reported gender differences (Fink & Neubauer, 2006). For this reason, only male students attending the last years of Engineering courses of study were asked to volunteer.

Analysis of the Entire Alpha Band

Despite most past studies separately analysed the neuronal activity in the upper and lower alpha frequency band, any clear evidence emerged from such distinction. In some studies (Fink, Grabner, Benedek, & Neubauer, 2006; Grabner, Fink, & Neubauer, 2007; Razumnikova, 2007) lower alpha band was the one influenced by divergent thinking tasks, in others (Fink et al., 2009; Fink, Schwab, & Papousek, 2011) it was the upper alpha band and in others (Fink & Neubauer, 2008; Jauk et al., 2012; Jaušovec, 2000) no significant difference emerged between the two sub-bands. In light of these findings no distinction between lower and upper alpha frequency band was made during the analysis.

3.2. Materials and Methods

The selection of the sample will be presented in the first part of the present section. Then, the experimental task will be described as well as the randomization of the stimuli, their translation and their presentation during the experiment. Furthermore, both the apparatus employed and the experimental setting will be presented. In the end of the section the experimental procedure will be reported such as the improvements made on the design of the experiment.

3.2.1. Participants

Sample

Fourteen volunteers took part to the study. All participants were male engineering students attending the last three years of their courses of study. The average age was 24.6 years (SD = 2.77, range = 21-31 years). In order not to affect the eye tracker measures, only volunteers with normal or corrected-to-normal vision (contact lenses) and with no strabismus or other medical conditions affecting vision were selected. Only two of the 14 volunteers wore contact lenses. Participants gave written informed consent before starting the study (Appendix A). In the end of the experiment the volunteers received two gadgets for their participation (keychains, T-shirts or hats, etc.)

Recruitment

Potential volunteers were engaged through mailing lists, Facebook groups, presentations during classes, posters and by word of mouth. Participants were driven by the desire to try on themselves the technologies employed in the experiment and by the gadgets they received. Volunteers applied through online form and later they were contacted to set the day of the experiment and to get their head measures in order to setup the EEG bands before their arrival the day of the experiment.

3.2.2. Experimental Task and Conditions

In this study an adaptation of the well-established Alternative Uses task proposed in a previous study (Jauk et al., 2012) was employed. Alternate Uses task (Torrance, 1966) is a verbal creative ideation task widely used in neuroscientific research, which requires to find creative uses for everyday objects. The task was performed under two different experimental conditions: under *common response condition*, participants were required to find a highly common solution to the task, while under *uncommon response condition*, participants were required to find a highly uncommon solution. For example, if the stimulus word *pen* was showed, participants could respond “to write notes” under the common response condition or “to dig a hole in the ground” under the uncommon response condition. The task was presented to participants as a game, because in this way the subjects are more likely to generate original ideas (Runco & Yoruk, 2014). During the performance of the task, participants' EEG and eye tracking signals were recorded.

Items selected for the task were the same employed in a previous study (Benedek et al., 2014): vase, can, basket, bed, book, ball, pot, ring, helmet, tent, rag, axe, flour, trousers, bread, stick, coffin, magnifier, rope, colander. All 20 items were used once for each participant, 10 items per condition. The items were randomly assigned to each condition and presented in an individually randomized sequence, to avoid that participants could anticipate the response condition.

The trial sequence was the same for both conditions and was composed of four phases. The trial began with the reference phase, during which a fixation cross was shown for 5 seconds on the screen. Later, during the preparation phase, the cue representing the response condition to adopt during the trial was shown for five seconds. During this phase an "n" was shown for the common response condition and an "u" for the uncommon response condition. Such symbols were chosen because their shape is exactly the same once rotated by 180° degrees (Jauk et al., 2012). During the idea generation phase the stimulus word was displayed and participants had to push the response button as soon as they wanted to declare their solution. A speech balloon was then displayed, indicating that participants could vocalize their idea. After participants vocalized their response, they had to press the button again; in this way, the following trial started after three seconds. The timeout duration for idea generation was set to 30 seconds. Participants were instructed to keep their eyes open during the trials and not to speak except during the response phase.

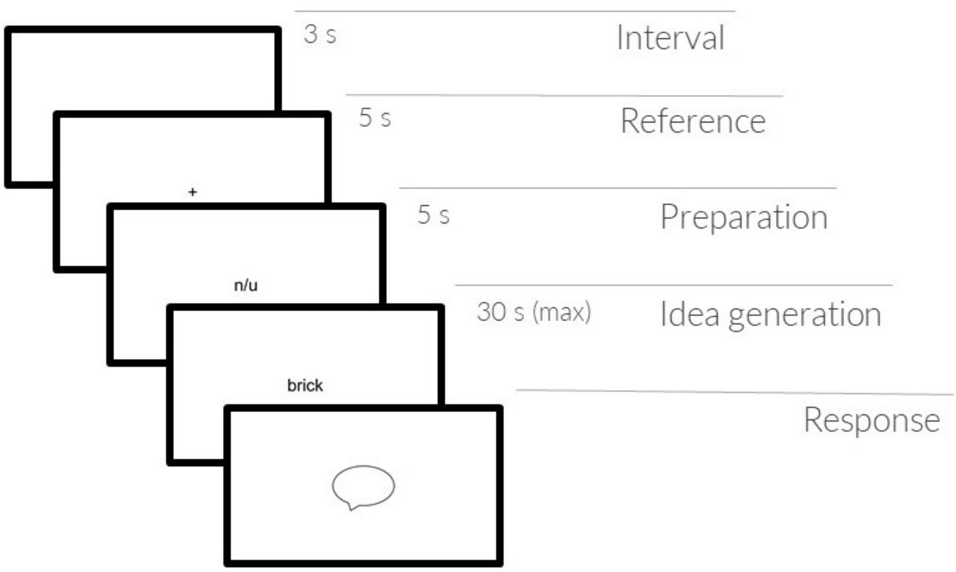


Figure 4: Trial Sequence

3.2.3. Stimuli

The description of the randomization of the response conditions and of the items presentation sequence will be reported below, as well as the graphic parameters adopted for the exposition of stimuli during the experiment. In the end the adopted translation of the items will also be discussed.

Randomization

The web application RANDOM.ORG was used to generate the random sequences described below. The service was built by Dr Mads Haahr of the School of Computer Science and Statistics at Trinity College, Dublin in Ireland, and today is operated by Randomness and Integrity Services Ltd. Such service was chosen because it does not rely on simple mathematical formula to generate pseudo-random numbers, but it includes atmospheric noise in order to generate randomness.

Response condition randomization In order to guarantee that each item was assigned to each experimental condition for an equal number of times, randomized block design was employed. Each participant was randomly assigned within a block of "trials" depending on of the day and the time he took part to the experiment. Each block dimension was two as the number of the experimental conditions. Therefore, the total number of blocks was seven.

Block 1		Block 2		Block 3		Block 4		Block 5		Block 6		Block 7	
Subject 1	Subject 2	Subject 3	Subject 4	Subject 5	Subject 6	Subject 7	Subject 8	Subject 9	Subject 10	Subject 11	Subject 12	Subject 13	Subject 14

Figure 5: Blocked Design

All the items were previously sorted in random order. For each block a random sequence of numbers between 1 and 20 (the number of items) was generated, and such sequence was randomly associated to one of the two participants in the block. As soon as the numbers were extracted they were assigned to the sorted items on the base of their order of extraction. If the number extracted was even, then for that subject the condition of the corresponding item would have been of common response, whilst if the number extracted was odd, then the item's condition for that subject would have been of uncommon response. For the other subject within the same block the complementary conditions were applied to each item (Figure 6). This guaranteed that each subject performed half of the items under one condition and half under the other. This type of design was also chosen to guarantee that, in case there would have not been enough volunteers to reach the desired sample dimension, the maximum difference in sample size between the two conditions would have been at most of one participant.

Experimental sequence randomization In order to guarantee that each participant performed a different sequence of items, for each subject a random presentation sequence was generated. Each item was assigned to an identification number between 1 and 20 (the number of items). For each subject a randomized sequence of numbers between 1 and 20 was generated. The order of extraction of the sequence determined the order of presentation of the items. So, the item associated to the first number extracted was the first stimulus of the experimental sequence for that subject and so on.

CONDITIONS	Block 1		Block 2		Block 3	
Stimulus	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5	Subject 6
vase	n	13 = u				
can	n	9 = u				
basket	u	10 = n				
bed	n	11 = u				
book	u	12 = n				
ball	n	5 = u				
pot	u	8 = n				
ring	n	7 = u				
helmet	n	17 = u				
tent	n	15 = u				
rag	u	20 = n				
axe	n	19 = u				
flour	u	6 = n				
trousers	n	1 = u				
bread	u	14 = n				
stick	n	3 = u				
coffin	u	18 = n				
magnifier	u	4 = n				
rope	u	16 = n				
colander	u	2 = n				

even no. = common r. (n)
odd no. = uncommon r. (u)

Figure 6: Response condition randomization for block one

Stimuli Presentation

All the words, cues and icons were presented in the centre of the screen. All letters were presented in black Arial on white background and the font size was 15 points: the characters width was kept to just 0.39° visual angle in order not to affect the number of fixations during the reading of the item. The monitor employed was 52.5 × 29.5 cm, it run at 60 Hz and the resolution was 1920 × 1080 pixels. Participants comfortably sat at about 60 centimetres from the screen.

Translation of the Items

The items of the experiment were the same employed in a previous study (Benedek et al., 2014). Such study was conducted on German speakers and researchers reported both the German and the English translations of the items in their paper. In the present study the items were translated into the mother tongue of participants, in order not to involve the translation cognitive process in the analysis. Most part of the participants were Swedish; however, one participant's mother tongue was French, one's was Spanish and one's was Italian. The items were translated by selecting the words that better fitted the original German definition. In Appendix A all the definitions and the translations are reported. The standardized instructions were in English for all the participants.

3.2.4. Apparatus and Experimental Setting

In the present paragraph the hardware as well as the software apparatus will be presented.

EEG Data Acquisition

The EEG data was recorded with a B-Alert X10 (Advanced Brain Monitoring) by means of a nine channels silver-silver chloride sensor strip with electrodes located in frontal (Fz, F3, F4), central (Cz, C3, C4) and parietal-occipital (POz, P3, P4) sites and with a linked mastoid reference. The sampling frequency was 256 Hz. The device converted the signal from analogic to digital and transmitted it via radio frequencies to the recording station. In order to enhance conductivity, sensors worked with a foam interface and highly conductive electrode cream.

Eye Tracking Data Acquisition

The binocular data was recorded with a Tobii X2-30 Eye Tracker Compact Edition (Tobii). The sampling frequency was 30 Hz. The eye tracker was screen-based and it was installed on the lower border of the monitor. Participants set at about 60 cm from the display, the ideal distance for the operation of the device. No chin rest was employed.

Galvanic Skin Response

Galvanic skin response data was collected with Shimmer3 (Shimmer). The sampling frequency was 256 Hz. The device was placed on the non-dominant hand and the two sensors were placed on the proximal phalanges of the index and middle fingers. Data were collected for analysis purposes beyond the present study.

Cameras

Two Logitech c920 (Logitech) cameras were employed in the experiment. The sampling frequency of both the cameras was 30 Hz. One of the two was the environmental camera. It filmed the respondents' mid and lower body from the right side. The other camera was placed upon the monitor frontally to the respondent and filmed the upper body. The side camera and the frontal camera allowed the researcher to see if the respondent was excessively moving during the experiment, affecting in this way the EEG and the eye tracker recordings. The frontal camera also recorded the verbalization of the answers of the subjects. The frontal camera was also employed for analysis purposes beyond the present study.

Software

Data from all the sensors was collected in iMotions (2018), Version 7.0. The software also managed the stimuli presentation as well as the benchmark and the nine-point calibration procedure respectively for the EEG device and the eye tracker before the beginning of the experiment.

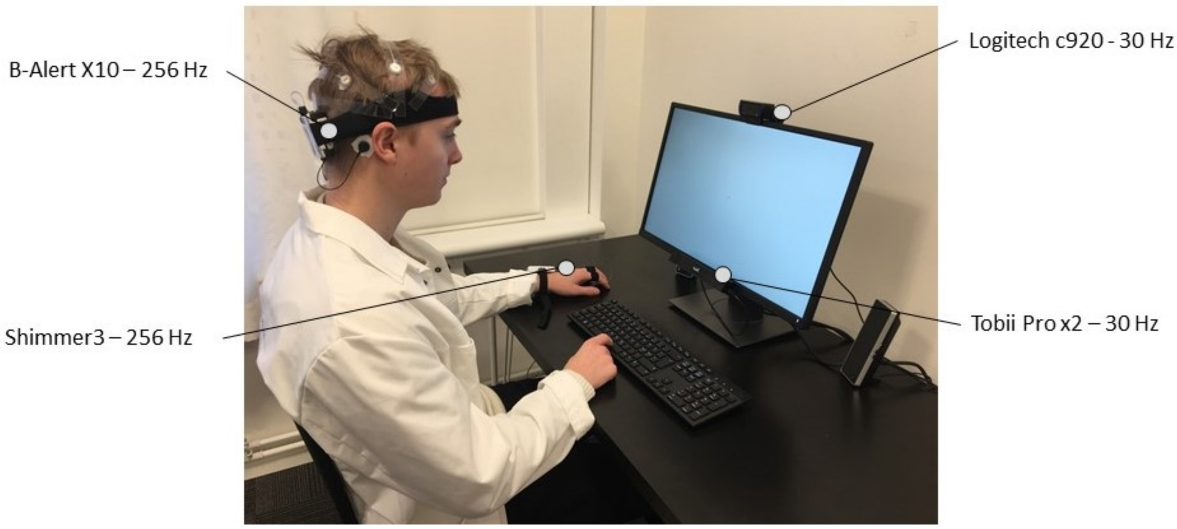


Figure 7: Recording Devices

Experimental Setting

The laboratory was adapted to the experiment in order to avoid that potentially distractive elements could influence the measures. Pictures were removed from the walls and the participant station was placed facing a white wall. The recording station was placed behind the participant's station (Figure 8). Curtains were closed in order to have similar lighting conditions despite the time of the day. Participants comfortably sat at about 60 centimetres from the screen, arms comfortably laying on the table and one hand near the response button. No chinrest was employed.

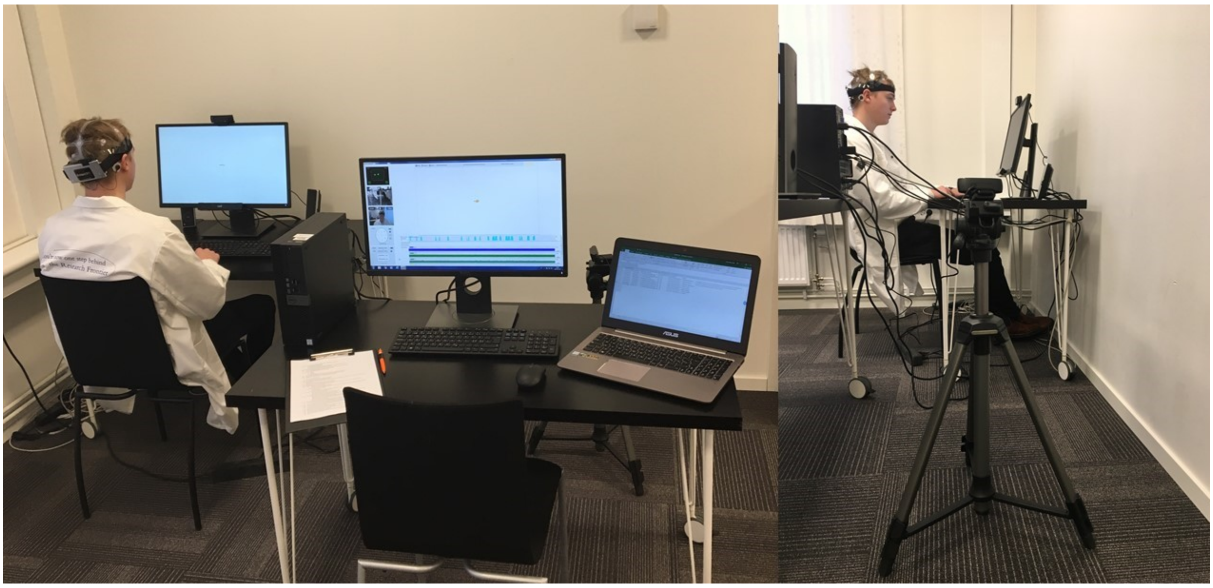


Figure 8: Experimental setting - posterior and lateral view

3.2.5. Procedure

A checklist was created in order to follow the exact experimental procedure for each participant. Such checklist is reported in Appendix A and it also contains a detailed presentation of the experimental setup.

Prior to the recording session participants read and filled the consent form. Then the EEG device was installed. The conductivity between the scalp and the electrodes was also enhanced by moving the hair, by rubbing the scalp with alcohol and by adding conductive cream until the impedance test reported impedance values below 40 kΩ for each electrode. Later the galvanic skin response recording device was installed and then the participant was moved until his eyes were at about 60 centimetres from the screen (the best working distance for the eye tracker).

Participants were instructed about the experimental task through a slide presentation, in order to provide the same standard instructions to all the subjects. Each participant familiarized with the task performing four trials, two per condition, before beginning the recording session. Two one-minute-long resting conditions were recorded, one with open eyes and one with closed eyes. These two EEG recording sessions were not used in the analysis in the end. Before starting the experiment, the EEG benchmark was run in order to create a profile of the subjects' brain activity and to allow further analysis beyond the present study. Afterwards, a nine-point calibration procedure of the eye tracking followed. Then, the experiment started and the 20 items were presented under the two experimental conditions in random order. After the task was completed, the idea generated were checked together with the participants. The subjects were entertained with a demo showing the potential applications of physiological experiments and, after having removed the recording devices, they received two gadgets for their participation. The whole procedure took about 100 minutes.

3.2.6. Experiment Refinement

Before performing the actual experiment three different tests were conducted. The first test was aimed to become familiar with the EEG installation and with data recording. In the second test all the apparatus was tested and the subject performed the whole experiment. In the third test the definitive procedure was employed, as well as the definitive instruction slides.

Such tests allowed to shorten the installation of the apparatus, to modify the process in order to make it more effective and shorter and to provide better and clearer standardized instructions.

One of the refinements to the procedure was to move the measuring of the head dimensions to the days before the experiment, in order to prepare the EEG strip (by applying the foam and the conductive gel) before the arrival of the volunteer the day of the experiment. In Appendix A the original duration of the experiment is reported. Also, the EEG was the first device to be installed because it took about 30 minutes to get the best signal quality.

One important part of the experiment was to communicate clearly what “uncommon response condition” actually meant. The objective of the experiment was to assess the creative cognitive process, and creativity is commonly defined as the ability to produce work that is both original and unique, namely novel, and useful within a social context (Fink & Benedek, 2012). Nevertheless, it was necessary to modify the instructions after the first two subjects performed the actual experiment, because one of the two subjects reported he was thinking about how to translate his idea in English before pressing the response button (the task was in the mother tongue of the participant, but the ideas had to be expressed in English). Furthermore, he did not understand the uncommon response condition, by giving bizarre ideas. For these reasons his recording session was excluded from the analysis and it was substituted with the one of another volunteer. Whereas for the other subject such problems were not observed and his recordings were kept. As a consequence, the instructions were modified. It was specified that the subjects had not to think of the translation in English of their ideas before pressing the response button, in order not to involve the translation cognitive process in the idea generation. Furthermore, it was specified that the idea generated should not had to be just uncommon, but also somehow useful. The modified instruction worked with any more problem for the remaining subjects.

3.3. Data Analysis

In the following pages the measures adopted will be presented first, then the statistical analysis both for the task performance, the cortical activity and the ocular activity of the participants involved in the experiment.

The software employed for the statistical analysis was IBM SPSS Statistics for Windows (Released 2017).

3.3.1. Behavioural Analysis

Task performance was assessed by looking at the reaction times and at the originality levels of the ideas generated for each subject. After having defined such measures, the following pages will explain the statistical analysis employed to assess the differences in the originality level and in the reaction time between the two experimental conditions. Furthermore, inter-rater reliability will also be evaluated for the raters who scored the originality of the ideas.

Task Performance Rating and Reaction Time

Each idea generated by the participants was transcribed and a survey was created for each subject. Four volunteers rated the originality level of the single ideas for each subject. The volunteers were two male and two female students attending the last year of Master of Science in Management and Engineering in order to have peer assessment. The survey was created on Google Forms and was divided into two sections. In the first section the raters could read all the ideas generated by the current subject evaluated to get an overall perception of his originality level. In the second section the raters could evaluate the originality level of the single ideas. The rating was expressed through a four-point ordinal scale ranging from level 1 (very common idea) to level 4 (very uncommon idea). The raters were instructed to use the whole scale for each subject and each idea was rated relatively to the originality level of the ideas within the same subject. In Appendix B one sample of survey with the instructions is reported as well as the ideas generated from each subject and the respective evaluation from the four raters.

Reaction time was defined as the elapsed time before the response button was pressed by the participants after the appearance of the experimental item on the screen.

Statistical Analysis of Task Performance Rating

Below the statistical analysis, the tests and the choices regarding the task performance rating will be presented step by step.

Objective of the Analysis The aim of the following statistical analysis was to statistically determine whether the median difference between the paired observations of the two response conditions was significantly different from zero.

The Variables The dependent variable was the median originality score of the 14 subjects. Such variable has been collected from four raters evaluating the originality level of the ideas generated under two different response conditions. Response condition was the independent variable in the analysis and it consisted of two related groups: common response and uncommon response condition.

The Statistical Model Wilcoxon Signed-Rank Test was employed for the statistical analysis. Such test is suitable when the same participants undergo two different conditions on the same dependent variable, such as in the present study. The factor was the response condition (common, uncommon) and the dependent variable was the median originality rating. The null hypothesis asserted that the median difference between the paired values was equal to zero.

The Statistical Assumptions The first step of the analysis consisted in verifying if the experimental data violated the assumptions at the base of the Wilcoxon signed-rank test. Such assumptions are presented below. The results of the tests and consequential choices are discussed as well.

> **Dependent variable in the continuous or ordinal level.** Median originality rating of the subjects is an ordinal variable. The raters did not perceived an equal distance between categories indeed, but they evaluated the originality level of each item relatively to the originality level of the other items within the same subject. In light of that, the present assumption was not violated.

Categorical independent variable with two related groups. In the present study response condition is a categorical variable which consists of two related groups. The two groups of the independent variable are related because the same participants underwent both the response conditions. Thus, the present assumption was not violated.

Differences between the two related groups should be symmetrically distributed. In order to run Wilcoxon signed-rank test the distribution of the differences between the two experimental conditions need to be symmetrical. The data of the present study met such assumption (Appendix C).

The Results All of the 14 participants in the study manifested higher originality level under uncommon response condition when compared to the common response condition. The task elicited a statistically significant median increase (2.00) in originality level of the subjects under uncommon response condition (3.00) compared to the common response condition (1.00), $z = 3.438$, $p = 0.001$ (Appendix C).

Statistical Analysis of Inter-rater Reliability

Below the statistical analysis, the tests and the choices adopted to assess inter-rater reliability will be presented step by step. This test was performed to assess the significance of the ratings used to evaluate the originality level of the participants' ideas.

Objective of the Analysis The aim of the following statistical analysis was to determine the agreement between the four raters about the originality level of the ideas generated by each single subject of the experiment.

The Variable The dependent variable was the originality score of the ideas of the evaluated subject. Such variable has been collected from four raters evaluating the originality level of the ideas generated.

The Statistical Model Kendall's Coefficient of Concordance (*W*) was employed for the statistical analysis. The null hypothesis of the test asserts that Kendall's *W* is equal to zero in the population, i.e. the null hypothesis states that there is no inter-rater agreement.

The Statistical Assumptions The first step of the analysis consisted in verifying if the experimental data violated the assumptions at the base of the Kendall's Coefficient of Concordance. Such assumptions are presented below. The results of the tests and consequential choices are discussed as well.

Dependent variable in the continuous or ordinal level. Originality rating of the subjects is an ordinal variable. The raters did not perceived an equal distance between categories indeed, but they evaluated the originality level of each item relatively to the originality level of the other items within the same subject. In light of that, the present assumption was not violated.

Raters are assessing the same object. In the present study all the four raters are exclusively assessing the originality level of the ideas generated by the subject.

Raters are independent. The four raters assessed the originality level of the ideas on their own from their homes, without interacting and thus without affecting the judgment of each other.

The Results For all the subjects the agreement between the four raters on the originality level of the ideas was always significant ($p < 0.0005$) and null hypothesis asserting that the Kendall's

W was equal to zero in the population could be rejected for each subject. Kendall’s W lowest value was 0.741, for subject three (Appendix D).

Statistical Analysis of Reaction Time

The statistical analysis of the differences in reaction time between the two response conditions will be presented step by step below.

Objective of the Analysis The aim of the following statistical analysis was to test the statistical significance of the mean difference between the paired observations of the reaction time under the two response conditions, that are common and uncommon response condition.

The Variables The dependent variable was the reaction time of the subjects, assessed as the time passed between the exposure of the item and when the subject pressed the response button. Such variable has been collected under two different response conditions. Response condition was the independent variable.

The Statistical Model Paired-samples t-test was employed for the statistical analysis. Such test is suitable when the same participants undergo two different conditions on the same dependent variable, such as in the present study. The independent variable was the response condition (common, uncommon response) and the dependent variable was the time to respond. Paired t-test assesses the null hypothesis asserting that the mean difference between the paired values is equal to zero. If the test rejects such null hypothesis, the alternative hypothesis asserts that the mean difference is not equal to zero.

The Statistical Assumptions The first step of the analysis consisted in verifying if the experimental data violated the assumptions at the base of the paired-samples t-test. Such assumptions are presented below. The results of the tests and consequential choices are discussed as well.

Dependent variable in the continuous level. Time to respond is a ratio variable and it is continuous. In light of that, the present assumption was not violated.

Categorical independent variable with two related groups. Response condition is a categorical variable that consists of two related groups. The two groups of the independent variable are related because the same participants underwent both the response conditions. Thus, the present assumption was not violated.

There should not be outliers in the related groups. Outliers can affect the statistical test results by heavily influencing the mean and the standard deviation of the differences. In order to assess the present assumption, the differences between the paired-values were computed. No outliers were found in the data (Appendix D). The threshold fixed to have an outlier was 3 interquartile ranges from the edges of the boxplot.

Differences between the two related groups should be normally distributed. Paired-samples t-test is robust to violations of normality, for such reason only approximated normality is required. The assumption of normality was tested on the differences between the paired-values by way of Shapiro-Wilk test (Appendix E). Such test is particularly suited for assessing normality assumption in samples with less than fifty participants. The difference scores for the uncommon response condition and the common response condition trial could not be assumed normally distributed, as assessed by Shapiro-Wilk's test (p = 0.029). Nevertheless, data seemed generally normally distributed in the normal Q-Q Plot, except for one point. Because paired-samples t-test is fairly robust to deviations from normality, it was decided to carry on with the test.

The Results Participants had higher reaction time during the uncommon response condition (*M* = 11.931 s, *SD* = 5.059 s) as opposed to the common response condition (*M* = 4.668 s, *SD* = 2.057 s). According to paired-samples t-test such difference between the two experimental conditions was statistically significant $t(13) = 5.470$, $p < 0.0005$, Cohen's $d = 1.462$. The difference between common response condition and uncommon response condition was 7.263 s, 95% CI [4.394, 10.131] (*SE* = 1.328). In light of that, the null hypothesis asserting that the difference between the two conditions is equal to zero could be rejected (Appendix E).

3.3.2. Cortical Activity

After having evaluated task performance of the sample under the two experimental conditions, the same was done for cortical activity. In the following pages first the quantification method adopted will be explained and then the statistical analysis employed to assess the differences in cortical activity between the two experimental conditions.

Quantification of Cortical Activity

Below the type of cortical measures extracted from the data are reported as well as the main analysis techniques adopted. In Appendix F a detailed description of the procedures followed to extract the measures of cortical activity is presented, as well as the reason of the analysis choices.

The EEG signal was automatically corrected for artifacts generated by eye blinking by means of an algorithm embedded in iMotions software and developed by Advanced Brain Monitoring (ABM), the producer of the EEG recording device used in the experiment. Such algorithm also replaces artifacts generated from electrodes saturation with zero values. A quick visual inspection of EEG automatically decontaminated data confirmed the good quality of the recording sessions (Appendix F) and zeros were not excluded from the following analysis because of their very small number. Because of time limits to complete the analysis, no further deep visual inspection of the data was performed to detect and eliminate the remaining artifacts. In particular, artifacts generated by muscles' contractions affect the beta band (13-25 Hz) (*B-alert live user manual*), whilst the present study was focused on assessing the cortical activity in the alpha frequency band (8-12 Hz).

Time frequency analysis was performed on decontaminated EEG signal by means of Cartool software by Denis Brunet (cartoolcommunity.unige.ch). Band power in the alpha band (8-12 Hz) was computed by way of Short-Term Fast Fourier Transform (STFFT) applied to time windows of 1000 ms with 250 ms windows step, no averaging across windows and Hanning windowing function. The power coefficients were automatically squared by the software.

In order to assess cortical activity during the performance of the experimental task, task-related power changes in EEG signals were calculated for each subject. The first step consisted in horizontally averaging the power across the time windows for each trial and then across trials for the two response conditions and for each electrode (Fink, Schwab, & Papousek, 2011). Then, the average power was log-transformed. Then, the log-transformed average power collected during the idea generation was subtracted to the log-transformed average power collected during the reference interval for each condition and each electrode. According to De Silva and Pfurtscheller (1999), increases in power should correspond to Event-Related Synchronization (ERS) of the underlying neural population in the alpha band, while decreases in power (negative values) should correspond to Event-Related Desynchronization (ERD) in the alpha band. However, in the discussion chapter a short consideration will be provided about how the reference electrode could potentially affect the interpretation of neuronal activity provided by such measures. The first and the last 500 ms of power generated during both the reference and the idea generation periods were excluded from the following analysis (Jauk et al., 2012). In trials included in the analyses the subjects had generated an idea within 30 seconds from the appearance of the stimulus and had correctly verbalized their ideas only after having pressed the response button; otherwise the trials, including the idea generation phase and the corresponding reference period, were excluded from the analysis. In the following statistical analysis electrode positions were not aggregated. Middle electrodes (Fz, Cz, POz) were excluded from the analysis in order to assess differences between the two hemispheres.

Statistical Analysis of Cortical Activity

The present paragraph will outline the statistical method employed and the results of comparison analysis of cortical activity between the two response conditions.

Objective of the Analysis The aim of the following statistical analysis was to test the statistical significance of the mean differences emerged among the response conditions and the different regions of the scalp. The test was also aimed to assess the interactions between the experimental conditions, the lobes and the hemispheres, which are the three experimental variables influencing the electrical activity on the scalp, that is the dependent variable.

The Variables The dependent variable is the average variation of the log-transformed power spectral density of the subjects. Such variable has been collected under two different experimental conditions, that are common response and uncommon response condition, and from different regions of the scalp, distinct in area and hemisphere: thus, response condition, area and hemisphere are the independent variables. All the subjects have undergone all the experimental conditions and electrical activity was collected under each electrode on the scalp.

The Statistical Model Three-way within-subjects Factorial Analysis of Variance for repeated measures was employed for the statistical analysis. The repeated measures approach was needed because the same subjects underwent all the experimental conditions. The three within-subject factors are Condition (common, uncommon response), Hemisphere (right, left) and Area (frontal, central, parietal). Frontal area referred to F3 and F4 electrodes, central area to C3 and C4, parietal area to P3 and P4. Left hemisphere referred to electrodes with odd numbers and right hemisphere to electrodes with even numbers. Midline electrodes (Fz, Cz, POz) were not included in the analysis in order to assess the difference in electric potential between the two hemispheres.

The Statistical Assumptions The first step of the analysis consisted in verifying if the experimental data violated the assumptions at the base of ANOVA for repeated measures. Such assumptions are presented below. The results of the tests and consequential choices are discussed as well.

> **Dependent variable in the continuous level.** Log-transformed difference of power spectral density is a ratio variable and it is continuous. In light of that, the present assumption has not been violated.
>
> **All the factors must consist of at least two categorical related groups.** The measures in each group refer to the same subjects. In other words, each subject contributed to the measures both grouped in common and uncommon response groups for the condition

factor, in right and left groups for the hemisphere factor and in frontal, central and parietal groups for the area factor. In light of that, in the model under investigation all of the groups are related and the assumption has not been violated.

There should not be outliers in any combination of the related groups. No outliers should be included in the data, because outliers distort the difference between the related groups and affect the accuracy of the results when they are generalized to the entire population. Boxplot of the dataset (Appendix G) highlighted two significant outliers for subject 5 and one for subject 14. Such outliers could be measurement errors or genuinely unusual values. Both subjects' recording signal quality is at the same average level of all the subjects (Appendix F). Thus, there is no particular reason to suppose measurement errors for these subjects. Because the detection of outliers depends on the distribution of all the values considered, the present assumption was tested on the same dataset after that subject 7 and subject 12 were excluded from the analysis, indeed they were the only two subjects with less than 90% of good data quality (Appendix F). The dataset without the two subjects did not contain any significant outlier, but the ANOVA did not lead to any significant result (Appendix H). In light of the considerations upon, all the subjects are included in the following statistical analysis.

Residual errors should be normally distributed for all the combinations of the levels of the three within-subjects factors. ANOVA for repeated measures is robust even when such assumption is violated, for such reason just an approximation of normal distribution is usually required. In order to assess the present assumption, Shapiro-Wilk's normality test was run on the dependent variable (Appendix G). Assumption of normality resulted to be violated for the combinations "common response, right hemisphere, frontal area" p = 0.011 and "uncommon response, left hemisphere, frontal area" p = 0.033. However by looking at the Normal Q-Q plot (Appendix G) for "common response, right hemisphere, frontal area" and "uncommon response, left hemisphere, frontal area" data seem to be approximately normal distributed. Because ANOVA is robust to deviations from normality, it was decided to carry on with the analysis.

Variances of the differences between the levels of the factors should be equal. This is also known as assumption of sphericity. Such as normality, this assumption is necessary to guarantee the statistical significance of the factorial ANOVA. Such assumption has been tested for each factor and interaction of the analysis involving more than two levels (with two levels the assumption is automatically met) by means of Mauchly's test of sphericity (Appendix G). Mauchly's test of sphericity indicated that the assumption of sphericity was violated for the three-way interaction of Condition, Hemisphere and Area ($\chi^2(2) = 8.535$, $p = 0.014$, $\varepsilon = 0.663$), for the two-way interaction of Hemisphere and Area ($\chi^2(2) = 8.953$, $p = 0.011$, $\varepsilon = 0.655$) and for the factor Area ($\chi^2(2) = 16.524$, $p < 0.0005$, $\varepsilon = 0.572$). In light of that, the standard results in the following analysis were biased, because they could return more easily statistical significance. As a consequence, the degrees of freedom were adjusted when calculating the p-values by means of the Greenhouse-Geisser correction for all the violations. Greenhouse-Geisser correction was selected because the Greenhouse-Geisser estimate of sphericity was less than 0.750 (otherwise the Huynh-Feldt correction would have been used).

The Results ANOVA for repeated measures (Appendix G) did not evidence any statistically significant three-way interaction between Condition, Hemisphere and Area ($F(2, 26) = 0.329$, p =

0.636, ε = 0.663). All the two-way interactions were not statistically significant as well: Condition and Hemisphere ($F(1, 13) = 0.319$, p = 0,582), Condition and Area ($F(2, 26) = 0.071$, $p = 0.932$), Hemisphere and Area ($F(2, 26) = 0.154$, $p = 0.767$, $\varepsilon = 0.669$). There was no statistical significance either for Condition ($F(1, 13) = 1.087$, $p = 0.316$), Hemisphere ($F(1, 13) = 0.192$, $p = 0.669$) and Area ($F(2, 26) = 2.667$, $p = 0.120$, $\varepsilon = 0.572$).

3.3.3. Ocular Activity

Finally, the same analyses were performed to evaluate ocular activity in the sample. In the following pages first the quantification method adopted will be presented and then the statistical analysis employed to assess the differences in ocular activity between the two experimental conditions.

Quantification of Ocular Activity

The main characteristics of the analysis techniques adopted to extract the fixation rate are here presented. In Appendix I a detailed description of the analysis choices is reported, as well as the procedures followed to extract the ocular activity measures.

The number of fixations was calculated using I-VT fixation algorithm embedded in iMotions (2018) software, Version 7.0. Fixations were defined as periods with no saccades nor blinks. Saccades were defined as samples with visual angular velocity lower than 30°/s. Such threefold was chosen in accordance to a past study (Walcher et al., 2017). Blinks were defined as periods with pupil data missing for at least one sample (33 ms). No interpolations were applied to samples with missing data. No moving average of the visual angular velocity nor other noise reduction techniques were adopted.

Fixation rates (Hz) were calculated within each subject for each item: the number of fixations occurred during the idea generations was divided to the corresponding response time. The fixation rates were then averaged across trials for each condition and each subject. Items with ideas generated after thirty seconds from the appearance of the stimulus (timeout), items with no ideas generated by the respondent and items with ideas verbalized before the subject had pressed the response button were excluded from the analysis.

Statistical Analysis of Ocular Activity

Below the statistical analysis, the tests and the subsequent analytical choices made in the assessment of ocular activity are presented step by step.

Objective of the Analysis The aim of the following analysis was to test the statistical significance of the mean difference between the paired observations of the two response conditions, i.e. common and uncommon response condition.

The Variables The dependent variable is the average fixation rate of the subjects. Such variable has been collected under two different response conditions. Response condition is the independent variable.

The Statistical Model Paired-samples t-test was employed for the statistical analysis. Such test is suitable when the same participants undergo two different conditions on the same dependent variable, such as in the present study. The factor is the response condition (common, uncommon response) and the dependent variable is the average fixation rate. Paired t-test assesses the null hypothesis asserting that the mean difference between the paired values is equal to zero.

If the test rejects such null hypothesis, the alternative hypothesis asserts that the mean difference is not equal to zero.

The Statistical Assumptions The first step of the analysis consisted in verifying if the experimental data violated the assumptions at the base of the paired-samples t-test. Such assumptions are presented below. The results of the tests and consequential choices are discussed as well.

Dependent variable in the continuous level. Average fixation rate is a ratio variable and it is continuous. In light of that, the present assumption was not violated.

Categorical independent variable with two related groups. In the present study response condition is a categorical variable that consists of two related groups. The two groups of the independent variable are related because the same participants underwent both the response conditions. Thus, the present assumption was not violated.

There should not be outliers in the related groups. Outliers can affect the statistical test results by heavily influencing the mean and the standard deviation of the differences. Their effect is greater in small samples. In order to assess the present assumption, the differences between the paired-values were computed. No outliers were found in the data (Appendix L). The threshold fixed to have an outlier was 3 interquartile ranges from the edges of the boxplot.

Differences between the two related groups should be normally distributed. Paired-samples t-test is robust to violations of normality, for such reason only approximated normality is required. The assumption of normality was tested on the differences between the paired-values by way of Shapiro-Wilk test (Appendix L). Such test is particularly suited for assessing normality assumption in samples with less than fifty participants. The difference scores for the uncommon response condition and the common response condition trial was assumed normally distributed, as assessed by Shapiro-Wilk's test (p = 0.653). The p-value for the present sample was not significant enough to reject the normal distribution assumption.

The Results Participants had higher fixation rate during the common response condition (M = 1.068 Hz, SD = 0.470 Hz) as opposed to the uncommon response condition (M = 1.038 Hz, SD = 0.562 Hz). However, according to paired-samples t-test such difference between the two experimental conditions was not statistically significant $t(13)$ = 0.370, p = 0.717, Cohen's d = 0.099. The difference between common response condition and uncommon response condition was 0.030 Hz, 95% CI [-0.146, 0.207] (SE = 0.082). In light of that, the null hypothesis asserting that the difference between the two conditions is equal to zero could not be rejected (Appendix L).

3.4. Results

Results from task performance analysis, cortical analysis and ocular analysis of the previous paragraph are summarized below.

3.4.1. Behavioural Results

Originality level of participants' ideas was assessed by four raters on a four points ordinal scale. Data are medians unless otherwise stated. All of the 14 participants in the study manifested higher originality levels under uncommon response condition when compared to the common response condition. The difference scores were symmetrically distributed, as assessed by a histogram. A

Wilcoxon signed-rank test determined that there was a statistically significant median increase in originality level (2.00) the subjects performed the task under uncommon response condition (3.00) compared to the common response condition (1.00), $z = 3.438$, $p = 0.001$. Kendall's W was run to determine if there was agreement between the four raters' judgement on the originality level of the ideas generated by the 14 participants. The raters were peers attending the last year of Master of Science in Management and Engineering. The originality level of the ideas generated was assessed for each subject on a 4-point ordinal scale from level 1 (very common idea) to level 4 (very uncommon idea). The four raters statistically significantly agreed in their assessments, $W > 0.740$, $p < 0.0005$.

Paired-samples t-test was used to determine whether there was a statistically significant mean difference between the average reaction time during the two response conditions. One outlier was detected that was more than 1.5 box-lengths from the edge of the box in a boxplot. Because such distance was minor than 3 interquartile ranges, it was kept in the analysis. The assumption of normality was violated, as assessed by Shapiro-Wilk's test ($p = 0.029$), but data seemed generally normally distributed in the normal Q-Q Plot, except for one point, and it was decided to carry on with the test. Participants had higher reaction time when responding during the uncommon response condition ($M = 11.931$ s, $SD = 5.059$ s) as opposed to the common response condition ($M = 4.668$ s, $SD = 2.057$ s), and the average difference of 7.263 s was statistically significant, 95% CI [4.394, 10.131] ($SE = 1.328$), $t(13) = 5.470$, $p < 0.0005$, Cohen's $d = 1.462$.

3.4.2. EEG Results

Three-way repeated measures Analysis of Variance was conducted to determine the effects of response condition, hemisphere and area on Event Related De-\Synchronization. There were three outliers assessed as values greater than 3 interquartile ranges from the edges of the box. Data were normally distributed ($p > 0.05$) except for two groups ("common response, right hemisphere, frontal area", $p= 0.011$, and "uncommon response, left hemisphere, frontal area", $p= 0.033$), as assessed by Shapiro-Wilk's test of normality. There was no statistically significant three-way interaction between response condition, hemisphere and area ($F(2, 26) = 0.329$, $p = 0.636$, $\varepsilon = 0.663$). There was no statistically significant simple two-way interaction between response condition and hemisphere ($F(1, 13) = 0.319$, $p = 0,582$), between condition and area ($F(2, 26) = 0.071$, $p = 0.932$) nor between hemisphere and area ($F(2, 26) = 0.307$, $p = 0.652$, $\varepsilon = 0.669$). Furthermore, no within-subject factors were statistically significant: neither condition ($F(1, 13) = 1.087$, $p = 0.316$), hemisphere ($F(1, 13) = 0.192$, $p = 0.669$) nor area ($F(2, 26) = 2.667$, $p = 0.120$, $\varepsilon = 0.572$).

3.4.3. Ocular Behaviour Results

Paired-samples t-test was used to determine whether there was a statistically significant mean difference between the average fixation rates during the two response conditions. Two outliers were detected that were more than 1.5 box-lengths from the edge of the box in a boxplot. Because such distance was minor than 3 interquartile ranges, they were kept in the analysis. The assumption of normality was not violated, as assessed by Shapiro-Wilk's test ($p = 0.653$). Participants had higher fixation rate when thinking during the common response condition ($M = 1.068$ Hz, $SD = 0.470$ Hz) as opposed to the uncommon response condition ($M = 1.038$ Hz, $SD = 0.562$ Hz), but the average difference of 0.030 Hz was not statistically significant, 95% CI [-0.146, 0.207] ($SE = 0.082$), $t(13) = 0.370$, $p = 0.717$, Cohen's $d = 0.099$.

3.5. Discussion

The present discussion will open with the comparison between the results of the present study and the results of the previous studies with the most similar experimental design. Possible causes of the non-negligible differences in findings will be thus analysed in the experimental settings and in analytical methods employed in the present study. Finally two important limitations will be introduced as food for thought for future studies, one related the EEG methodology and one related to the Alternate Uses task employed in neuroscientific studies and its adaptation (Jauk, Benedek, & Neubauer, 2012).

3.5.1. Comparing Results with Other Studies

Despite the design adopted in the present study and in some of the previous studies was similar, the differences emerged between convergent and divergent thinking failed to reach statistically significance in both cortical and ocular analysis.

EEG Results

The findings of the present study do not reflect the results of previous research. As it was presented before, past studies led to highly variegated results and they adopted different experimental designs. Thus, in order to have an overall impression of the divergence between the present study and the previous ones, a comparison with three studies (Benedek et al., 2014; Fink et al., 2009; Jauk et al., 2012) with the most experimental similar design will be presented.

All the studies selected adopted the Alternate Uses task. However, only one study (Jauk et al., 2012) adopted the same task with two different conditions to evaluate the brain activity both during convergent and divergent thinking such as in the present study; the other two studies employed the classic Alternate Uses task to evaluate divergent thinking and specific convergent thinking tasks to evaluate convergent thinking. All the selected studies compared the alpha power during the Alternate Uses task idea generation with the power collected in the reference period preceding the idea generation in order to assess the variations in the alpha power. Furthermore, in all the studies except one (Fink et al., 2009) the participants had to press the response bottom as soon as they had generated an idea.

In all the past studies within-subject factors are statistically significant and researchers also report statistically significant interactions among the factors, as reported in the table below (Table 4); whilst in the present study all the factors fail to reach statistical significance.

All the studies report higher alpha power levels during the divergent thinking task or the divergent thinking condition. The presented study reports the same findings (Profile Plots in Appendix G), but such differences fail to reach statistical significance, as mentioned above.

Table 4: Significance level of factors - Comparison

Study	Task (T)	Hemi (H)	Area (A)	T*A	A*H	H*T	T*H*A
Fink et al., 2009 (lower α)	< 0.01	< 0.05	< 0.01	< 0.01	-	< 0.01	< 0.01
Fink et al., 2009 (upper α)	< 0.01	-	< 0.01	< 0.01	< 0.05	< 0.01	< 0.01
Jauk et al., 2012 (condition*)	< 0.001	< 0.001	< 0.001	< 0.001	-	-	-
Benedek et al., 2014	< 0.001	0.01	-	< 0.001	< 0.001	-	-
Present Study (condition*)	0.316	0.669	0.120	0.932	0.652	0.582	0.636

Note: Hemi = Hemisphere factor; Condition* = Task factor has to be intended as response condition factor for Jauk et al., 2012 and the present study; Lower α = Lower alpha frequency band; Upper α = Upper alpha frequency band; - = Significance level not reported, probably higher than 0.05.

Ocular Behaviour Results

Results about the ocular activity contrast the results from the reference study (Walcher et al., 2017). Despite the previous study report higher fixation rate during the traditional Alternate Uses task, hence during divergent thinking, in the present study the findings are opposite, with lower fixation rate during the uncommon response condition (Appendix L), which consisted in the traditional Alternate Uses task; but such evidence fail to reach statistical significance (p = 0.717).

Task Performance Results

On the task performance side, the findings are in agreement with the previous studies. There was a statistically significant median increase in originality level when participants performed the Alternate Uses task under the uncommon response condition compared to the common response condition, as assessed by the four raters (W > 0.740). Furthermore, such as in the other studies, participants had statistically significant higher reaction times when responding during the uncommon response condition as opposed to the common response condition.

3.5.2. Experimental Setting and Analysis Method

The differences in findings compared to previous studies could be at least partially explained by the differences in the experimental setting and in the analytical method adopted in the present study.

Experimental Setting

On the EEG side, there are two main differences in the experimental setting between the present study and the other studies considered. The first difference consists in the position of the reference electrode. The EEG device employed in the present study relies on the references signal provided by two digitally-linked electrodes placed on the mastoids, which are the bones behind the ears; whilst in the previous studies the reference electrode was placed on the tip of the nose of the participants. As it will be presented later in this chapter, the electrical activity captured by the reference electrode heavily influences the potential captured by all the electrodes on the scalp and thus the position of the reference electrode could have impacted on the results of the experiment. Moreover, in the present study no electrooculography (EOG) was employed, unlike in the previous studies. EOG captures the electrical potential generated by eye movements and blinking. The electric potential generated by the eye activity, captured through electrodes placed near the eyes of the participants, can propagate through the scalp affecting the EEG signal and thus generating artifacts (Zeng & Song, 2014). The employment of EOG allows to accurately clean the EEG recordings from the artifacts with specific techniques.

On the eye tracking side, no chin rest was employed during the present experiment, unlike in Walcher et al.'s study (2017). Some qualitative tests performed by the author of the present study proved that excessive head movements cause missing data in the eye tracking recordings. Reasonably, gaze positions captured by the eye tracker could have been affected by small and natural head movements and the precision of the measurements probably would have benefited from the employment of a chin rest. However, the Tobii X2 -30 was designed by the producer to be able to operate with no chin rest. The last main difference with the previous study is the sampling rate of the eye tracker employed, 30 Hz versus 500 Hz. Usage of an eye tracker device with higher sampling rate would have allowed to adopt noise-correction algorithms and to avoid possible overcounting of fixations during the analysis (see Appendix I for more details).

Analysis Method

Analysis choices made about artifacts and noise correction both for EEG and eye tracking data could have significantly affected the results and thus the comparability with the previous studies.

EEG On the EEG side, no visual inspection of the EEG tracks was performed in the present study, whilst the other studies did it. Such choice was adopted because of time constraints. Artifacts affecting the brain signals were identified and corrected only by means of algorithms, but visual inspection would have helped to exclude remaining affected segments. Furthermore, only automatic blink detection and interpolation of the data guaranteed ocular artifacts correction because no EOG was employed, as mentioned before.

Another analytical difference with the previous studies consists in the alpha band limits. As reported in Table 5 there is not concordance on the alpha band limits in literature. Additionally, in the present study the alpha band was not divided in alpha sub-bands, specifically in lower and upper alpha frequency band. Such choice was made because in past studies any clear evidence emerged from such distinction. Benedek et al. (2014) did not distinguish in sub-bands either and Jauk et al. (2012), after having found that the two sub-bands were highly corelated, performed the statistical analysis on the entire alpha frequency band. Of the three studies considered only Fink et al. (2009) separately analysed the two sub-bands. However, despite such dissimilarities in the alpha limits and sub-bands, the other studies were all able to collect statistically significant findings (Table 4).

Finally, from the comparison with the other studies one last analytical difference emerges in the fast Fourier transform parameters adopted to calculate the alpha power. In the present study the transform was applied to 1000 ms long time-windows with 250 ms windows step, with Hanning windowing function and without averaging across windows; whilst in the previous studies researchers employed an overlap of 900 ms among the 1000 ms long time-windows and no windowing was adopted (also known as rectangular windowing). However, considering that the final measures were obtained by averaging the power across windows, such analytical difference should not have affected the divergence between the results.

Before moving on, calculating alpha frequency band limits for each single subject could have led to more significant results. None of the studies reported above employed such analytical techniques, but past studies (Da Silva & Pfurtscheller, 1999) advocated the need of such analysis choice because of the large inter-individual differences influencing the alpha frequency limits. Fixed frequency windows, like the one adopted in the present study (8-12 Hz), could generate misleading interpretations by excluding from the analysis significant individual power variations located in the frequency bands adjacent to the fixed limits.

Table 5: Experimental settings and analytical method - Comparison

Study	Reference	EOG	Visual Inspection	Band
Fink et al., 2009	Nose	Yes	Yes	8-10 Hz / 10-12 Hz
Jauk et al., 2012	Nose	Yes	Yes	7.5-12.5 Hz
Benedek et al., 2014	Nose	Yes	Yes	8.5-12.5 Hz
Present Study	Mastoids	No	No	8-12 Hz

Ocular Analysis On the ocular analysis side, in light of the low sampling rate of the recording device employed, no noise correction was adopted in order not to affect the results. More in detail, fixations were defined as periods with no saccades nor blinks. Fixation rate could thus have been affected by missing sample data, which could determine the distinction of one single fixation in two or more. Indeed, data loss can affect specific eye tracking samples not only because of the blinking but also because of momentary problems in the hardware such as delays in data transfers or malfunctions (Olsen, 2012). However, because in the present study the time covered by an eye tracking sample (33 ms) is similar to the possible duration of a blink (minimum duration of a blink was considered 6 ms (Walcher, Körner, & Benedek, 2017)) it was not possible to distinguish between actual blinks and data missing; thus no interpolation technique was adopted.

Furthermore, noise due to interferences from the environment or minor eye movements such as microsaccades and tremor could bring to an overestimation of saccades to detriment of fixations. However, eye tracking data sampled at a frequency lower than 60 Hz could be sensibly tampered with noise correction filters (Olsen, 2012), therefore no correction was adopted. More details about the ocular analysis are reported in Appendix I.

3.5.3. The Intrinsic Analytical Limitation

Brain signals recorded by EEG electrodes on the scalp are the postsynaptic potential generated by groups of neurons exchanging information with each other. Electric potential is by its own definition the amount of work needed to move one positive charge from a reference point to the specific point of interest. EEG devices collect the electrical potential difference between the electrodes on the scalp and their common reference electrode. In light of that, the electrical activity captured by the reference electrode plays a heavy role in the quantification of the electrical activity captured by each electrode on the scalp.

Considering that, voltage fluctuations collected by each electrode on the scalp are not absolute fluctuations, by they are relative to the voltage fluctuations captured by the reference electrode at the same time. Therefore, if potentials in the two electrodes oscillate in opposite directions, i.e. the potential under one electrode grows while under the other one decreases, the voltage fluctuation will be amplified. Vice versa, if the two potentials oscillate in the same direction, the voltage fluctuation under the electrode of interest will result reduced. In Figure 9 a qualitative representation of the concept is illustrated. As a consequence, the electrical signal collected by the electrodes does not represent the actual underlying neuronal communication activity, but only its relationship with the activity captured under the reference electrode. Therefore, under these conditions, increases in power in the frequency band considered does not necessarily correspond to increases in synchrony of the neuronal population underlying the electrode of interest.

Such analytical limitation is not new in literature. In one study Michel et al. (2004) stated that while for the analysis of topographic maps the position of the reference electrode is irrelevant, because the only interest is the relative difference in power among the electrodes at the same time, the reference electrode position heavily influences waveforms analysis. In divergent thinking studies here presented, the interest was in comparing the frequency power collected at different times under different conditions. Nevertheless, none of the previous studies clearly addressed the problem.

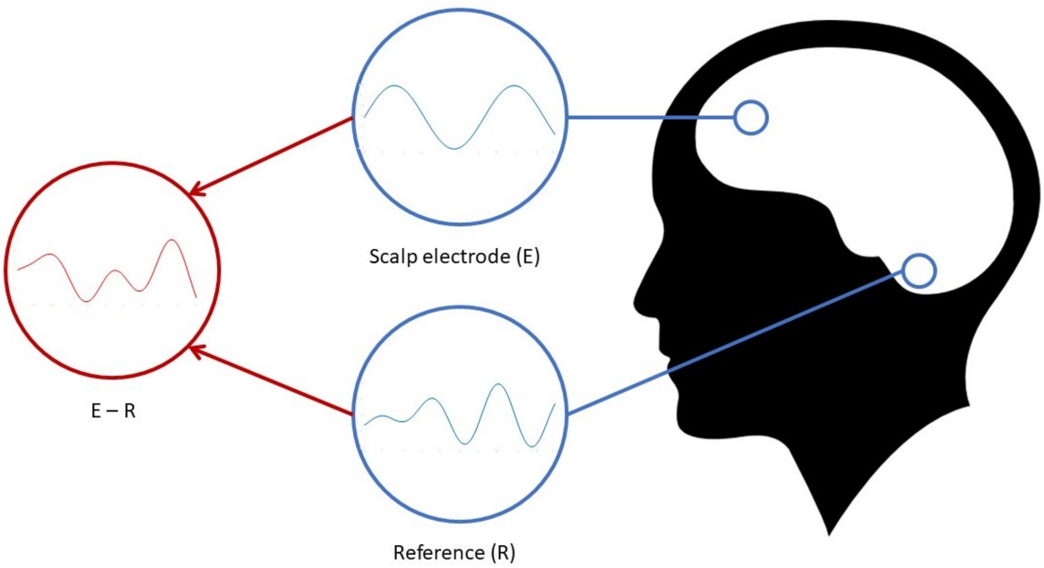


Figure 9: EEG signal (Freepik)

One possible solution to the problem would be to create an average reference signal among all the electrodes on the scalp. Indeed, Ohm's law states that electrical currents summed across an entire electrically isolated sphere should be equal to zero. That could approximately be the case for high-density EEG recordings with evenly distributed electrodes, if one assumes no current passing through the neck to the body because of the low conductance of the skull (Swartz Center for Computational Neuroscience, 2014).

It is not the purpose of the present study to delve into such issue, however tackling this problem could help to understand why alpha power increases reported by EEG studies during divergent thinking could correspond to deactivation of the right-parietal lobe in fMRI studies (Benedek, Schickel, Jauk, Fink, & Neubauer, 2014).

3.5.4. The Task Limitations

The purpose of the study was primarily to explore the employment of EEG and eye tracking in cognitive research, but some consideration about the construct investigated are a must. The study focused on the construct of creativity proposed by Guilford (1950). The original definition of divergent thinking involved the production of many and different ideas from available information (Cropley, 2006), whilst in the present experiment, such as in the other study considered, participants were required to express one single idea during the divergent thinking condition. Even if in the present study the subjects were required not to stop on the first idea generated, but to try to express the most original idea possible, the 30 seconds response-time constraint could have limited the creativity level of the subjects. However, unlike what has been done in the other studies, the task was presented as a game in order to enhance the creativity level of the subjects (Runco & Yoruk, 2014). Furthermore, convergent thinking should be oriented toward finding a single answer, by logic and by using and manipulating previous knowledge (Cropley, 2006), whilst in the present study the common response condition was more similar to a memory retrieval then to a creative process.

4. Conclusion

In conclusion, for many years until now traditional protocol analysis gave valuable insight into the design process. Today, physiological recording devices allow to delve further into the research questions of science of design by objectively assessing the internal cognitive process of the designer for the first time. However physiological studies in design research field are still in their infancy and we need more exploratory studies to evaluate the possibilities and the actual limitations of this new research technique. This has been the purpose of the present study.

After having provided an overview of science of design today and of the research tools available in the introduction, the second part of the work consisted in a detailed literature review of the intricate neuroscientific research on creative cognition. In order to find some overlapping in results the review focused on the construct of creativity grounded on the concepts of divergent and convergent thinking as proposed by Guilford (1950). The last part of the review analysed the findings of two oculometric studies which shed new light on the functional interpretation of the brain activity during divergent thinking. From the variegated evidence of EEG creativity studies, it seems that alpha power synchronization in the right parietal lobe would be characteristic of specific cognitive processes occurring during divergent thinking. Such cortical activity was interpreted as top-down inhibition of task-irrelevant cognitive processes, but findings in oculomteric studies seem to suggest a button-up task shielding operated by active visual-gating of the eyes.

In the third chapter the experiment conducted in the present study was presented as well as the rationale of the design choices adopted. The novelty of the experiment consisted in the combined employment of two physiological recording devices, the electroencephalogram and the eye tracker. Although the apparatus available for the present study did not have the necessary specifications to test the aforementioned functional interpretations of alpha power activation in the right posterior lobe, it was still possible to try to replicate part of the previous findings. Furthermore, the specific experimental design adopted, consisting in employing the same experimental task under two response conditions simulating convergent and divergent thinking (Jauk, Benedek, & Neubauer, 2012), would have allowed to verify if findings of the reference oculometric study (Walcher, Körner, & Benedek, 2017) were task-dependent or if they actually represented internally focused cognition, which characterizes divergent thinking. Unfortunately, the comparison between the convergent and divergent experimental condition failed to reach statistical significance, except for the behavioural analysis which, consistently with the previous studies, resulted in higher reaction times and higher originality levels during divergent thinking (inter-rater agreement $W > 0.740$). The ending part of the third chapter contrasted the present study with the previous ones with the most similar experimental design. The aim was to assess the main differences which could have caused such difference in the statistical significance of the results. Differences the experimental setting and the analysis method were identified as possible reasons. On one side the previous studies employed EEG devices with reference electrodes located in different places; this can have led to significantly different results. Furthermore, the researchers employed electrooculogram (EOG) devices which collected useful data to clean the cortical signal from ocular artifacts during the analysis. Finally, the adoption of an eye tracker with higher sampling rate and of a chin rest such in the reference study would have been beneficial for the quality of the ocular data. On the other side, the main source of dissimilarity in results was identified in artifacts and noise correction of the data in the analysis. EEG data were not visually inspected such as in other studies to remove the artifacts that had not been detected by the automatic algorithms employed; moreover, no further corrections for ocular artifacts were adopted because of the lack of EOG data. Also, no noise correction was employed on the ocular data in order not to distort the results because of the low temporal resolution of the eye tracker. Finally, one last consideration was presented about the intrinsic limitation apparently common to all the EEG studies reviewed. EEG data collected from the scalp is heavy influenced by the electrical activity captured by the reference electrode, thus positioning of the reference electrode influences the general results of the studies. Many details about the analytical choices and procedures were reported in the appendices in order to lighten the exposition of the present work.

Summing up, the present study reported the fragmentation of evidences in neuroscientific approach to creativity originated from variegated experimental designs and analytical procedures. More in detail, differences in the nature of the creative tasks employed, in their duration, in the response modalities and in the selected reference periods contributed to the low comparability of the findings in literature. Furthermore, the same quantification of cortical activity was based on different measures and analytical techniques. The experiment itself, conducted in the present study, showed how small changes in the experimental design and in the analysis can lead to significantly different results.

The employment of neuroscientific and oculometric tools to the study of cognition is still in its infancy. In the next future it will be useful to create a methodological frame in order to make the findings comparable. Particularly on the EEG side it would be very important to delve into the influences of the experimental settings and analysis methods on results, starting from the influence of the reference electrodes. Apparently, none of the studies reported in the present work took in account the considerable influence of reference signal on the final results. Before science of design could take advantage of these new physiological instruments a sound empirical and theoretical background must have been built on the most elementary cognitive processes, in order to ultimately delve into more complex ones such as the design process. Research of the future will probably focus on these issues and partially it is already doing it. Future studies will likely employ several physiological recording devices simultaneously, such as in the present work, in order to obtain more accurate functional interpretations of the findings.

The present work wanted to be an exploratory study and of course incurred in some limitations. The aforementioned choices about the experimental setting and the analysis method did not make possible to have results entirely comparable to the previous studies. Delving further into the analytical techniques of EEG data would have probably led to more significant results. Finally, despite the purpose of the study was primarily to explore the employment of EEG and eye tracking in cognitive research, it should be noted that the experimental task adopted in the present study and in literature (Jauk, Benedek, & Neubauer, 2012) did not resemble completely Guilford's (1950) original definition of convergent and divergent thinking.

The present study, even if not confirming the evidences described by other authors, contributed to the design cognition field by providing a framework to position the different research questions and useful insights for setting future experiments.

5. Appendices

In the present section many details about the present study are reported in order to lighten the exposition in the body of the work.

5.1. Appendix A

The present appendix reports further material mentioned in the chapter Materials and Methods concerning the experiment conducted in the study.

5.1.1. Participants

Fourteen volunteers took part to the study. All participants were male engineering students attending the last three years of their courses of study. In order not to affect the eye tracker's measures, only volunteers with normal, corrected-to-normal vision and with no strabismus or other medical conditions affecting vision were selected. The experimental items were translated into the mother tongue of the participants, in order not to involve the translation cognitive process in the analysis.

Table 6: Participants' attributes

Subject	Age	Course of study	Year	Contact lenses	Language
Subject 1	29	Architectural Engineering	3rd	Yes	Swedish
Subject 2	21	Mechanical Engineering	4th	No	French
Subject 3	23	Civil Engineering	3rd	No	Swedish
Subject 4	26	Mechanical Engineering	5th	No	Swedish
Subject 5	23	Industrial Design Engineering	4th	No	Swedish
Subject 6	22	Industrial Design Engineering	3rd	No	Swedish
Subject 7	31	Industrial Design Engineering	3rd	No	Swedish
Subject 8	26	Industrial Design Engineering	3rd	No	Swedish
Subject 9	24	Industrial Design Engineering	5th	No	Swedish
Subject 10	26	Industrial Design Engineering	5th	No	Spanish
Subject 11	25	Information Engineering	5th	Yes	Italian
Subject 12	24	Industrial Design Engineering	5th	No	Swedish
Subject 13	21	Civil Engineering	3rd	No	Swedish
Subject 14	23	Physics and Electrical Engineering	5th	No	Swedish

5.1.2. Recruiting Volunteers

Poster were posted in the university campus and on Facebook in order to reach engineering students. Mailing lists were also employed. Volunteers were directed to an online form with the description above. Finally, they submitted their personal details (name, age, mother tongue, course and year of study, poor eyesight, phone number and email address) and selected the dates in which they were available for the experiment.

Call for the experiment

Try eye tracking and EEG!

We are looking for volunteers to perform a study on how our brain works during creative thinking.

If you are interested, read the following section, select the day and the time you prefer and leave your contact!

What's the study about

The study aims to identify different patterns in eye movements and brain signals during the performance of a simple task. The task consists in finding possible uses for several objects under two different conditions: one condition of high originality and one condition of low originality.

The study employs EEG (electroencephalogram) and eye tracking technologies. A remote infrared device will be used to track your eyes movements and, to capture your brain signals, you will wear an EEG cap. You will also wear a GSR device to record your sweat glands activity during the task.

Participating in the study you'll have the opportunity to try EEG, eye tracking and GSR technologies on yourself. The experiment will take about two hours, and you will receive two gadgets from LTU shop: one (indispensable for every student) led torch key chain with bottle opener and one gadget of your choice among hats, t-shirts, buff and pen-drives.

Who is conducting the study

My name is Alessandro Laspia. This study is part of my master thesis and I'm conducting it under the supervision of Prof. Peter Törlind, Luleå Tekniska Universitet, and Prof. Francesca Montagna, Polytechnic University of Turin, Italy.

Who can participate

For statistical reasons we are looking for male students, attending the third, fourth or fifth year in Engineering.

Because of the sensitivity of the eye tracker, we need people with normal vision, i.e. not wearing glasses, or corrected to normal, i.e. wearing soft contact lenses, and reporting no strabismus or other medical conditions affecting vision.

5.1.3. Consent Form

Before the beginning of the experiment participants had to read and sign the following consent form.

Luleå Tekniska Universitet
97187 Luleå
Sweden

Participant Consent Form

Purpose:
The purpose of this study is to identify different patterns in eye movements and brain signals during the performance of a simple creative task. The study is part of Alessandro Laspia's master thesis in Management and Engineering, under the supervision of Prof. Peter Törlind, Luleå Tekniska Universitet, and of Prof. Francesca Montagna, Polytechnic University of Turin, Italy.

Procedure:
If you agree to be in this study, you will be asked to do the following:

1. Wear the sensors. The study employs EEG (electroencephalogram) and eye tracking technologies. A remote infrared device will be used to track your eyes movements and, to capture your brain signals, you will wear an EEG cap. You will also wear a GSR device to record your sweat glands' activity during the task. The experimental session will be video recorded;
2. Read the instructions and try a brief simulation of the experiment;
3. Perform the actual experimental task. The task consists in finding possible uses for several objects displayed on a monitor under two different conditions: one condition of high originality and one condition of low originality.

The total time required to complete the study, including the setup, should be approximately 2 hours. You will receive two gadgets from LTU's merchandise shop for participating.

Benefits/Risks to Participant:
Participating in the study you'll have the opportunity to try EEG, eye tracking and GSR technologies on yourself and you will receive two gadgets from LTU shop.
There are no expected risks in the experiment. There may be unknown risks.

Voluntary Nature of the Study/Confidentiality:
Your participation in this study is entirely voluntary and you may refuse to complete the study at any point during the experiment, or refuse to answer any questions with which you are uncomfortable. You may also stop at any time and ask the researcher any questions you may have. Your name will never be connected to your results or to your responses on the questionnaires; instead, a number will be used for identification purposes. Information that would make it possible to identify you or any other participant will never be included in any sort of report. The data will be accessible only to those working on the project.

Contacts and Questions:
At this time you may ask any questions you may have regarding this study. If you have questions later, you may contact Alessandro Laspia at alessandrolaspia@outlook.com, or his faculty supervisor Peter Törlind at peter.torlind@ltu.se.

Statement of Consent:
I have read the above information. I have asked any questions I had regarding the experimental procedure and they have been answered to my satisfaction. I consent to participate in this study.

Name of Participant ____Date: __________
(please print)

Signature of Participant ____

Thanks for your participation!

Figure 10: Consent form

5.1.4. Experiment Outline

Below the checklist followed to perform the experiments is reported. The checklist was created in order not to miss any step of the experimental procedure and it was modified several times during the experimental test.

Experiment preparation

- □ Disposables have been procured:
    - o EEG foam;
    - o EEG conductivity gel;
    - o Alcohol;
    - o Latex gloves;
    - o Swabs and cotton swabs;
    - o Gadgets for participants;
    - o Consent form, experiment outline and items table sheets.
- □ iMotions software has been updated to the last version (only until the first subject of the sample has been recorded);
- □ Lab's lights automatic switching off has been deactivated;
- □ Participants have been selected;
- □ Participants have an appointment for the recording day and time;
- □ Participants have confirmed their presence and have communicated their head's measures;
- □ Participants have been asked to carefully wash their hair at least the day before the recording and to not apply wax nor styling gel to their hair;
- □ A profile for the subject has been created on iMotions and all the useful information have been collected (name, age, gender, education).
- □ The experimental stimuli sequence has been prepared:
    - o Randomization has been completed for the size of the sample;
    - o .csv file and images have been loaded on iMotions.
- □ The coupling and the right configuration between computer and recording devices is tested:
    - o EEG;
    - o GSR;
    - o Eye tracking;
    - o Cameras.
- □ The instructions have been tested:
- □ The experimental stimuli sequence has been tested;
- □ EEG amplifier has been charged during the night;
- □ GSR device has been charged during the night;
- □ Laptop has been charged during the night.

Setup

- □ Materials for the experiment have been collected:
    - o Recording devices (EEG and GSR), conductivity gel and foam;
    - o Alcohol, latex gloves, napkins, swabs and cotton swabs;
    - o Scissors, pins;
    - o Gadgets for participants;

- Consent form, experiment outline and items table sheets;
    - Laptop for transcribing the responses.
- ☐ On the lab's doors a notice reporting that an experiment is running has been affixed;
- ☐ All potentially distractive elements have been removed:
    - Pictures on the wall;
    - Curtains are closed;
    - Recording station is moved behind the participant's station.
- ☐ The environment camera has been placed;
- ☐ The computer that will record the experimental data has been started;
    - The audio volume has been set to 40%.
- ☐ Devices' connectivity has been tested:
    - EEG;
    - GSR;
    - Cameras.
- ☐ Foam has been applied on EEG's strips of the subject's head size;
- ☐ Conductivity gel has been applied to the foam of the EEG strip;
- ☐ Laptop for transcription of the responses is ready.

The experiment

- ☐ The subject has signed the consent form;
- ☐ The subject has communicated his age;
- ☐ All the devices that can produce noise have been switched off, except for the ones needed in the experiment;
- ☐ White coat and latex gloves have been worn;
- ☐ The subject has sat at the participant's station;
- ☐ Subject head has been measured once more and the measures have been written down:
    - Nasion-inion distance;
    - Ear-Ear (Crests of Helix) distance.
- ☐ The areas where the EEG sensors will be placed have been wiped down using an alcohol swab:
    - 9 points on the scalp;
    - Two mastoids.
- ☐ The EEG headset has been placed on the subject's head:
    - The two straps have been placed;
    - The amplifier is centred;
    - The strap is not resting on the subject's ears.
- ☐ The strip has been placed on the subject's head:
    - Electrodes have been placed in the right positions on the scalp (strip centred, inion aligned to the strip's alignment hole);
    - Reference electrodes have been applied to the mastoids;
    - Hair has been removed has much as possible from under the electrodes.
- ☐ The connector has been plugged;
- ☐ The participant has been questioned about the comfort:
    - In case of discomfort individual strip arms have been loosened.
- ☐ The EEG headset has been switched on and connected;

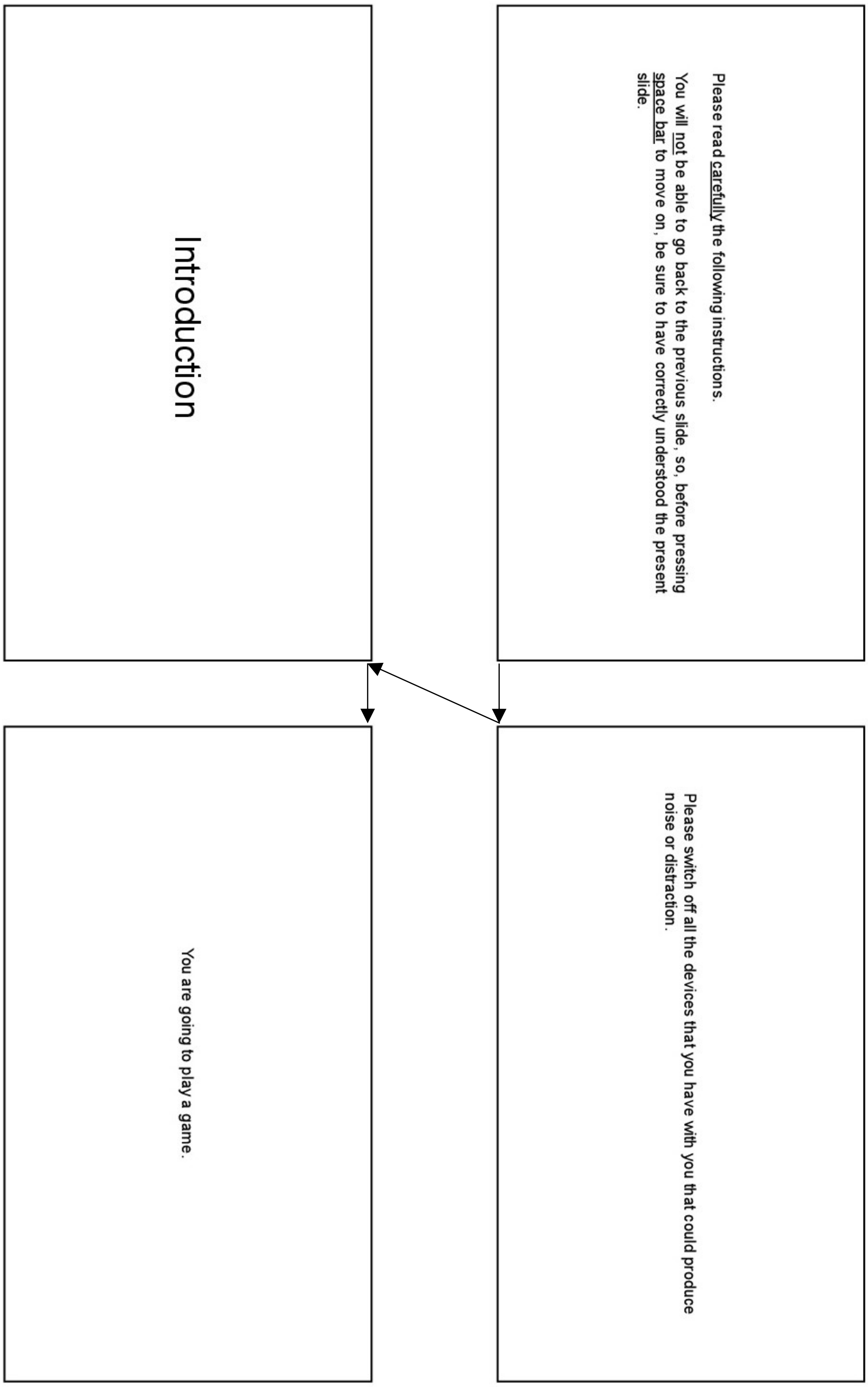
- ☐ The impedance has been checked on iMotions software;
- ☐ The electrodes with impedance above 5 (or 40) kΩ have been relocated on the scalp or more conductive gel has been added;
- ☐ GSR device has been installed on the subject on the secondary hand (red cable on the index);
- ☐ GSR has been switched on and connected;
- ☐ The subject has been positioned at the right distance from the monitor (60 cm);
- ☐ The eye tracker has been calibrated;
- ☐ Slides with the instructions for the experiment have been showed to the subject;
- ☐ The researcher has controlled the recording test in real time;
- ☐ The subject has been questioned about doubts;
- ☐ Impedance has been checked again;
- ☐ The EEG benchmark phase has been recorded directly in the folder of the experiment;
- ☐ The subject's distance from the monitor has been checked;
- ☐ The eye tracker has been calibrated for the experiment;
- ☐ The experiment has started;
- ☐ The researcher has controlled the recording in real time;
- ☐ The experiment is over;
- ☐ A demo has been showed to the participant;
- ☐ GSR device has been removed;
- ☐ EEG headset has been removed and hair has been wiped up from the conductive gel;
- ☐ Responses have been transcribed on the questionnaire with the participant (ask to explain);
- ☐ Participant has received the gadget and has been thanked.

After the experiment

- ☐ Foam has been removed from the EEG strip;
- ☐ Reference electrodes have been removed;
- ☐ EEG strip has been cleaned and disinfected;
- ☐ EEG band has been cleaned and disinfected;
- ☐ GSR devices has been cleaned and disinfected;
- ☐ Devices have been replaced;
- ☐ Backup of recorded data has been created;
- ☐ Computer has been shut down;
- ☐ The lab has been turned to its original configuration;
- ☐ A team of reviewers has scored the originality of the responses for each participant.

5.1.5. Instructions Presentation

A slide show was employed in order to provide to all of the participants the same standard instructions for the experiment.



During this game, names of everyday life's objects will be displayed on the screen, one at the time.

You have to think how you could use each of these objects.

Before the object's name is displayed, you will see one letter.

This letter could randomly be one of these:

n or **u**

If you see a **u**,
then you will have to think to the most uncommon way you could use the object that is going to be displayed.

If you see a **n**,
then you will have to think to the most common way you could use the object that is going to be displayed.

When you see **u** ("most uncommon" condition)
you don't have to think how to realize your idea in detail, nevertheless the idea you generate should be somehow feasible and <u>useful</u>.

For example: if the word is "pencil", it wouldn't make any sense thinking that you could use it "to fly" (unless you are thinking of using it as a cloche on an airplane, for example), but you could think that a pencil could be used "to dig a hole".

Let's see an example. Consider that the object's name that has been displayed is:

brick

If you had seen a n before the object's name was showed, then you could think that a highly common way in which you could use a brick is "to build a wall".

If you had seen a u before the object's name was showed, then you could think that a highly uncommon way in which you could use a brick is "for a karate demonstration".

As soon as you have thought of a way to use that object, you have to press the space bar. Soon a speech balloon will signal that you can speak aloud to express your idea.

After you verbalized your idea, you have to press the space bar to move on to the next object.

When you express your idea, please do it in English. But keep in mind: you don't have to think how to translate your idea in English before pressing the space bar. After you press the space bar, you can take the time you need to translate your idea in English and to verbalize it. If you don't find a translation that satisfies you, you can say your idea in Swedish and in the end of the experiment you will explain it to the researcher.

<u>Remember</u>: during the experiment you don't have to speak, except when the speech balloon is displayed and only to express your idea.

Remember: the sensors you wear are very sensitive to your movements.

For this reason, it is very important that during the task you avoid any body movement. Your arms, your legs and even your face have to stay relaxed. Avoid lip sucking and every movement that could affected the data recorded by the sensors.

Remember: during the task you don't have to look away from the screen. If you want you can look away from the word while you think, but you have to keep your eyes inside the screen's perimeter.

Before proceeding…

Before proceeding we need to record two minutes of EEG signal.

In the next slides you will be asked to rest one minute with open eyes and one minute with closed eyes. Please, follow the instructions.

Please, look at the white screen for one minute
until you see the next instruction.

Press the space bar when you are ready.

Please, now close your eyes for one minute.
You can open your eyes only when you will hear an acoustic signal.

When you are ready, close your eyes and press the space bar.

Keep your eyes closed.

Open your eyes

Press the space bar to move on.

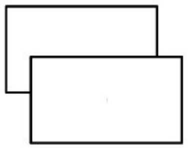
Time to try

You are going to try how to play.

Here is how it works in detail:

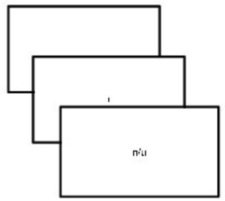
The screen will be white for a while

Here is how it works in detail:



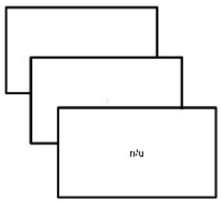
A cross will be displayed for few seconds, you have to stare at it.

Here is how it works in detail:



A letter will be displayed for few seconds:
- n for highly common solutions;
- u for highly uncommon solutions.

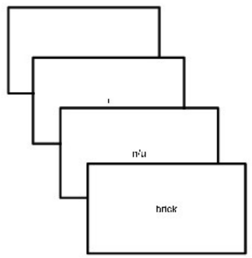
Here is how it works in detail:



A letter will be displayed for few seconds:
- n for highly common solutions;
- u for highly uncommon solutions.

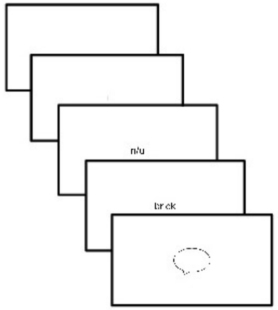
Remember: when you see an “u” you have to think of the most original use you can think of. So you don’t have to stop necessarily on the first idea that pops up in your mind. Also, your idea should be somehow possible to realize.

Here is how it works in detail:



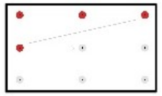
The name of the object will be displayed in Swedish.
You will have maximum 30 seconds to think to a solution and to press the space bar.

Here is how it works in detail:

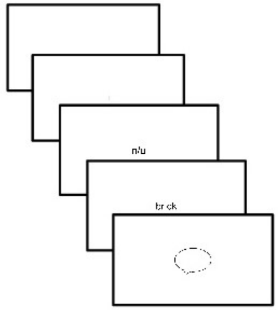


When the speech balloon is displayed you can vocalize your idea in English. After you have to press the space bar.

Here is how it works in detail:



Before the beginning of the experiment you will see a circular shape moving. Follow it with your eyes and try to focus on the middle of it, without moving your head.



The game will take less than 10 minutes.

Remember:

- You don't have to talk during the experiment, except when it's time to express the solution, after that you have pressed the space bar;
- You don't have to move and you must also avoid the smaller movements;
- You don't have to look away from the screen.

Find a comfortable position.

The arms should lie on the table and one hand should be close to the space bar so that you have to move only the fingers to press it and you <u>don't</u> need to <u>look at the space bar</u>.

If you don't have any question, press the space bar to start a brief simulation.

(SIMULATION)

Introduction completed.

Before starting the real game, you are going to perform 3 simple tasks. They will take about 10 minutes .

If you don't have any question, press the space bar when you are ready.

5.1.6. Translations of the Items

In the present study the items were translated into the mother tongue of participants, in order not to involve the translation cognitive process in the analysis

English	German	Definition applied	Swedish	French	Spanish	Italian
vase	vase	(for flowers)	vas	vase	jarrón	vaso
can	dose	(metal container)	burk	bidon	lata	lattina
basket	korb	(woven container)	korg	panier	cesta	cesto
bed	bett	(furniture for sleeping)	säng	lit	cama	letto
book	buch	(bound printed work)	bok	livre	libro	libro
ball	ball	(round body for games)	boll	ballon	balón	palla
pot	topf	(for cooking)	gryta	marmite	olla	pentola
ring	ring	(jewellery worn on finger; cirlular band)	ring	bague	anillo	anello
helmet	helm	(for head in armour or workman)	hjälm	casque	casco	casco
tent	zelt	(camping)	tält	tente	tienda de campaña	tenda
rag	tuch	(cleaning cloth)	trasa	chiffon	trapo	straccio
axe	beil	(chopping instrument)	yxa	hache	hacha	accetta
flour	mehl	(ground cereal)	mjöl	farine	harina	farina
trousers	hose	(clothing for the legs)	byxor	pantalon	pantalones	pantaloni
bread	brot	(type of food)	bröd	pain	pan	pane
stick	stab	(small branch, twig)	pinne	bâton	palo	bastone
coffin	sarg	(burial)	kista	cercueil	ataúd	bara
magnifier	lupe	(lens that enlarges)	förstoringsglas	loupe	lente de aumento	lente d'ingrandimento
rope	seil	(thick cord)	rep	corde	cuerda	corda
colander	sieb	(bowl for draining food)	durkslag	passoire	colador	colino

Figure 11: Translations of the items

5.1.7. Procedure Refinement

Test Duration

Monitoring of the duration of the tests allowed to reduce the duration of the experiment. The duration of the procedure was reduced from 2 hours and 15 minutes to about 1 hour and 45 minutes.

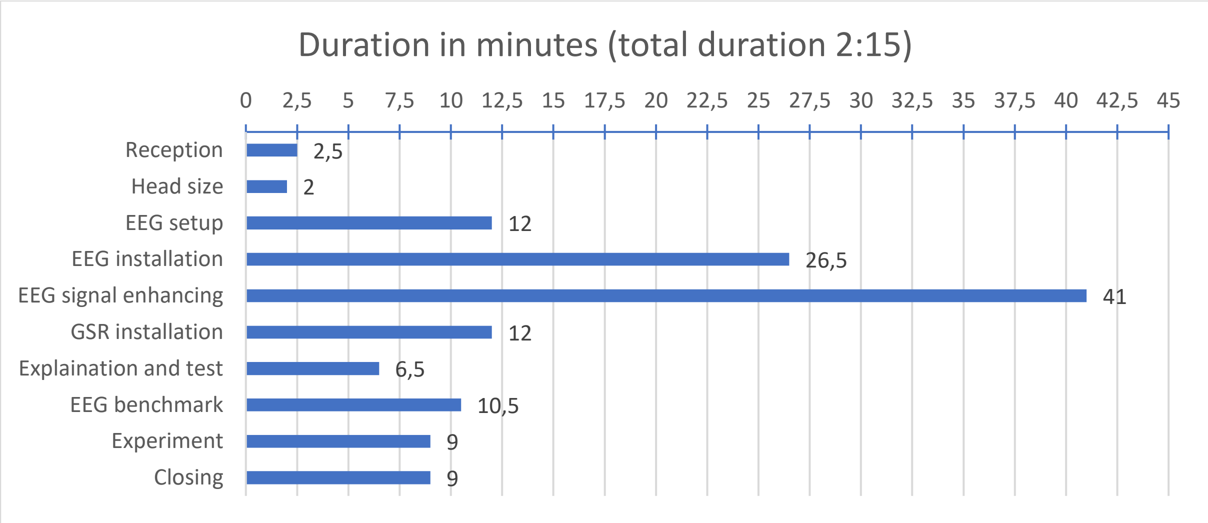


Figure 12: Duration of the experimental phases - test

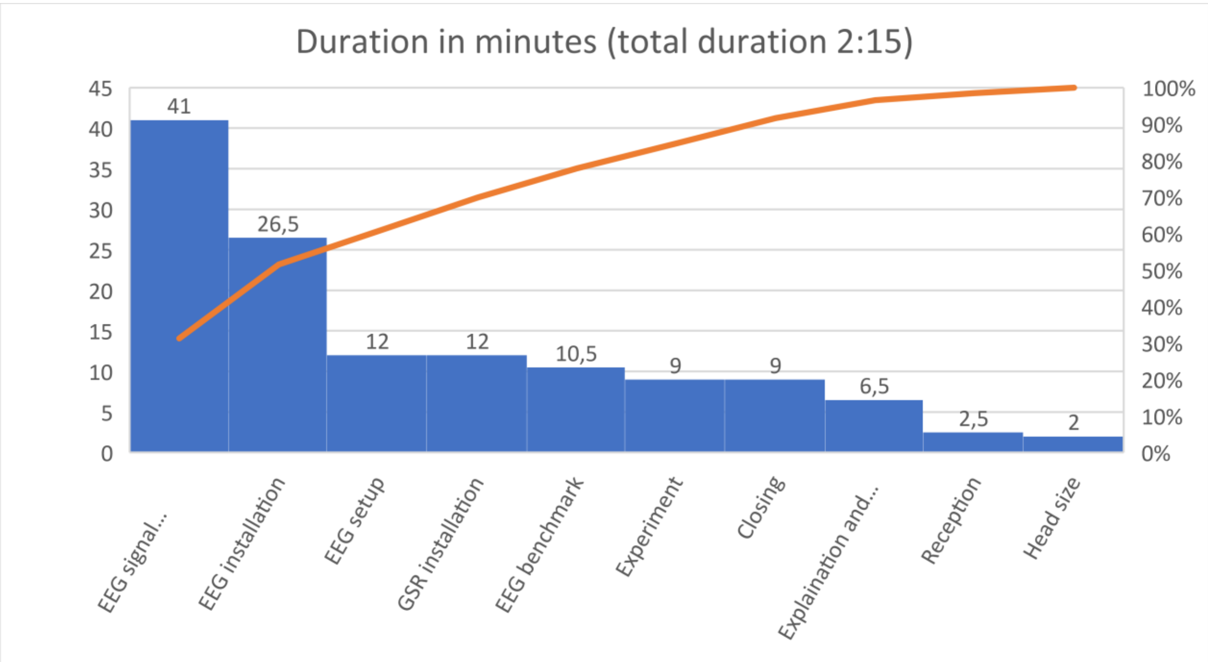


Figure 13: Cumulative duration of the experimental phases - test

Outline Modification

The outline was improved thanks to the tests of the experiment.

ref check
dt

→ □ burial failed (don't know the word)

0' **2. The experiment**

- All the devices that can produce noise have been shut down except for the ones needed in the experiment; – put on first slide
- The subject has sat at the participant's station;
- 2'30'' White coat and latex gloves have been worn ~~by the researcher~~;
- Subject head has been measured and the measures have been written down: Maybe do measure before?
  - Nasion-inion distance; 26 cm
  - 4'30'' Ear-Ear distance. 31 cm → XS
- 13' problems 15'40'' Foam has been applied on EEG's strips of the participant's head size.
- Conductivity gel has been applied to the foam of the EEG strip;
- 25' The areas where the EEG sensors will be placed have been wiped down using an alcohol swab:
  - 9 points on the scalp; → ? come ?
  - 29 Two mastoids.
- The EEG headset has been placed on the subject's head:
  - The sensor is centered;
  - The strap is not resting on the subject's ears.
- The strip has been placed on the subject's head:
  - Electrodes have been placed in the right positions (strip centered, inion and alignment hole); Reference electrode
  - Hair has been removed has much as possible from under the electrodes.
- 46'30'' The connector has been plugged; + 5' min (mastoid) → 52'
- The participant has been questioned about the comfort:
  - In case of discomfort individual strip arms have been loosened.
- The subject has signed the consensual form;
- The EEG headset has been switched on and connected;
- The impedance has been checked on iMotions software;
- 1h 33' The electrodes with impedance above 5 (or 40) kΩ have been relocated on the scalp or more conductive gel has been added;
- GSR device has been installed on the subject on the secondary hand; 60 cm
- 1h 45' GSR has been switched on and connected; → □ EEG benchmark 1/2
- Slides with the instructions for the experiment have been showed to the subject;
- The subject has been questioned about doubts;
- The subject has been positioned at the right distance from the monitor (60 cm);
- Impedance has been checked again;
- The EEG benchmark phase has been recorded;
- Impedance has been checked for the last time;
- The eye tracker has been calibrated; □ distanza 60 cm controllata per l'ultima volta
- 2h 05' 2h 07' The experiment has been started;
- The researcher has controlled the recording in real time;
- 2h 16' The experiment has been ended;
- ~~A survey has been filled by the subject;~~ – paper / imotions
- GSR device has been removed;
- EEG headset has been removed and the hair has been cleaned from the gel;
- Responses has been transcribed on the questionnaire; – to long time?
- 2h 25'' paper Participant has rated the originality of his own responses;
- Participants have received the gadget with many thanks.

- Separare introduzione della prova (nel bottom per monitor) l'EEG
-

Figure 14: Test outline notes

5.2. Appendix B

This appendix concerns the evaluation of the ideas generated by participants. Four peers rated the originality level of the ideas generated within each subject on a four-point ordinal scale.

5.2.1. Survey sample

Items in the survey were reported in Swedish. In the first section the raters could have an overall impression of the originality level of the subject. In the second section they could rate the single ideas.

Ideas' originality assessment (Subject 1)

Please, read all the ideas reported below to get an overall impression of the originality level of the answers. Try to identify since now the most and less original ideas and then, in the next section, rate the originality of each single idea using the whole scale range as far as possible.

Read all the ideas before rating them:

- "vas" can be used ..."to cook food in it"
- "burk" can be used ..."as a speaker"
- "kista" can be used ..."to store a dead body"
- "bok" can be used ..."to read"
- "durkslag" can be used ..."when cooking pasta"
- "pinne" can be used ..."to write"
- "yxa" can be used ..."to slice an onion"
- "rep" can be used ..."to tie a knot"
- "bröd" can be used ..."to eat"
- "tält" can be used ..."as wing in an aircraft"
- "säng" can be used ..."to slide down a hill"
- "hjälm" can be used ..."as a basket"
- "förstoringsglas" can be used ..."to read small letters"
- "byxor" can be used ..."as a flag"
- "mjöl" can be used ..."as ingredient in bread"
- "boll" can be used ..."as a pillow"
- "korg" can be used ..."to store food in it"
- "ring" can be used ..."to look into it"
- "trasa" can be used ..."to clean a table"
- "gryta" can be used ..."to cook a soup"

Figure 15: Survey - Section 1 (Subject 1)

Now rate the originality of the single ideas

The rating scale ranges from 1 " very common idea" to 4 "very uncommon idea": try to use the whole scale. Your judgment parameter should be only the ideas you read before: do not compare the originality of following ideas with the ones you read from other respondents.

"vas" can be used ..."to cook food in it" *

	1	2	3	4	
very common idea	○	○	○	○	very uncommon idea

"burk" can be used ..."as a speaker" *

	1	2	3	4	
very common idea	○	○	○	○	very uncommon idea

"kista" can be used ..."to store a dead body" *

	1	2	3	4	
very common idea	○	○	○	○	very uncommon idea

"bok" can be used ..."to read" *

1 2 3 4

Figure 16: Survey - Section 2 (Subject 1)

5.2.2. Ideas generated

In the present section all the ideas generated by the subjects are reported with the relative ratings.

"Failed" mark refers to ideas generated after thirty seconds from the appearance of the stimulus (timeout) were not considered in the analysis. Items with no ideas by the respondent or with ideas verbalized before pressing the response button were not transcribed and were not submitted to the evaluation of the raters.

Subject 1

Table 7: Ideas and rating - Subject 1

Stimulus	Condition	Ideas generated	Rater 1	Rater 2	Rater 3	Rater 4
bread	n	"bröd" can be used …"to eat"	1	1	1	1
book	n	"bok" can be used …"to read"	1	1	1	1
ball	u	"boll" can be used …"as a pillow"	3	2	3	2
can	failed	"burk" can be used …"as a speaker"	3	2	2	2
trousers	u	"byxor" can be used …"as a flag"	3	2	3	3
colander	n	"durkslag" can be used …"when cooking pasta"	1	1	1	1
magnifier	n	"förstoringsglas" can be used …"to read small letters"	1	1	1	1
pot	n	"gryta" can be used …"to cook a soup"	1	1	1	1
helmet	u	"hjälm" can be used …"as a basket"	4	2	3	3
coffin	n	"kista" can be used …"to store a dead body"	1	1	1	1
basket	n	"korg" can be used …"to store food in it"	2	1	1	1
flour	n	"mjöl" can be used …"as ingredient in bread"	1	1	1	1
stick	u	"pinne" can be used …"to write"	3	2	1	3
rope	n	"rep" can be used …"to tie a knot"	2	1	2	2
ring	failed	"ring" can be used …"to look into it"	3	3	4	1
bed	u	"säng" can be used …"to slide down a hill"	4	4	4	4
tent	u	"tält" can be used …"as wing in an aircraft"	4	4	3	3
rag	n	"trasa" can be used …"to clean a table"	1	1	1	1
vase	u	"vas" can be used …"to cook food in it"	4	3	4	2
axe	u	"yxa" can be used …"to slice an onion"	4	2	2	2

Count	Condition	Median
10	n	1,0
8	u	3,0

Subject 2

Table 8: Ideas and rating - Subject 2

Stimulus	Condition	Ideas generated	Rater 1	Rater 2	Rater 3	Rater 4
bread	u	"bröd" can be used …"to throw it to someone"	3	2	4	3
book	u	"bok" can be used …"to make a high tower of books"	3	2	3	3
ball	n	"boll" can be used …"to play football"	1	1	1	1
can	n	"burk" can be used …"to pour some water in it"	2	2	2	2
trousers	n	"byxor" can be used …"to wear them to go to school"	1	1	1	1
colander	u	"durkslag" can be used …"as a costume at a party"	3	4	4	4
magnifier	u	"förstoringsglas" can be used …"to start a fire with"	3	3	3	2
pot	u	"gryta" can be used …"to hide yourself in it (in a big one)"	4	4	2	4
helmet	n	"hjälm" can be used …"to protect yourself during hockey game"	2	2	1	1
coffin	u	"kista" can be used …"to sleep in"	3	3	3	4
basket	u	"korg" can be used …"to hide something inside"	3	2	3	1
flour	u	"mjöl" can be used …"to use it as construction material, like sand, to build something"	4	4	4	4
stick	n	"pinne" can be used …"to go hiking on mountains with your stick"	2	3	1	1
rope	u	"rep" can be used …"to drag something with"	2	1	1	1
ring	n	"ring" can be used …"to wear it at your wedding"	1	1	1	1
bed	n	"säng" can be used …"to have a nap"	1	1	1	1
tent	n	"tält" can be used …"to go camping near a lake"	1	1	1	1
rag	u	"trasa" can be used …"to cut it in pieces to use it as material for something new (bricolage)"	3	2	4	3
vase	n	"vas" can be used …"to put a flower inside"	1	1	1	1
axe	n	"yxa" can be used …"to chop some wood with"	1	1	1	1

Count	Condition	Median
10	n	1,0
10	u	3,0

Subject 3

Table 9: Ideas and rating - Subject 3

Stimulus	Condition	Ideas generated	Rater 1	Rater 2	Rater 3	Rater 4
bread	u	"bröd” can be used …"to feed the birds"	2	2	2	1
book	u	“bok” can be used …"to stack it on other books"	2	1	3	1
ball	n	“boll” can be used …"to play soccer"	1	1	1	1
can	n	“burk” can be used …"to drink out of it"	2	2	1	1
trousers	u	“byxor” can be used …"as a rope"	3	3	3	3
colander	n	“durkslag” can be used …"to pour water in it"	2	1	1	2
magnifier	n	“förstoringsglas” can be used …"to make things larger"	1	1	2	1
pot	u	“gryta” can be used …"to keep water in it"	3	3	1	1
helmet	u	“hjälm" can be used …"as a basket"	4	3	3	3
coffin	n	“kista” can be used …"to store things in it"	3	4	1	3
basket	n	“korg” can be used …"to store things in it"	1	2	1	1
flour	n	“mjöl” can be used …"to bake"	1	1	1	1
stick	u	“pinne” can be used …"to build something"	3	4	2	3
ring	n	“ring” can be used …"to wear it"	1	1	1	1
bed	n	“säng” can be used …"to sleep in it"	1	1	1	1
tent	n	“tält” can be used …"to sleep in it"	1	1	1	1
rag	u	“trasa” can be used …"to clean the toilet"	2	2	1	1
vase	u	“vas” can be used …"for digging"	4	3	4	3
axe	u	“yxa” can be used …"to cut food"	3	3	3	2

Count	Condition	Median
10	n	1,0
9	u	3,0

Subject 4

Table 10: Ideas and rating - Subject 4

Stimulus	Condition	Ideas generated	Rater 1	Rater 2	Rater 3	Rater 4
bread	n	"bröd” can be used …"to eat"	1	1	1	1
book	n	“bok” can be used …"as thickness layer, to put it under something"	3	2	3	2
ball	n	“boll” can be used …"to make ball bearings"	4	3	4	2
can	u	“burk” can be used …"to build a miniature stove"	3	2	3	4
trousers	u	“byxor” can be used …"as a carrying basket"	4	2	4	4
colander	u	“durkslag” can be used …"to dig a hole"	3	3	3	2
magnifier	u	“förstoringsglas” can be used …"for starting a fire"	3	2	3	2
pot	u	“gryta” can be used …"as an umbrella"	4	2	4	3
helmet	failed	“hjälm" can be used …"as a protection device"	1	1	1	1
coffin	u	“kista” can be used …"as a box for ski to put on the rack of a car"	4	4	4	4
basket	n	“korg” can be used …"to carry mushrooms"	2	1	1	1
flour	n	“mjöl” can be used …"to bake a cake with"	1	1	1	1
stick	n	“pinne” can be used …"as a fishing pole"	3	2	2	3
rope	u	“rep” can be used …"as a measurement tape"	3	2	2	2
ring	u	“ring” can be used …"as door stop"	4	4	4	3
bed	u	“säng” can be used …"as a trampoline"	3	4	3	3
tent	n	“tält” can be used …"as sun protector"	2	2	1	2
rag	u	“trasa” can be used …"as a painting brush"	4	3	3	3
vase	n	“vas” can be used …"as a decorative item"	2	1	1	1
axe	failed	“yxa” can be used …"to open doors with it"	2	3	3	2

Count	Condition	Median
8	n	2,0
10	u	3,0

Subject 5

Table 11: Ideas and rating - Subject 5

Stimulus	Condition	Ideas generated	Rater 1	Rater 2	Rater 3	Rater 4
bread	n	"bröd” can be used …"to eat during breakfast"	1	1	1	1
book	n	“bok” can be used …"to read with"	1	1	1	1
ball	u	“boll” can be used …"as a bowling ball (supposing that the ball was a football ball)"	3	2	2	2
can	u	“burk” can be used …"as a part of your drums made up of cans"	3	3	4	2
magnifier	u	“förstoringsglas” can be used …"as an accessory on your steampunk hat"	4	3	4	4
pot	n	“gryta” can be used …"to cook soup with"	1	1	1	1
helmet	n	“hjälm" can be used …"to protect your head if you fall"	1	1	1	1
coffin	u	“kista” can be used …"as a bookshelf with some modifications"	4	4	4	4
basket	u	“korg” can be used …"as a hat"	3	3	3	3
flour	u	“mjöl” can be used …"to paint the lines in a football field"	4	2	4	3
rope	n	“rep” can be used …"to climb with"	2	2	1	1
ring	u	“ring” can be used …"as a pencil stand"	4	4	2	3
bed	u	“säng” can be used …"as a raft"	4	4	3	3
tent	u	“tält” can be used …"as a hammock between two trees"	3	3	3	2
rag	n	“trasa” can be used …"to clean up spread milk"	1	2	1	1
vase	n	“vas” can be used …"to put flowers in"	1	1	1	1
axe	n	“yxa” can be used …"to cut down trees"	1	1	1	1

Count	Condition	Median
8	n	1,0
9	u	3,0

Subject 6

Table 12: Ideas and rating - Subject 6

Stimulus	Condition	Ideas generated	Rater 1	Rater 2	Rater 3	Rater 4
bread	u	"bröd” can be used …"as a pillow"	3	4	4	3
book	u	“bok” can be used …"as stairs"	4	4	4	3
ball	u	“boll” can be used …"as a chair"	3	4	4	2
can	n	“burk” can be used …"to store things in"	1	2	3	3
trousers	n	“byxor” can be used …"to wear on your lower body"	1	1	1	1
colander	n	“durkslag” can be used …"to strain out the water from pasta"	1	1	1	1
magnifier	n	“förstoringsglas” can be used …"to enlarge something so that you can see it better"	1	1	1	1
pot	n	“gryta” can be used …"to cook in"	1	1	1	1
helmet	u	“hjälm" can be used …"to carry stuff like a purse"	4	2	3	2
coffin	n	“kista” can be used …"to keep stuff in it"	3	3	2	3
basket	u	“korg” can be used …"as a hat"	3	2	3	3
flour	u	“mjöl” can be used …"to make fake snow as decoration"	4	3	2	3
stick	u	“pinne” can be used …"to poke down something that is high up"	2	2	2	1
rope	n	“rep” can be used …"to climb up a tree house"	2	3	3	1
ring	n	“ring” can be used …"to wear on your finger"	1	1	1	1
bed	n	“säng” can be used …"to sleep in"	1	1	1	1
tent	u	“tält” can be used …"as a kite"	4	3	3	2
rag	n	“trasa” can be used …"to wipe off a table"	1	1	1	1
vase	u	“vas” can be used …"to drink out of"	3	2	3	2
axe	u	“yxa” can be used …"to climb an ice wall"	3	3	4	2

Count	Condition	Median
10	n	1,0
10	u	3,0

Subject 7

Table 13: Ideas and rating - Subject 7

Stimulus	Condition	Ideas generated	Rater 1	Rater 2	Rater 3	Rater 4
bread	n	"bröd” can be used …"for making a sandwich"	1	1	1	1
book	n	“bok” can be used …"for reading"	1	1	1	1
ball	u	“boll” can be used …"to support a wooden house (leveling its floor off)"	4	4	4	4
can	u	“burk” can be used …"as a candle holder"	3	2	4	3
trousers	n	“byxor” can be used …"for wearing them"	1	1	1	1
colander	n	“durkslag” can be used …"for making pasta"	1	1	1	1
magnifier	n	“förstoringsglas” can be used …"for burning ants"	3	3	3	3
pot	failed	“gryta” can be used …"as paperweight"	3	3	4	4
helmet	failed	“hjälm" can be used …"as a bowling ball protection"	4	2	2	3
coffin	u	“kista” can be used …"for gardening, putting "	4	3	4	4
basket	n	“korg” can be used …"for moving stuff"	2	1	1	3
flour	n	“mjöl” can be used …"for baking"	1	1	1	1
stick	u	“pinne” can be used …"for fencing"	3	3	1	2
ring	n	“ring” can be used …"for getting engage"	2	1	1	2
bed	failed	“säng” can be used …"as landing area to jump form a high apartment"	3	4	4	4
tent	u	“tält” can be used …"to make a bath (as a bathtub, after turning it over and filling it with water)"	4	4	4	4
rag	failed	“trasa” can be used …"for cleaning car tires"	3	1	1	3
vase	n	“vas” can be used …"for holding a flower"	1	1	1	1
axe	n	“yxa” can be used …"for chopping wood"	1	1	1	1

Count	Condition	Median
10	n	1,0
5	u	4,0

Subject 8

Table 14: Ideas and rating - Subject 8

Stimulus	Condition	Ideas generated	Rater 1	Rater 2	Rater 3	Rater 4
bread	u	"bröd" can be used …"as a pillow"	4	4	3	3
book	u	"bok" can be used …"to not burn the table when you take something hot from the oven"	4	3	3	4
ball	n	"boll" can be used …"to be kicked"	1	1	1	3
can	n	"burk" can be used …"to have a strawberry jam in it"	3	3	2	4
trousers	u	"byxor" can be used …"as a bag, tying the legs together"	4	3	2	4
colander	u	"durkslag" can be used …"as a hat"	3	2	3	3
magnifier	u	"förstoringsglas" can be used …"as a tray with a glass surface"	4	4	4	3
pot	n	"gryta" can be used …"to cook food"	1	1	1	1
helmet	n	"hjälm" can be used …"to put on your head to protect you when you fall and you hit the ground"	1	1	1	1
coffin	n	"kista" can be used …"to put stuff in it, to put them away"	3	1	4	3
basket	u	"korg" can be used …"as a chair, after turning it upside down so you can sit on"	3	4	2	2
flour	u	"mjöl" can be used …"to fake it's snowing outside"	4	2	3	3
stick	n	"pinne" can be used …"to stir water or soup in a pot"	3	3	2	2
rope	n	"rep" can be used …"to tie two things together"	2	1	1	1
ring	u	"ring" can be used …"as a measurement tool, to determine portions (like for spaghetti)"	4	4	4	3
bed	n	"säng" can be used …"to sleep in it"	1	1	1	1
tent	n	"tält" can be used …"as a shelter when you are out in the nature"	1	1	1	2
rag	n	"trasa" can be used …"to wipe dust away from a table or other forniture"	1	1	1	1
vase	u	"vas" can be used …"as a glass to drink"	3	3	3	3
axe	u	"yxa" can be used …"as a door stop"	4	1	3	4

Count	Condition	Median
10	n	1,0
10	u	3,0

Subject 9

Table 15: Ideas and rating - Subject 9

Stimulus	Condition	Ideas generated	Rater 1	Rater 2	Rater 3	Rater 4
bread	u	"bröd” can be used …"to feed birds"	2	2	2	1
book	u	“bok” can be used …"to provide a fire (burning it)"	3	2	3	1
ball	n	“boll” can be used …"to play soccer"	1	1	1	1
can	n	“burk” can be used …"to eat from"	2	2	2	2
trousers	u	“byxor” can be used …"as a flag"	4	3	2	3
colander	n	“durkslag” can be used …"to cook food with"	2	1	3	3
magnifier	n	“förstoringsglas” can be used …"to look at small objects"	1	1	1	1
pot	n	“gryta” can be used …"to make a stew"	1	1	1	1
helmet	u	“hjälm" can be used …"as a glove on your hand (to fight)"	3	4	4	3
coffin	u	“kista” can be used …"as a stool to sit on"	3	3	4	3
basket	failed	“korg” can be used …"as handle on a cableway (you grab it and you slide along the cableway)"	4	3	4	4
flour	n	“mjöl” can be used …"to make pancakes"	2	1	1	1
stick	u	“pinne” can be used …"to write in the sand"	3	2	2	2
rope	u	“rep” can be used …"as a belt"	3	2	2	3
ring	n	“ring” can be used …"to have it on your finger"	1	1	1	1
bed	n	“säng” can be used …"to sleep"	1	1	1	1
tent	u	“tält” can be used …"as a soft light (putting a lamp inside it)"	4	3	4	2
rag	n	“trasa” can be used …"for cleaning the table with"	1	1	1	1
vase	n	“vas” can be used …"to have a flower in it"	1	1	1	1
axe	u	“yxa” can be used …"to hammer with"	3	1	3	3

Count	Condition	Median
10	n	1,0
9	u	3,0

Subject 10

Table 16: Ideas and rating - Subject 10

Stimulus	Condition	Ideas generated	Rater 1	Rater 2	Rater 3	Rater 4
bread	n	"bröd” can be used …"to make a sandwich"	2	1	1	1
ball	u	“boll” can be used …"to pretend to be pregnant, by wearing it under your clothes"	3	3	2	2
can	u	“burk” can be used …"to build a boat (collecting several cans)"	4	4	4	4
trousers	n	“byxor” can be used …"to go out on a cold day"	1	1	1	1
colander	u	“durkslag” can be used …"to wear as a hat"	3	3	3	3
magnifier	u	“förstoringsglas” can be used …"to start a fire"	3	3	3	2
pot	u	“gryta” can be used …"to use it as a drum and start a rock band"	3	3	4	3
helmet	n	“hjälm" can be used …"when you drive a motorbike"	1	1	1	1
coffin	n	“kista” can be used …"to put a dead person inside it"	1	1	1	1
basket	n	“korg” can be used …"to carry my stuff from the supermarket"	2	1	1	1
flour	u	“mjöl” can be used …"to throw it during a festival, to play"	4	2	4	4
stick	n	“pinne” can be used …"to hit a baseball ball"	3	2	2	1
rope	n	“rep” can be used …"to pull a car"	2	1	3	2
ring	u	“ring” can be used …"to fix a chain"	4	4	4	3
bed	u	“säng” can be used …"to build a fort (children game)"	3	3	2	2
tent	n	“tält” can be used …"to go for a camping day"	1	1	1	1
rag	u	“trasa” can be used …"to hide my face in a public speech"	3	4	3	3
vase	u	“vas” can be used …"to put dirty clothes in it"	3	4	3	3
axe	n	“yxa” can be used …"to cut a tree"	1	1	1	1

Count	Condition	Median
9	n	1,0
10	u	3,0

Subject 11

Table 17: Ideas and rating - Subject 11

Stimulus	Condition	Ideas generated	Rater 1	Rater 2	Rater 3	Rater 4
bread	n	"bröd” can be used …"to eat"	1	1	1	1
book	u	“bok” can be used …"to put it under something when you need some thickness"	2	3	2	2
ball	n	“boll” can be used …"to play football"	1	1	1	1
can	failed	“burk” can be used …"as a telephone with a a cable"	3	2	2	3
trousers	failed	“byxor” can be used …"to wear them"	1	1	1	1
colander	n	“durkslag” can be used …"to drain the pasta after cooking it"	1	1	1	1
magnifier	u	“förstoringsglas” can be used …"to burn paper"	2	2	3	3
pot	n	“gryta” can be used …"to cook something"	1	1	1	1
helmet	failed	“hjälm" can be used …"as costume for Halloween"	3	2	3	3
coffin	n	“kista” can be used …"for dead people"	1	1	1	1
basket	n	“korg” can be used …"to carry something inside it"	2	1	1	1
flour	u	“mjöl” can be used …"to throw it during a bachelor party"	3	1	4	4
stick	n	“pinne” can be used …"for old people to walk"	2	1	2	1
rope	failed	“rep” can be used …"to build a wooden bridge"	3	3	4	4
bed	failed	“säng” can be used …"as a trampoline to jump on it"	3	3	4	3
tent	failed	“tält” can be used …"for children to pretend to live in their own house when they play"	3	2	3	2
rag	u	“trasa” can be used …"to drain a cloth enveloped in it, by squeezing it in order to transfer the water from the cloth to the rag"	4	1	3	2
vase	n	“vas” can be used …"to put plants inside"	1	1	1	1

Count	Condition	Median
8	n	1,0
4	u	2,5

Subject 12

Table 18: Ideas and rating - Subject 12

Stimulus	Condition	Ideas generated	Rater 1	Rater 2	Rater 3	Rater 4
bread	u	"bröd” can be used …"for sword fighting"	4	4	4	4
book	n	“bok” can be used …"to read"	1	1	1	1
ball	u	“boll” can be used …"as a pillow"	3	2	3	2
can	n	“burk” can be used …"to store things in"	3	3	2	3
trousers	u	“byxor” can be used …"as a sail"	4	4	4	2
colander	u	“durkslag” can be used …"as a helmet"	3	2	3	3
magnifier	n	“förstoringsglas” can be used …"for looking closer at scribble"	1	1	2	1
pot	u	“gryta” can be used …"as a helmet"	3	3	2	3
helmet	n	“hjälm" can be used …"to protect your head"	1	1	1	1
coffin	u	“kista” can be used …"as a bob sled"	4	4	4	4
basket	u	“korg” can be used …"as a boat"	4	4	4	4
flour	n	“mjöl” can be used …"to bake"	1	1	1	1
stick	u	“pinne” can be used …"to sit on"	3	2	2	3
rope	n	“rep” can be used …"to tie something up"	2	1	1	1
bed	n	“säng” can be used …"to sleep in"	1	1	1	1
tent	n	“tält” can be used …"for camping"	1	1	1	1
rag	n	“trasa” can be used …"to wipe something with it"	1	1	1	1
vase	u	“vas” can be used …"to kick like a football"	4	4	3	4
axe	n	“yxa” can be used …"for chopping wood"	1	1	1	1

Count	Condition	Median
10	n	1,0
9	u	3,5

Subject 13

Table 19: Ideas and rating - Subject 13

Stimulus	Condition	Ideas generated	Rater 1	Rater 2	Rater 3	Rater 4
bread	n	"bröd” can be used …"to eat"	1	1	1	1
book	n	“bok” can be used …"for learning"	2	1	1	1
ball	u	“boll” can be used …"as a reference point"	3	4	2	2
can	u	“burk” can be used …"as a receiver (like for a microphone to capture noise)"	3	4	3	3
trousers	u	“byxor” can be used …"to reinforce something (by tearing the trousers apart and mixing them with glow to obtain, once dried, a strong surface around something you want to reinforce)"	4	4	4	3
colander	u	“durkslag” can be used …"as a mold"	4	2	3	3
magnifier	n	“förstoringsglas” can be used …"to magnify what you see"	1	2	1	1
pot	u	“gryta” can be used …"to kill bacteria boiling them"	2	2	2	3
helmet	n	“hjälm" can be used …"for protection during sport"	2	1	2	1
coffin	n	“kista” can be used …"to put dead people in"	1	1	1	1
basket	n	“korg” can be used …"to store things in"	1	1	1	2
flour	n	“mjöl” can be used …"for baking"	1	1	1	1
stick	u	“pinne” can be used …"to measure something when you don't have a tape (you can replicate the same length more times)"	3	3	2	2
rope	u	“rep” can be used …"to make some knot art"	4	2	2	1
ring	n	“ring” can be used …"as a connection point between two parallel strings"	3	3	3	2
bed	n	“säng” can be used …"for sleeping"	1	1	1	1
tent	n	“tält” can be used …"for camping"	1	1	1	1
trousers	u	“trasa” can be used …"to grow a bacterial colony"	3	4	4	4
vase	u	“vas” can be used …"as a material"	4	4	4	3
axe	u	“yxa” can be used …"to throw it far for fun"	3	3	3	4

Count	Condition	Median
10	n	1,0
10	u	3,0

Subject 14

Table 20: Ideas and rating - Subject 14

Stimulus	Condition	Ideas generated	Rater 1	Rater 2	Rater 3	Rater 4
book	u	“bok” can be used …"to press leaves and make them flat"	3	2	2	2
ball	n	“boll” can be used …"to play football or some other ball game"	1	1	1	1
can	n	“burk” can be used …"to keep gel in it"	2	4	2	3
trousers	n	“byxor” can be used …"to wear them"	1	1	1	1
colander	n	“durkslag” can be used …"to get water out of pasta"	1	1	1	1
magnifier	u	“förstoringsglas” can be used …"to light a fire"	3	3	2	2
pot	n	“gryta” can be used …"to make a stew"	1	1	1	1
helmet	u	“hjälm" can be used …"as a football instead of a ball"	3	4	3	3
coffin	u	“kista” can be used …"as fire wood"	3	1	3	3
basket	u	“korg” can be used …"as a chair, by turning it upside down"	3	1	2	2
flour	u	“mjöl” can be used …"to pour it on a surface to check for fingerprints"	4	4	4	3
stick	n	“pinne” can be used …"to play catch with your dog"	2	1	2	1
rope	n	“rep” can be used …"to tie things together"	2	1	1	1
bed	u	“säng” can be used …"as a cushion when jumping from the third floor"	3	3	4	4
tent	u	“tält” can be used …"as a parachute, to jump from a cliff"	4	3	4	3
rag	n	“trasa” can be used …"to wipe a bench"	1	1	2	1
vase	n	“vas” can be used …"to keep flowers in"	1	1	1	1
axe	n	“yxa” can be used …"to chop down a tree"	1	1	1	1

Count	Condition	Median
10	n	1,0
8	u	3,0

5.3. Appendix C

Wilcoxon Signed-Rank Test was employed for the statistical analysis of the originality level of all the 14 subjects under the two experimental conditions. The factor was the response condition (common, uncommon) and the dependent variable was the median originality rating. The null hypothesis asserted that the median difference between the paired values was equal to zero.

5.3.1. SPSS Input Data

	n	u	Difference
1	1,00	3,00	2,00
2	1,00	3,00	2,00
3	1,00	3,00	2,00
4	2,00	3,00	1,00
5	1,00	3,00	2,00
6	1,00	3,00	2,00
7	1,00	4,00	3,00
8	1,00	3,00	2,00
9	1,00	3,00	2,00
10	1,00	3,00	2,00
11	1,00	2,50	1,50
12	1,00	3,50	2,50
13	1,00	3,00	2,00
14	1,00	3,00	2,00

Figure 17: SPSS data view - Median originality levels Wilcoxon signed-rank test

In Figure 18 Measure column reports scale measures. The variables are ordinal in reality, but such setting was needed to overcome software limitations when running the Wilcoxon Signed-Rank Test.

	Name	Type	Width	Decimals	Label	...	...	Columns	...	Measure	Role
1	n	Numeric	8	2	Median rating under common response condition	...	...	8		Scale	None
2	u	Numeric	8	2	Median rating under uncommon response condition	...	...	8		Scale	None
3	Difference	Numeric	8	2		...	...	12		Scale	None

Figure 18: SPSS variable view - Median originality levels Wilcoxon signed-rank test

5.3.2. Descriptive Statistics

Distribution of the differences

All of the 14 participants in the study manifested higher originality level under uncommon response condition when compared to the common response condition. Indeed, al the differences in the histogram are positive.

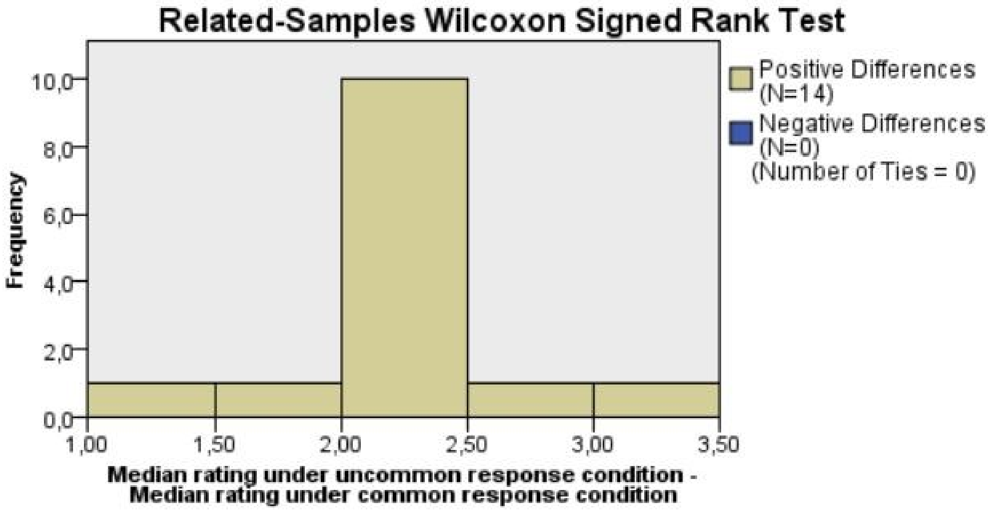


Figure 19: Distribution of the differences between the two related groups

Median

The following table reports the median originality level of the sample under the two experimental conditions.

Table 21: Median of originality level

Report

Median

Median rating under common response condition	Median rating under uncommon response condition	Difference
1,0000	3,0000	2,0000

5.3.3. Wilcoxon Signed-Rank Test

The test assessed that the differences between the two experimental conditions were significantly different from zero.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of differences between Median rating under common response condition and Median rating under uncommon response condition equals 0.	Related-Samples Wilcoxon Signed Rank Test	,001	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is ,05.

Figure 20: Hypothesis Wilcoxon signed-rank test summary

Total N	14
Test Statistic	105,000
Standard Error	15,268
Standardized Test Statistic	3,438
Asymptotic Sig. (2-sided test)	,001

Figure 21: Wilcoxon signed-rank test

5.4. Appendix D

Kendall's Coefficient of Concordance (*W*) was employed for the statistical analysis to determine the agreement between the four raters about the originality level of the ideas generated by each single subject of the experiment. The null hypothesis of the test asserts that Kendall’s *W* is equal to zero in the population, i.e. the null hypothesis states that there is no inter-rater agreement.

5.4.1. SPSS Input Data

	VAR0000 1	VAR0000 2	VAR0000 3	VAR0000 4	VAR0000 5	VAR0000 6	VAR0000 7	VAR0000 8	VAR00 9
1	4	3	1	1	1	3	4	2	
2	3	2	1	1	1	2	2	1	
3	4	2	1	1	1	1	2	2	
4	2	2	1	1	1	3	2	2	

Figure 22: SPSS partial data view for one subject - Kendall's W

	Name	Type	Width	Decimals	Label	...	...	Columns	Al...	Measure	Role
1	VAR00001	Numeric	8	0		...	...	8		Ordinal	None
2	VAR00002	Numeric	8	0		...	...	8		Ordinal	None
3	VAR00003	Numeric	8	0		...	...	8		Ordinal	None
4	VAR00004	Numeric	8	0		...	...	8		Ordinal	None
5	VAR00005	Numeric	8	0		...	...	8		Ordinal	None
6	VAR00006	Numeric	8	0		...	...	8		Ordinal	None
7	VAR00007	Numeric	8	0		...	...	8		Ordinal	None
8	VAR00008	Numeric	8	0		...	...	8		Ordinal	None
9	VAR00009	Numeric	8	0		...	...	8		Ordinal	None
10	VAR00010	Numeric	8	0		...	...	8		Ordinal	None
11	VAR00011	Numeric	8	0		...	...	8		Ordinal	None
12	VAR00012	Numeric	8	0		...	...	8		Ordinal	None
13	VAR00013	Numeric	8	0		...	...	8		Ordinal	None
14	VAR00014	Numeric	8	0		...	...	8		Ordinal	None
15	VAR00015	Numeric	8	0		...	...	8		Ordinal	None
16	VAR00016	Numeric	8	0		...	...	8		Ordinal	None
17	VAR00017	Numeric	8	0		...	...	8		Ordinal	None
18	VAR00018	Numeric	8	0		...	...	8		Ordinal	None
19	VAR00019	Numeric	8	0		...	...	8		Ordinal	None
20	VAR00020	Numeric	8	0		...	...	8		Ordinal	None

Figure 23: SPSS variable view for one subject - Kendall's W

5.4.2. Kendall's W table

The test assessed that there was inter-rater agreement for all the participants (W > 0.741).

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distributions of VAR00001, VAR00002, VAR00003, VAR00004, VAR00005, VAR00006, VAR00007, VAR00008, VAR00009, VAR00010, VAR00011, VAR00012, VAR00013, VAR00014, VAR00015, VAR00016, VAR00017, VAR00018, VAR00019 and VAR00020 are the same.	Related-Samples Kendall's Coefficient of Concordance	,000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is ,05.

Figure 24: Hypothesis test summary of subject 1 - Kendall's W

Total N	4
Kendall's W	,861
Test Statistic	65,444
Degrees of Freedom	19
Asymptotic Sig. (2-sided test)	.

Figure 25: Kendall's table of subject 1

Different degrees of freedom in the following table are due to the exclusion of the ideas without solution, declared before pressing the response button or generated after the timeout.

Table 22: Kendall's W table summary of all the subjects

Subject	Total N	Kendall's W	Test Statistic	Degrees of Freedom	Asymptotic Sig. (2-sided test)
1	4	0,861	65,444	19	< 0,0005
2	4	0,867	65,873	19	< 0,0005
3	4	0,741	53,338	18	< 0,0005
4	4	0,822	62,507	19	< 0,0005
5	4	0,907	58,057	16	< 0,0005
6	4	0,815	61,961	19	< 0,0005
7	4	0,886	63,766	18	< 0,0005
8	4	0,744	56,578	19	< 0,0005
9	4	0,832	63,261	19	< 0,0005
10	4	0,889	64,003	18	< 0,0005
11	4	0,822	55,909	17	< 0,0005
12	4	0,945	68,023	18	< 0,0005
13	4	0,844	64,139	19	< 0,0005
14	4	0,851	57,852	17	< 0,0005

5.5. Appendix E

Paired-samples t-test was employed for the statistical analysis to test the statistical significance of the mean difference between the paired observations of the reaction time under the two response conditions. The independent variable was the response condition (common, uncommon response) and the dependent variable was the time to respond. Paired t-test assesses the null hypothesis asserting that the mean difference between the paired values is equal to zero.

5.5.1. SPSS Input Data

Below a screenshot form SPSS (Figure 26) of the average response times for each subject is reported. In Appendix I the detailed reaction times are reported for each subject.

	n	u	Difference
1	6,842	10,843	4,00
2	5,357	8,165	2,81
3	4,438	14,002	9,56
4	9,812	17,175	7,36
5	1,948	4,735	2,79
6	3,180	9,475	6,30
7	2,294	23,259	20,97
8	4,621	14,148	9,53
9	2,784	9,018	6,23
10	4,255	5,853	1,60
11	5,968	18,507	12,54
12	5,225	10,684	5,46
13	3,297	11,145	7,85
14	5,332	10,019	4,69

Figure 26: SPSS data view - Response time paired t-test

	Name	Type	Width	Decimals	Label	...	...	Columns	A...	Measure	Role
1	n	Numeric	8	3	Avg.response_time[s] common_response_condition	...	...	8		Scale	None
2	u	Numeric	8	3	Avg.response_time[s] uncommon_response_condition	...	...	8		Scale	None
3	Difference	Numeric	8	2		...	...	12		Scale	None

Figure 27: SPSS variable view - Response time paired t-test

5.5.2. Descriptive Statistics

Boxplot

Circular points in the SPSS boxplot are data distant more than 1.5 interquartile ranges from the edges of the box (the box is encompassed between the lower and the upper quartiles, that are the 25th and 75th percentiles). Asterisks represent data with values distant more than 3 interquartile ranges from the edges of the box. This last distance was considered the threshold to categorize outlier values.

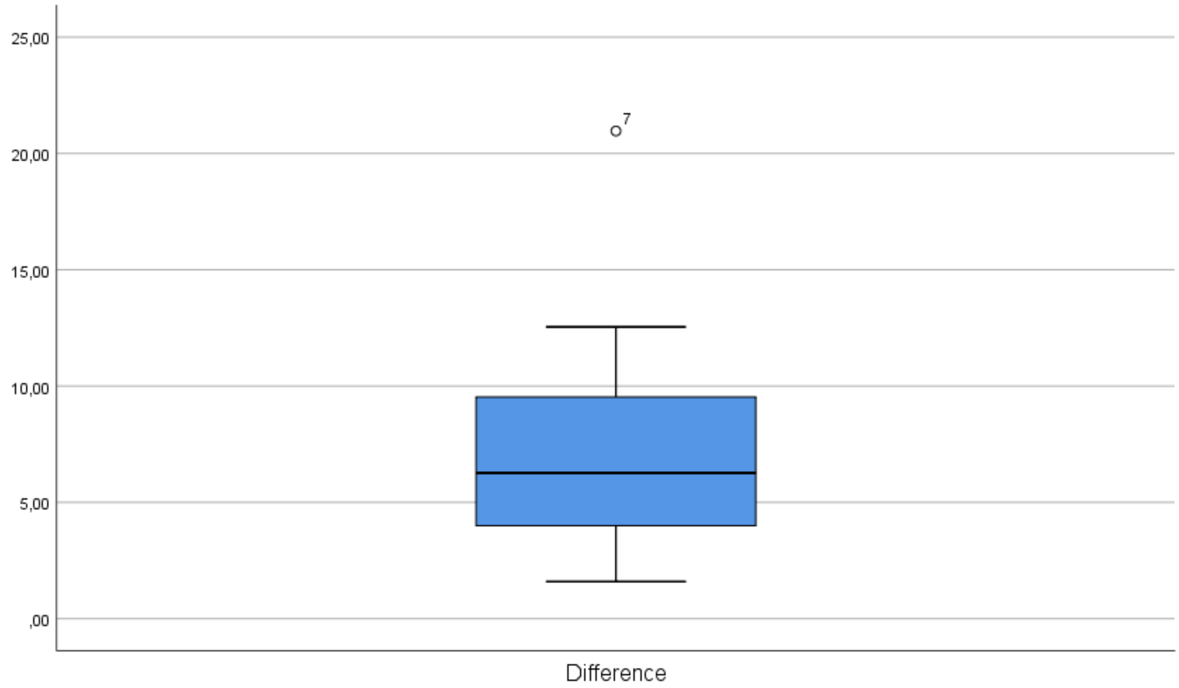


Figure 28: Boxplot - Response time

Test of Normality

The difference scores for the uncommon response condition and the common response condition trial could not be assumed normally distributed according to Shapiro-Wilk's test (p = 0.029).

Table 23: Test of normality - Response time

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Difference	,179	14	,200*	,858	14	,029

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Normal Q-Q Plots

The differences between the fixation rate in the common and uncommon response condition seems to be normally distributed by visual inspection of the Normal Q-Q Plot, except for one point.

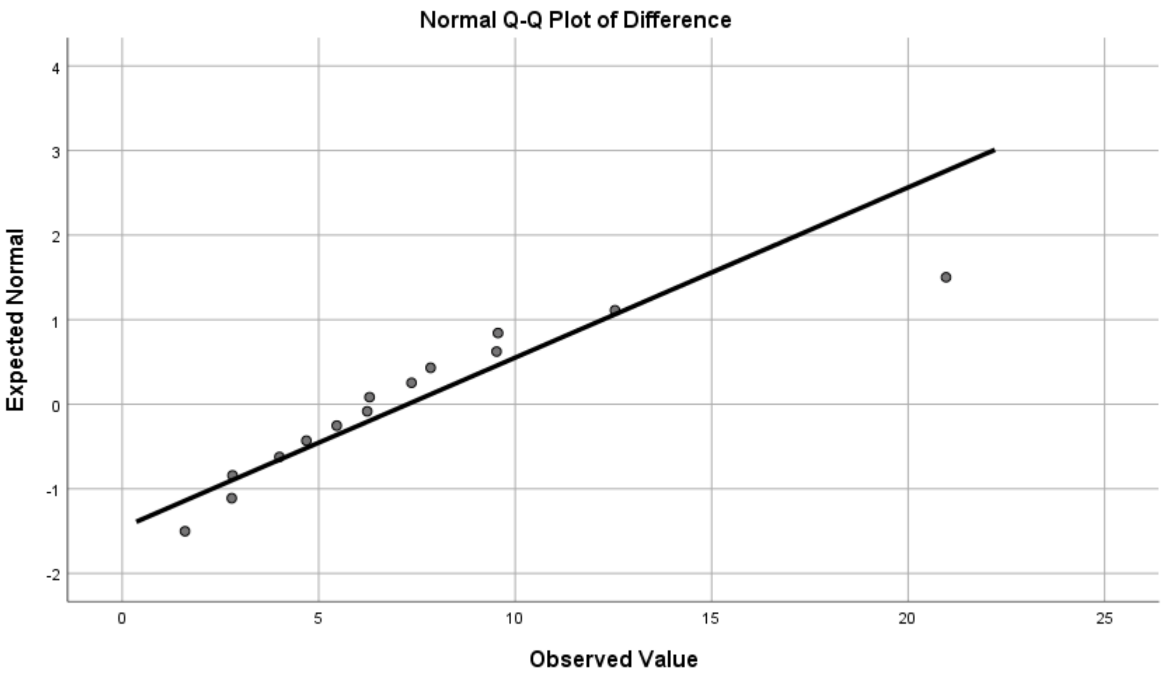


Figure 29: Normal Q-Q plot of difference of response time

5.5.3. Paired-Samples t-Test

Participants had higher reaction time during the uncommon response condition (M = 11.931 s, SD = 5.059 s) as opposed to the common response condition (M = 4.668 s, SD = 2.057 s).

Table 24: Paired sample statistics - Response time

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Avg.response_time[s] uncommon_response_condition	11,93057	14	5,058945	1,352060
	Avg.response_time[s] common_response_condition	4,66807	14	2,056997	,549756

According to paired-samples t-test the difference between the two experimental conditions was statistically significant $t(13) = 5.470$, $p < 0.0005$, Cohen's d = 1.462. The difference between common response condition and uncommon response condition was 7.263 s, 95% CI [4.394, 10.131] (SE = 1.328). In light of that, the null hypothesis asserting that the difference between the two conditions is equal to zero could be rejected.

Table 25: Paired samples t-test - Response time

Paired Samples Test

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	95% Confidence Interval of the Difference Upper			
Avg.response_time[s] uncommon_response_condition - Avg.response_time[s] common_response_condition	7,262500	4,968006	1,327755	4,394059	10,130941	5,470	13	,000

5.6. Appendix F

In the following pages the main steps followed to extract the brain activity measures are described in detail. Such steps were repeated for each subject of the study. The somehow complexity of the procedure was due to the recording software adopted, iMotions (2018), Version 7.0. Such software is a very good platform to manage the stimuli presentation and recording of data from multiple physiological sensors. However, it lacks advanced tools for EEG analysis.

5.6.1. Data Preparation

Data Exportation

EEG time-course voltage variations for each electrode was exported from iMotions software in text (.txt) file format for each respondent. Only the five-seconds long reference cross events and the idea generation periods were exported in order to reduce the file dimension and the computational power needed in the following analysis.

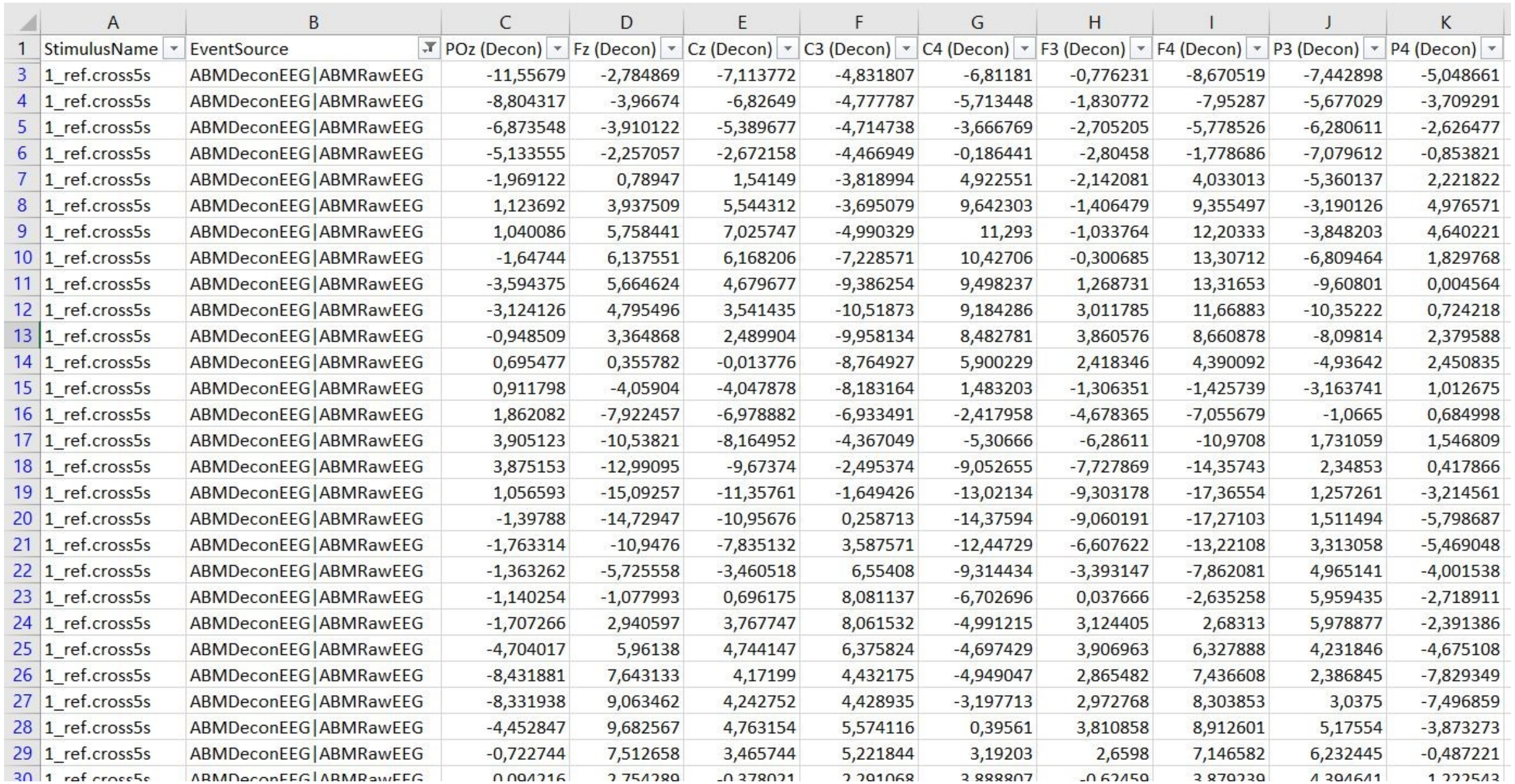
Each participant file was imported into Microsoft Excel through Excel Text Import Wizard and in advanced settings the decimal separator was set to decimal point. This last step was necessary because the Italian version of Excel does recognise points as thousand separators, whilst in the export (.txt) file the points are decimal separators. The file sequentially reports in the rows the EEG samples collected. Since sampling frequency of ABM B-Alert X10 is 256 Hz, on average the time between two samples is about 33 milliseconds. Each EEG sample belongs to an event that is specified in the StimulusName column. The file also contains other columns. EventSource column specifies the event that triggered the sample, i.e. the recording device source (e.g. EEG device, eye tracker, webcam device) or the user interaction with the keyboard. It should be noted that in such samples the values from the nearest sample appertaining to other event sources are often used to fill the empty columns reporting measures form those event sources. Timestamp column reports the elapsed time since the beginning of the experiment. Timestamp reports when iMotions software receives the data of the samples collected by the recording devices. Other columns reporting the time elapsed refer to the internal clock of the recording devices (such as Timesignal for the eye tracker's clock). The interval of few milliseconds between values contained in such columns and the values reported in the Timestamp column are due to transmission lags. Electrodes columns are labelled with the names of the nine electrodes position according to the 10-20 system. The electrodes columns report the electric potential in microvolts (μV) between the electrodes and the two digitally linked reference electrodes placed on the mastoids. There are two groups of electrodes columns: the first group reports the raw signal and the second one, "(Decon)" labelled, reports the decontaminated signal.

All the columns were removed from the file except for the columns containing the stimulus name, the event source and the nine electrodes decontaminated signals. The rows were filtered for the ABMDeconEEG|ABMRawEEG event source (Figure 30).

Data Decontamination

Eye blinking (EOG) and muscular contraction (EMG) can affect respectively the theta (4-8 Hz) and the beta (13-25 Hz) frequency bands (*B-alert live user manual*) and they are one of the artifacts sources affecting the potential fluctuations captured by the EEG device. Such signals do not reflect the phenomenon investigated, thus they are treated like noise and have to be excluded from the analysis. The artifacts-correction algorithm embedded in iMotions software was developed by

Advanced Brain Monitoring (ABM), the producer of the EEG recording device used in the experiment B-Alert X10. According to the producer (*B-alert live user manual*) electric potentials identified as spikes caused by artifacts are interpolated with the adjacent samples in order to delete the artifact effect. Another source of artifacts consists in electrodes saturation, that is due to galvanic voltages generated by the interaction between substances on the scalp (skin, sebum, sweat, conductive paste) and the electrode material (EEG info - impedance measurement.). The related excursion segments are not interpolated but replaced with zero values. EMG are not corrected by ABM algorithm. Since EMG does not affect alpha band, it was decided to carry on with automatically decontaminated data.



	A	B	C	D	E	F	G	H	I	J	K
1	StimulusName	EventSource	POz (Decon)	Fz (Decon)	Cz (Decon)	C3 (Decon)	C4 (Decon)	F3 (Decon)	F4 (Decon)	P3 (Decon)	P4 (Decon)
3	1_ref.cross5s	ABMDeconEEG|ABMRawEEG	-11,55679	-2,784869	-7,113772	-4,831807	-6,81181	-0,776231	-8,670519	-7,442898	-5,048661
4	1_ref.cross5s	ABMDeconEEG|ABMRawEEG	-8,804317	-3,96674	-6,82649	-4,777787	-5,713448	-1,830772	-7,95287	-5,677029	-3,709291
5	1_ref.cross5s	ABMDeconEEG|ABMRawEEG	-6,873548	-3,910122	-5,389677	-4,714738	-3,666769	-2,705205	-5,778526	-6,280611	-2,626477
6	1_ref.cross5s	ABMDeconEEG|ABMRawEEG	-5,133555	-2,257057	-2,672158	-4,466949	-0,186441	-2,80458	-1,778686	-7,079612	-0,853821
7	1_ref.cross5s	ABMDeconEEG|ABMRawEEG	-1,969122	0,78947	1,54149	-3,818994	4,922551	-2,142081	4,033013	-5,360137	2,221822
8	1_ref.cross5s	ABMDeconEEG|ABMRawEEG	1,123692	3,937509	5,544312	-3,695079	9,642303	-1,406479	9,355497	-3,190126	4,976571
9	1_ref.cross5s	ABMDeconEEG|ABMRawEEG	1,040086	5,758441	7,025747	-4,990329	11,293	-1,033764	12,20333	-3,848203	4,640221
10	1_ref.cross5s	ABMDeconEEG|ABMRawEEG	-1,64744	6,137551	6,168206	-7,228571	10,42706	-0,300685	13,30712	-6,809464	1,829768
11	1_ref.cross5s	ABMDeconEEG|ABMRawEEG	-3,594375	5,664624	4,679677	-9,386254	9,498237	1,268731	13,31653	-9,60801	0,004564
12	1_ref.cross5s	ABMDeconEEG|ABMRawEEG	-3,124126	4,795496	3,541435	-10,51873	9,184286	3,011785	11,66883	-10,35222	0,724218
13	1_ref.cross5s	ABMDeconEEG|ABMRawEEG	-0,948509	3,364868	2,489904	-9,958134	8,482781	3,860576	8,660878	-8,09814	2,379588
14	1_ref.cross5s	ABMDeconEEG|ABMRawEEG	0,695477	0,355782	-0,013776	-8,764927	5,900229	2,418346	4,390092	-4,93642	2,450835
15	1_ref.cross5s	ABMDeconEEG|ABMRawEEG	0,911798	-4,05904	-4,047878	-8,183164	1,483203	-1,306351	-1,425739	-3,163741	1,012675
16	1_ref.cross5s	ABMDeconEEG|ABMRawEEG	1,862082	-7,922457	-6,978882	-6,933491	-2,417958	-4,678365	-7,055679	-1,0665	0,684998
17	1_ref.cross5s	ABMDeconEEG|ABMRawEEG	3,905123	-10,53821	-8,164952	-4,367049	-5,30666	-6,28611	-10,9708	1,731059	1,546809
18	1_ref.cross5s	ABMDeconEEG|ABMRawEEG	3,875153	-12,99095	-9,67374	-2,495374	-9,052655	-7,727869	-14,35743	2,34853	0,417866
19	1_ref.cross5s	ABMDeconEEG|ABMRawEEG	1,056593	-15,09257	-11,35761	-1,649426	-13,02134	-9,303178	-17,36554	1,257261	-3,214561
20	1_ref.cross5s	ABMDeconEEG|ABMRawEEG	-1,39788	-14,72947	-10,95676	0,258713	-14,37594	-9,060191	-17,27103	1,511494	-5,798687
21	1_ref.cross5s	ABMDeconEEG|ABMRawEEG	-1,763314	-10,9476	-7,835132	3,587571	-12,44729	-6,607622	-13,22108	3,313058	-5,469048
22	1_ref.cross5s	ABMDeconEEG|ABMRawEEG	-1,363262	-5,725558	-3,460518	6,55408	-9,314434	-3,393147	-7,862081	4,965141	-4,001538
23	1_ref.cross5s	ABMDeconEEG|ABMRawEEG	-1,140254	-1,077993	0,696175	8,081137	-6,702696	0,037666	-2,635258	5,959435	-2,718911
24	1_ref.cross5s	ABMDeconEEG|ABMRawEEG	-1,707266	2,940597	3,767747	8,061532	-4,991215	3,124405	2,68313	5,978877	-2,391386
25	1_ref.cross5s	ABMDeconEEG|ABMRawEEG	-4,704017	5,96138	4,744147	6,375824	-4,697429	3,906963	6,327888	4,231846	-4,675108
26	1_ref.cross5s	ABMDeconEEG|ABMRawEEG	-8,431881	7,643133	4,17199	4,432175	-4,949047	2,865482	7,436608	2,386845	-7,829349
27	1_ref.cross5s	ABMDeconEEG|ABMRawEEG	-8,331938	9,063462	4,242752	4,428935	-3,197713	2,972768	8,303853	3,0375	-7,496859
28	1_ref.cross5s	ABMDeconEEG|ABMRawEEG	-4,452847	9,682567	4,763154	5,574116	0,39561	3,810858	8,912601	5,17554	-3,873273
29	1_ref.cross5s	ABMDeconEEG|ABMRawEEG	-0,722744	7,512658	3,465744	5,221844	3,19203	2,6598	7,146582	6,232445	-0,487221
30	1_ref.cross5s	ABMDeconEEG|ABMRawEEG	0,094216	2,754289	-0,378021	2,291068	3,888807	-0,62459	3,879239	4,394641	1,222543

Figure 30: Decontaminated potential in Excel - Subject 6

5.6.2. Power Spectral Density (PSD) Computation

iMotions software only provides log-transformed squared PSDs computed from electrodes raw data, i.e. from not decontaminated data. Furthermore, iMotions only employs ABM's standard PSD-computation algorithm (time windows of 1000 ms with 500 ms of overlap and rectangular windowing (*B-alert live user manual*)). For such reasons PSD were computed again by means of Cartool software by Denis Brunet (cartoolcommunity.unige.ch).

Creation of Cartool Input Files

Decontaminated time-course voltage fluctuations for all the nine electrodes were used to create the evoked potential input file (.eph) for Cartool EEG software. The first row of the file reports respectively the number of EEG channels (Poz, Fz, Cz, C3, C4, F3, F4, P3, P4), the number of samples contained in the file and the number of samples per second (256). Such file contains in its rows the sequence of EEG samples of the events exported from iMotions (Figure 31). The rows of the file do not contain any time nor event information related to the single samples. For such reason a marker file (.mrk) was created in order to mark each row of the input file with the correspondent stimulus name during the following analysis. The first and the second columns in the marker files report the first and the last sample marked with the event name, that is reported in the third column (Figure 32).

	A	B	C	D	E	F	G	H	I
1	9	57938	256						
2	-11,5568	-2,78487	-7,11377	-4,83181	-6,81181	-0,77623	-8,67052	-7,4429	-5,04866
3	-8,80432	-3,96674	-6,82649	-4,77779	-5,71345	-1,83077	-7,95287	-5,67703	-3,70929
4	-6,87355	-3,91012	-5,38968	-4,71474	-3,66677	-2,70521	-5,77853	-6,28061	-2,62648
5	-5,13356	-2,25706	-2,67216	-4,46695	-0,18644	-2,80458	-1,77869	-7,07961	-0,85382
6	-1,96912	0,78947	1,54149	-3,81899	4,922551	-2,14208	4,033013	-5,36014	2,221822
7	1,123692	3,937509	5,544312	-3,69508	9,642303	-1,40648	9,355497	-3,19013	4,976571
8	1,040086	5,758441	7,025747	-4,99033	11,293	-1,03376	12,20333	-3,8482	4,640221
9	-1,64744	6,137551	6,168206	-7,22857	10,42706	-0,30069	13,30712	-6,80946	1,829768
10	-3,59438	5,664624	4,679677	-9,38625	9,498237	1,268731	13,31653	-9,60801	0,004564
11	-3,12413	4,795496	3,541435	-10,5187	9,184286	3,011785	11,66883	-10,3522	0,724218
12	-0,94851	3,364868	2,489904	-9,95813	8,482781	3,860576	8,660878	-8,09814	2,379588
13	0,695477	0,355782	-0,01378	-8,76493	5,900229	2,418346	4,390092	-4,93642	2,450835
14	0,911798	-4,05904	-4,04788	-8,18316	1,483203	-1,30635	-1,42574	-3,16374	1,012675
15	1,862082	-7,92246	-6,97888	-6,93349	-2,41796	-4,67837	-7,05568	-1,0665	0,684998
16	3,905123	-10,5382	-8,16495	-4,36705	-5,30666	-6,28611	-10,9708	1,731059	1,546809
17	3,875153	-12,991	-9,67374	-2,49537	-9,05266	-7,72787	-14,3574	2,34853	0,417866
18	1,056593	-15,0926	-11,3576	-1,64943	-13,0213	-9,30318	-17,3655	1,257261	-3,21456
19	-1,39788	-14,7295	-10,9568	0,258713	-14,3759	-9,06019	-17,271	1,511494	-5,79869
20	-1,76331	-10,9476	-7,83513	3,587571	-12,4473	-6,60762	-13,2211	3,313058	-5,46905
21	-1,36326	-5,72556	-3,46052	6,55408	-9,31443	-3,39315	-7,86208	4,965141	-4,00154
22	-1,14025	-1,07799	0,696175	8,081137	-6,7027	0,037666	-2,63526	5,959435	-2,71891
23	-1,70727	2,940597	3,767747	8,061532	-4,99122	3,124405	2,68313	5,978877	-2,39139
24	-4,70402	5,96138	4,744147	6,375824	-4,69743	3,906963	6,327888	4,231846	-4,67511
25	-8,43188	7,643133	4,17199	4,432175	-4,94905	2,865482	7,436608	2,386845	-7,82935
26	-8,33194	9,063462	4,242752	4,428935	-3,19771	2,972768	8,303853	3,0375	-7,49686
27	-4,45285	9,682567	4,763154	5,574116	0,39561	3,810858	8,912601	5,17554	-3,87327
28	-0,72274	7,512658	3,465744	5,221844	3,19203	2,6598	7,146582	6,232445	-0,48722
29	0,094216	2,754289	-0,37802	2,291068	3,888807	-0,62459	3,879239	4,394641	1,222543

Figure 31: (.eph) File overview - Subject 6

In the following screenshot of the marker (.mrk) file some rows were hidden to show the next event of the sequence. In each row the numbers in the two columns are paired in order to mark each single EEG sample in the (.eph) file. The number of rows in the marker file corresponds to the number of samples in the evoked potential (.eph) file.

	A	B	C
1	TL02		
2	0	0	"1_ref.cross5s"
3	1	1	"1_ref.cross5s"
4	2	2	"1_ref.cross5s"
5	3	3	"1_ref.cross5s"
6	4	4	"1_ref.cross5s"
7	5	5	"1_ref.cross5s"
8	6	6	"1_ref.cross5s"
9	7	7	"1_ref.cross5s"
10	8	8	"1_ref.cross5s"
11	9	9	"1_ref.cross5s"
12	10	10	"1_ref.cross5s"
1493	1491	1491	"book"
1494	1492	1492	"book"
1495	1493	1493	"book"
1496	1494	1494	"book"
1497	1495	1495	"book"
1498	1496	1496	"book"
1499	1497	1497	"book"
1500	1498	1498	"book"

Figure 32: (.mrk) File overview - Subject 6

Short-Term Fast Fourier Transform

Data collected by the EEG device are voltage fluctuations over time, i.e. signal is represented in the time domain. According to Fourier's theorem any waveform in the time domain can be represented by the weighted sum of sines and cosines of different amplitudes and frequencies. Time domain voltage signal can be deconstructed in the frequency domain trough a Fourier Transform, which breaks the signal down into sine waves of different frequencies and amplitudes. Because the signal collected by the EEG device is discrete, Fast Fourier Transform is adopted, which is an optimized implementation of a discrete Fourier transform. Discrete Fourier transform generates discrete frequency domain components also known as bins. Deconstructing the signal in the frequency domain enables to acknowledge the amount of potential existing in different frequencies of the signal analysed. Short-Term Fourier Transform (STFFT), also known as short-time fast Fourier transform, divides the time signal to be analysed in equally long segments (windows) and then it applies the fast Fourier transform separately on each segment. Windows can overlap and be averaged. From the signal analysed STFFT generates complex numbers containing magnitude and phase information for each frequency bin and for each time window (Wikipedia contributors,). Fast Fourier transform assumes that the time window analysed contains one entire period of the signal, but this is not actually true. The windows truncate the waveform and this interruption is interpreted by the Fourier transform as a sharp transition in the signal. Such artificial discontinuities are thus recorded as high frequency components not existing in the original signal. This phenomenon is known as spectral leakage. In order to minimize this effect, a windowing function can be employed. Windowing consists in gradually reducing the amplitude of the signal at the edges of the windows, in order to avoid sharp transactions (*Understanding FFTs and windowing,* 2016). Hanning is one of the most versatile types of windowing. This a window function is characterized by sinusoidal shape (bell shape) that reaches zero amplitude in the edges and thus completely eliminates discontinuity. The application of no windowing function is often referred as rectangular windowing in literature.

Power Spectral Density Coefficient In order to obtain the Power Spectral Density coefficient for a specific frequency band, the magnitude component of the frequency band of interest, obtained by the STFFT, is squared and then log-transformed. PSD is technically unit-less, but it is often expressed in $\log_{10}(\mu V^2)$.

Processing PSD

For each respondent the evoked potential file (.eph) and electrodes setup file (.els) were imported in Cartool software for EEG analysis. Electrodes setup file associates to the columns of the evoked potential file the information about the electrodes positions and names. Such file, specific for ABM B-Alert X10 device, was downloaded from iMotions's Help Center. The correspondent marker file (.mrk) was imported as well (Markers > Import markers form another file). Matching between the markers and the EEG sequence took a few minutes of elaboration. Then, data were band-pass filtered applying a high-pass filter at 0.5 Hz and a low-pass filter at 45 Hz (Figure 33).

Then, power spectral density was calculated by way of a Short-Term Fast Fourier Transform (Tools > Frequency > Frequency Analysis of EEG Files) (Figure 34).

The settings Short-term fast Fourier transform was applied to the data for 8-12 Hz frequency band. Windows size for the current analysis was 1000 ms (256 samples). Windows step was set to 25% (250 ms) and no averaging of time windows was adopted. Hanning windowing function was employed. The output power was squared but not log-transformed.

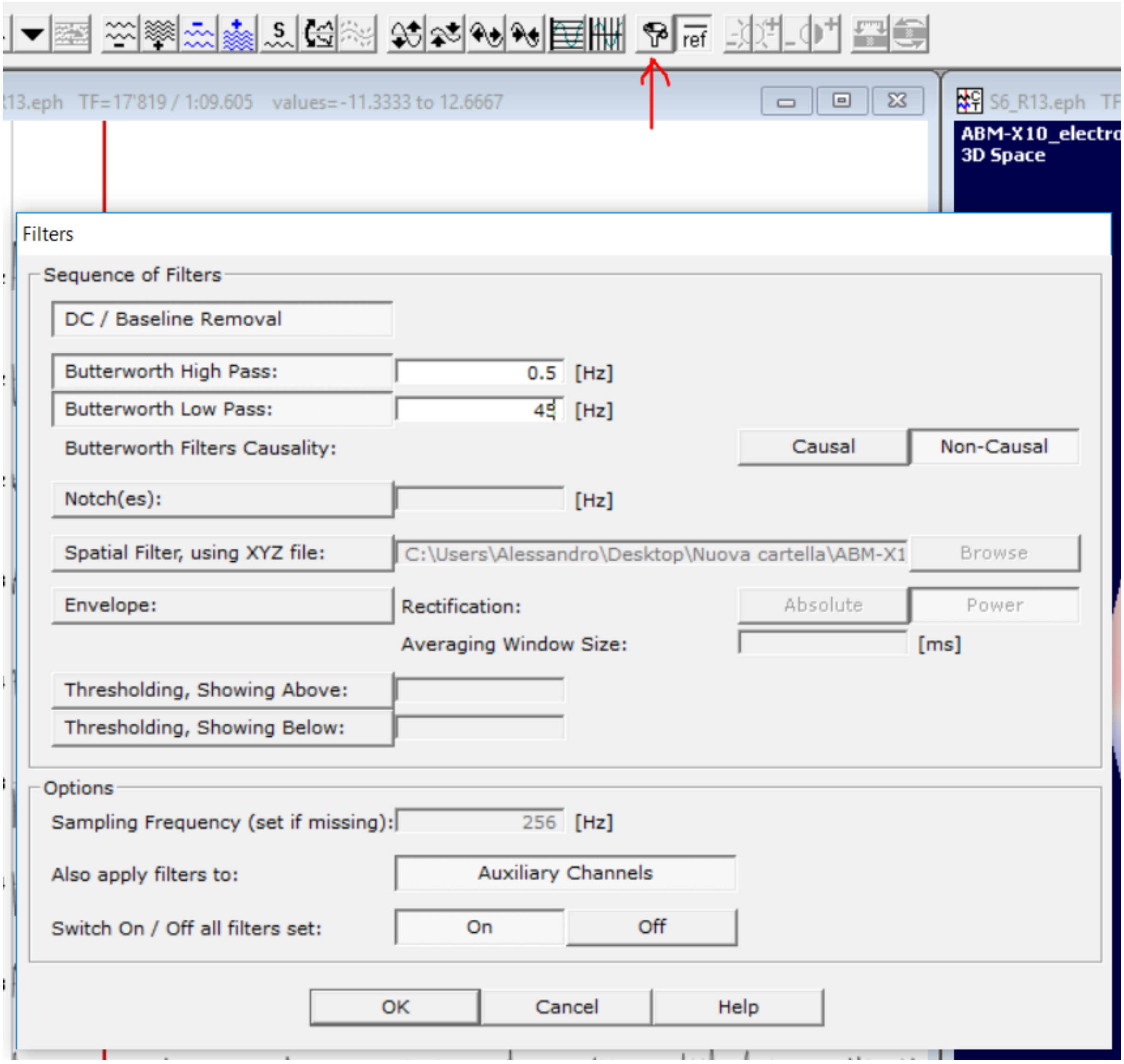


Figure 33: Cartool - Filters window

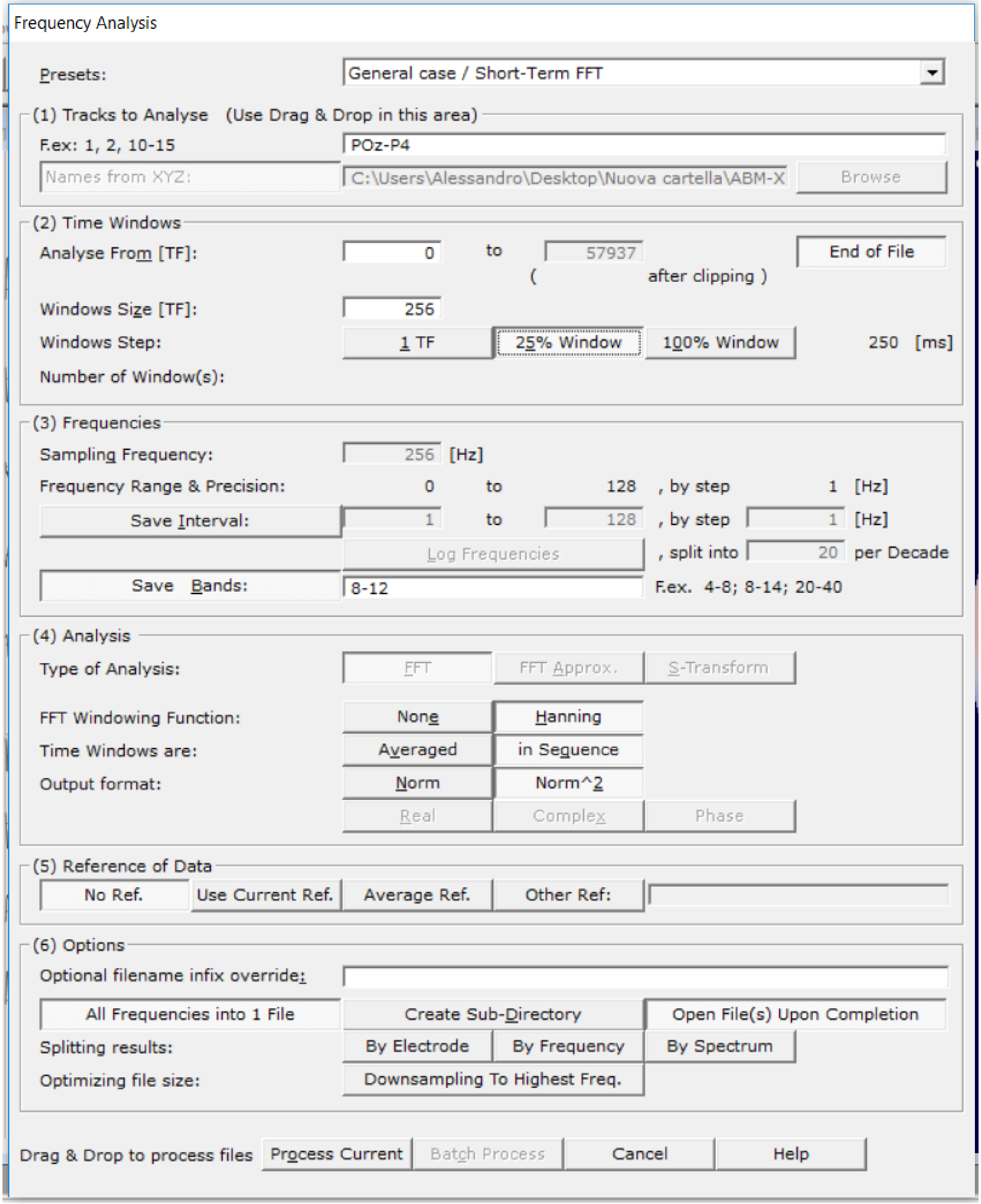


Figure 34: Cartool - Frequency analysis Wwndow

5.6.3. Power Spectral Density (PSD) Elaboration

Exporting PSD Data

Power spectral density file was exported in text (.txt) format (Tools > EEG and Tracks > Exporting/Reprocessing Tracks).

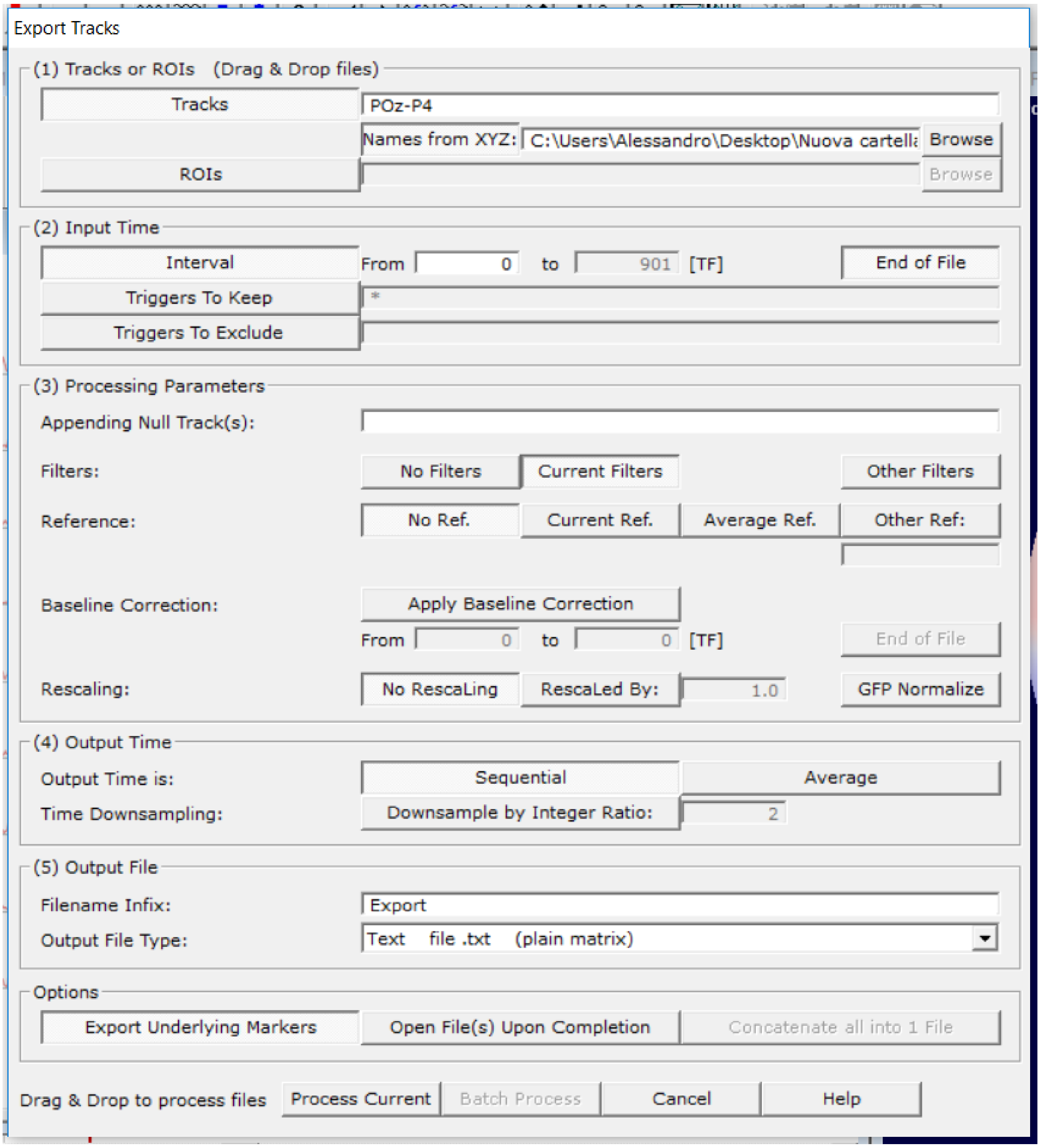


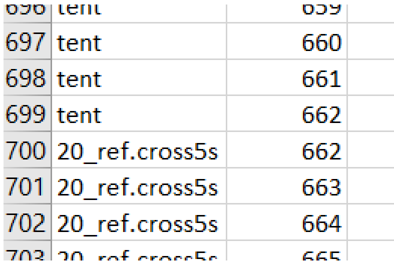
Figure 35: Cartool - Export tracks window

PSD Data Elaboration

Cartool generated a text (.txt) file containing the power spectral density (not log-transformed) and a marker (.mrk) file associated to it.

The PSD coefficients reported in each row of the PSD file represented 250 ms of power estimation in the alpha band. More in detail, one PSD row represented 250 ms of data because FFT was calculated on one second long sliding windows, with 25% window step (250 ms). The marker file was converted to text file (.txt) and both files were imported to Excel.

The rows in the marker file columns contained the identification number and the stimulus name related to the corresponding rows in the PSD file. When passing from one event to the next, the last row of the previous event and the first row of the next event could share the same identification number. In such circumstance the PSD row corresponding to that identification number was computed using potential samples belonging to two different consecutive events in the evoked potential (.eph) file (each PSD row was generated from 256 samples of the signal). PSD rows corresponding to those identification markers were excluded from the analysis, because the two events were not actually consecutive.



696	tent	659
697	tent	660
698	tent	661
699	tent	662
700	20_ref.cross5s	662
701	20_ref.cross5s	663
702	20_ref.cross5s	664
703	20_ref.cross5s	665

Figure 36: 662th PSD sample shared between two stimuli

Furthermore, the remaining first two and last two PSD samples of each event were removed from the analysis, in order to exclude the first 500 ms after the stimulus presentation and the last 500 ms before the ending of the stimulus. Some ideas were generated in very short time (about one second) and sometimes no PSD data survived after excluding these PSD rows. In the following screenshot (Figure 37) five samples are missing between “1_ref.cross5s” and “rope” stimuli: the PSD row shared between the two stimuli was deleted and the last two samples (500 ms) of “1_ref.cross5s” and the first two samples (500 ms) of “rope” were deleted as well.

	A	B	C	D	E	F	G	H	I	J	K	L
1	Stimulus	N.1	N.2	POz	Fz	Cz	C3	C4	F3	F4	P3	P4
2	1_ref.cross5s	2	2	40,39565	81,00079	76,161	101,3393	48,72898	56,82528	46,0418	75,81013	53,35787
3	1_ref.cross5s	3	3	102,3128	109,0092	157,384	132,3171	109,2334	79,40203	99,6039	100,8275	116,3762
4	1_ref.cross5s	4	4	184,9093	75,15005	102,5318	38,46113	67,11662	51,9673	52,12561	43,53002	95,40141
5	1_ref.cross5s	5	5	351,9002	124,1158	141,4345	20,66718	103,4669	75,35036	72,72055	44,46748	141,6288
6	1_ref.cross5s	6	6	168,1889	98,87185	98,43644	35,50144	103,3253	86,15139	70,07046	57,23533	99,295
7	1_ref.cross5s	7	7	321,7091	64,88206	66,4728	106,6204	67,39436	34,9727	117,0968	213,9547	76,87325
8	1_ref.cross5s	8	8	358,4564	69,38731	86,83881	76,97395	73,18037	17,40027	72,8955	136,6908	146,2197
9	1_ref.cross5s	9	9	115,2201	137,1777	176,6378	54,73588	71,56871	23,52054	57,38425	65,31033	131,7733
10	1_ref.cross5s	10	10	77,67299	135,6743	160,3678	49,67321	103,1643	38,55963	63,37176	77,37956	98,21783
11	1_ref.cross5s	11	11	100,3107	102,0707	84,07185	53,19648	97,19511	76,59615	120,6629	113,1522	109,4274
12	1_ref.cross5s	12	12	44,09896	57,29889	24,75128	21,24488	103,3016	44,12962	38,07609	34,63087	72,42432
13	1_ref.cross5s	13	13	49,43042	102,1899	66,78291	34,36525	113,0875	51,61723	53,35381	32,15846	41,2001
14	1_ref.cross5s	14	14	46,33758	223,8368	135,4177	114,7891	113,7521	147,4873	92,80377	30,0971	39,44161
15	1_ref.cross5s	15	15	10,298	160,5204	95,88083	111,2172	35,86923	134,5453	67,50223	20,73704	40,47433
16	1_ref.cross5s	16	16	66,20669	15,92387	35,75654	19,20152	37,89111	18,16712	29,54429	41,46852	52,97988
17	1_ref.cross5s	17	17	310,3282	4,931125	32,40385	15,22497	24,44384	10,12794	16,57762	64,37092	97,7307
18	rope	23	23	12,34121	45,1945	30,70896	27,96339	68,83802	31,13837	22,65822	18,19928	37,73843
19	rope	24	24	11,02124	96,04308	70,36079	29,64212	46,80054	22,65003	46,78193	14,73399	26,41921
20	rope	25	25	66,31041	88,55981	30,25097	31,24386	21,25165	35,13793	64,22234	21,30184	64,71913
21	rope	26	26	75,79383	109,9005	38,25188	33,65957	12,80897	42,50004	76,4826	23,38496	42,01714
22	rope	27	27	49,4559	39,44701	36,57337	32,3597	21,82094	18,46316	19,72077	39,9383	49,09775
23	rope	28	28	35,6793	57,49125	67,21366	36,49049	40,65782	33,83275	27,69175	49,70139	66,94519
24	rope	29	29	91,53922	91,48998	41,98408	37,78642	66,86332	44,79153	52,6196	31,43599	102,3008
25	rope	30	30	163,849	135,7437	66,53867	125,2306	72,9793	128,2335	50,58284	61,70238	126,7984
26	rope	31	31	114,8844	71,40515	71,53642	127,8967	28,01512	75,74255	19,58805	107,6651	48,16587
27	rope	32	32	61,87222	64,34801	33,43713	35,96708	10,29104	48,52201	38,36732	56,86032	28,88336

Figure 37: Remaining PSD samples

The remaining PSD values were horizontally averaged (across time) for each stimulus and each electrode through a pivot table. In This way for each stimulus only one average PSD value for each electrode remained.

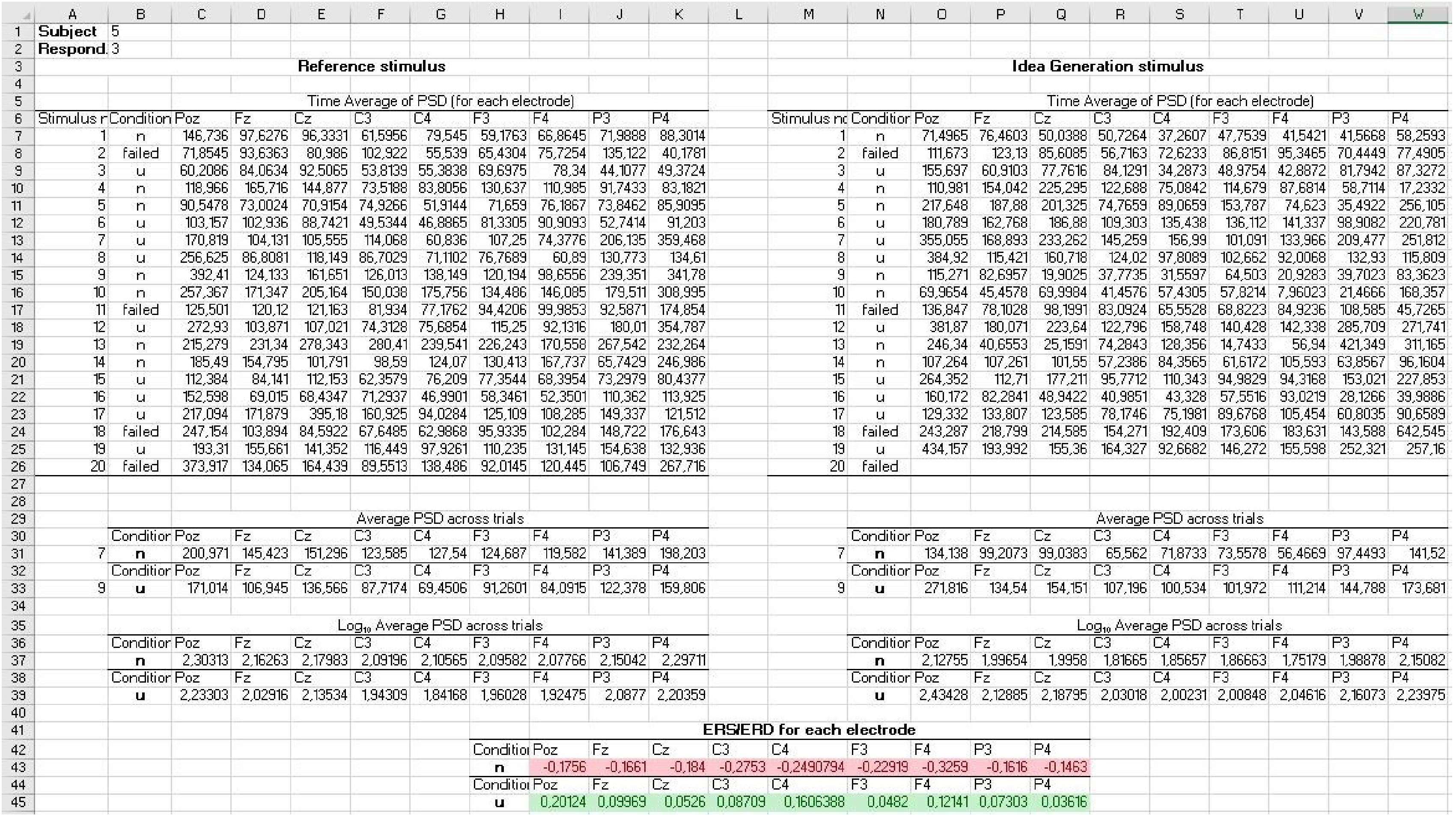
3	Events	Mean POz	Mean Fz	Mean Cz	Mean C3	Mean C4	Mean F3	Mean F4	Mean P3	Mean P4
4	1_ref.cross5s	146,7359954	97,62755007	96,33311928	61,5955531	79,54495954	59,17626185	66,86445558	71,98880661	88,30136346
5	10_ref.cross5s	257,3674789	171,3466263	205,1639351	150,0382115	175,7564351	134,4856635	146,0845467	179,5113541	308,9945507
6	11_ref.cross5s	125,5012767	120,1197118	121,163467	81,93399837	77,1761893	94,4206243	99,98525428	92,58714981	174,8538389
7	12_ref.cross5s	272,9299725	103,8711864	107,0211391	74,31279386	75,68541439	115,2498604	92,13157271	180,0099412	354,7870906
8	13_ref.cross5s	215,2791448	231,3398992	278,3433629	280,4103546	239,5412587	226,2428256	170,5575264	267,5417987	232,2642815
9	14_ref.cross5s	185,4895098	154,7946111	101,7906631	98,58997191	124,0702413	130,4130372	167,7370829	65,74287283	246,9863497
10	15_ref.cross5s	112,3838056	84,14095025	112,153446	62,35785243	76,20899365	77,35440662	68,39535356	73,29791056	80,43769302
11	16_ref.cross5s	152,5982424	69,01497561	68,4346831	71,29367147	46,99007351	58,34614055	52,35005511	110,3623659	113,9249744
12	17_ref.cross5s	217,0943424	171,8789881	395,1798804	160,9245569	94,02837385	125,1091047	108,2848878	149,3366301	121,5115179
13	18_ref.cross5s	247,1535676	103,8938588	84,59223482	67,64850224	62,98679044	95,93346617	102,2841795	148,721987	176,6428558
14	19_ref.cross5s	193,3099661	155,6612602	141,351696	116,4489859	97,92610259	110,235055	131,1445819	154,6378157	132,9358026
15	2_ref.cross5s	71,85453707	93,63631796	80,98595275	102,9218539	55,53895847	65,43039628	75,72538606	135,1219409	40,17812731
16	20_ref.cross5s	373,9171967	134,0653509	164,4385793	89,55130946	138,4861029	92,01446738	120,4448943	106,7487465	267,716047
17	3_ref.cross5s	60,20860839	84,06336366	92,50647999	53,81385487	55,38379484	69,69748426	78,3400393	44,10774725	49,37240893
18	4_ref.cross5s	118,9661727	165,7161892	144,8767489	73,51878716	83,80560545	130,6365568	110,9851378	91,74325333	83,18207092
19	5_ref.cross5s	90,54776763	73,00243326	70,91538137	74,92657191	51,91444626	71,65904719	76,18674557	73,84616037	85,90945562
20	6_ref.cross5s	103,1568522	102,9360583	88,74210917	49,53436259	46,88649586	81,33048902	90,90928064	52,74139934	91,20303129
21	7_ref.cross5s	170,8188477	104,131262	105,5553983	114,0680496	60,83604177	107,2495216	74,37756767	206,1345383	359,4679125
22	8_ref.cross5s	256,6254759	86,8081073	118,149056	86,70285073	71,11022835	76,76888683	60,89000117	130,7725205	134,610139
23	9_ref.cross5s	392,4103533	124,1327484	161,6510286	126,0132684	138,1487018	120,1943575	98,65558934	239,3514984	341,779641
24	axe	246,3398132	40,6552925	25,1591377	74,2842636	128,3558807	14,7432899	56,9399834	421,3491821	311,1654358
25	ball	264,3517096	112,7096948	177,2111796	95,77118769	110,3434288	94,98291416	94,3167868	153,0211429	227,8534316
26	basket	160,1716309	82,2840729	48,94224925	40,9851284	43,32798955	57,55163005	93,02185055	28,12662315	39,9885845
27	bed	129,3318882	133,8070891	123,5847306	78,17464674	75,19811678	89,67678953	105,4540572	60,80350125	90,65886309
28	book	110,980835	154,0419006	225,294693	122,6880264	75,0842285	114,6790009	87,6814346	58,7113991	17,2332039

Figure 38: PSD mean values - Subject 5

Calculating Event-Related De-\Synchronization

For each subject and response condition the PSDs were averaged across trials, then log-transformed. Log-transformed average PSD collected during idea generation was subtracted to log-transformed average PSD collected during the reference cross stimulus for each electrode. Increases in power corresponded to Event-Related Synchronization (ERS) of the underlying neural population in the alpha band, while decrease in power corresponded to Event-Related Desynchronization (ERD) in the alpha band (Da Silva & Pfurtscheller, 1999).

$$ERS \backslash ERD = \log_{10} \overline{PSD}_{n/u} - \log_{10} \overline{PSD}_{ref}$$



Subject	5
Respond.	3

Reference stimulus

Time Average of PSD (for each electrode)

Stimulus r	Condition	Poz	Fz	Cz	C3	C4	F3	F4	P3	P4
1	n	146,736	97,6276	96,3331	61,5956	79,545	59,1763	66,8645	71,9888	88,3014
2	failed	71,8545	93,6363	80,986	102,922	55,539	65,4304	75,7254	135,122	40,1781
3	u	60,2086	84,0634	92,5065	53,8139	55,3838	69,6975	78,34	44,1077	49,3724
4	n	118,966	165,716	144,877	73,5188	83,8056	130,637	110,985	91,7433	83,1821
5	n	90,5478	73,0024	70,9154	74,9266	51,9144	71,659	76,1867	73,8462	85,9095
6	u	103,157	102,936	88,7421	49,5344	46,8865	81,3305	90,9093	52,7414	91,203
7	u	170,819	104,131	105,555	114,068	60,836	107,25	74,3776	206,135	359,468
8	u	256,625	86,8081	118,149	86,7029	71,1102	76,7689	60,89	130,773	134,61
9	n	392,41	124,133	161,651	126,013	138,149	120,194	98,6556	239,351	341,78
10	n	257,367	171,347	205,164	150,038	175,756	134,486	146,085	179,511	308,995
11	failed	125,501	120,12	121,163	81,934	77,1762	94,4206	99,9853	92,5871	174,854
12	u	272,93	103,871	107,021	74,3128	75,6854	115,25	92,1316	180,01	354,787
13	n	215,279	231,34	278,343	280,41	239,541	226,243	170,558	267,542	232,264
14	n	185,49	154,795	101,791	98,59	124,07	130,413	167,737	65,7429	246,986
15	u	112,384	84,141	112,153	62,3579	76,209	77,3544	68,3954	73,2979	80,4377
16	u	152,598	69,015	68,4347	71,2937	46,9901	58,3461	52,3501	110,362	113,925
17	u	217,094	171,879	395,18	160,925	94,0284	125,109	108,285	149,337	121,512
18	failed	247,154	103,894	84,5922	67,6485	62,9868	95,9335	102,284	148,722	176,643
19	u	193,31	155,661	141,352	116,449	97,9261	110,235	131,145	154,638	132,936
20	failed	373,917	134,065	164,439	89,5513	138,486	92,0145	120,445	106,749	267,716

Average PSD across trials

	Conditior	Poz	Fz	Cz	C3	C4	F3	F4	P3	P4
7	**n**	200,971	145,423	151,296	123,585	127,54	124,687	119,582	141,389	198,203
	Conditior	Poz	Fz	Cz	C3	C4	F3	F4	P3	P4
9	**u**	171,014	106,945	136,566	87,7174	69,4506	91,2601	84,0915	122,378	159,806

Log_{10} Average PSD across trials

Conditior	Poz	Fz	Cz	C3	C4	F3	F4	P3	P4
n	2,30313	2,16263	2,17983	2,09196	2,10565	2,09582	2,07766	2,15042	2,29711
Conditior	Poz	Fz	Cz	C3	C4	F3	F4	P3	P4
u	2,23303	2,02916	2,13534	1,94309	1,84168	1,96028	1,92475	2,0877	2,20359

Idea Generation stimulus

Time Average of PSD (for each electrode)

Stimulus nc	Conditior	Poz	Fz	Cz	C3	C4	F3	F4	P3	P4
1	n	71,4965	76,4603	50,0388	50,7264	37,2607	47,7539	41,5421	41,5668	58,2593
2	failed	111,673	123,13	85,6085	56,7163	72,6233	86,8151	95,3465	70,4449	77,4905
3	u	155,697	60,9103	77,7616	84,1291	34,2873	48,9754	42,8872	81,7942	87,3272
4	n	110,981	154,042	225,295	122,688	75,0842	114,679	87,6814	58,7114	17,2332
5	n	217,648	187,88	201,325	74,7659	89,0659	153,787	74,623	35,4922	256,105
6	u	180,789	162,768	186,88	109,303	135,438	136,112	141,337	98,9082	220,781
7	u	355,055	168,893	233,262	145,259	156,99	101,091	133,966	209,477	251,812
8	u	384,92	115,421	160,718	124,02	97,8089	102,662	92,0068	132,93	115,809
9	n	115,271	82,6957	19,9025	37,7735	31,5597	64,503	20,9283	39,7023	83,3623
10	n	69,9654	45,4578	69,9984	41,4576	57,4305	57,8214	7,96023	21,4666	168,357
11	failed	136,847	78,1028	98,1991	83,0924	65,5528	68,8223	84,9236	108,585	45,7265
12	u	381,87	180,071	223,64	122,796	158,748	140,428	142,338	285,709	271,741
13	n	246,34	40,6553	25,1591	74,2843	128,356	14,7433	56,94	421,349	311,165
14	n	107,264	107,261	101,55	57,2386	84,3565	61,6172	105,593	63,8567	96,1604
15	u	264,352	112,71	177,211	95,7712	110,343	94,9829	94,3168	153,021	227,853
16	u	160,172	82,2841	48,9422	40,9851	43,328	57,5516	93,0219	28,1266	39,9886
17	u	129,332	133,807	123,585	78,1746	75,1981	89,6768	105,454	60,8035	90,6589
18	failed	243,287	218,799	214,585	154,271	192,409	173,606	183,631	143,588	642,545
19	u	434,157	193,992	155,36	164,327	92,6682	146,272	155,598	252,321	257,16
20	failed									

Average PSD across trials

	Conditior	Poz	Fz	Cz	C3	C4	F3	F4	P3	P4
7	**n**	134,138	99,2073	99,0383	65,562	71,8733	73,5578	56,4669	97,4493	141,52
	Conditior	Poz	Fz	Cz	C3	C4	F3	F4	P3	P4
9	**u**	271,816	134,54	154,151	107,196	100,534	101,972	111,214	144,788	173,681

Log_{10} Average PSD across trials

Conditior	Poz	Fz	Cz	C3	C4	F3	F4	P3	P4
n	2,12755	1,99654	1,9958	1,81665	1,85657	1,86663	1,75179	1,98878	2,15082
Conditior	Poz	Fz	Cz	C3	C4	F3	F4	P3	P4
u	2,43428	2,12885	2,18795	2,03018	2,00231	2,00848	2,04616	2,16073	2,23975

ERS/ERD for each electrode

Conditior	Poz	Fz	Cz	C3	C4	F3	F4	P3	P4
n	-0,1756	-0,1661	-0,184	-0,2753	-0,2490794	-0,22919	-0,3259	-0,1616	-0,1463
Conditior	Poz	Fz	Cz	C3	C4	F3	F4	P3	P4
u	0,20124	0,09969	0,0526	0,08709	0,1606388	0,0482	0,12141	0,07303	0,03616

Figure 39: Event-Related De-\Synchronization - Subject 5

All the operations above described were repeated for each subject, until ERS/ERD measures were defined for each subject and each condition (Table 26 and Table 27).

Table 26: ERS/ERD during common response condition

Subject	F4	C4	P4	F3	C3	P3
1	0,0657	0,0035	-0,0725	0,0371	-0,0427	-0,1438
2	-0,0143	0,0212	-0,0730	-0,0262	-0,0125	-0,0205
3	0,0339	0,0379	-0,0122	-0,0739	-0,0857	-0,0645
4	-0,0293	-0,0283	0,0633	-0,0686	-0,0714	-0,0608
5	-0,3259	-0,2491	-0,1463	-0,2292	-0,2753	-0,1616
6	0,0225	0,0009	0,0772	-0,0022	0,0575	0,1077
7	-0,0197	0,0044	0,0695	0,0359	-0,0189	-0,0907
8	-0,0223	-0,1143	-0,0699	-0,0608	-0,0242	0,0569
9	0,0784	0,0271	-0,0861	0,1381	0,0963	0,0471
10	-0,1183	-0,0252	0,1686	-0,1163	0,0129	0,0113
11	0,0394	0,1498	0,2915	0,0387	0,1197	0,1929
12	-0,0465	0,0273	-0,0244	0,0025	0,0880	0,1353
13	0,0730	0,0589	0,0873	0,0220	0,0502	0,1783
14	-0,1275	-0,1763	-0,2800	-0,0466	0,0246	0,1043

Table 27: ERS/ERD during uncommon response condition

Subject	F4	C4	P4	F3	C3	P3
1	-0,0265	-0,0341	-0,0723	0,0180	-0,0168	-0,1070
2	-0,0406	-0,0786	-0,0141	-0,0708	-0,0629	-0,0019
3	-0,0487	-0,0154	-0,0185	-0,0241	0,0141	-0,0104
4	-0,0478	-0,0406	0,0909	-0,0656	-0,0739	0,0092
5	0,1214	0,1606	0,0362	0,0482	0,0871	0,0730
6	-0,0241	0,0608	0,0867	-0,1031	0,0211	0,0235
7	-0,0012	0,0113	0,0058	0,0225	0,0278	0,0528
8	-0,0065	-0,0273	-0,0200	-0,0094	-0,0229	-0,0336
9	0,0728	0,0281	0,0224	0,0381	0,0370	0,0050
10	-0,0325	-0,0116	0,0422	0,0478	0,0900	0,1250
11	0,0941	0,0871	0,2010	0,0922	0,0412	0,0715
12	-0,0295	-0,0488	0,0119	-0,0618	-0,0084	-0,0457
13	0,0150	0,0502	0,0423	0,0511	0,0260	0,0336
14	0,0490	0,0793	0,1133	0,0828	0,1523	0,2621

5.6.4. EEG Data Quality

Quality of the raw EEG data collected as assessed by means of GETDATAQUALITY command in ABM LabX software, version 04.01.00.00.

Table 28: Average EEG data quality per electrode

Channel	Artifact (%)	EMG (%)	Loss (%)	GoodData (%)
POZ	0,32	3,28	0,00	96,69
FZ	0,34	3,28	0,00	96,71
CZ	0,36	3,18	0,00	96,81
C3	1,03	5,82	0,00	94,07
C4	1,33	5,85	0,00	94,05
F3	0,78	4,97	0,00	94,95
F4	0,80	4,82	0,00	95,09
P3	0,51	4,43	0,00	95,55
P4	0,57	4,87	0,00	95,13

Table 29: Average EEG data quality per subject

Subject	Artifact (%)	EMG (%)	Loss (%)	GoodData (%)
1	0,34	1,25	0,00	98,75
2	0,20	0,36	0,00	99,64
3	1,08	9,36	0,00	90,49
4	0,28	0,37	0,00	99,63
5	1,05	2,26	0,00	97,51
6	0,20	0,31	0,00	99,69
7	0,69	25,74	0,00	74,16
8	0,15	0,27	0,00	99,73
9	1,94	4,31	0,00	95,65
10	0,38	0,87	0,00	99,08
11	0,77	1,22	0,00	98,76
12	1,38	14,85	0,00	85,15
13	0,36	1,01	0,00	98,97
14	0,58	0,85	0,00	99,08
Average	0,67	4,50	0,00	95,45

5.7. Appendix G

The present appendix reports the ANOVA outputs of EEG analysis conducted on the entire sample of 14 subjects.

Three-way within-subjects Factorial Analysis of Variance for repeated measures was employed for the statistical analysis to test the statistical significance of the mean differences emerged among the response conditions and the different regions of the scalp. The three within-subject factors are Condition (common, uncommon response), Hemisphere (right, left) and Area (frontal, central, parietal). Frontal area referred to F3 and F4 electrodes, central area to C3 and C4, parietal area to P3 and P4. Left hemisphere referred to electrodes with odd numbers and right hemisphere to electrodes with even numbers. Midline electrodes (Fz, Cz, POz) were not included in the analysis in order to assess the difference in electric potential between the two hemispheres.

5.7.1. SPSS Input Data

	n_r_f	n_r_c	n_r_p	n_l_f	n_l_c	n_l_p	u_r_f	u_r_c	u_r_p	u_l_f	u_l_c	u_l_p
1	,0657	,0035	-,0725	,0371	-,0427	-,1438	-,0265	-,0341	-,0723	,0180	-,0168	-,1070
2	-,0143	,0212	-,0730	-,0262	-,0125	-,0205	-,0406	-,0786	-,0141	-,0708	-,0629	-,0019
3	,0339	,0379	-,0122	-,0739	-,0857	-,0645	-,0487	-,0154	-,0185	-,0241	,0141	-,0104
4	-,0293	-,0283	,0633	-,0686	-,0714	-,0608	-,0478	-,0406	,0909	-,0656	-,0739	,0092
5	-,3259	-,2491	-,1463	-,2292	-,2753	-,1616	,1214	,1606	,0362	,0482	,0871	,0730
6	,0225	,0009	,0772	-,0022	,0575	,1077	-,0241	,0608	,0867	-,1031	,0211	,0235
7	-,0197	,0044	,0695	,0359	-,0189	-,0907	-,0012	,0113	,0058	,0225	,0278	,0528
8	-,0223	-,1143	-,0699	-,0608	-,0242	,0569	-,0065	-,0273	-,0200	-,0094	-,0229	-,0336
9	,0784	,0271	-,0861	,1381	,0963	,0471	,0728	,0281	,0224	,0381	,0370	,0050
10	-,1183	-,0252	,1686	-,1163	,0129	,0113	-,0325	-,0116	,0422	,0478	,0900	,1250
11	,0394	,1498	,2915	,0387	,1197	,1929	,0941	,0871	,2010	,0922	,0412	,0715
12	-,0465	,0273	-,0244	,0025	,0880	,1353	-,0295	-,0488	,0119	-,0618	-,0084	-,0457
13	,0730	,0589	,0873	,0220	,0502	,1783	,0150	,0502	,0423	,0511	,0260	,0336
14	-,1275	-,1763	-,2800	-,0466	,0246	,1043	,0490	,0793	,1133	,0828	,1523	,2621

Figure 40: SPSS data view – EEG ANOVA entire sample

	Name	Type	Width	Decimals	Label	...	...	Columns	Al...	Measure	Role
1	n_r_f	Numeric	8	4	Common response, right hemisphere, frontal area	...	...	8		Scale	None
2	n_r_c	Numeric	8	4	Common response, right hemisphere, central area	...	...	8		Scale	None
3	n_r_p	Numeric	8	4	Common response, right hemisphere, parietal area	...	...	8		Scale	None
4	n_l_f	Numeric	8	4	Common response, left hemisphere, frontal area	...	...	8		Scale	None
5	n_l_c	Numeric	8	4	Common response, left hemisphere, central area	...	...	8		Scale	None
6	n_l_p	Numeric	8	4	Common response, left hemisphere, parietal area	...	...	8		Scale	None
7	u_r_f	Numeric	8	4	Uncommon response, right hemisphere, frontal area	...	...	8		Scale	None
8	u_r_c	Numeric	8	4	Uncommon response, right hemisphere, central area	...	...	8		Scale	None
9	u_r_p	Numeric	8	4	Uncommon response, right hemisphere, parietal area	...	...	8		Scale	None
10	u_l_f	Numeric	8	4	Uncommon response, left hemisphere, frontal area	...	...	8		Scale	None
11	u_l_c	Numeric	8	4	Uncommon response, left hemisphere, central area	...	...	8		Scale	None
12	u_l_p	Numeric	8	4	Uncommon response, left hemisphere, parietal area	...	...	8		Scale	None

Figure 41: SPSS variable view – EEG ANOVA entire sample

5.7.2. Descriptive Statistics

Boxplot

Along the horizontal axis are all the interactions of the factors. Circular points in the SPSS boxplot are data distant more than 1.5 interquartile ranges from the edges of the box (the box is encompassed between the lower and the upper quartiles, that are the 25th and 75th percentiles). Asterisks represent data with values distant more than 3 interquartile ranges from the edges of the box. This last distance was considered as threshold to categorize outlier values.

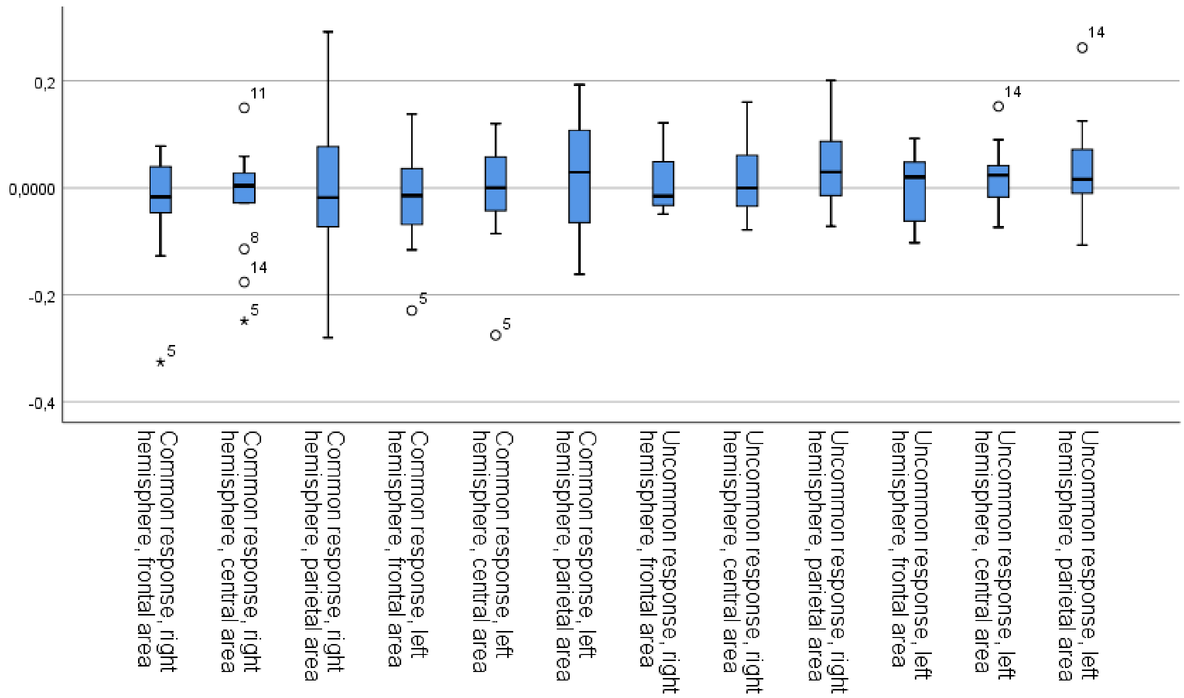


Figure 42: Boxplot – EEG ANOVA entire sample

Boxplot of the dataset shows two significant outliers for subject 5 and one for subject 14. Such outliers could be measurement errors or genuinely unusual values. Both subjects' recording signal quality is at the same average level of all the subjects (Appendix F). Thus, there is no particular reason to suppose measurement errors for these subjects.

Test of Normality

Assumption of normality resulted to be violated for the combinations "common response, right hemisphere, frontal area" $p = 0.011$ and "uncommon response, left hemisphere, frontal area" $p = 0.033$.

Table 30: Test of normality – EEG ANOVA entire sample

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Common response, right hemisphere, frontal area	,217	14	,074	,828	14	,011
Common response, right hemisphere, central area	,248	14	,020	,891	14	,083
Common response, right hemisphere, parietal area	,129	14	,200*	,972	14	,898
Common response, left hemisphere, frontal area	,160	14	,200*	,950	14	,566
Common response, left hemisphere, central area	,141	14	,200*	,888	14	,077
Common response, left hemisphere, parietal area	,123	14	,200*	,958	14	,690
Uncommon response, right hemisphere, frontal area	,210	14	,095	,863	14	,033
Uncommon response, right hemisphere, central area	,162	14	,200*	,953	14	,608
Uncommon response, right hemisphere, parietal area	,187	14	,197	,946	14	,494
Uncommon response, left hemisphere, frontal area	,157	14	,200*	,940	14	,413
Uncommon response, left hemisphere, central area	,163	14	,200*	,964	14	,787
Uncommon response, left hemisphere, parietal area	,179	14	,200*	,911	14	,163

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Normal Q-Q Plots

By looking at the Normal Q-Q plot for "common response, right hemisphere, frontal area" and "uncommon response, left hemisphere, frontal area" data seem to be approximately normal distributed.

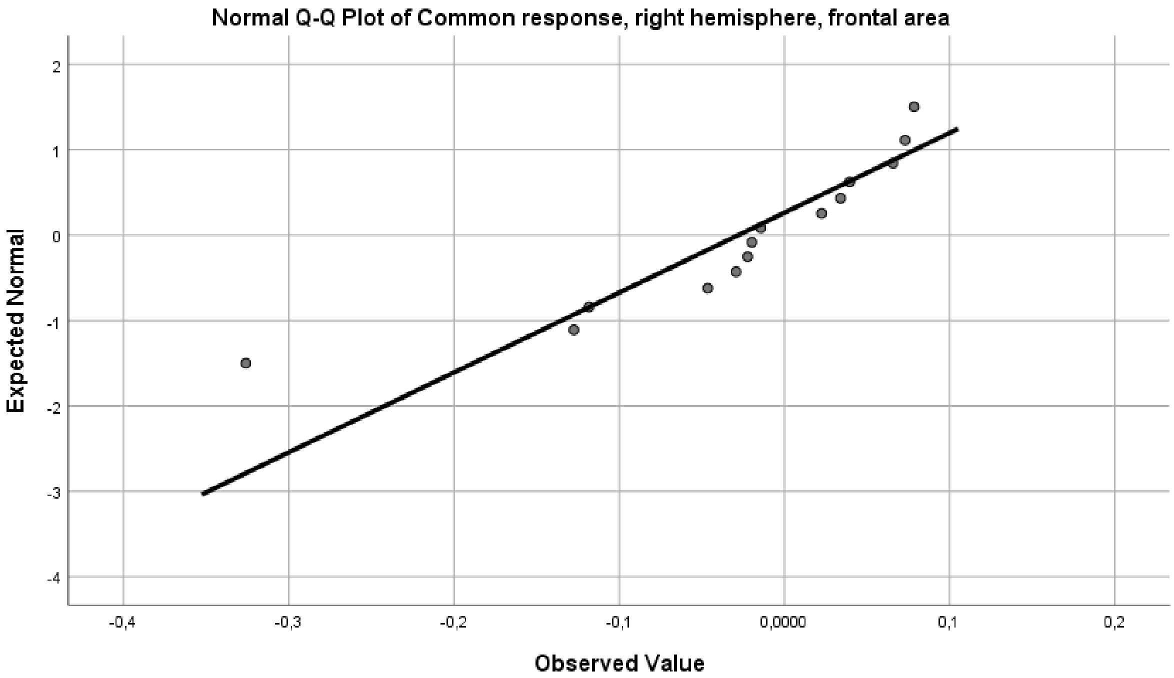


Figure 43: Normal Q-Q plot of Common response, right hemisphere, frontal area – EEG ANOVA entire sample

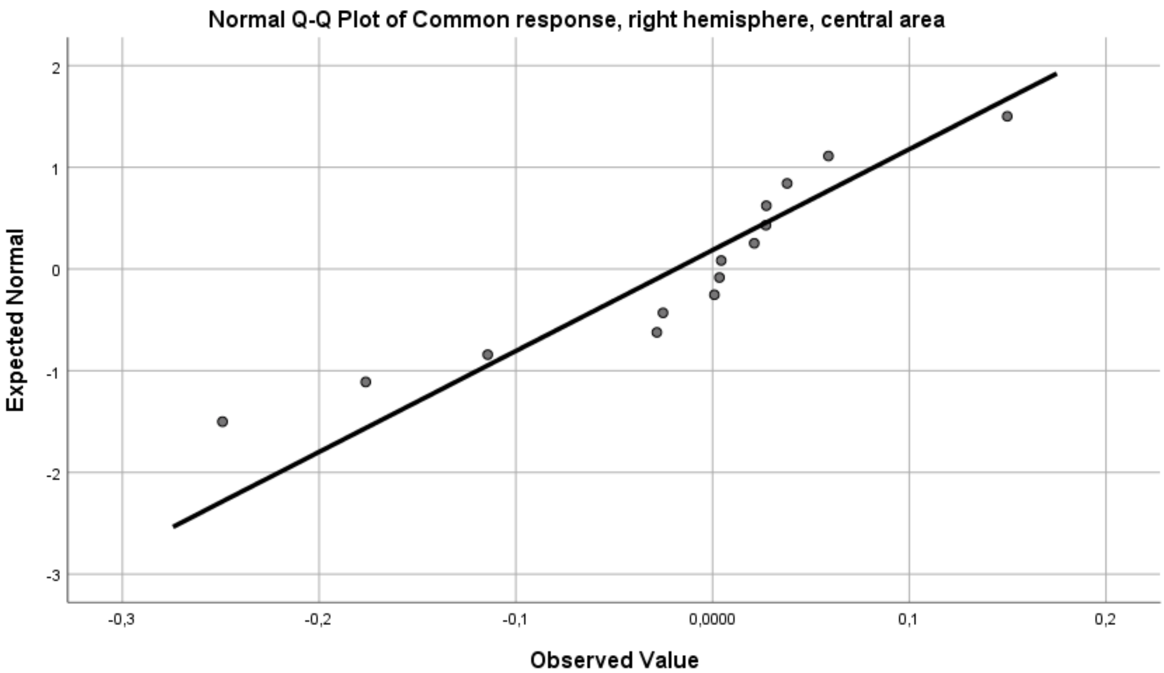


Figure 44: Normal Q-Q plot of Common response, right hemisphere, central area – EEG ANOVA entire sample

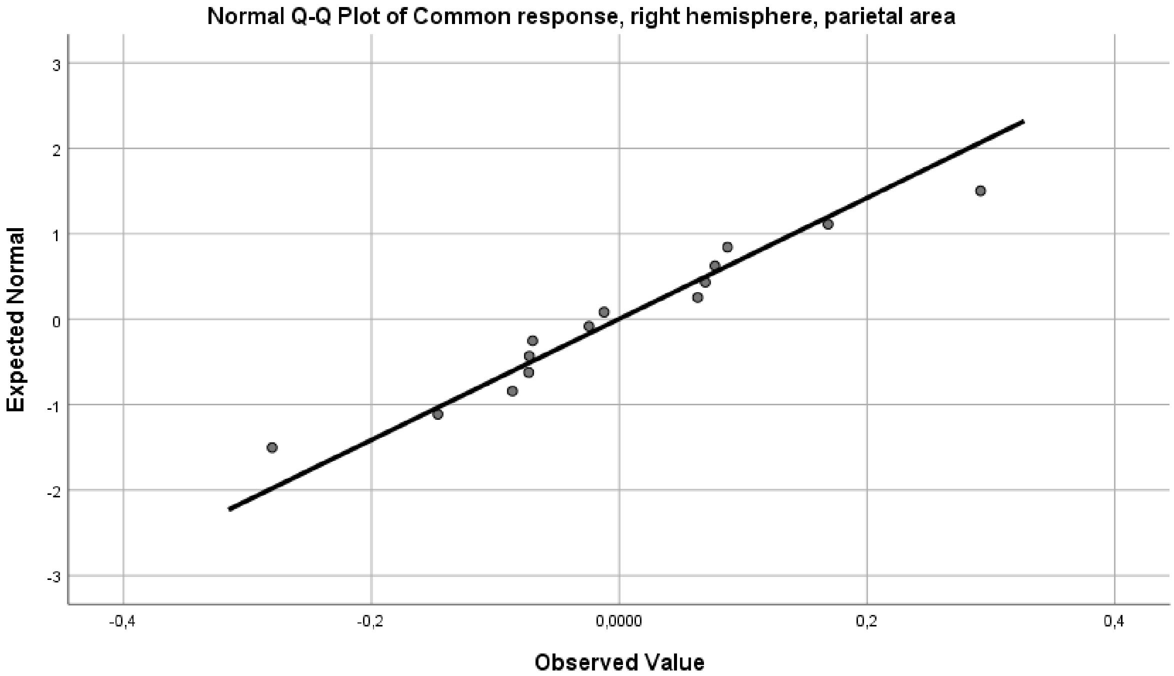


Figure 45: Normal Q-Q plot of Common response, right hemisphere, parietal area – EEG ANOVA entire sample

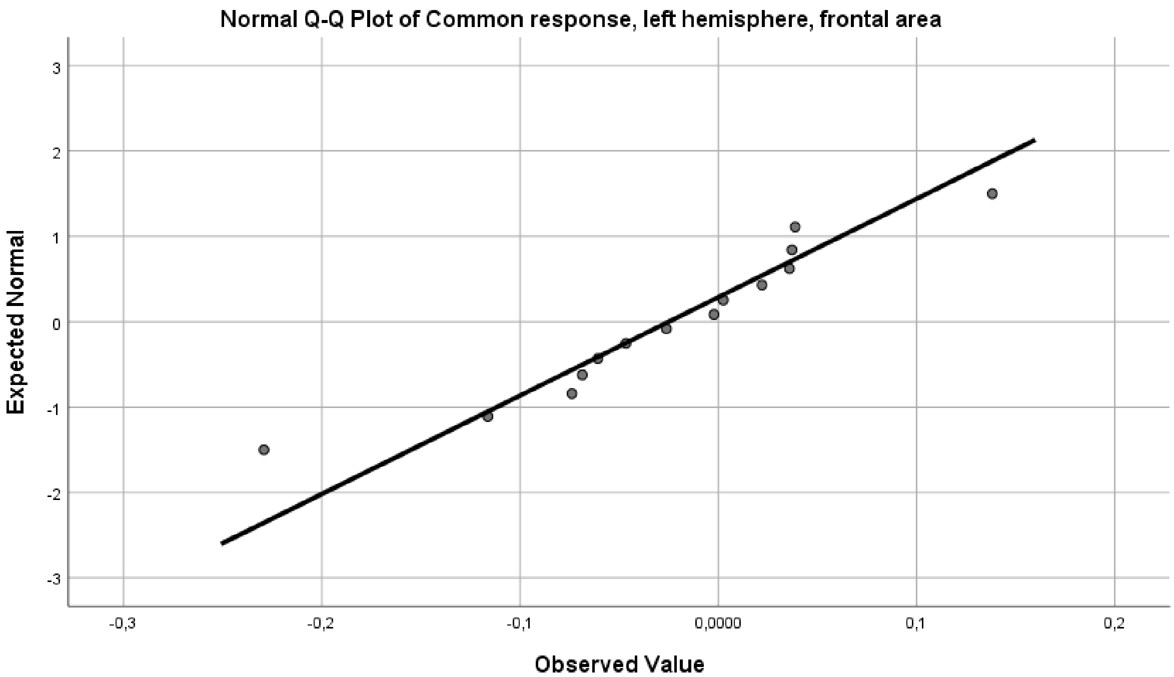


Figure 46: Normal Q-Q plot of Common response, left hemisphere, frontal area – EEG ANOVA entire sample

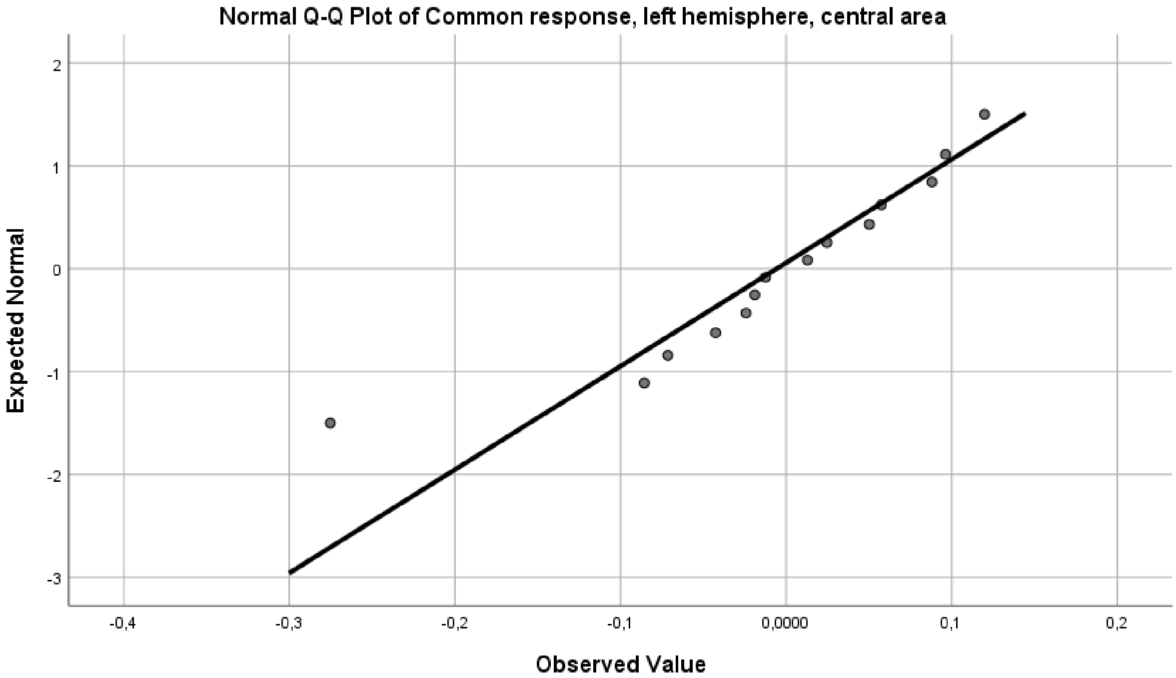


Figure 47: Normal Q-Q plot of Common response, left hemisphere, central area – EEG ANOVA entire sample

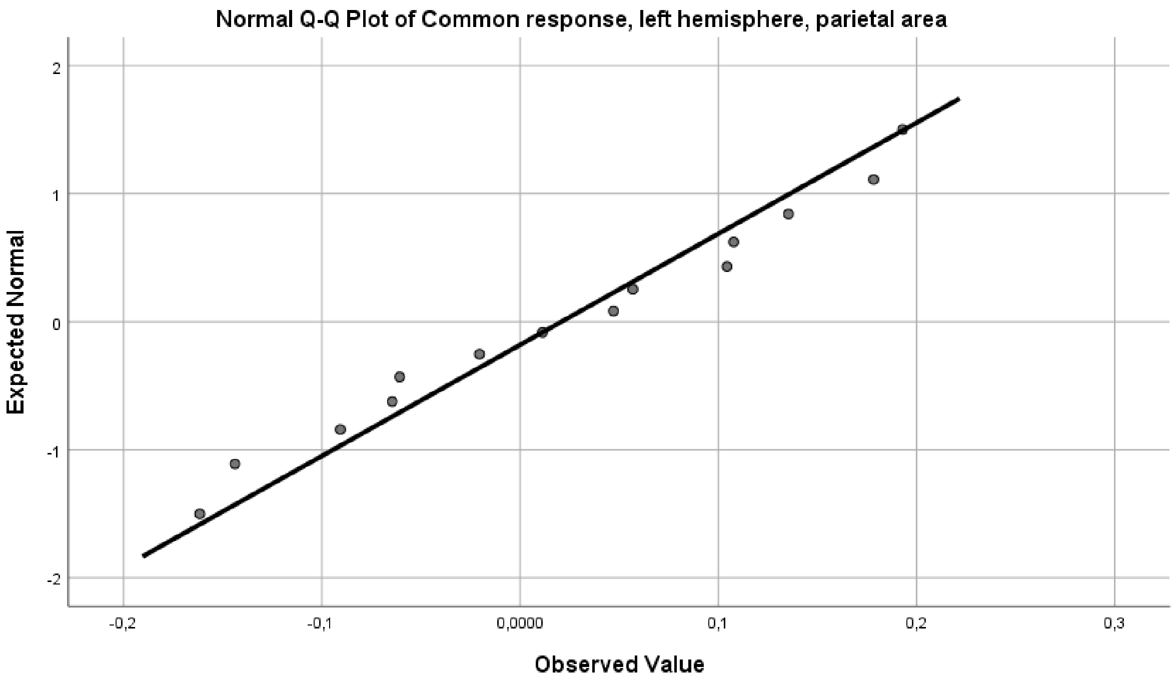


Figure 48: Normal Q-Q plot of Common response, left hemisphere, parietal area – EEG ANOVA entire sample

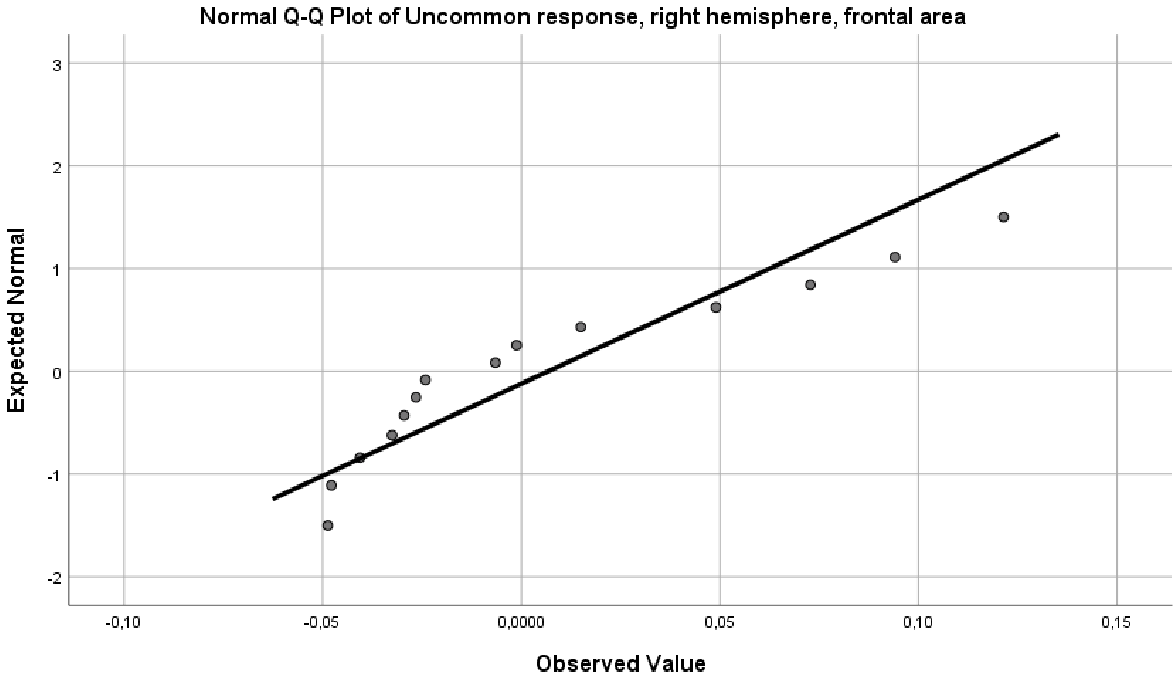


Figure 49: Normal Q-Q plot of Uncommon response, right hemisphere, frontal area – EEG ANOVA entire sample

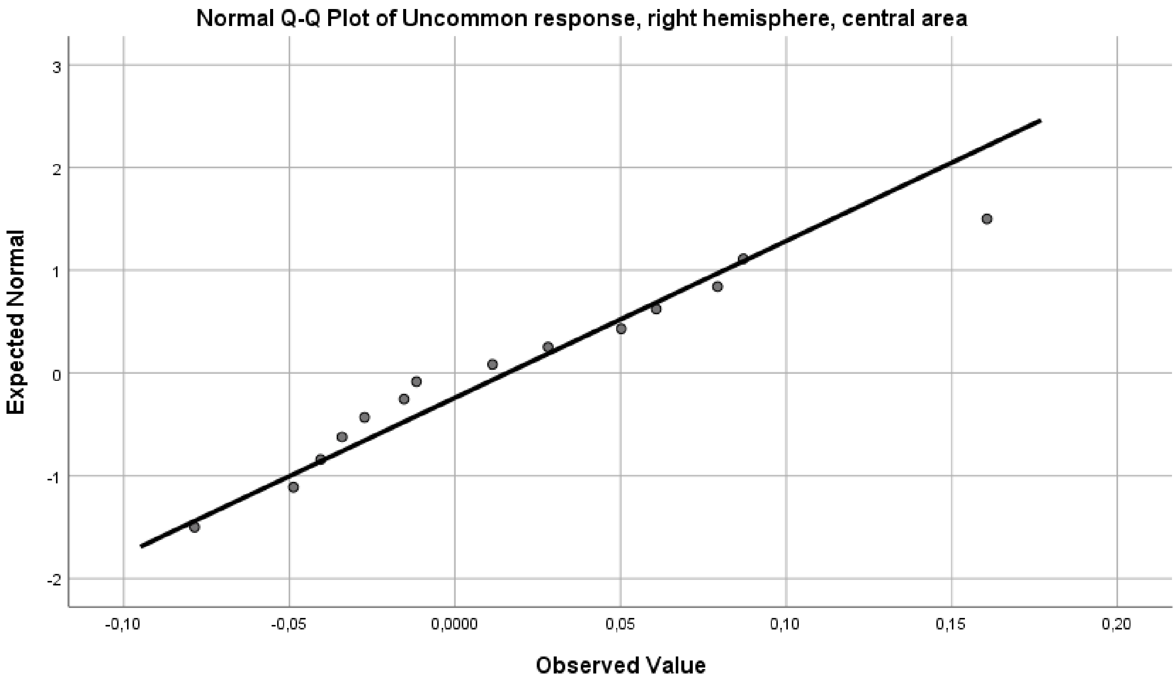


Figure 50:: Normal Q-Q plot of Uncommon response, right hemisphere, central area – EEG ANOVA entire sample

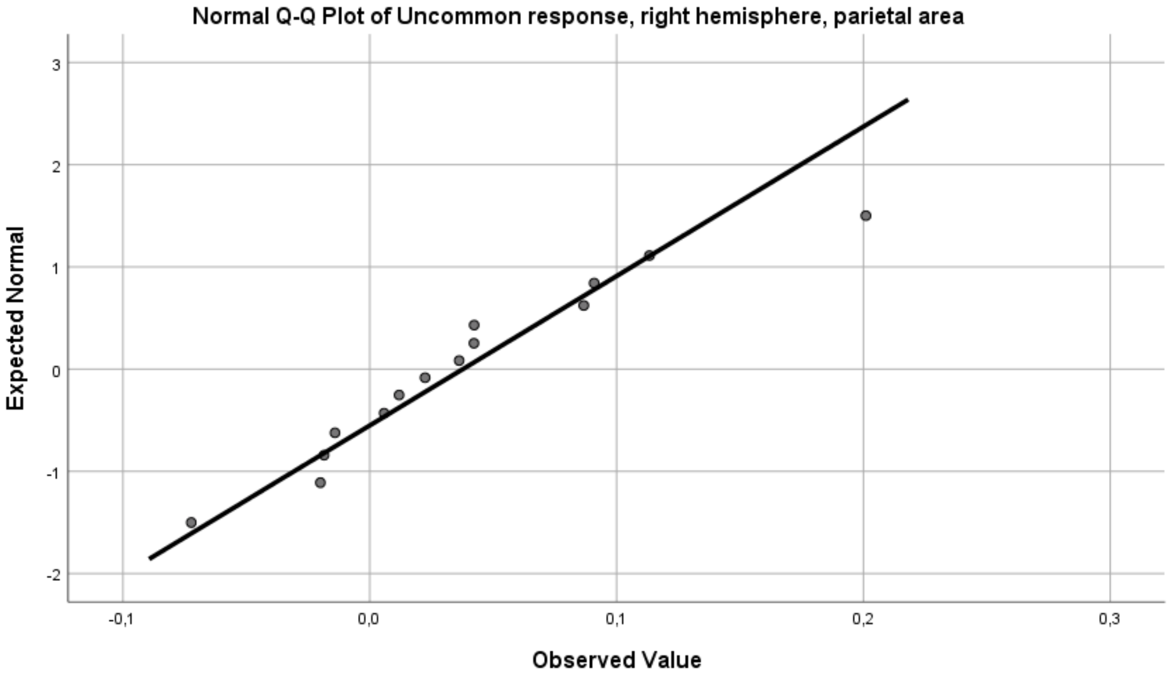


Figure 51: Normal Q-Q plot of Uncommon response, right hemisphere, parietal area – EEG ANOVA entire sample

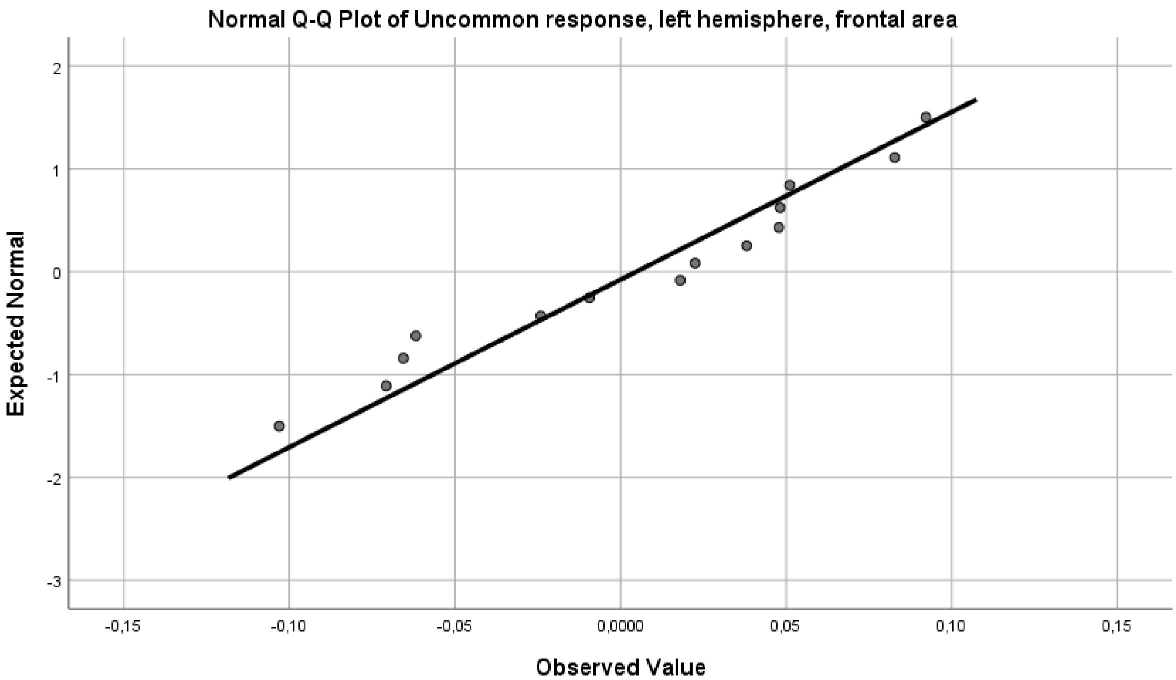


Figure 52: Normal Q-Q plot of Uncommon response, left hemisphere, frontal area – EEG ANOVA entire sample

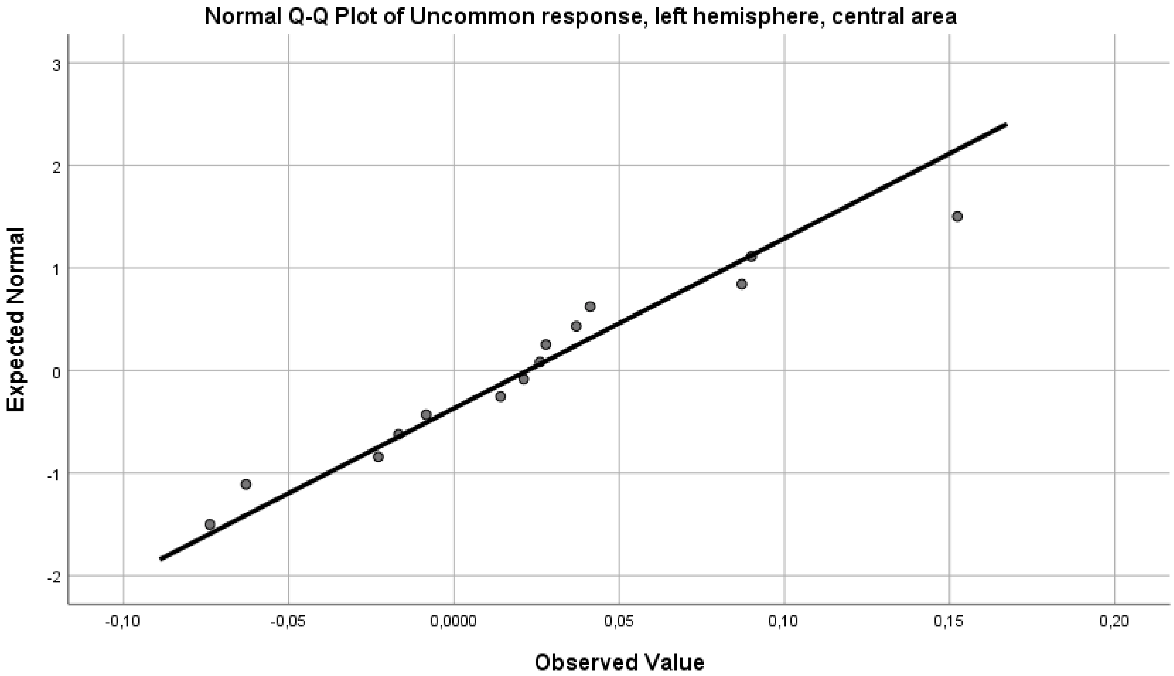


Figure 53: Normal Q-Q plot of Uncommon response, left hemisphere, central area – EEG ANOVA entire sample

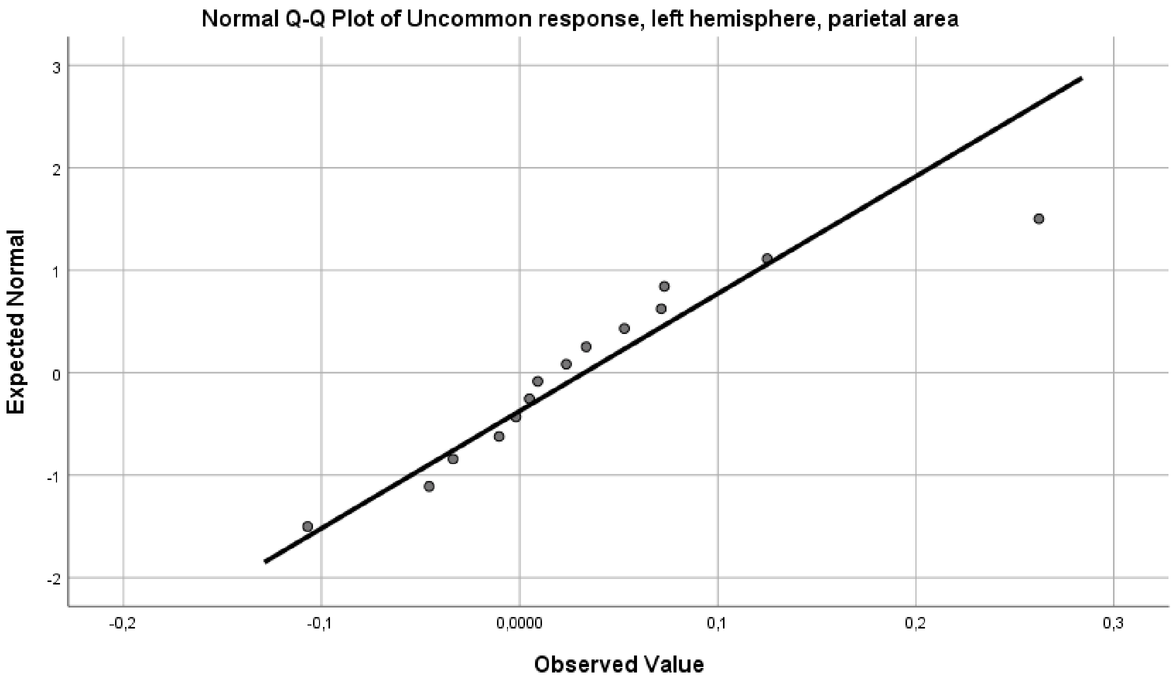


Figure 54: Normal Q-Q plot of Uncommon response, left hemisphere, parietal area– EEG ANOVA entire sample

Test of Sphericity

Mauchly's test of sphericity shows that the assumption of sphericity is violated for the three-way interaction of Condition, Hemisphere and Area ($\chi^2(2) = 8.535$, $p = 0.014$, $\varepsilon = 0.663$), for the two-way interaction of Hemisphere and Area ($\chi^2(2) = 8.953$, $p = 0.011$, $\varepsilon = 0.655$) and for the factor Area ($\chi^2(2) = 16.524$, $p < 0.0005$, $\varepsilon = 0.572$).

Table 31: Mauchly's test of sphericity – EEG ANOVA entire sample

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Condition	1,000	,000	0	.	1,000	1,000	1,000
Hemisphere	1,000	,000	0	.	1,000	1,000	1,000
Area	,252	16,524	2	,000	,572	,591	,500
Condition * Hemisphere	1,000	,000	0	.	1,000	1,000	1,000
Condition * Area	,684	4,558	2	,102	,760	,840	,500
Hemisphere * Area	,474	8,953	2	,011	,655	,699	,500
Condition * Hemisphere * Area	,491	8,535	2	,014	,663	,709	,500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept
Within Subjects Design: Condition + Hemisphere + Area + Condition * Hemisphere + Condition * Area + Hemisphere * Area + Condition * Hemisphere * Area

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

5.7.3. ANOVA for Repeated Measures

In Table 32 is reported the numerical association of the SPSS variables to the factors of the analysis.

Degrees of freedom in Table 33 were adjusted when calculating the *p*-values by means of the Greenhouse-Geisser correction for all the violations of sphericity.

Table 32: ANOVA SPSS factors – EEG ANOVA entire sample

Within-Subjects Factors

Measure: MEASURE_1

Condition	Hemisphere	Area	Dependent Variable
1	1	1	n_r_f
		2	n_r_c
		3	n_r_p
	2	1	n_l_f
		2	n_l_c
		3	n_l_p
2	1	1	u_r_f
		2	u_r_c
		3	u_r_p
	2	1	u_l_f
		2	u_l_c
		3	u_l_p

Condition 1: Common response; Condition 2: Uncommon response; Hemisphere 1: Right; Hemisphere 2: Left; Area 1: Frontal; Area 2: Central; Area 3: Parietal.

Table 33: Within-subjects effects – EEG ANOVA entire sample

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Condition	Sphericity Assumed	,037	1	,037	1,087	,316
	Greenhouse-Geisser	,037	1,000	,037	1,087	,316
	Huynh-Feldt	,037	1,000	,037	1,087	,316
	Lower-bound	,037	1,000	,037	1,087	,316
Error(Condition)	Sphericity Assumed	,437	13	,034		
	Greenhouse-Geisser	,437	13,000	,034		
	Huynh-Feldt	,437	13,000	,034		
	Lower-bound	,437	13,000	,034		
Hemisphere	Sphericity Assumed	,002	1	,002	,192	,669
	Greenhouse-Geisser	,002	1,000	,002	,192	,669
	Huynh-Feldt	,002	1,000	,002	,192	,669
	Lower-bound	,002	1,000	,002	,192	,669
Error(Hemisphere)	Sphericity Assumed	,106	13	,008		
	Greenhouse-Geisser	,106	13,000	,008		
	Huynh-Feldt	,106	13,000	,008		
	Lower-bound	,106	13,000	,008		
Area	Sphericity Assumed	,031	2	,015	2,667	,088
	Greenhouse-Geisser	,031	1,144	,027	2,667	,120
	Huynh-Feldt	,031	1,183	,026	2,667	,119
	Lower-bound	,031	1,000	,031	2,667	,126
Error(Area)	Sphericity Assumed	,150	26	,006		

	Greenhouse-Geisser	,150	14,877	,010		
	Huynh-Feldt	,150	15,375	,010		
	Lower-bound	,150	13,000	,012		
Condition * Hemisphere	Sphericity Assumed	,002	1	,002	,319	,582
	Greenhouse-Geisser	,002	1,000	,002	,319	,582
	Huynh-Feldt	,002	1,000	,002	,319	,582
	Lower-bound	,002	1,000	,002	,319	,582
Error(Condition*Hemisphere)	Sphericity Assumed	,068	13	,005		
	Greenhouse-Geisser	,068	13,000	,005		
	Huynh-Feldt	,068	13,000	,005		
	Lower-bound	,068	13,000	,005		
Condition * Area	Sphericity Assumed	,000	2	,000	,071	,932
	Greenhouse-Geisser	,000	1,520	,000	,071	,886
	Huynh-Feldt	,000	1,679	,000	,071	,904
	Lower-bound	,000	1,000	,000	,071	,794
Error(Condition*Area)	Sphericity Assumed	,079	26	,003		
	Greenhouse-Geisser	,079	19,757	,004		
	Huynh-Feldt	,079	21,828	,004		
	Lower-bound	,079	13,000	,006		
Hemisphere * Area	Sphericity Assumed	,001	2	,000	,154	,858
	Greenhouse-Geisser	,001	1,311	,001	,154	,767
	Huynh-Feldt	,001	1,399	,000	,154	,782
	Lower-bound	,001	1,000	,001	,154	,701
Error(Hemisphere*Area)	Sphericity Assumed	,058	26	,002		
	Greenhouse-Geisser	,058	17,040	,003		
	Huynh-Feldt	,058	18,185	,003		

	Lower-bound	,058	13,000	,004		
Condition * Hemisphere * Area	Sphericity Assumed	,001	2	,001	,329	,722
	Greenhouse-Geisser	,001	1,325	,001	,329	,636
	Huynh-Feldt	,001	1,418	,001	,329	,650
	Lower-bound	,001	1,000	,001	,329	,576
Error(Condition*Hemisphere*Area)	Sphericity Assumed	,040	26	,002		
	Greenhouse-Geisser	,040	17,230	,002		
	Huynh-Feldt	,040	18,435	,002		
	Lower-bound	,040	13,000	,003		

5.7.4. Profile Plots

Profile plots show that variation of alpha power was higher during uncommon response condition for all the areas in both the hemispheres. However, according to ANOVA such differences are not statistically significant.

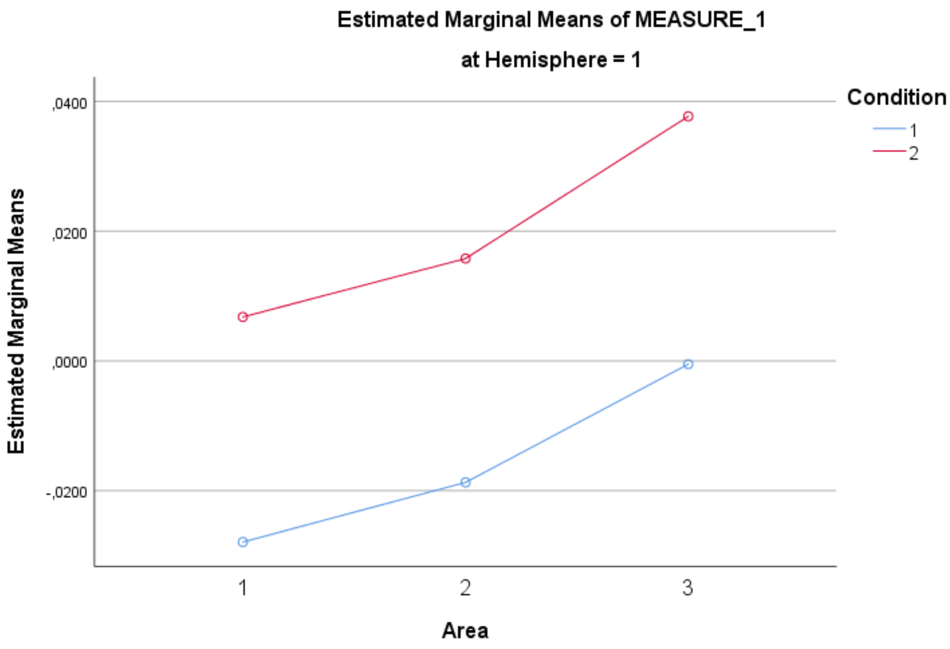


Figure 55: Marginal mean in right hemisphere – EEG ANOVA entire sample

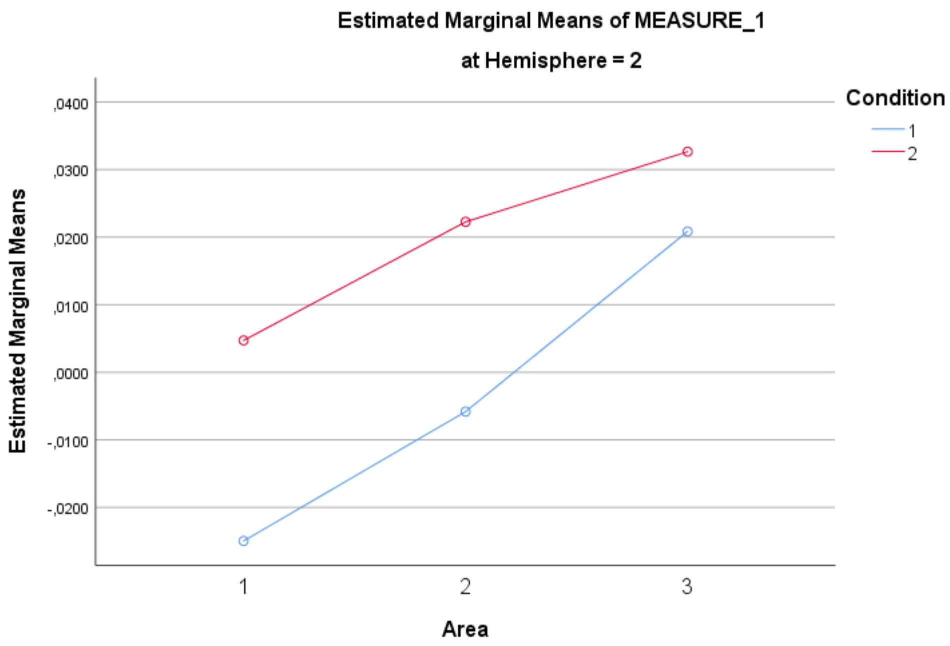


Figure 56: Marginal mean in left hemisphere – EEG ANOVA entire sample

5.8. Appendix H

The present appendix reports the ANOVA outputs of EEG analysis conducted on the sample without subjects 7 and 12.

Three-way within-subjects Factorial Analysis of Variance for repeated measures was employed for the statistical analysis to test the statistical significance of the mean differences emerged among the response conditions and the different regions of the scalp. The three within-subject factors are Condition (common, uncommon response), Hemisphere (right, left) and Area (frontal, central, parietal). Frontal area referred to F3 and F4 electrodes, central area to C3 and C4, parietal area to P3 and P4. Left hemisphere referred to electrodes with odd numbers and right hemisphere to electrodes with even numbers. Midline electrodes (Fz, Cz, POz) were not included in the analysis in order to assess the difference in electric potential between the two hemispheres.

5.8.1. Descriptive Statistics

Boxplot

Circular points in the SPSS boxplot are data distant more than 1.5 interquartile ranges from the edges of the box (the box is encompassed between the lower and the upper quartiles, that are the 25th and 75th percentiles). Asterisks represent data with values distant more than 3 interquartile ranges from the edges of the box. This last distance was considered the threshold to categorize outlier values.

No significant outliers characterised the sample without subjects 7 and 12.

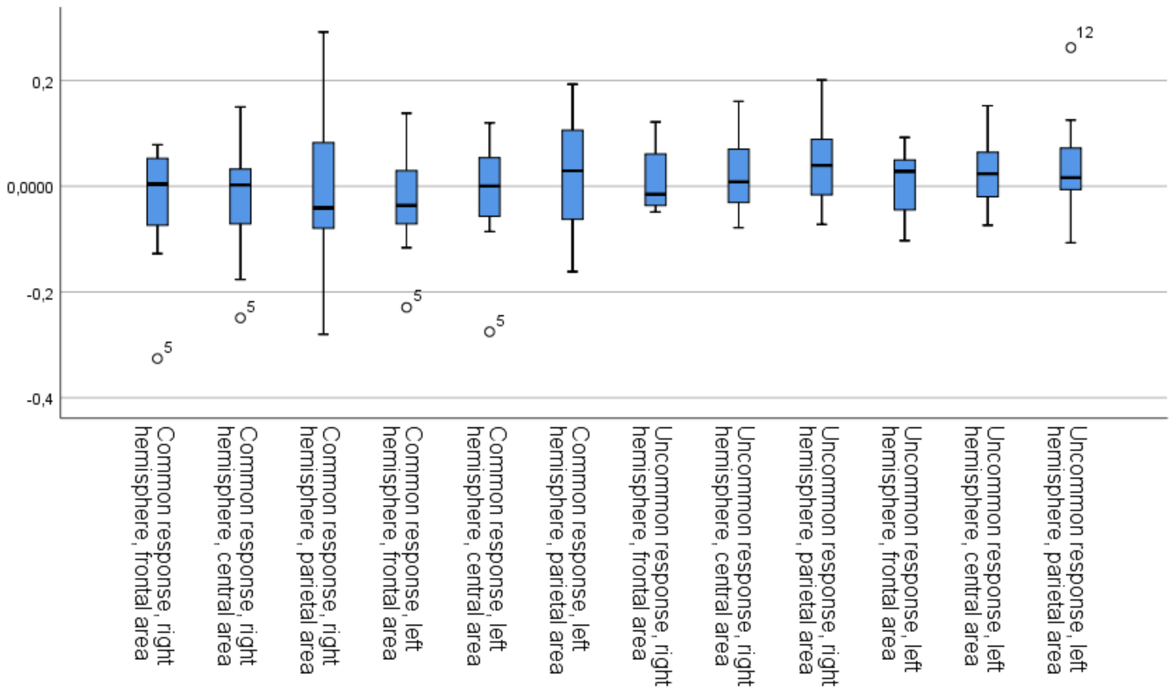


Figure 57: Boxplot – EEG ANOVA sub-sample

Test of Normality

Assumption of normality resulted to be violated for the combinations "common response, right hemisphere, frontal area" *p* = 0.015.

Table 34: Test of Normality – EEG ANOVA sub-sample

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Common response, right hemisphere, frontal area	,242	12	,050	,819	12	,015
Common response, right hemisphere, central area	,236	12	,064	,925	12	,333
Common response, right hemisphere, parietal area	,167	12	,200*	,972	12	,928
Common response, left hemisphere, frontal area	,159	12	,200*	,965	12	,855
Common response, left hemisphere, central area	,158	12	,200*	,898	12	,149
Common response, left hemisphere, parietal area	,099	12	,200*	,962	12	,808
Uncommon response, right hemisphere, frontal area	,219	12	,115	,873	12	,071
Uncommon response, right hemisphere, central area	,186	12	,200*	,956	12	,727
Uncommon response, right hemisphere, parietal area	,168	12	,200*	,959	12	,770
Uncommon response, left hemisphere, frontal area	,179	12	,200*	,933	12	,417
Uncommon response, left hemisphere, central area	,148	12	,200*	,969	12	,898
Uncommon response, left hemisphere, parietal area	,184	12	,200*	,905	12	,183

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Normal Q-Q Plots

By looking at the normal Q-Q plot for “common response, right hemisphere, frontal area” the measures seem to be approximately normally distributed, excepted one data point.

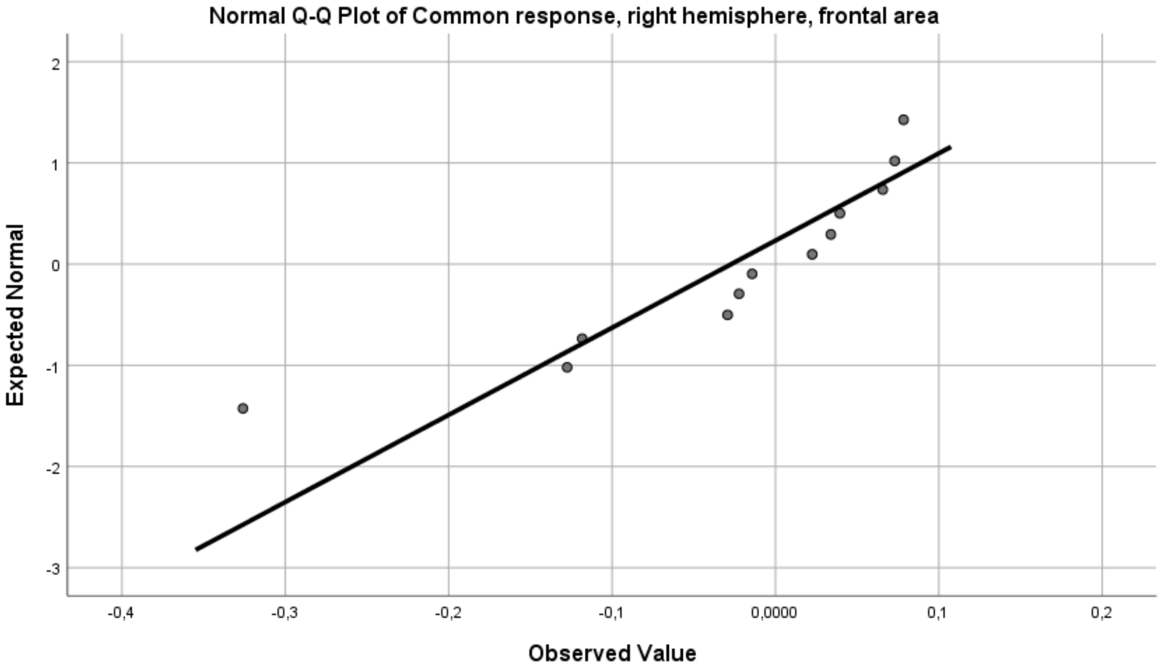


Figure 58: Normal Q-Q plot of Common response, right hemisphere, frontal area – EEG ANOVA sub-sample

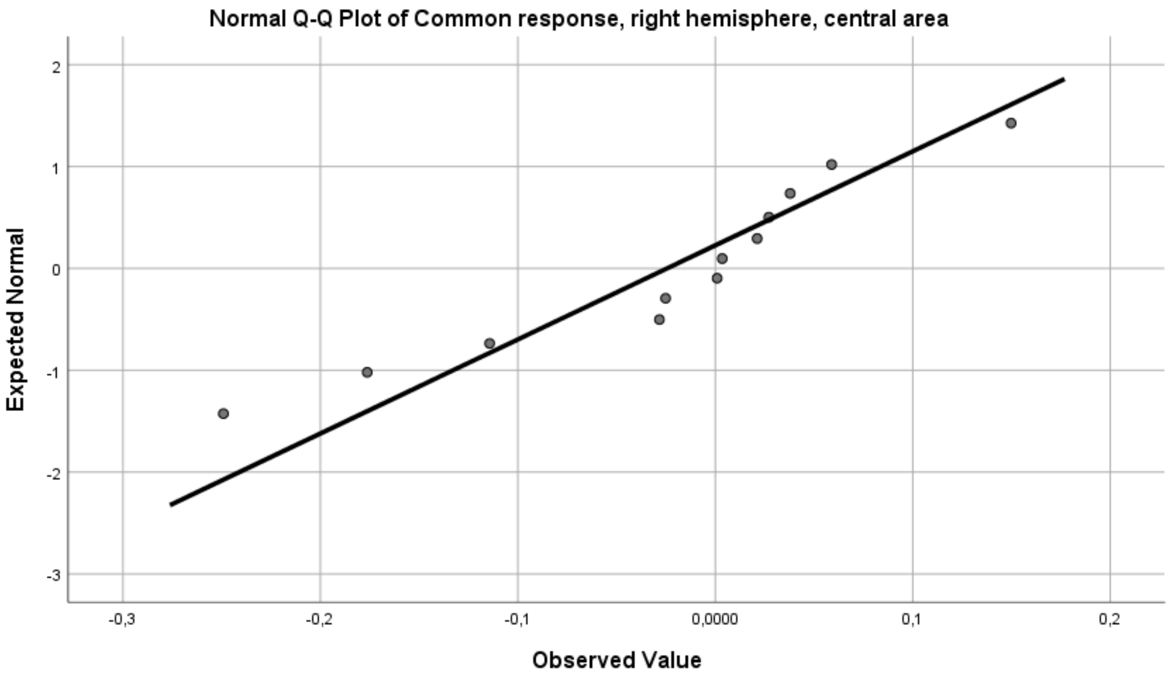


Figure 59: Normal Q-Q plot of Common response, right hemisphere, central area – EEG ANOVA sub-sample

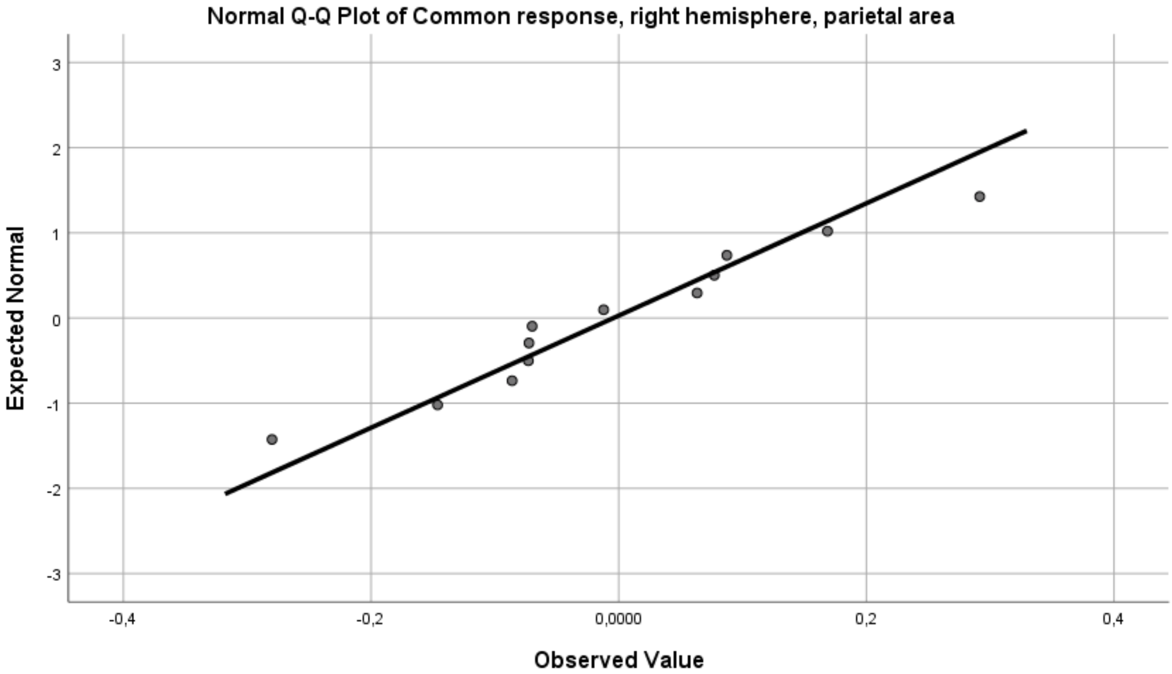


Figure 60: Normal Q-Q plot of Common response, right hemisphere, parietal area – EEG ANOVA sub-sample

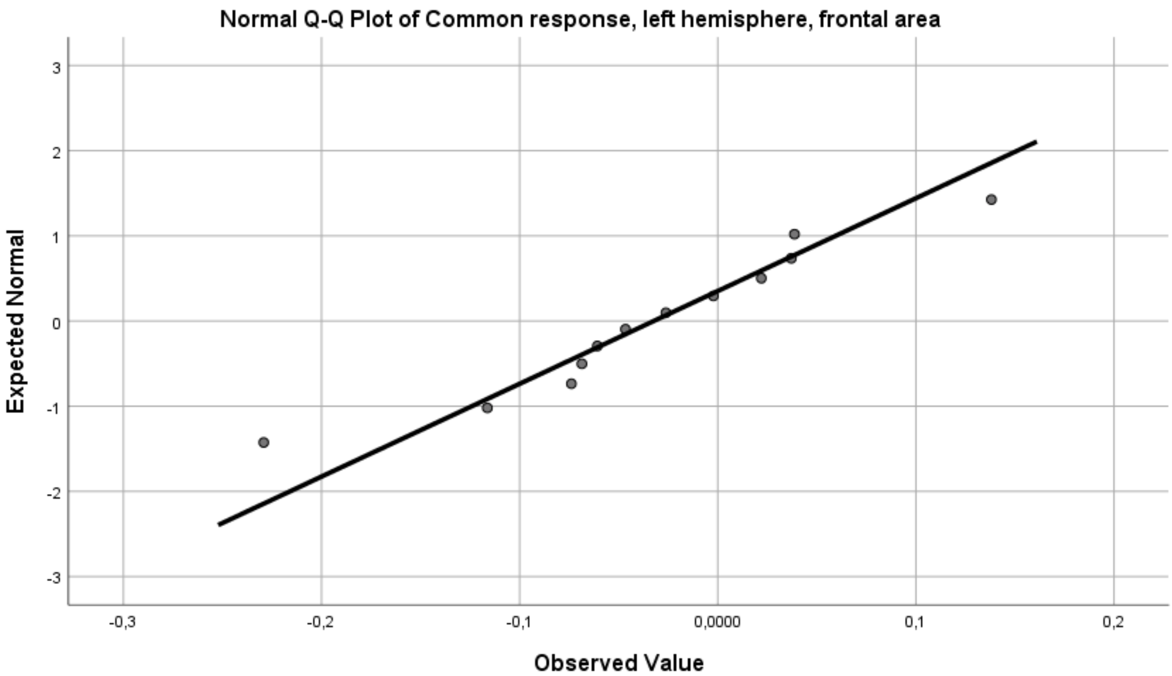


Figure 61: Normal Q-Q plot of Common response, left hemisphere, frontal area – EEG ANOVA sub-sample

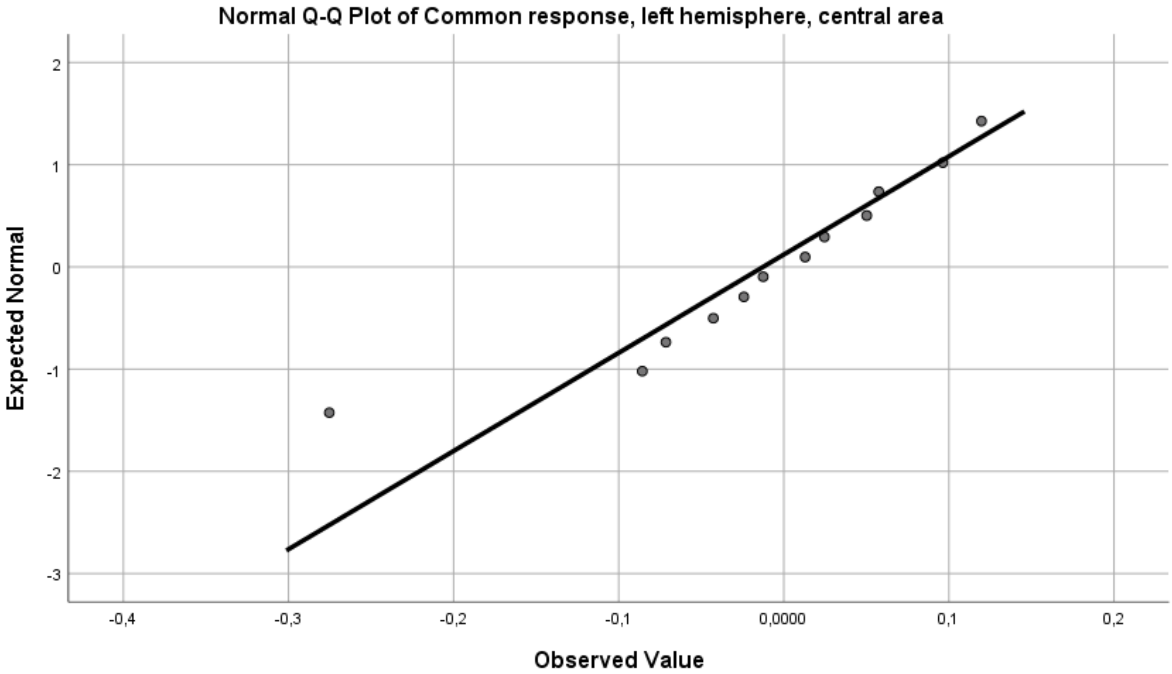


Figure 62: Normal Q-Q plot of Common response, left hemisphere, central area – EEG ANOVA sub-sample

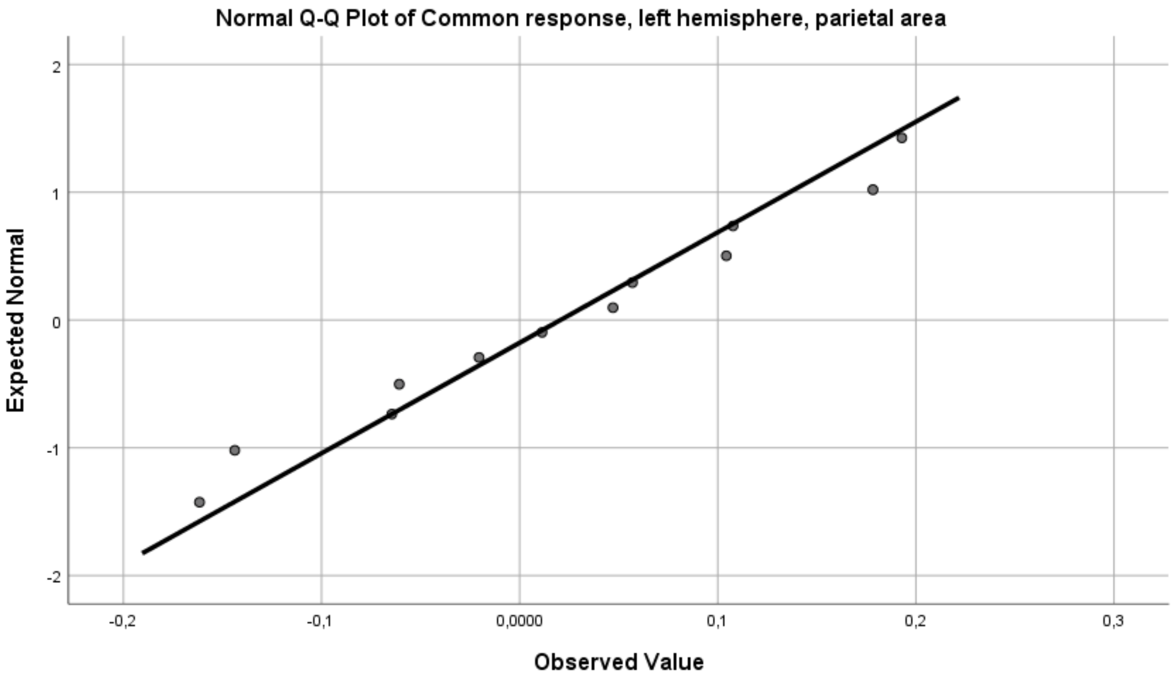


Figure 63: Normal Q-Q plot of Common response, left hemisphere, parietal area – EEG ANOVA sub-sample

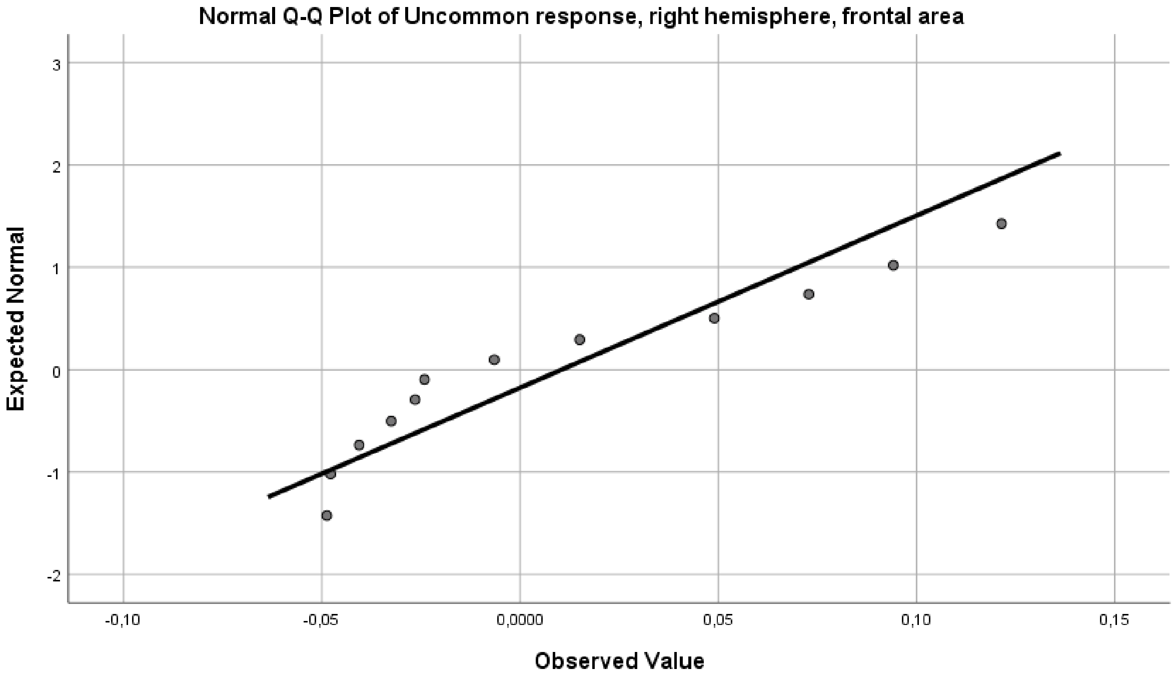


Figure 64: Normal Q-Q plot of Uncommon response, right hemisphere, frontal area – EEG ANOVA sub-sample

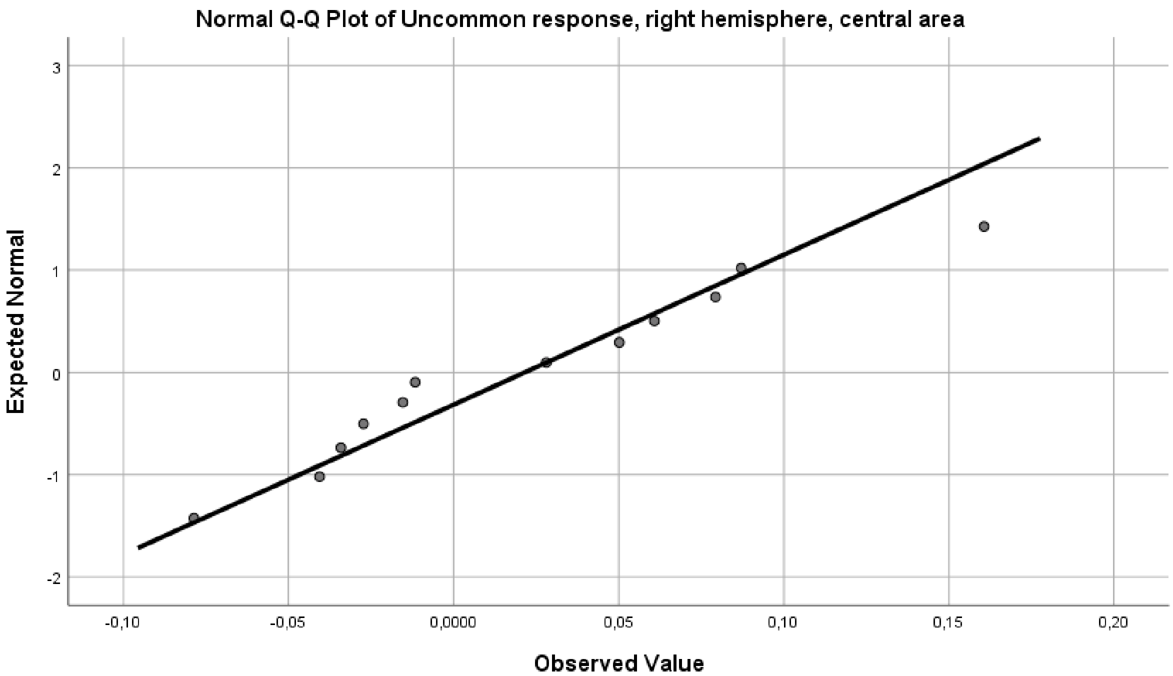


Figure 65: Normal Q-Q plot of Uncommon response, right hemisphere, central area – EEG ANOVA sub-sample

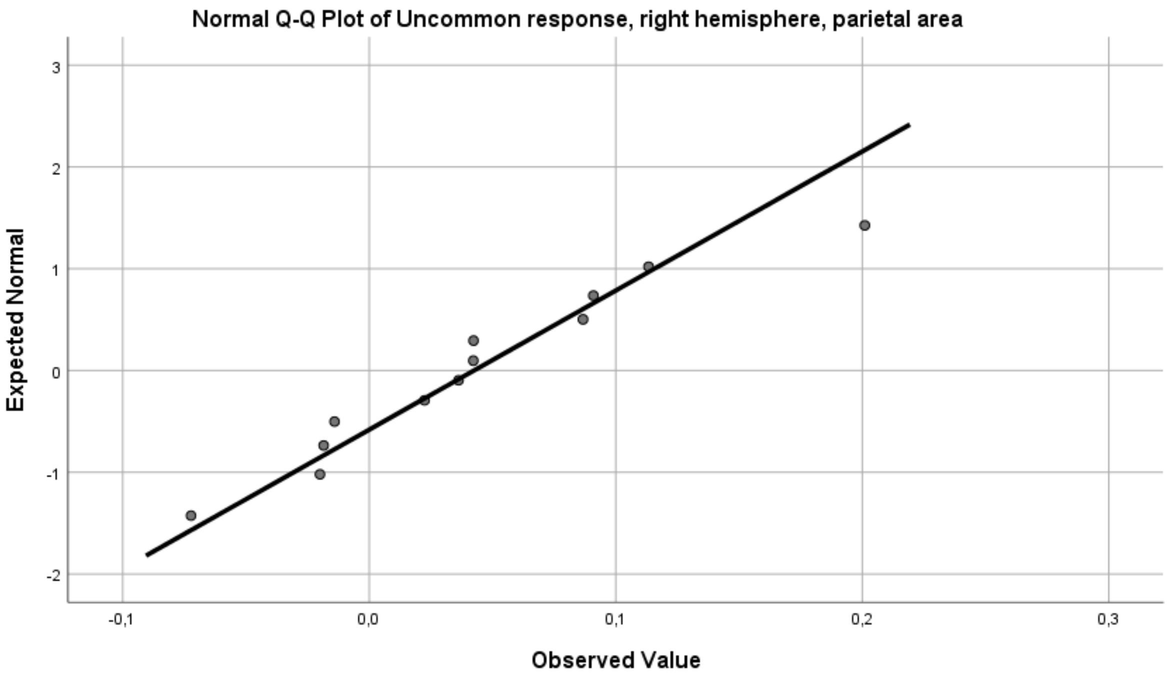


Figure 66: Normal Q-Q plot of Uncommon response, right hemisphere, parietal area – EEG ANOVA sub-sample

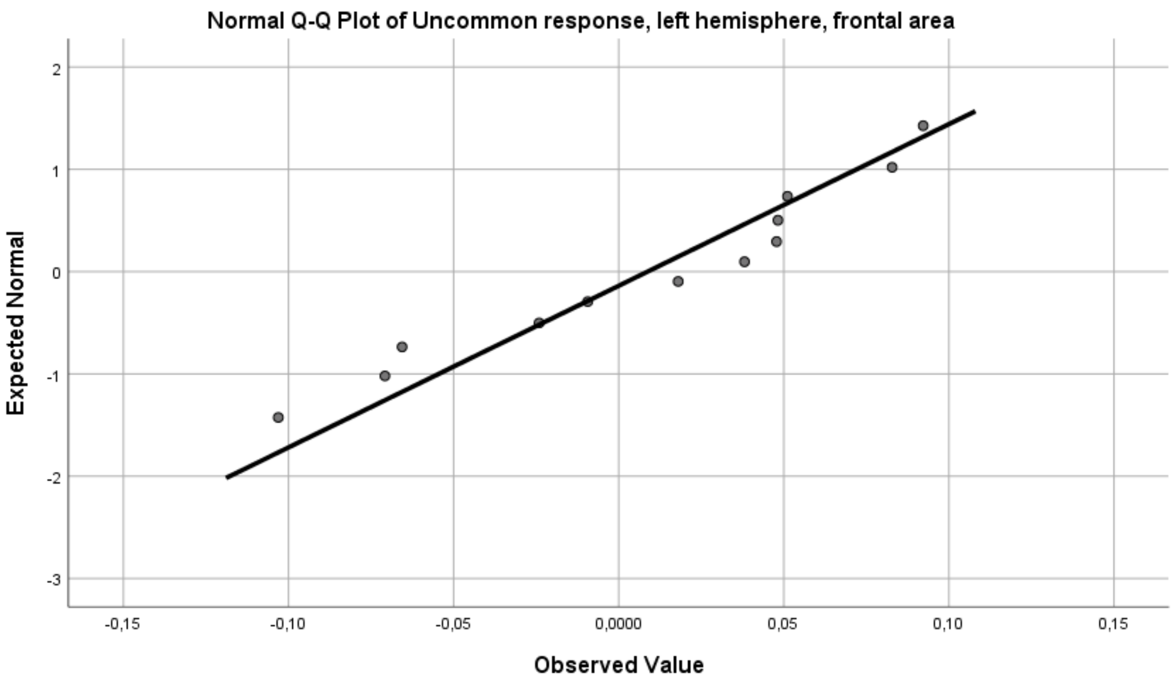


Figure 67: Normal Q-Q plot of Uncommon response, left hemisphere, frontal area – EEG ANOVA sub-sample

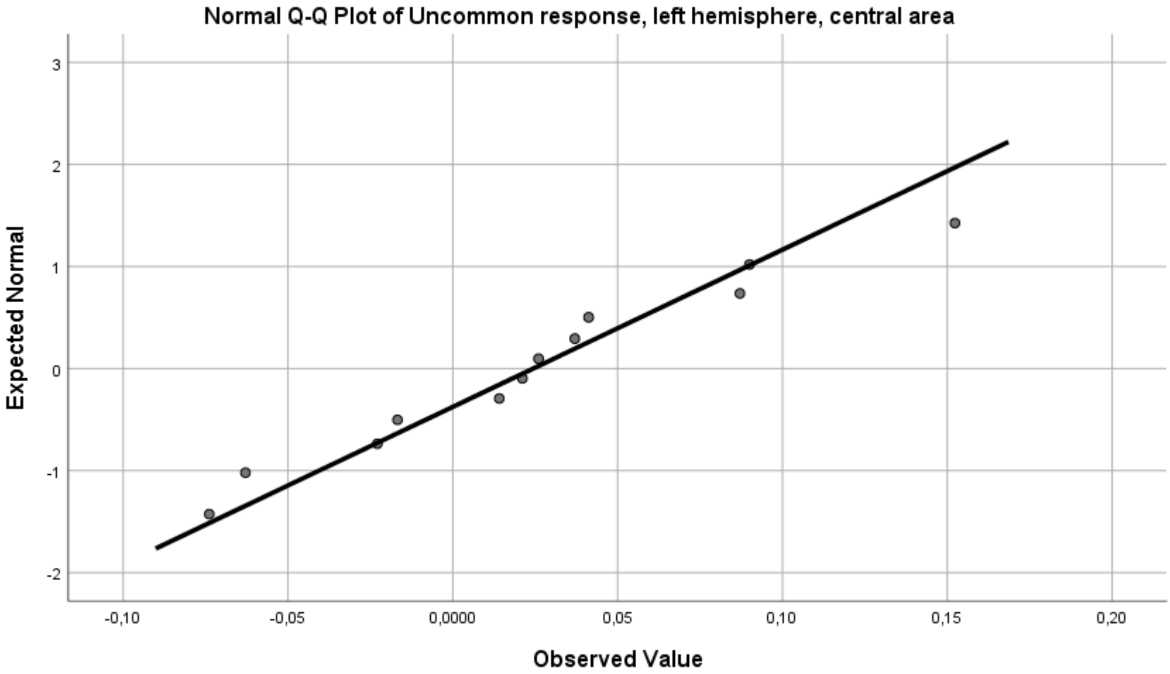


Figure 68: Normal Q-Q plot of Uncommon response, left hemisphere, central area – EEG ANOVA sub-sample

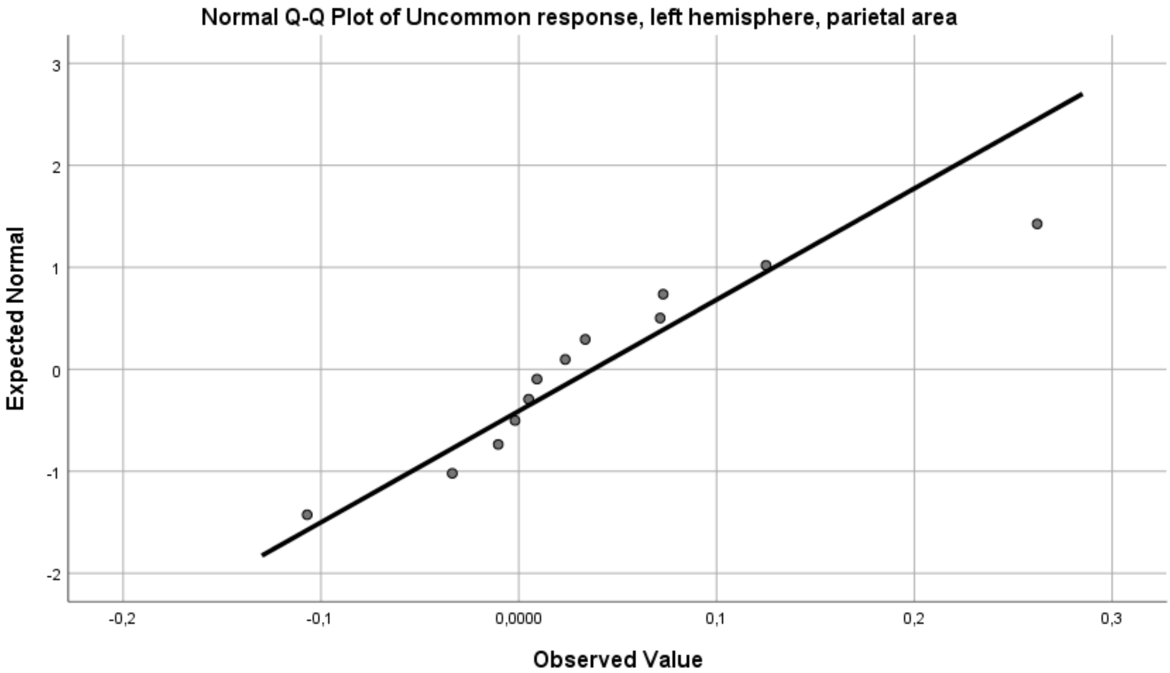


Figure 69: Normal Q-Q plot of Uncommon response, left hemisphere, parietal area – EEG ANOVA sub-sample

Test of Sphericity

For all the factors and interactions which violated test of sphericity, degrees of freedom in ANOVA were adjusted when calculating the *p*-values by means of the Greenhouse-Geisser correction.

Table 35: Mauchly's test of sphericity – EEG ANOVA sub-sample

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Condition	1,000	,000	0	.	1,000	1,000	1,000
Hemisphere	1,000	,000	0	.	1,000	1,000	1,000
Area	,212	15,531	2	,000	,559	,578	,500
Condition * Hemisphere	1,000	,000	0	.	1,000	1,000	1,000
Condition * Area	,652	4,279	2	,118	,742	,830	,500
Hemisphere * Area	,491	7,111	2	,029	,663	,719	,500
Condition * Hemisphere * Area	,503	6,872	2	,032	,668	,726	,500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept

Within Subjects Design: Condition + Hemisphere + Area + Condition * Hemisphere + Condition * Area + Hemisphere * Area + Condition * Hemisphere * Area

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

5.8.2. ANOVA for Repeated Measures

In Table 36 it is reported the numerical association of the SPSS variables to the factors of the analysis.

Table 36: ANOVA SPSS factors – EEG ANOVA sub-sample

Within-Subjects Factors

Measure: MEASURE_1

Condition	Hemisphere	Area	Dependent Variable
1	1	1	n_r_f
		2	n_r_c
		3	n_r_p
	2	1	n_l_f
		2	n_l_c
		3	n_l_p
2	1	1	u_r_f
		2	u_r_c
		3	u_r_p
	2	1	u_l_f
		2	u_l_c
		3	u_l_p

Condition 1: Common response; Condition 2: Uncommon response; Hemisphere 1: Right; Hemisphere 2: Left; Area 1: Frontal; Area 2: Central; Area 3: Parietal.

Table 37: Within-subjects effects – EEG ANOVA sub-sample

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Condition	Sphericity Assumed	,051	1	,051	1,361	,268
	Greenhouse-Geisser	,051	1,000	,051	1,361	,268
	Huynh-Feldt	,051	1,000	,051	1,361	,268
	Lower-bound	,051	1,000	,051	1,361	,268
Error(Condition)	Sphericity Assumed	,410	11	,037		
	Greenhouse-Geisser	,410	11,000	,037		
	Huynh-Feldt	,410	11,000	,037		
	Lower-bound	,410	11,000	,037		
Hemisphere	Sphericity Assumed	,001	1	,001	,083	,779
	Greenhouse-Geisser	,001	1,000	,001	,083	,779
	Huynh-Feldt	,001	1,000	,001	,083	,779
	Lower-bound	,001	1,000	,001	,083	,779
Error(Hemisphere)	Sphericity Assumed	,102	11	,009		
	Greenhouse-Geisser	,102	11,000	,009		
	Huynh-Feldt	,102	11,000	,009		
	Lower-bound	,102	11,000	,009		
Area	Sphericity Assumed	,029	2	,014	2,166	,138
	Greenhouse-Geisser	,029	1,118	,026	2,166	,166
	Huynh-Feldt	,029	1,156	,025	2,166	,165
	Lower-bound	,029	1,000	,029	2,166	,169
Error(Area)	Sphericity Assumed	,146	22	,007		

	Greenhouse-Geisser	,146	12,302	,012		
	Huynh-Feldt	,146	12,712	,011		
	Lower-bound	,146	11,000	,013		
Condition * Hemisphere	Sphericity Assumed	,001	1	,001	,247	,629
	Greenhouse-Geisser	,001	1,000	,001	,247	,629
	Huynh-Feldt	,001	1,000	,001	,247	,629
	Lower-bound	,001	1,000	,001	,247	,629
Error(Condition*Hemisphere)	Sphericity Assumed	,056	11	,005		
	Greenhouse-Geisser	,056	11,000	,005		
	Huynh-Feldt	,056	11,000	,005		
	Lower-bound	,056	11,000	,005		
Condition * Area	Sphericity Assumed	,001	2	,000	,088	,916
	Greenhouse-Geisser	,001	1,484	,000	,088	,861
	Huynh-Feldt	,001	1,661	,000	,088	,883
	Lower-bound	,001	1,000	,001	,088	,772
Error(Condition*Area)	Sphericity Assumed	,076	22	,003		
	Greenhouse-Geisser	,076	16,319	,005		
	Huynh-Feldt	,076	18,266	,004		
	Lower-bound	,076	11,000	,007		
Hemisphere * Area	Sphericity Assumed	,001	2	,001	,260	,773
	Greenhouse-Geisser	,001	1,325	,001	,260	,684
	Huynh-Feldt	,001	1,437	,001	,260	,702
	Lower-bound	,001	1,000	,001	,260	,620
Error(Hemisphere*Area)	Sphericity Assumed	,052	22	,002		
	Greenhouse-Geisser	,052	14,580	,004		
	Huynh-Feldt	,052	15,811	,003		

	Lower-bound	,052	11,000	,005		
Condition * Hemisphere * Area	Sphericity Assumed	,002	2	,001	,722	,497
	Greenhouse-Geisser	,002	1,336	,001	,722	,448
	Huynh-Feldt	,002	1,452	,001	,722	,458
	Lower-bound	,002	1,000	,002	,722	,414
Error(Condition*Hemisphere*Area)	Sphericity Assumed	,026	22	,001		
	Greenhouse-Geisser	,026	14,696	,002		
	Huynh-Feldt	,026	15,972	,002		
	Lower-bound	,026	11,000	,002		

5.8.3. Profile Plots

Profile plots show that variation of alpha power was higher during uncommon response condition for all the areas in both the hemispheres. However, according to ANOVA such differences are not statistically significant.

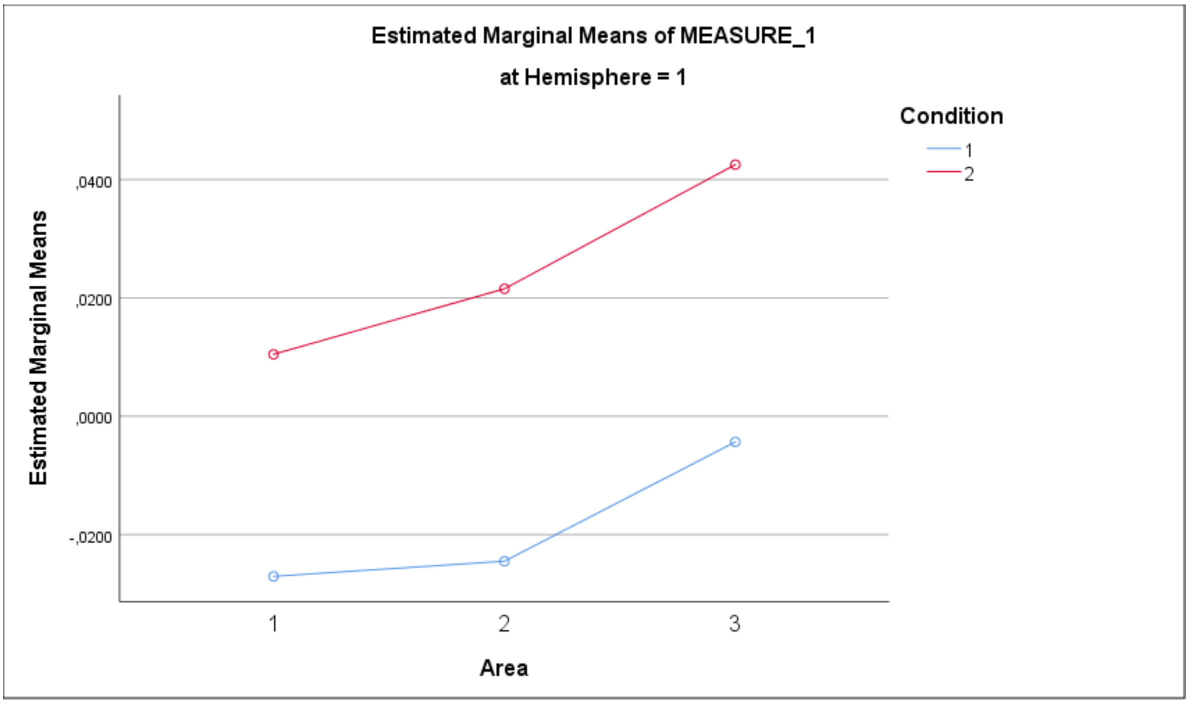


Figure 70: Marginal mean in right hemisphere – EEG ANOVA sub-sample

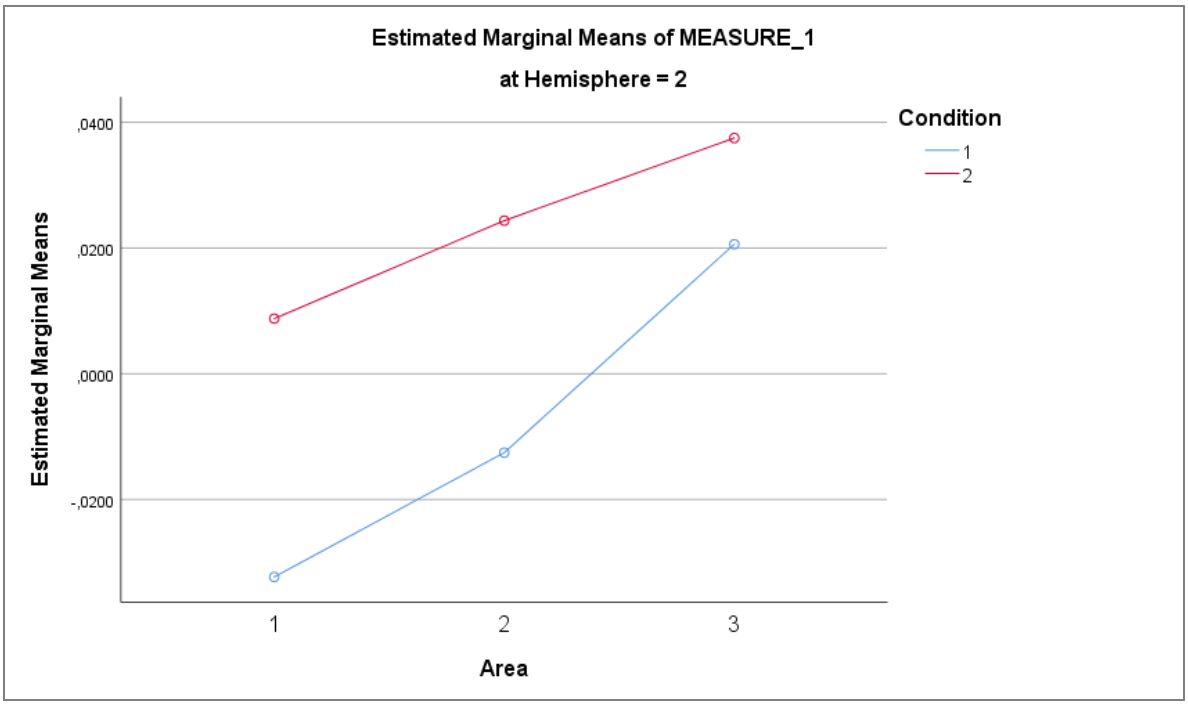


Figure 71: Marginal mean in left hemisphere – EEG ANOVA sub-sample

5.9. Appendix I

In the present appendix all the choices and the steps adopted during the analysis of eye tracking data are presented.

5.9.1. I-VT Fixation Algorithm

iMotions (2018) software, Version 7.0, was used to analyse eye tracking data. This software includes Tobii x2-30 producer's I-VT fixation algorithm which provides several measures regarding fixations and saccades among others. It should be noted that, because the eye tracker employed had a sampling frequency lower than 250 Hz, the data were not fine grained enough to provide an accurate saccade classification (Olsen & Matos, 2012), therefore the results concerning this measure were just used to calculate the number of fixations.

I-VT fixation algorithm supports several parameters to identify fixations and some noise corrections. The options available are presented below as well as the reasons of the configuration selected (Figure 72).

Only fixations directed to the screen could be counted because of the screen-based eye tracker employed. In future studies glass-based eye tracking could improve the results.

Fixation filter parameters

I-VT fixation algorithm identifies fixations by filtering the eye directional shift on the base of its visual angular velocity, expressed in visual degrees per second (°/s) (Olsen, 2012). In other words, by considering the period between two consecutive samples, the algorithm compares the gaze positions of the two samples and classifies the current sample as part of a fixation if the gaze coordinates are within a limited spatial range. Otherwise, if the velocity necessary to go from one point to another is greater than the angular velocity threshold, the sample is categorized as part of a saccade. The threshold to discriminate fixations from saccades was 30°/s. Such threefold was chosen in accordance to a past study (Walcher et al., 2017).

Gap Fill-in Interpolation

During data collection, data loss can affect specific samples because of blinking or because the subject looks away from the screen. Furthermore, in digital measurement systems it can also happen that a sample could not be collected because of momentary problems in the hardware such as delays in data transfers or malfunctions (Olsen, 2012). In order not to interpret such data loss as interruption of a fixation or of a saccade, the software provides a gap fill in function that inserts gaze values were data are missing. However, because the time covered by a sample (33 ms) is similar to the possible duration of a blink, the gap fill-in function was not used in order not to underestimate the number of blinks and thus not to overestimate the number of fixations.

Noise reduction

Noise can affect the measures because of interferences from the environment or minor eye movements such as microsaccades and tremor. To reduce the noise effect, filters embedded in I-VT can average gaze position among consecutive samples through a non-weighted moving average: the wider the average window, centred on the sample of interest, the lower the noise. But smoothing the differences among consecutive samples implicates lower instant velocity estimation, with consequent overstatement of fixations to the detriment of saccades. Otherwise median noise reduction filter can be applied. The operating principle is the same, however replacing the middle data point with a median does not severely reduce velocity peaks as the moving average. However, ocular data sampled at a frequency lower than 60 Hz could be sensibly tampered with such a filter (Olsen, 2012). In this kind of noise reduction algorithms, the minimum window size is three (the sample of interest, the preceding one and the following one), therefore for data sampled at 30 Hz the window size would be 100 ms. The minimum window size is then very near to the typical fixation duration of 200 ms and very likely the categorization of the samples would be negatively affected. For this reason, no noise filter was applied to the data. However, because noise affects gaze's position with the same amplitude regardless of the sampling rate and because angular velocity is computed looking at the different gazes' position between two consecutive ocular data samples, the lower the temporal distance between the two samples the higher the effects of the noise on angular velocity calculated. So, not applying noise filter to data recorded from low sampling frequency rate devices, like the one used in the study, generates smaller distortion on classification of fixations when compared to higher frequency devices.

Merge Adjacent Fixations

Adjacent fixations were not merged, in order not to join fixations potentially separated by a blink happened between the two samples.

Discard Short Fixations

No minimum threefold was set for the duration of a fixation.

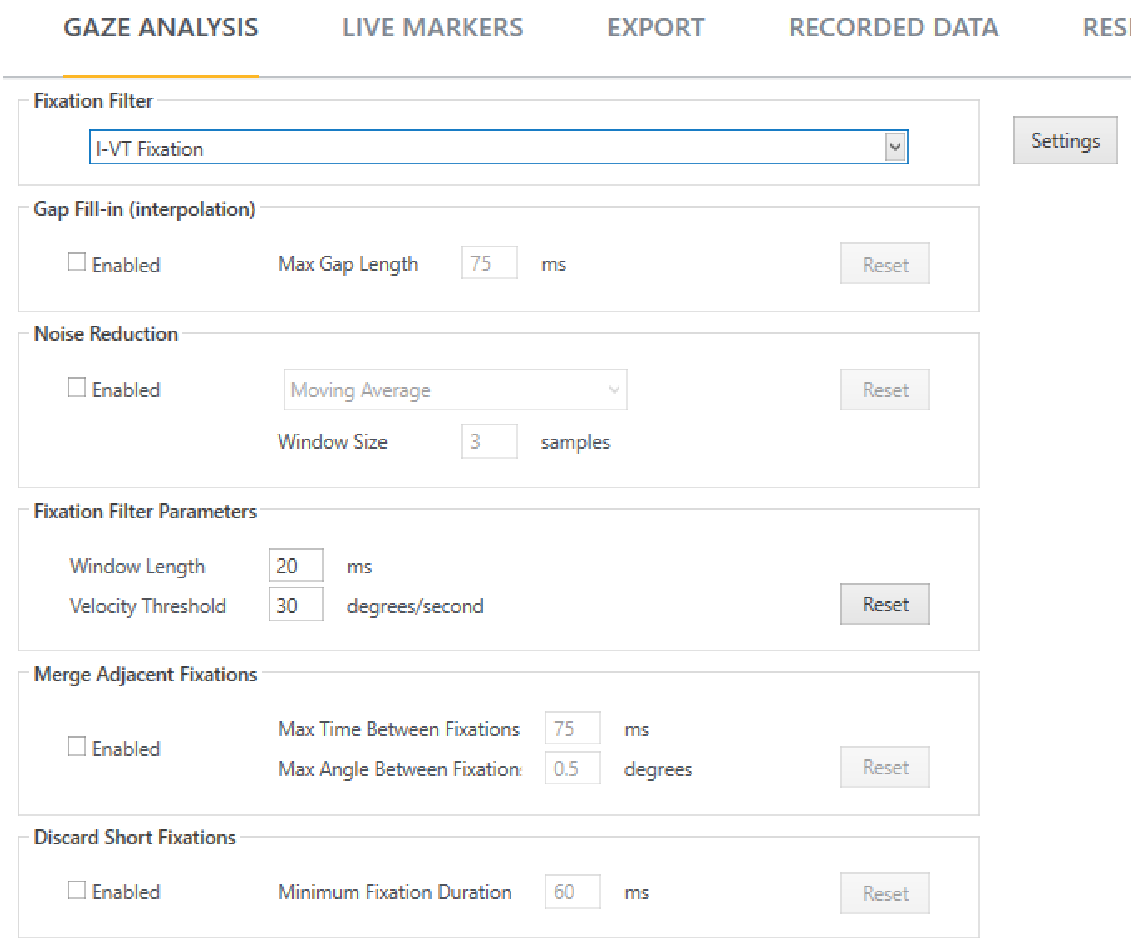


Figure 72: Gaze Analysis Window – iMotions

5.9.2. Fixation Rate

Fixation rate was calculated by averaging the single fixation rates across trials for each condition and each subject.

Data exportation

For each participant an eye tracking (.txt) export file was generated from iMotions. The file was imported to Microsoft Excel. Each row identified as fixation reported the corresponding sequential number within the current stimulus.

Fixation rate computation

Within each subject for each item the number of fixations occurred during the idea generation was collected, then it was divided to the response time of each corresponding item (response times of the subjects were exported from iMotions). The fixation rates were averaged for each condition and each subject. Items with response times higher than 30 seconds (timeouts) were excluded from the average.

5.9.3. Fixations and Response Times Data

In the following pages the number of fixations, the response times and the related fixation rates for each subject are reported. "Failed" mark refers to item with ideas generated after thirty seconds from the appearance of the stimulus (timeout), items with no ideas generated by the respondent and items with ideas verbalized before the subject had pressed the response button. Such items were not averaged and thus were not considered in the following analysis.

Subject 1

Table 38: Fixations and response times - Subject 1

Stimulus	Condition	Response time (ms)	Number of fixations	Fixation rate (Hz)
axe	u	10979	13	1,184
ball	u	13276	12	0,904
basket	n	8453	6	0,710
bed	u	8227	12	1,459
book	n	3080	4	1,299
bread	n	3106	3	0,966
can	failed	30050	82	2,729
coffin	n	8942	25	2,796
colander	n	12183	11	0,903
flour	n	5893	24	4,073
helmet	u	7481	8	1,069
magnifier	n	6037	9	1,491
pot	n	4386	4	0,912
rag	n	4943	5	1,012
ring	failed	30045	181	6,024
rope	n	11392	18	1,580
stick	u	6849	5	0,730
tent	u	12722	76	5,974
trousers	u	16747	64	3,822
vase	u	10464	13	1,242

Count	Condition	Avg. fixation rate (Hz)
10	n	1,574
8	u	2,048

Subject 2

Table 39: Fixations and response times - Subject 2

Stimulus	Condition	Response time (ms)	Number of fixations	Fixation rate (Hz)
axe	n	4047	1	0,247
ball	n	5543	1	0,180
basket	u	9751	3	0,308
bed	n	4112	1	0,243
book	u	5765	1	0,173
bread	u	5321	2	0,376
can	n	5225	2	0,383
coffin	u	9696	1	0,103
colander	u	5912	1	0,169
flour	u	11546	4	0,346
helmet	n	6811	2	0,294
magnifier	u	7034	2	0,284
pot	u	6599	2	0,303
rag	u	11463	4	0,349
ring	n	6467	1	0,155
rope	u	8562	2	0,234
stick	n	6222	3	0,482
tent	n	6247	1	0,160
trousers	n	5398	1	0,185
vase	n	3494	3	0,859

Count	Condition	Avg. fixation rate (Hz)
10	n	0,319
10	u	0,265

Subject 3

Table 40: Fixations and response times - Subject 3

Stimulus	Condition	Response time (ms)	Number of fixations	Fixation rate (Hz)
axe	u	11217	12	1,070
ball	n	3860	6	1,554
basket	n	3690	6	1,626
bed	n	3470	5	1,441
book	u	28375	32	1,128
bread	u	11876	12	1,010
can	n	4580	5	1,092
coffin	n	7761	10	1,288
colander	n	6428	9	1,400
flour	n	3948	7	1,773
helmet	u	8522	13	1,525
magnifier	n	5301	8	1,509
pot	u	18834	28	1,487
rag	u	6712	9	1,341
ring	n	2853	4	1,402
rope	failed	30022	33	1,099
stick	u	16155	20	1,238
tent	n	2488	4	1,608
trousers	u	11305	15	1,327
vase	u	13022	17	1,305

Count	Condition	Avg. fixation rate (Hz)
10	n	1,469
9	u	1,270

Subject 4

Table 41: Fixations and response times - Subject 4

Stimulus	Condition	Response time (ms)	Number of fixations	Fixation rate (Hz)
axe	failed	3395	0	0,000
ball	n	14434	13	0,901
basket	n	7255	5	0,689
bed	u	19747	28	1,418
book	n	15122	22	1,455
bread	n	6020	2	0,332
can	u	14134	13	0,920
coffin	u	18705	16	0,855
colander	u	19331	16	0,828
flour	n	10141	22	2,169
helmet	failed	29931	30	1,002
magnifier	u	12162	12	0,987
pot	u	11036	14	1,269
rag	u	11307	5	0,442
ring	u	29947	19	0,634
rope	u	9196	3	0,326
stick	n	7401	3	0,405
tent	n	7280	4	0,549
trousers	u	26185	36	1,375
vase	n	10844	11	1,014

Count	Condition	Avg. fixation rate (Hz)
8	n	0,939
10	u	0,905

Subject 5

Table 42: Fixations and response times - Subject 5

Stimulus	Condition	Response time (ms)	Number of fixations	Fixation rate (Hz)
axe	n	1659	4	2,411
ball	u	6502	11	1,692
basket	u	1853	3	1,619
bed	u	3295	5	1,517
book	n	1434	3	2,092
bread	n	1667	2	1,200
can	u	3421	5	1,462
coffin	u	3156	6	1,901
colander	failed	5765	8	1,388
flour	u	2608	2	0,767
helmet	n	2217	4	1,804
magnifier	u	7777	18	2,315
pot	n	1499	4	2,668
rag	n	1815	2	1,102
ring	u	8768	19	2,167
rope	n	3864	6	1,553
stick	failed	3090	3	0,971
tent	u	5236	10	1,910
trousers	failed	5155	14	2,716
vase	n	1428	2	1,401

Count	Condition	Avg. fixation rate (Hz)
8	n	1,779
9	u	1,705

Subject 6

Table 43: Fixations and response times - Subject 6

Stimulus	Condition	Response time (ms)	Number of fixations	Fixation rate (Hz)
axe	u	6248	7	1,120
ball	u	4617	2	0,433
basket	u	8905	7	0,786
bed	n	3517	1	0,284
book	u	6383	3	0,470
bread	u	5475	3	0,548
can	n	4667	2	0,429
coffin	n	3340	2	0,599
colander	n	2651	1	0,377
flour	u	23018	17	0,739
helmet	u	6021	9	1,495
magnifier	n	1902	2	1,052
pot	n	1905	3	1,575
rag	n	2897	2	0,690
ring	n	2075	1	0,482
rope	n	6234	5	0,802
stick	u	8900	8	0,899
tent	u	16805	11	0,655
trousers	n	2614	1	0,383
vase	u	8382	4	0,477

Count	Condition	Avg. fixation rate (Hz)
10	n	0,667
10	u	0,762

Subject 7

Table 44: Fixations and response times - Subject 7

Stimulus	Condition	Response time (ms)	Number of fixations	Fixation rate (Hz)
axe	n	2094	2	0,955
ball	u	6005	7	1,166
basket	n	2146	4	1,864
bed	failed	30014	21	0,700
book	n	1598	3	1,877
bread	n	2104	4	1,901
can	u	27658	24	0,868
coffin	u	30032	20	0,666
colander	n	2485	4	1,610
flour	n	1480	4	2,703
helmet	failed	30019	18	0,600
magnifier	n	2711	3	1,107
pot	failed	30021	20	0,666
rag	failed	30019	8	0,266
ring	n	4187	6	1,433
rope	failed	30028	21	0,699
stick	u	30016	30	0,999
tent	u	22583	22	0,974
trousers	n	2252	2	0,888
vase	n	1880	2	1,064

Count	Condition	Avg. fixation rate (Hz)
10	n	1,540
5	u	0,935

Subject 8

Table 45: Fixations and response times - Subject 8

Stimulus	Condition	Response time (ms)	Number of fixations	Fixation rate (Hz)
axe	u	12201	17	1,393
ball	n	2217	4	1,804
basket	u	15294	22	1,438
bed	n	2104	3	1,426
book	u	11276	24	2,128
bread	u	7963	12	1,507
can	n	4498	5	1,112
coffin	n	6869	9	1,310
colander	u	15208	16	1,052
flour	u	17276	38	2,200
helmet	n	2072	4	1,931
magnifier	u	13858	16	1,155
pot	n	2963	5	1,687
rag	n	4409	7	1,588
ring	u	16854	25	1,483
rope	n	7876	15	1,905
stick	n	10003	15	1,500
tent	n	3195	6	1,878
trousers	u	12857	22	1,711
vase	u	18694	21	1,123

Count	Condition	Avg. fixation rate (Hz)
10	n	1,614
10	u	1,519

Subject 9

Table 46: Fixations and response times - Subject 9

Stimulus	Condition	Response time (ms)	Number of fixations	Fixation rate (Hz)
axe	u	2977	2	0,672
ball	n	988	1	1,012
basket	failed	30030	8	0,266
bed	n	1172	3	2,560
book	u	4298	3	0,698
bread	u	6269	3	0,479
can	n	4335	1	0,231
coffin	u	20436	7	0,343
colander	n	5082	2	0,394
flour	n	2087	2	0,958
helmet	u	21439	11	0,513
magnifier	n	3176	1	0,315
pot	n	3176	2	0,630
rag	n	3274	1	0,305
ring	n	2298	2	0,870
rope	u	6848	2	0,292
stick	u	4924	2	0,406
tent	u	8419	3	0,356
trousers	u	5555	3	0,540
vase	n	2248	2	0,890

Count	Condition	Avg. fixation rate (Hz)
10	n	0,816
9	u	0,478

Subject 10

Table 47: Fixations and response times - Subject 10

Stimulus	Condition	Response time (ms)	Number of fixations	Fixation rate (Hz)
axe	n	2243	2	0,892
ball	u	6168	2	0,324
basket	n	3584	2	0,558
bed	u	7078	4	0,565
book	failed	3451	2	0,580
bread	n	4163	4	0,961
can	u	4367	3	0,687
coffin	n	3584	3	0,837
colander	u	5600	3	0,536
flour	u	6087	3	0,493
helmet	n	3411	3	0,880
magnifier	u	4119	2	0,486
pot	u	4009	4	0,998
rag	u	6995	4	0,572
ring	u	6340	4	0,631
rope	n	5941	3	0,505
stick	n	4999	3	0,600
tent	n	4829	2	0,414
trousers	n	5537	3	0,542
vase	u	7764	4	0,515

Count	Condition	Avg. fixation rate (Hz)
9	n	0,688
10	u	0,581

Subject 11

Table 48: Fixations and response times - Subject 11

Stimulus	Condition	Response time (ms)	Number of fixations	Fixation rate (Hz)
axe	failed	30038	42	1,398
ball	n	5191	20	3,853
basket	n	6185	9	1,455
bed	failed	30039	105	3,495
book	u	17620	26	1,476
bread	n	1706	1	0,586
can	failed	30015	37	1,233
coffin	n	2865	4	1,396
colander	n	7793	8	1,027
flour	u	16389	53	3,234
helmet	failed	30054	47	1,564
magnifier	u	16115	26	1,613
pot	n	3853	2	0,519
rag	u	23903	32	1,339
ring	failed	13097	17	1,298
rope	failed	30030	40	1,332
stick	n	12825	13	1,014
tent	failed	30032	43	1,432
trousers	failed	4450	15	3,371
vase	n	7325	6	0,819

Count	Condition	Avg. fixation rate (Hz)
8	n	1,334
4	u	1,915

Subject 12

Table 49: Fixations and response times - Subject 12

Stimulus	Condition	Response time (ms)	Number of fixations	Fixation rate (Hz)
axe	n	3729	2	0,536
ball	u	6176	6	0,972
basket	u	11838	13	1,098
bed	n	3090	3	0,971
book	n	3120	3	0,962
bread	u	5899	6	1,017
can	n	5374	3	0,558
coffin	u	12072	8	0,663
colander	u	5143	5	0,972
flour	n	3371	3	0,890
helmet	n	4521	4	0,885
magnifier	n	11305	5	0,442
pot	u	4240	3	0,708
rag	n	6398	3	0,469
ring	failed	30019	24	0,799
rope	n	5174	6	1,160
stick	u	19728	19	0,963
tent	n	6163	3	0,487
trousers	u	15147	11	0,726
vase	u	15912	13	0,817

Count	Condition	Avg. fixation rate (Hz)
10	n	0,736
9	u	0,882

Subject 13

Table 50: Fixations and response times - Subject 13

Stimulus	Condition	Response time (ms)	Number of fixations	Fixation rate (Hz)
axe	u	12099	6	0,496
ball	u	5044	3	0,595
basket	n	2076	3	1,445
bed	n	2293	2	0,872
book	n	4447	3	0,675
bread	n	1836	2	1,089
can	u	4299	4	0,930
coffin	n	6183	6	0,970
colander	u	11438	6	0,525
flour	n	2375	2	0,842
helmet	n	1944	2	1,029
magnifier	n	4321	3	0,694
pot	u	8003	5	0,625
rag	u	15721	8	0,509
ring	n	5254	5	0,952
rope	u	2612	3	1,149
stick	u	4774	4	0,838
tent	n	2243	2	0,892
trousers	u	22604	12	0,531
vase	u	24856	11	0,443

Count	Condition	Avg. fixation rate (Hz)
10	n	0,946
10	u	0,664

Subject 14

Table 51: Fixations and response times - Subject 14

Stimulus	Condition	Response time (ms)	Number of fixations	Fixation rate (Hz)
axe	n	2372	2	0,843
ball	n	4997	1	0,200
basket	u	15877	6	0,378
bed	u	5672	4	0,705
book	u	4761	3	0,630
bread	failed	14105	3	0,213
can	n	7728	3	0,388
coffin	u	17215	12	0,697
colander	n	6730	4	0,594
flour	u	11912	11	0,923
helmet	u	7509	5	0,666
magnifier	u	7948	3	0,377
pot	n	2120	1	0,472
rag	n	5826	3	0,515
ring	failed	30010	14	0,467
rope	n	9556	4	0,419
stick	n	9143	4	0,437
tent	u	9256	4	0,432
trousers	n	3072	1	0,326
vase	n	1779	2	1,124

Count	Condition	Avg. fixation rate (Hz)
10	n	0,532
8	u	0,601

5.10. Appendix L

Paired-samples t-test was employed for the statistical analysis. to test the statistical significance of the mean difference in fixation rates between the two response conditions. The factor is the response condition (common, uncommon response) and the dependent variable is the average fixation rate. Paired t-test assesses the null hypothesis asserting that the mean difference between the paired values is equal to zero.

5.10.1. SPSS Input Data

	n	u	Difference
1	1,574	2,048	-,47
2	,319	,265	,05
3	1,469	1,270	,20
4	,939	,905	,03
5	1,779	1,705	,07
6	,667	,762	-,09
7	1,540	,935	,61
8	1,614	1,519	,10
9	,816	,478	,34
10	,688	,581	,11
11	1,334	1,915	-,58
12	,736	,882	-,15
13	,946	,664	,28
14	,532	,601	-,07

Figure 73: SPSS data view – Fixation rate paired-samples t-test

	Name	Type	Width	Decimals	Label	...	...	Columns	A...	Measure	Role
1	n	Numeric	8	3	Avg.fixation_rate common_response_condition	...	...	8		Scale	None
2	u	Numeric	8	3	Avg.fixation_rate uncommon_response_condition	...	...	8		Scale	None
3	Difference	Numeric	8	2	Difference n - u	...	...	12		Scale	None

Figure 74: SPSS variable view - Fixation rate paired-samples t-test

5.10.2. Descriptive Statistics

Boxplot

Circular points in the SPSS boxplot are data distant more than 1.5 interquartile ranges from the edges of the box (the box is encompassed between the lower and the upper quartiles, that are the 25th and 75th percentiles). Asterisks represent data with values distant more than 3 interquartile ranges from the edges of the box. This last distance was considered the threshold to categorize outlier values.

No significant outliers characterised the sample.

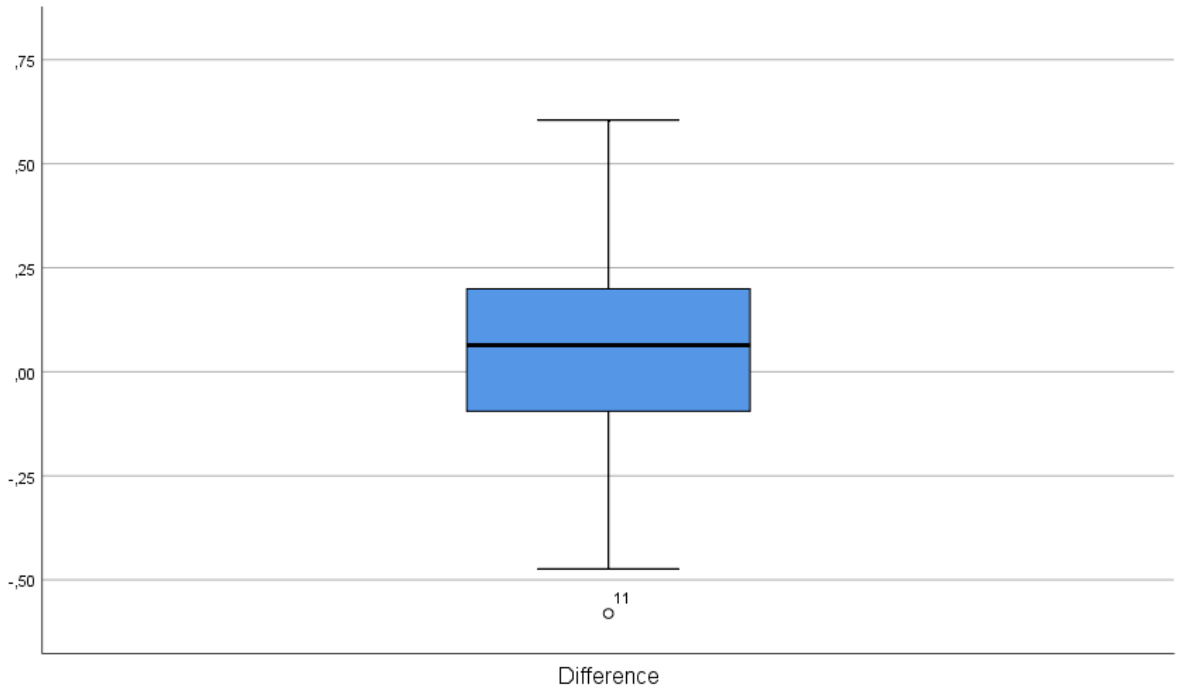


Figure 75: Boxplot of fixation rate difference – Fixation rate paired-samples t-test

Test of Normality

The difference between conditions is approximately normally distributed according to Shapiro-Wilk's test of normality (p = 0.653).

Table 52: Test of normality - Fixation rate paired-samples t-test

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Difference	,148	14	,200*	,956	14	,653

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Normal Q-Q Plots

The differences between the fixation rate in the common and uncommon response condition seems to be normally distributed also by visual inspection of the Normal Q-Q Plot.

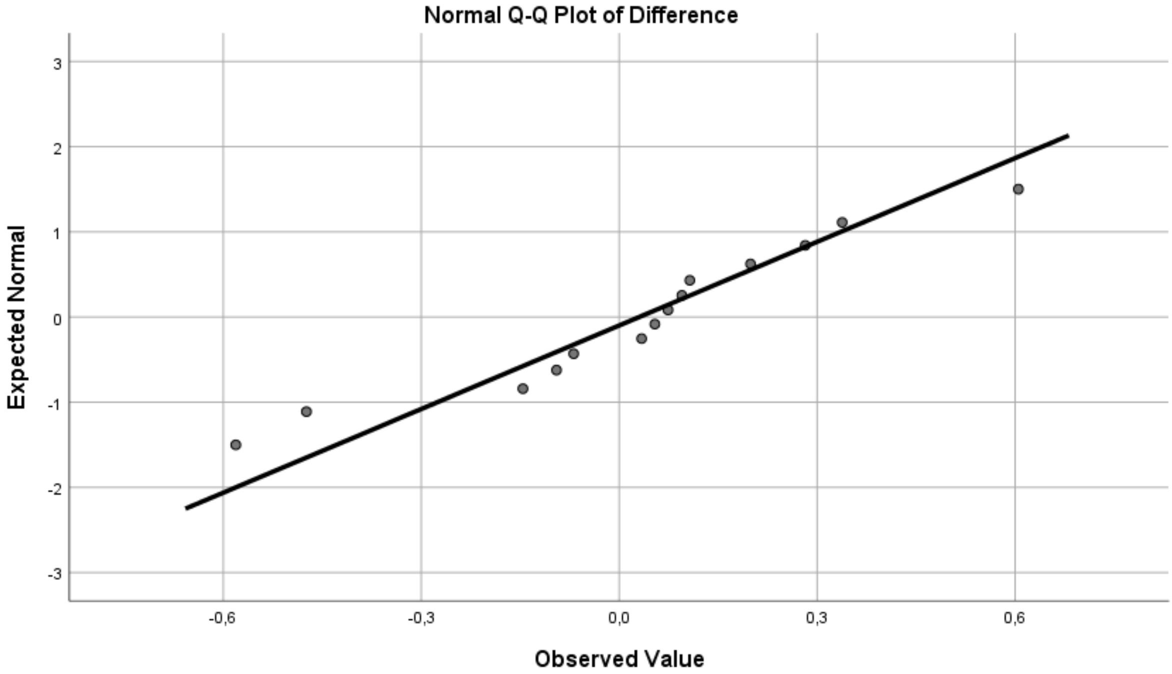


Figure 76: Normal Q-Q plot of difference - Fixation rate paired-samples t-test

5.10.3. Paired-samples t-test

Participants had higher fixation rate during the common response condition (*M* = 1.068 Hz, *SD* = 0.470 Hz) as opposed to the uncommon response condition (*M* = 1.038 Hz, *SD* = 0.562 Hz).

Table 53: Paired samples statistics – Fixation rate paired-samples t-test

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Avg.fixation_rate common_response_condition	1,06807	14	,470087	,125636
	Avg.fixation_rate uncommon_response_condition	1,03786	14	,561518	,150072

However, according to paired-samples t-test such difference between the two experimental conditions was not statistically significant $t(13) = 0.370$, $p = 0.717$, Cohen's $d = 0.099$. The difference between common response condition and uncommon response condition was 0.030 Hz, 95% CI [-0.146, 0.207] ($SE = 0.082$). In light of that, the null hypothesis asserting that the difference between the two conditions is equal to zero could not be rejected.

Table 54: Paired samples t-test – Fixation rate paired-samples t-test

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Avg.fixation_rate common_response_condition - Avg.fixation_rate uncommon_response_condition	,030214	,305586	,081671	-,146226	,206654	,370	13	,717

References

Advanced Brain Monitoring. (2009). *B-alert live user manual*

Amabile, T. M. (1982). A consensual assessment technique. *Journal of Personality and Social Psychology, 43*, 997-1013.

Benedek, M., Bergner, S., Knen, T., Fink, A., & Neubauer, A. C. (2011). EEG alpha synchronization is related to top-down processing in convergent and divergent thinking. *Neuropsychologia, 49*(12), 3505-3511.

Benedek, M., Schickel, R. J., Jauk, E., Fink, A., & Neubauer, A. C. (2014). Alpha power increases in right parietal cortex reflects focused internal attention. *Neuropsychologia, 56*, 393-400.

Cantamessa, M., & Montagna, F. (2016). *Management of innovation and product development - integrating business and technological perspectives* Springer, London.

Cropley, A. (2006). In praise of convergent thinking. *Creativity Research Journal, 18*(3), 391-404.

Da Silva, F. L., & Pfurtscheller, G. (1999). Basic concepts on EEG synchronization and desynchronization. *Event-Related Desynchronizataion.Handbook of Electroencephalography and Clinical Neurophysiology.Revised Series, Vol.6,* , 3-11.

Danko, S. G., Shemyakina, N. V., Nagornova, Z. V., & Starchenko, M. G. (2009). Comparison of the effects of the subjective complexity and verbal creativity on EEG spectral power parameters. *Human Physiology, 35*(3), 381-383.

Dietrich, A., & Kanso, R. (2010). A review of EEG, ERP, and neuroimaging studies of creativity and insight. *Psychological Bulletin, 136*(5), 822.

EEG info - impedance measurement. Retrieved from http://www.eeginfo-europe.com/neurofeedback/support/technical-infos-faq/impedance-measurement.html

Elul, R. (1972). The genesis of the EEG. *International Review of Neurobiology, 15*, 227-272.

Fink, A., & Benedek, M. (2012). EEG alpha power and creative ideation. *Neuroscience & Biobehavioral Reviews, 44*, 111-123.

Fink, A., Benedek, M., Grabner, R. H., Staudt, B., & Neubauer, A. C. (2007). Creativity meets neuroscience: Experimental tasks for the neuroscientific study of creative thinking. *Methods, 42*(1), 68-76.

Fink, A., Grabner, R. H., Benedek, M., & Neubauer, A. C. (2006). Divergent thinking training is related to frontal electroencephalogram alpha synchronization. *European Journal of Neuroscience, 23*(8), 2241-2246.

Fink, A., Grabner, R. H., Benedek, M., Reishofer, G., Hauswirth, V., Fally, M., . . . Neubauer, A. C. (2009). The creative brain: Investigation of brain activity during creative problem solving by means of EEG and fMRI. *Human Brain Mapping, 30*(3), 734-748.

Fink, A., & Neubauer, A. C. (2006). EEG alpha oscillations during the performance of verbal creativity tasks: Differential effects of sex and verbal intelligence. *International Journal of Psychophysiology, 62*(1), 46-53.

Fink, A., & Neubauer, A. C. (2008). Eysenck meets martindale: The relationship between extraversion and originality from the neuroscientific perspective. *Personality and Individual Differences, 44*(1), 299-310.

Fink, A., Schwab, D., & Papousek, I. (2011). Sensitivity of EEG upper alpha activity to cognitive and affective creativity interventions. *International Journal of Psychophysiology, 82*(3), 233-239.

Freepik. *Brain inside human head* www.flaticon.com.

Grabner, R. H., Fink, A., & Neubauer, A. C. (2007). Brain correlates of self-rated originality of ideas: Evidence from event-related power and phase-locking changes in the EEG. *Behavioral Neuroscience, 121*(1), 224.

Guilford, J. (1959). Personality McGraw hill. *New York,*

Guilford, J. P. (1950). Creativity. *American Psychologist, 5*(9), 444–454.

Hürsen, Ç, Kaplan, A., & Özdal, H. (2014). Assessment of creative thinking studies in terms of content analysis. *Procedia-Social and Behavioral Sciences, 143*, 1177-1185.

iMotions. (2016). *EEG pocket guide* iMotions Biometric Research Platform.

iMotions. (2017). *Human behavior* iMotions Biometric Research Platform.

Jauk, E., Benedek, M., & Neubauer, A. C. (2012). Tackling creativity at its roots: Evidence for different patterns of EEG alpha activity related to convergent and divergent modes of task processing. *International Journal of Psychophysiology, 84*(2), 219-225.

Jaušovec, N. (2000). Differences in cognitive processes between gifted, intelligent, creative, and average individuals while solving complex problems: An EEG study. *Intelligence, 28*(3), 213-237.

Jiang, H., & Yen, C. (2009). Protocol analysis in design research: A review. *Journal Paper, 78*(24), 16.

Martindale, C., & Hasenfus, N. (1978). EEG differences as a function of creativity, stage of the creative process, and effort to be original. *Biological Psychology, 6*(3), 157-167.

Mathias Benedek, Robert Stoiser, Sonja Walcher, & Christof Körner. (2017). Eye behavior associated with internally versus externally directed cognition. *Frontiers in Psychology, 8*10.3389/fpsyg.2017.01092 Retrieved from https://doaj.org/article/497872cebadb4789886fe6f6846adf83

Michel, C. M., Murray, M. M., Lantz, G., Gonzalez, S., Spinelli, L., & de Peralta, R. G. (2004). EEG source imaging. *Clinical Neurophysiology, 115*(10), 2195-2222.

Mölle, M., Marshall, L., Wolf, B., Fehm, H. L., & Born, J. (1999). EEG complexity and performance measures of creative thinking. *Psychophysiology, 36*(1), 95-104.

Nguyen, T. A., & Zeng, Y. (2010). (2010). Analysis of design activities using EEG signals. Paper presented at the *ASME 2010 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference,* 277-286.

Olsen, A. (2012). The tobii I-VT fixation filter. *Tobii Technology,*

Olsen, A., & Matos, R. (2012). (2012). Identifying parameter values for an I-VT fixation filter suitable for handling data sampled with various sampling frequencies. Paper presented at the *Proceedings of the Symposium on Eye Tracking Research and Applications,* 317-320.

Pfurtscheller, G., & Da Silva, F. L. (1999). Event-related EEG/MEG synchronization and desynchronization: Basic principles. *Clinical Neurophysiology, 110*(11), 1842-1857.

Razumnikova, O. M. (2005). (2005). Hemispheric activity during creative thinking: Role of gender factor. Paper presented at the *Science and Technology, 2005. KORUS 2005. Proceedings. the 9th Russian-Korean International Symposium On,* 1027-1031.

Razumnikova, O. M., Volf, N. V., & Tarasova, I. V. (2009). Strategy and results: Sex differences in electrographic correlates of verbal and figural creativity. *Human Physiology, 35*(3), 285-294.

Razumnikova, O. M. (2007). Creativity related cortex activity in the remote associates task. *Brain Research Bulletin, 73*(1), 96-102.

Runco, M. A., & Yoruk, S. (2014). The neuroscience of divergent thinking. *Activitas Nervosa Superior, 56*(1-2), 1-16.

Sebastian023.*LobesCaptsLateral* In Wikipedia. Retrieved from https://commons.wikimedia.org/wiki/File:LobesCaptsLateral.png

Shemyakina, N. V., & Danko, S. G. (2007). Changes in the power and coherence of the β 2 EEG band in subjects performing creative tasks using emotionally significant and emotionally neutral words. *Human Physiology, 33*(1), 20-26.

Steinert, M., & Jablokow, K. (2013). (2013). Triangulating front end engineering design activities with physiology data and psychological preferences. Paper presented at the *DS 75-7: Proceedings of the 19th International Conference on Engineering Design (ICED13), Design for Harmonies, Vol. 7: Human Behaviour in Design, Seoul, Korea, 19-22.08. 2013,* Swartz Center for Computational Neuroscience. (2014). Preprocessing tools. Retrieved from https://sccn.ucsd.edu/wiki/Chapter_04:_Preprocessing_Tools

Tobii. (2018). Types of eye movement. Retrieved from https://www.tobiipro.com/learn-and-support/learn/eye-tracking-essentials/types-of-eye-movements/

Torrance, E. P. (1966). *Torrance test of creative thinking: Figural form A* Personnel Press.

Understanding FFTs and windowing (2016). National Instruments. Retrieved from http://www.ni.com/white-paper/4844/en/

Varela, F., Lachaux, J., Rodriguez, E., & Martinerie, J. (2001). The brainweb: Phase synchronization and large-scale integration. *Nature Reviews Neuroscience, 2*(4), 229-239.

Vijn, P. C., Van Dijk, B. W., & Spekreijse, H. (1991). Visual stimulation reduces EEG activity in man. *Brain Research, 550*(1), 49-53.

Walcher, S., Körner, C., & Benedek, M. (2017). Looking for ideas: Eye behavior during goal-directed internally focused cognition. *Consciousness and Cognition, 53*, 165-175.

Ward, L. M. (2003). *Synchronous neural oscillations and cognitive processes*//doi.org/10.1016/j.tics.2003.10.012 Retrieved from http://www.sciencedirect.com/science/article/pii/S1364661303002894

Wikipedia contributors. (2017). Short-time fourier transform. Retrieved from https://en.wikipedia.org/w/index.php?title=Short-time_Fourier_transform&oldid=811271741

Zeng, H., & Song, A. (2014). Removal of EOG artifacts from EEG recordings using stationary subspace analysis. *The Scientific World Journal, 2014*