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Brain Activities in Creative Thinking Task

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Abstract

There are different approaches to study design processes, one of them is more scientific and it is called Science of Design. Its main aim is to define scientific methods to support design activity. Traditionally, it is studied through the protocol analysis. In last years, the neurophysiological aspects are more studied to define any internal cognitive design processes.

More precisely, the present document has the purpose to recognize neurocognitive and physiological patterns that can be detected through devices such as Electroencephalogram (EEG) and Eye Tracker. These devices allow to have a closer and more detailed view on what happens in the brains when we are requested to "be creative", recording our subconscious physiological responses. Particular interest is into finding possible differences of activation between two distinct cognitive processes involved in creative ideation, namely Convergent and Divergent thinking. This is done by observing people performing a revised version of the Alternative Uses test, designed by J.P. Guilford in 1967. This test requires finding alternative/uncommon uses for everyday objects.

So far, this field has been weakly investigated, and strong evidences are still lacking. Moreover, there is not a clear definition of the construct of creativity, nor a standardized procedure for its investigation from a neurophysiological point of view. With this work, the goal is to contribute in framing both these issues: defining specific creative processes and testing an analysis pipeline that can be replicated by further studies. Thus, it can bring benefits on two sides: it could extend the knowledge about creativity and give a precise replicable methodology for its investigation.

In future, the results (if any) could bring to the possibility of using this knowledge in order to facilitate those specific brain activities that happen during creative ideation, for example through environmental manipulation or direct brain stimulation. Having a clear view on creativity can help in exploiting it in an industry level in order to ameliorate the efficiency and effectiveness of ideas, taking into account a multidisciplinary that in recent times is always more and more required.

Acknowledgments

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“You need a really solid foundation of friends and family to keep you where you need to be” Anonimus.

Thank you!

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Introduction

This work rises in a cooperation project between the University of Turin (Italy), the Polytechnic of Turin (Italy) and the Luleå Technology University (Sweden). The intent of this work is to investigate the design processes that comes into play during the product development phase in industrial design, with a cognitive and physiological approach. This can be done in a multidisciplinary environment that involves Cognitive Neuroscience, Management Engineering and Technic Design.

The Problem

The role of design is increasingly in our reality. In this field, one of the main trends is studying the design process to understand how it could be improved and supported. It can be studied as a phenomenon with a scientific approach that is part of a design research that is classified as "Science of Design" (Cantamessa & Montagna, 2016). This point of view allows to deepen design activities, through the study of the designers and design processes as the focus of the research. There are different perspectives generally based on experimental or empirical studies, those define the protocol studies to measure and validate cognitive processes framework.

The protocol analysis in the design environment are based on the study of the behavioral and cognitive. The researchers collect and analyze all the outcomes from these session with individual and group approaches. Nowadays, one of the type of data that are growing in interest for the researchers are those relative to the designers' cognitive processes that are not expressed. In the past, with Guilford (1950), researchers started to qualify the design process and the attempt was to understand an internal cognitive process with a behavioral approach, based on the outcomes as sketches, representation and verbalization. In last years, researchers (Jauk, Benedek and Neubauer, 2012; Benedek et al., 2014; Fink, Schwab and Papousek, 2011; Fink et al., 2009; Schwab et al., 2014; Camarda et al., 2018; Fink et al., 2006; Fink and Neubauer, 2008; Fink, Graif and Neubauer, 2009; Grabner, Fink and Neubauer, 2007; Rataj, Nazareth and Van der Velde, 2018; Jausovec, 2000, exp. 1 and 2; Razumnikova, 2007) focused to understand if the cognitive design processes could be qualified with neuroimaging techniques. It is caused because of the gap between the reality of the thinking and their behavioral outcomes. To avoid the problem, the researchers are moving on the physiological and neurophysiological devices to collect these data in a standard impersonal manner. This branch of research is still at its beginnings and to make it more consistent further studies are required. The intent of the present study is to extend this branch and to provide a good point on the state of the art to build up an experiment in line with the previous researches.

The Purpose of the Project

The aim of this work is to recognize neurocognitive and physiological patterns that can be detected through devices such as electroencephalogram (EEG) and eye tracker. These devices allow us to have a closer and more detailed view on what happens in our brains when we are requested to find a solution in a phase of generation of idea, recording the neurophysiological responses. The interest is in finding possible differences of activation between two distinct cognitive processes involved in creative ideation, namely Convergent and Divergent thinking. It is done by observing people performing a revised version of the Alternative Uses test (AUT), designed by J. P. Guilford in 1967. This test is based on the creativity construct most used in literature so far and it requires finding alternative or uncommon uses for everyday objects.

This branch of the research on the science of design has been weakly investigated, and significant evidences are still lacking. As the starting point, this study is strongly focused on the review of the previous results to understand what and how investigate. To consolidate the trend of the actual results, the present work has the aim to replicate, with some adjustments, the Jauk, Benedeck and Neubauer, 2012 study and reinforce the design of the experiment. Moreover, there is not a clear definition of the construct of creativity, nor a standardized procedure for its investigation from a neurophysiological point of view.

In the document there is the explanation of the experiment conducted for this study, which involve 40 participants, that is a powerful presentation of how to use electroencephalogram and eye-tracker to detect any neuro and physiological results. The size and the complexity of the analysis needed to get some results would make the study too wide for only one study, for this reason they will be done in further studies.

With the present work, there is the attempt to contribute in framing both these issues: defining specific creative processes in design process and testing an analysis pipeline that can be replicated by further studies. It could extend the knowledge about creative cognitive process and it could give a precise replicable methodology for its investigation. The work is done to verify if findings of other studies are consistent, in particular Walcher, Körner and Benedek, 2017 for the eye-tracker and Jauk, Benedeck and Neubauer, 2012 for the EEG. At the moment, it is not possible to define if there are any difference or not from previous studies.

The study represents the starting point in this field, with the challenge to find preliminary empirical evidences that are easily replicable and thus could be helpful in addressing further studies. The findings (if any) could bring to the possibility of using this knowledge in order to facilitate those specific brain activities that happen during creative ideation, for example through environmental manipulation or direct brain stimulation.

Having a clear view on this cognitive process can help in understanding how the design process is structured. It must be done considering the multidisciplinary approach that in recent times is always more and more required.

Methodology

The approach to the problem was strongly based on the literature. Most of the time in the beginning was spent to understand how to structure a rigorous methodology with the literature review. The result of the review is the replication of the experimental paradigm of Jauk, Benedeck and Neubauer (2012) and Laspia, Montagna and Törlind (2019), using neuroimaging techniques to monitor cognitive design processes. In relation to the two previous studies, the present has few modifications, validated thanks for the support of the neuroscience department of University of Turin.

The design of the experiment consists in a single task (Alternative Uses Task), divided in two conditions (common and uncommon). The task is the most used to evaluate divergent thinking that represents one of the most important phases of the creative idea generation in literature. For the task, the stimuli (items) are in part the same of the Jauk, Benedeck, Neubauer (2012), the others were selected by a careful analysis of the uses, the meanings and the frequencies of the words.

As neuroimaging technique, the most used tools in this research branch is electroencephalogram. It is important to get as much data as possible because it is a new approach to a problem, thus in the present work eye tracker is used as an extra data source.

It was necessary to use a software able to manage and synchronize data from different sources, following the resources of the universities. For the analysis of the data the preprocessing and postprocessing activities are usually structured by MATLAB. The definition of the algorithm is not standard because it depends on the research paradigm and the intent. In the present work, it is being defined with the support of the department of biomedical engineering of the Polytechnic of Turin.

Document structure

The document is divided in 4 chapters, excluding the introduction and conclusions.

The first chapter is focused on the explanation of the context and all the knowledges those are necessary to understand the study. It is a summary presentation of all the basic concepts, in particular for the neuroscientific sections. It starts with the engineering environment and design processes where the research takes place and showing the neurophysiological approach to the problem. It includes a brief examination of the brain and the eye, with anatomic and functional point of views.

The second chapter contains an overview of the main neuroimaging instruments, lingering with a strong focus on the electroencephalogram and eye tracker, those are the tools used for the present project. On the base of the concepts explained in the first chapter, there is a deep discussion of the brain activities as outcome of the electroencephalography; the same is done for the eye and eye tracker.

The third chapter is the core of the document, with the literature review of the neuroscientific research on design processes, in particular on the cognitive creative processes. In this part, most of the papers are reported and analyzed to explain how they structured their researches and the results they obtained. Through the literature the reasons of each choice of the experiment paradigm is clarified.

The experiment conducted for the present work is detailed in the last part of the dissertation. All the previous considerations are gathered in one experiment with all the necessary adjustments to maintain the coherence and the consistence.

The conclusion of the document consists in a recap of the main aspects of the work. It presents the limitations and restrictions, those represent what should be expected from this research field in next years.

1. Contextualization and Basic Knowledges

1.1 Environment

1.1.1 New Product Development

This study fits in the macro area of the new product development process. It is a complex context, where many decisions are made. Each new product development project is a standalone from the others because it depends on a lot of variables as the industry, the product, the history of the firm and others. Despite this, there is the possibility to identify and define some common phases. The distinction of these phases is not simple because of they are led without a sequential structure, but with a *concurrent engineering* approach (Clark and Fujimoto 1991), with overlaps and iteratively structure. They can be basically summarized as following (*Figure 1* - Cantamessa & Montagna 2016), with few and simple adjustment in case of services.

(i) *Product planning* is the starting point where the firm define the new product, focusing on the data from the market, technology performance, the resources and the capabilities of the firm. From these data the product positioning is settled, with user needs and user requirements. In this phase is fixed the budget of the product that will be revised on the other steps.

(ii) *Conceptual design* is the phase were a technical solution is defined in order to get the positioning required, fulfilling the user needs. The outcome of this phase is a product concept.

(iii) *System-level design* is the concretization of the product concept, where important choices are made to define the product architecture. For instance, here there is the evaluation of make or buy the components and subsystems.

(iv) *Detailed design* is the most engineering process, because the previous solutions are reviewed and revised to find a feasible detailed solution.

(v) *Testing and prototyping* is the put into practice of the solutions defined, to verify if it is compliant with the user needs and requirements. It is important to carry out this phase for regulations and certification processes.

(vi) *Process design* is the clarification of the production and distribution of the product that came out from the previous steps.

(vii) *Product launch and production* is the arrival point of the product on the market, starting with a slow production and increasing it progressively with the development of the demand.

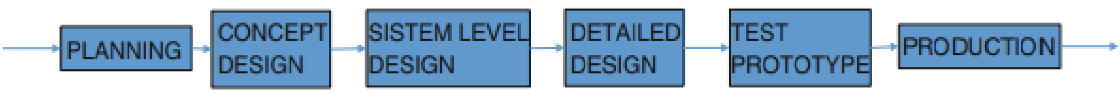


Figure 1 - Product Development Process (Cantamessa & Montagna, 2016)

In this complex environment, many choices are made with a growing structured problem. In the product planning and conceptual design is not declared what is the object of the choice, but it must be generated by the actors. Instead, in the process design there are a lot of strict outcomes to get those do not give a lot of alternative solutions. This study focuses on the conceptual design the phase where the designers are free to generate solutions and choose for the best one in their evaluations (divergent thinking). It is easy to oppose to a structured problem with a single one right solution (convergent thinking), to understand if there any differences in the brain activity.

1.1.2 Conceptual Design

The conceptual design is a partially iterative process starting with the identification of the user needs and requirements. The actors in this phase are the designers, with different technique to solve the problem of the product concept. It allows to define the problem, with the consequent exploration of the alternatives and the concept selection as the final step. It is structured with a concept generation, where as much as possible solutions are generated, with a wide field of alternatives. It consists in a creative generation of idea, that can be structured following different methods (brainstorming, TRIZ, etc.). After this, there is the concept screening and scoring with the point of view to declare the most suitable solutions, restricting the number of alternatives. Then, the outcomes of the screening are evaluated and modified to get more alternatives matching the users' requirements in different way. At the end of this part, there is the concept selection generating the concept that will be depth in the following steps.

In this phase the science of design becomes fundamental to facilitate the process, to give to the designer the necessary support to get the best solutions.

1.2 Science of Design

During the conceptual design there is the proper design activity in the new product development process. The designers, during this activity, pursue the goal to generate a technical solution that could be the answer to the users' requirements. Indeed, 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).

The concept of science of design derives from the study of this activity with a scientific method to obtain a support with new method and tools to improve the design activity. To understand better the science of design, it is necessary to discuss its history and its role in the design processes (A. Laspia, Master Thesis, 2018).

This study is centered on creative idea generation that is the starting point of the conceptual design and the science of design related to this phase. There are different benefits that came from the previous study of science of design about the idea generation in design processes. In particular, creativity constructs are proposed from the literature and the most established is proposed by Guilford in 1950. The Guilford studies are the first about the role of creativity in literature and they are depth in this section of the document.

1.2.1 Beginning

Everything about design has its beginning with Aristotele, two thousand and four hundred of years ago. The dichotomy between technology and science starts with the Greek philosopher, but it is necessary to wait the 1969 with Herbert Simon to get the acknowledgement of the study of the technology as a proper branch of the research. "The Sciences of the Artificial" suggests studying the design processes as the best way to understand how the world works, because design is the activity that give the shape to all the artifacts and the artificial world. The interesting thing about the H. Simon's book is that for the first time he introduced the idea to study the design activity with a cognitive perspective. Only later, in 2001 with Nigel Cross, it is qualified as science of design (A. Laspia, Master Thesis, 2018).

1.2.2 Improvement

The design activities are strongly based on the results of the science of design. These studies described a lot of practice to implement the design process in different ways. Donald Schön said with *protocol studies* the design activities are based on iterative feedback, with a progressively definition of the technical solution. It is the result of a continuous alternating of generating of ideas and the assessment of them, to understand if they are feasible and fitting with the users need.

In this perspective, Schön defined the starting point of this process as a phase were designers need to understand the design problem, with the classification of the key elements of the problem. After the clarification of the problem, as declared by Smith and Browne there is the cognitive process carried out by designer to move from the reality level to a more abstract level (A. Laspia, Master Thesis, 2018). It is a necessary step to generate solutions, having the possibilities to be freer in the definition of ideas, without less boundaries. After the idea generation, with another cognitive process, designers bring their idea and evaluate if they are good solutions for the problem.

The idea generation is heavily characterized by designers' individual aspects and here the creativity takes an important role.

1.3 The Role of Creativity and Divergent Thinking

One of the basic drivers of the idea generation is creativity. The meaning and the results of creativity is not univocal: it is hard to manage it.

As an individual perspective, in the literature, there is the identification of two phases during the creativity in the design process: *convergent thinking* and *divergent thinking*, both are necessary to get a great result of the phase of the conceptual design. While convergent processes are involved in straightforward problem solving, divergent thinking is the "kind which goes off in different directions" (Guilford, 1959a). This also implies that, regarding tests on divergent thinking, it should be possible to give more than only one correct answer – in other words "the unique feature of divergent productions is that a variety of responses is produced" (Guilford, 1959b). The distinction is important to discern the two cognitive processes during a creative idea generation, with the generation of alternatives and the validation of them. The two concepts were generated for the first time from J.P. Guilford (1950). The divergent thinking is identified as the moment when the mind faces problems without a unique solution and it represents the generation of the alternatives. But the alternatives need to be assessed: here there is the role of the convergent thinking. It represents the situation where the mind faces a more structured problem, where it is possible to solve it with a single answer, using logic and previous knowledges.

1.4 The State of the Art of Science of Design

In the past, the design activities were supported mainly by protocol analysis. With the new technologies, also in this field, new techniques are catching on, in order to monitor and to help each aspect that comes into play. These new tools and devices, as electroencephalogram (EEG), are changing the way to study the design activities.

1.4.1 Previous Studies and Protocol Analysis

Previous studies were based on the pure observation of the designers and their outputs. It consists in a factual approach that represent the protocol analysis, trying to understand how the environment and the techniques of communication could effect on the results. First studies started in 1960s, but the main studies with some significant results came out not before 1980s. The protocol analysis has become 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).

Before EEG and other devices, the only way to understand the designers' cognitive process was the protocol analysis with the verbalization of the thinking, trying to define the reasoning they follow to solve the design problem. The action to move from the reasoning to words involve the lack of some concepts, because of the nature of the design thinking (A. Laspia, Master Thesis, 2018). Indeed, creative thinking is a visual-graphic action, just later designer think about to vocalize the concept. Protocol analysis is based on trust designers during the explanation of their cognitive processes, but it is also supported by complementary materials, as sketches and audio-video recordings. Sometimes it is required to designers to do activities of think-aloud, in order to collect all of cognitive transitions. It is the situation were designers are as in a "laboratory environment", with all the consideration about the changing of a normal activity in relation to the laboratory activity. The collection of retrospective data by this category of protocol does not affect the result of the design activities, but there are no evidences of the integrity of the data. In other words, by its own nature introspection cannot be considered properly protocol analysis (Jiang & Yen, 2009), hence there is the need to avoid the lack of some essential and useful data.

The weakness in robustness of the introspective protocol analysis has had a fundamental role in the science of design, introducing the content analysis. In order to detect the presence of meaningful patterns in verbal protocols, some studies resort to content analysis (Hürsen et al., 2014). Studying the content, it is possible to work with wired amount of data, in a textual format, allowing further and different analysis (A. Laspia, Master Thesis, 2018).

Protocol analysis and, in particular, content analysis are both afflicted by a not objective point of view: on one hand there is the possibility by the researchers in the content analysis in the way to analyse textual data; on the other hand, the introspective protocol analysis for the designer that could miss something, because of some of the cognitive processes could be made in a subconscious way. In the last years, researchers are testing a lot of different techniques to overcome these problems.

1.4.2 Emerging Techniques and Instruments

The number of research studies in this field is not so blooming: it is a very sectorial field, but, regardless of it, there has been a heavy improvement in the last fifteen years. One of the main changes is the new approach with neuroscience methodologies to support the protocol analysis. Between the neuroscience tools, EEG is increasingly used to monitor and analyze the introspective cognitive process in the design activities (A. Laspia, Master Thesis, 2018).

The main aim of the use of EEG is to detect the different phases of the design process, following a protocol analysis fitted to these particular devices. With a neuroscientific approach the researchers have the opportunity to evaluate the brain activity, trying to qualify and categorize them. So far, there is not a specific and established solutions to the question "how does brain work during design processes" and if there are any differences between convergent and divergent thinking. It is important to highlight that not only EEG is used, but in the following paragraphs they are explained.

1.5 The Brain and Electroencephalogram

1.5.1 Macroscopic Anatomy

The human brain is the most complex organ in human body. A lot of its activities are not understood yet and how it works is not clear. The brain is the center location of the central nervous system. To have a synthetic overview of how the brain works, it is simpler to start with an anatomic subdivision of it with: brainstem, limbic system, cerebellum and cerebrum (Figure 2).

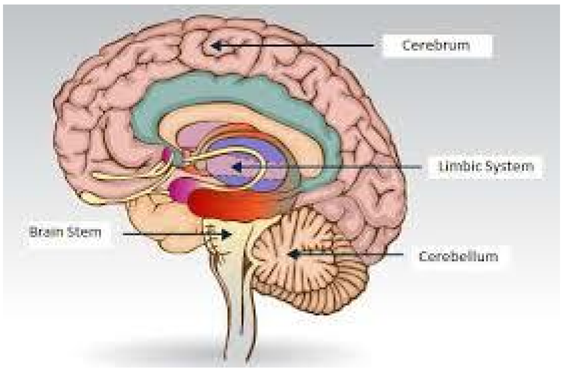


Figure 2 - Brain Anatomy by function (Malori Comer, 2015)

The *brainstem* is the basic part of the brain, that lead all the involuntary movements of the body, such as heartbeat, breathing, wakefulness and sleep rhythm, reflexes and control of many viscera to guarantee the survival of the human. It essential for the human life, indeed a damage in this area usually conducts the human to a brain death.

The *limbic system* is, with the brainstem, the most ancient part of the brain and it includes the others fundamental functions to the conservation of the species, such as sense of smell, short-term memory. As it comes up in the structure of the limbic system, there are more complex functions as the emotions, temperament and self-awareness.

The *cerebellum* is the fundamental director of all of body movements, in particular ocular and of limbs movements. Here some others cognitive processes take place, as concentration, memorization and language. The stimuli of movements do not take place here, but the cerebellum is the coordinator in space and timing of all the movements. A damage in this area could cause loss of balancing and posture.

This document is focused on the study of the last, but not least, the *cerebrum*, that is also called cerebral cortex. It is the area designated for the high complex cognitive processes, such as reasoning, decision making, etc. It controls most of the activities of the entire organism, elaborating, integrating and coordinating the information it receives from the sense organs and making decisions about the instructions to be sent to the rest of the body. The surface of the cerebrum is very peculiar, constituted by ridges, named *gyri*, surrounded by depressions, called *sulci*. The cerebrum is physically divided in two symmetrical areas called hemisphere, right and left, and they are connected by commissural nervous traits, the largest of which is the corpus callosum. Nevertheless, the hemispheres are essentially similar in shape and functions, some specific functions are one-side related. Each hemisphere is divided in other four cerebral lobes, separated by some fissures, named "*scissure*". They are named in correlation with the cranial bones above: frontal, temporal, parietal and occipital (Figure 3). Simplifying the functions, it is possible to define some specific functions for each cerebral lobe, but it is an approximation.

- *Frontal lobe* is the anterior part of the hemisphere. Here there are some fundamental capabilities for the correct reasoning, such as to pay attention, to formulate plans, of initiative, of deepening thought and the control of some aspects of personality. It acts as an attention filter, inhibiting information and stimuli that are less relevant to the task underway. This area is responsible of the voluntary movements, emotional and motivational control. In the left hemisphere there is the area of the articulated language, named "*Broca's area*".
- *Temporal lobe* is fundamental for sensorial and intellectual actions. The auditive area and some of mnemonic processes are here and the nervous

centers of the comprehension of spoken language, in the dominant hemisphere. It is also responsible of long-term memory.

- *Parietal lobe* is the place of areas of somatic sensitivity – tactile, thermal, painful and kinesthetic - and associative areas. In the parietal lobe, information relating to touch, the location of objects in space and attention to the contralateral visual fiels are processed. It merges data from external origins to internal processes.
- *Occipital lobe* is the posterior part of the cerebellum, it is essentially the place of the primary visual area. In addition, it contains areas for the psychic and motor integration of vision, which allow the recognition of visualized objects.

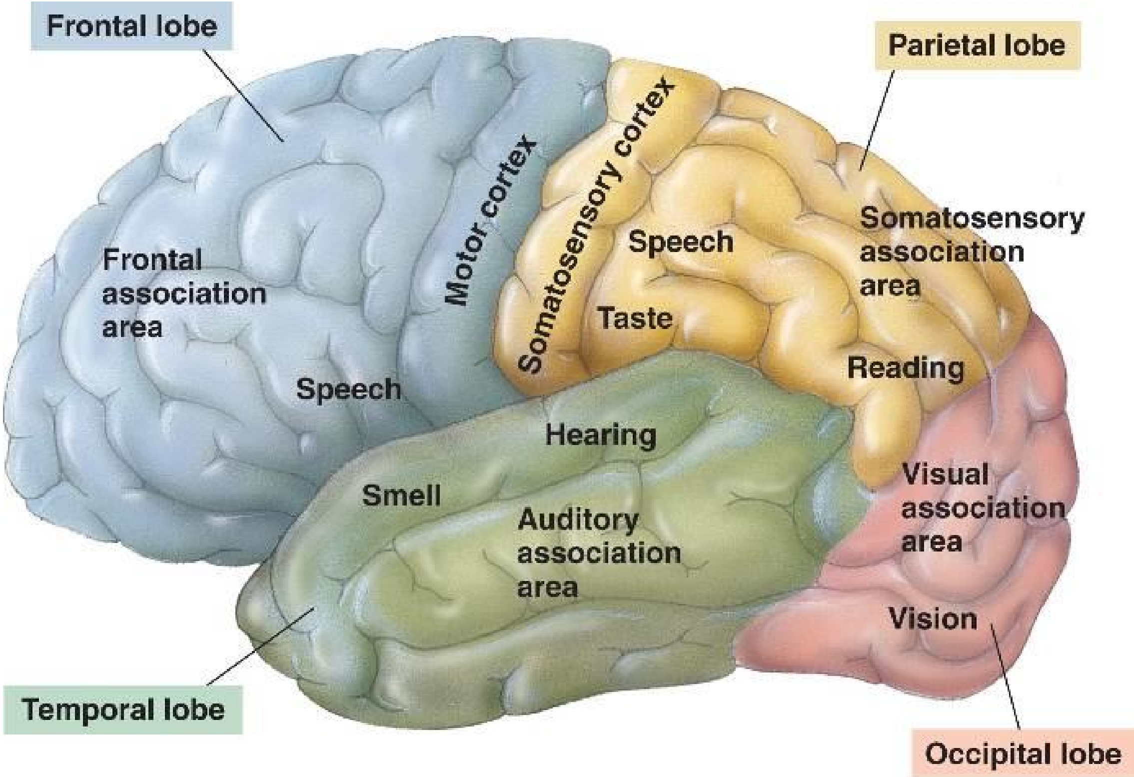


Figure 3- Brain Lobes and Functions – Source: www.mybraintest.org

1.5.2 Basic Knowledges about Brain

Human brain is made up of about one-hundred billion particular cells, called "*neurons*". Neurons are massively physically 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 (A. Laspia, 2018).

1.5.3 Brain Electrical Signals

Neurons produce *electric fields*. These fields are not generated by the action potential of neuron axons sending signals, but actually come from the *post synaptic potentials* (PSP) (Jackson and Bolger, 2014): after receiving an excitatory impulse, the membrane of the dendrites of the neuron depolarizes. This allows positive ions flowing inside the cell, creating a negative voltage in the extramembrane space around those dendrites, while the extramembrane voltage around the remaining neuron is still positive. The negatively charged region is called a *sink*; the positively charged region is called a *source* (Nunez, 2006). So, there are in this situation a negative and a positive pole along the neuron, and these create a current flow and thus an electric field. This also implies that an electrode placed on the scalp will record a positive deflection if it is close to a source and a negative deflection if it is close to a sink (Jackson and Bolger, 2014). As closer is the pole to the electrode, as bigger is the recorded voltage. Finally, the electrode will record no potential differences if it is midway between a sink and a source (Fig. 4).

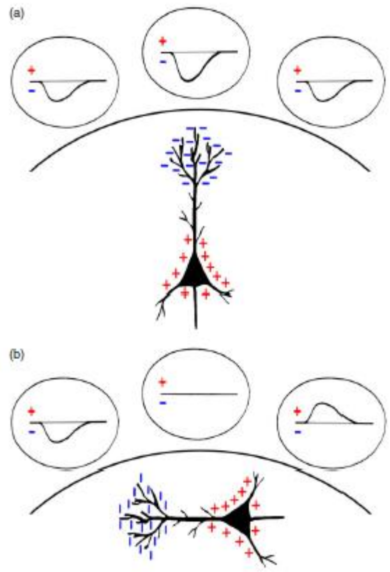


Figure 4 – Neurons Electrical Potential – Source: University of Turin, confidential material

The positive/negative polarity of the recorded signal depends on the orientation of the dipole: indeed, if the excited dendrites of the neuron are the ones closer to the electrode, then it will record a negative deflection; on the contrary, if the excited dendrites are those more far away from the electrode, then it will record a positive deflection (Jackson and Bolger, 2014). So, it is not possible to associate the polarity of the recorded voltage with the excited/inhibited status of the neuron.

The depolarization of the dendrites (PSP) lasts about 10-100 milliseconds, that is a long time if compared to the duration of the action potential in the axon – about 1 millisecond. Thus, PSP are more likely to happen at the same time. Moreover, dendrites happen to be often parallel with each other in pyramidal neurons.

1.6 The Eye

The eyes are another important source of data to understand internal and cognitive process. In line with the intent of this document, here just the behaviors and the activities those are interesting and noticeable by eye tracking tools.

1.6.1 Anatomy of the Eye

The eye, or *eyeball*, is the external organ of the visual apparatus. Its function is to collect data from the external environment through the light and an overview of its anatomy is summarized into figure 5. It collects the light, it has a diaphragm, the *cornea*, that regulates the intensity of the light. With an adjustable system of lenses, it focuses to create an image on the *retina*. The function of the retina is to transform images into a series of electrical signals that are sent to the brain, through the optic nerve. In the brain, they will be processed and interpreted.

The ideal optical condition of an eye that does not exhibit refractive abnormalities (ametropia) is called *emmetropia*. The emmetropia is the suitable condition to get good data for the eye tracker, indeed it is important to know if an experimental subject is affected by some ametropias, because of them it is possible to get some distorted data. Talking about the eyes, it is important to have some basic knowledges about its main components.

- The *cornea* is an anterior convex membrane and it is the most important and powerful lens of the visual apparatus. It consists in the 7% of all the external surface of the eye.
- The *iris* is a membrane of the eyeball of variable color with shape and function of diaphragm, pigmented, located behind the cornea and before the crystalline.
- The *pupil* is the hole at the center of the iris, from here the light comes from the environment to be internally processed. Its dimension is variable, related to the intensity of the external light (bigger with the darkness, smaller with a lot of light).
- The *sclera* is a fibrous opaque and white membrane, composed of collagen. It represents the 93% of the surface of the external eye.
- The *retina* is the internal membrane and it is the fundamental component of the eyesight, because it is made up of receptor cells. These cells convert the light energy in electrical potential.
- The *crystalline lens* it is a discoid and transparent lens. It is suspended between ligaments and it is automatically regulated to focus on the different distances of the objects.
- The *optical nerve* is the transmitter of the electrical signal from the retina to the brain.

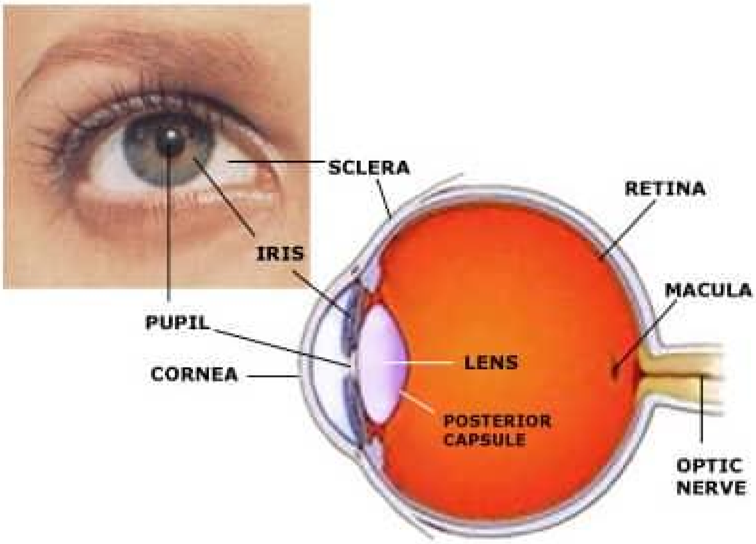


Figure 5- Eye Anatomy – Amazon.com

1.7 Different Analysis Tools

The brain and the eye are not the only two sources of information to detect some internal process related to design activities. They are studied with the support of devices as, respectively, electroencephalogram and eye tracker, those are presented and analyzed in the following chapter. There are some other devices those can help to study in a more complete approach, here there is a brief description of them and the source to whom they are related.

1.7.1 Galvanic Skin Response

The *galvanic skin response* (GSR) consists in the collection of data about the continuous variation of the electrical characteristics of the skin, such as *conductance* at the variation of the sweat. The resistance of the skin changes with the sweat and it is regulated by the *autonomous nervous system* (ANS). If the ANS is excited it involves in an increasing of the skin conductance. Through the GSR data it is possible to recognize some state of mind as stress, tiredness and attention. It works with two electrodes placed on the index and middle fingers of one hand. Nowadays, a lot of new comfortable tools are developed allowing to develop the domain of situations that can be studied by neuroscience, in different context of the laboratories (Sapienza, University of Rome).

1.7.2 Electrocardiography and Heart Rate

The *electrocardiography* (ECG) is a neuro-physical monitoring method used to observe the electrical activities correlated to the cardiac contractions. The main metric of the ECG is the *heart rate* (HR), that is measured by *beats per minute* (bpm). The HR can modify its trend depending on the oxygen request or the expulsion of carbon dioxide. There are several activities those can cause its variations, such as physical exercises, sleepiness, anxiety, stress, drugs intake or illnesses. The applications of the ECG are not only in the medical field, but also to study the emotional answers and states of mind of the subjects. The ECG signal is easy to be recorded with two electrodes on the wrists or on the chest (Sapienza, University of Rome).

1.7.3 Facial Expression

The *Facial Expression* is one branch of the *kinesiology*, the scientific study of human or non-human body movement. It consists in the analysis of the facial mimic, based on physiological and biomedical approaches. The humans leave their emotions and thinking show through their face and those contraction are called *micro-expressions.* They are brief and involuntary reaction to some external stimuli or internal cognitive processes. The facial mimic is one of the foundations of the interaction in human relationships, it has a huge role in the subject and social levels. Indeed, the brain has some specific areas to detect and explain the faces.

The techniques and the methods to analyze the facial expression are structured with a division in areas of the face: in the superior part, studying the contractions of the eyes, eyebrows and forehead; in the inferior part, studying the mouth and the lips. There are some softwares those automatize the processes of detecting the emotions and states of mind through the facial recording with cameras. Implicit emotions measures, compared to explicit subjective ones, generally have a large number of advantages: they are objective, independent of verbal language and they are not too complicated to use (Zaman and Smith, 2006). Objective measuring instruments of emotional states can measure the physiological component of emotions or the expressive one. The former focus on the recording of neurophysiological parameters, while the latter are based on the assessment of the manifest behavior where the expressive component of emotion is objectively evaluated through tools that measure facial expression. The measures that focus on these assessments start from the assumption that the different emotions are correlated with specific configurations of the face. Some of the basic emotions that are usually detected are fear, surprise, anger, sadness, disgust and joy (FaceReader, Noldus, 2016).

1.7.4 Electromyography

The *electromyography* (EMG) is a neuro-physical tool to analyze the muscular contractions. It allows to measure the electrical potential made by muscles, during their contractions. These events are caused by the electrical depolarization of the muscular fibers, after the electrical signal of the neuromuscular synapses. The EMG collects the tension between two electrodes on the surface of the skin (Alberto Cavallero & Chiara Dalla Man, 2014). It is a non-invasive and really reliable technique, to monitor the functionalities of the peripherical nerves and muscles. It is used also to monitor the activities of the eyes.

1.7.5 Virtual Reality

The *virtual reality* (VR) consists in a device able to create a simulation of reality, developed by informatic tools, within which the user can move freely. It is possible to integrate several features, as music, lightness, etc. The user comes in the simulation of reality through the special viewer and other accessories (joypad, shoes, gloves, etc.) to interact with that environment.

VR is a good tool to study the subjects' behavioral reactions and emotional aspects, integrating the VR with EEG, GSR and HR. There are several fields where the application of the VR is fundamental to develop new knowledges, with advantages in saving money and time. For instance, some of them are: interior design, psychotherapy, medicine, military, tourism, arts, gaming, advertising, testing and prototyping (Sapienza, University of Rome).

2. Electroencephalogram and Eye Tracker

2.1 Neuroimaging Instruments

In the past, the design activities come these problems to highlight that not only EEG is used, but in the following paragraphs they are explained. Neuroimaging techniques allow the study of the brain in a non-invasive way, highlighting anatomy and functions. These techniques are used for both diagnostic and research purposes, as they guarantee the visualization of brain activity and are experiencing a remarkable development, which could make very significant contributions to the knowledge of the mind, the brain and its dysfunctions and therefore psychiatric disorders. And for practical reasons, explained at 2.1.5 section, in the present study it was used EEG and it is described in a more detailed way in section 2.2.

2.1.1 PET

The *Positron Emission Tomography* (PET) is a method of nuclear medicine that allows to obtain images of three-dimensional distribution of radioactivity within a body section, thus recovering information in depth, not obtainable with scintigraphy. It has found widespread use in the clinic, especially in neurology, allowing a fine analysis of the metabolic activity of the central nervous system.

PET allows to investigate biochemical and metabolic functional aspects of the brain. The principle on which it is based is linked to the possibility of marking compounds of biological interest, such as glucose, H2O or neurotransmitters, with radioactive isotopes which, by not modifying the structure and biochemical behavior, allow us to follow their destiny inside the brain.

PET is both a medical and research tool. It is used heavily in clinical oncology (medical imaging of tumors and the search for metastases) and for clinical diagnosis of certain diffuse brain diseases, such as those causing various types of dementias. PET is also an important research tool to map normal human brain and heart function, and support drug development.

Beyond clinical uses, PET represents a unique tool for in vivo physiopathology studies, for its versatility and multiplicity of applications. The possibility of studying functional aspects, as cerebral blood flow, consumption and extraction of oxygen, glucose metabolism and, more recently, the brain neurotransmitter system. It has enabled significant progress in the field of neuroscience. With the use of short-lived tracers, it is also possible to study the phenomenon of activation of specific brain areas during the execution of precise cognitive tasks. Thus, the functional anatomy of language processes, attention and movement planning is identified. This allows us to acquire new knowledge about the way in which the brain processes and processes thought.

PET scans are dynamic because they allow to detect alterations at the molecular biological level that often precede anatomical alteration. This result is made possible by the use of molecular markers that have a different rate of absorption depending on the tissue involved. A PET scan allows physiological analysis as it is possible to visualize and quantify with discrete precision the change of blood flow in the various anatomical structures (by measuring the concentration of the injected positron emitter.)

2.1.2 SPECT

The *Single-Photon Emission Computed Tomography* (SPECT) is a medical-nuclear investigation technique that uses radionuclides emitting single gamma radiations, introduced from outside into the human body, which are distributed according to a specific affinity, in different body areas. The detection by gamma-cameras rotating of the radiations emitted by the tracer used allows a morpho-functional visualization of the organ under examination in the different planes of the space. SPECT is a technology similar to PET but simpler and less expensive. Use radioactive compounds that directly emit gamma radiation.

There are differences between SPECT and PET acquisition technologies. Diagnostics are always performed with gamma radiation, but the methods and equipment are different depending on the type of emission. In SPECT, after injection of radioactive substances, a device capable of detecting gamma radiation rotates around the patient acquiring images that are processed by the computer. SPECT is often used for the diagnosis of brain diseases and the neuroendocrine system. In the SPECT - based on a simpler technology - only the radiations directed perpendicularly to the detector are recorded, in the PET two detectors hit simultaneously by photons with an oblique direction with respect to the cylinder axis can also record the radiation. This complex of conditions makes PET faster than SPECT and with greater resolution. The speed of execution is an essential requirement because the radioisotopes used in PET generally have a shorter half-life than those used in SPECT. Like PET, SPECT (unlike CT, ultrasound and magnetic resonance) allows information on the entire body of the patient to be obtained on a specific organ.

2.2.3 fMRI

In *Functional Magnetic Resonance Imaging* (fMRI) the brain activity is visualized thanks to its hemodynamic correlates. The influx of oxygenated blood in cerebral districts characterized by increased neuronal activity determines a local variation of magnetic susceptibility highlighted in MRI images, acquired in appropriate ways. The fMRI has had an unprecedented expansion and is used in neuroscience, neuropsychology, neurophysiology and as a preparation for neurosurgery. The current evolution of MRI systems is in the direction of increasingly intense applied magnetic fields, because this allows to increase the spatial resolution and to reduce the time of image acquisition. This technique allows the in vivo exploration of the anatomical connectivity of the human brain, giving information on neuronal

The fMRI consists of the use of *magnetic resonance imaging* (MRI) to evaluate the functionality of an organ or an apparatus, in a way that is complementary to morphological imaging. This technique is able to visualize the hemodynamic response (changes in the oxygen content of the parenchyma and capillaries) related to the neuronal activity of the brain. The modification of the oxygenated state of hemoglobin in red blood cells is the theoretical principle of the *Blood Oxygen Level Dependent* (BOLD), on which fMRI is based and which is used as an endogenous contrast medium. The intrinsic characteristics of this method are the absence of invasiveness (paramagnetic contrast medium is not administered), the high spatial and temporal resolution, the easy reproducibility and the possibility of co-recording with high quality anatomical images. The fMRI allows to detect the connections between the activation of the brain and the tasks that the subject performs during the scan. The fMRI is used to study the different cognitive processes (language, attention, memory, decision) in the normal and in the pathological, in the stroke for the monitoring of functional recovery after cerebral ischemic insult, in degenerative diseases (Alzheimer's dementia), in the neurophysiological study of anxiety and panic disorders. Dependencies are one of the most recent fields of application, which allows the understanding of the mechanisms that create and sustain this type of pathology.

2.1.4 NIRS

Near infrared spectroscopy. - This technique, also known as NIRS, provides information on brain activity complementary to that provided by EEG, fMRI and MEG (Magnetoencephalography), and based on the different optical properties of absorption and reflection of oxygenated and deoxygenated hemoglobin, irradiated with wavelength light between 690 nm and 830 nm. Although the spatial resolution of the technique is not yet comparable with that of fMRI and it is impossible to localize deep sites of activations, important efforts are being made to realize high-resolution NIRS systems integrated with the other functional imaging systems. NIRS is able to measure parameters such as oxygenation and cerebral tissue blood flow at a regional level.

The instrumentation for NIR spectroscopy resolved in time (time domain, or frequency domain), based on the emission of light with variable intensity over time (in the frequency domain the optical radiation is modulated sinusoidally in amplitude at radiofrequency), allows to obtain data that reproduce the real state of oxygenation of the biological tissues investigated.

2.1.5 Choice of the tool

All of these instruments are able to detect brain activities in different ways and for the present work it was decided to use electroencephalography (well described in the following section) for several reasons:

(i) The *usability,* EEG is the less invasive of the most used neuroimaging techniques, it allows to use it in a situation very similar to the reality, with the reduction of the impact of the “laboratory environment”;

(ii) The *research question* requires more spatial resolution than temporal resolution, perfect for EEG application, because of the structure of the tasks and the literature;

(iii) The *popularity* in the previous studies, EEG was used in a lot, in particular in the Jauk, Benedek and Neubauer (2012) to have more comparable results;

(iv) The *availability* of the EEG was only for the present experiment, without overlap problems with other projects or similar, allowing the total freedom to schedule the experimental sessions;

(v) The *knowledges* of the use research group, in particular the neuroscience resources (University of Turin) were more confident with the EEG.

2.2 Electroencephalography

The *electroencephalography* (EEG) is one of the most powerful non-invasive brain imaging techniques, using a certain number of electrodes placed on the scalp to record electrical brain potentials continuously in time. It allows to infer a correlational association between the behavior and its neural basis, directly recording the brain activity during a task and giving functional information about the brain. On one hand, this technique has a very high temporal resolution, as it is possible to see the online recorded activity almost instantaneously, usually at a 250 or 500 Hz sampling rate; on the other hand, it has a low spatial resolution and cannot be used to get precise morphological information, as it can record activity with a centimeter-scale precision, thus at neural populations level (Cohen, 2017). Its output is a plot of voltage values in function of time, thus giving a course of voltage changes during time for each electrode. This process gives rise to the so-called *brain waves,* or neural oscillations (Fig.)

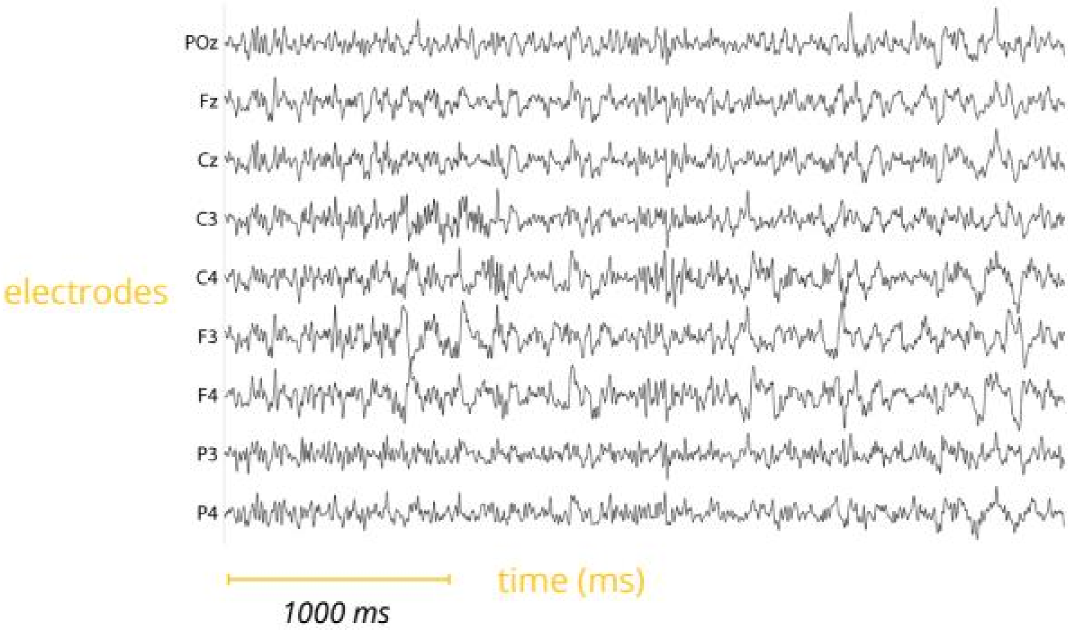


Figure 6- Neural Oscillations - iMotions, 2016

An EEG electrode can capture and record any electric field: hopefully, those coming from the brain. Singularly taken, the electric field produced by a neuron is too weak to be recorded with an EEG. An EEG electrode needs the simultaneous activity of hundreds of millions of neurons which, firing together, can sum up their potentials and create a sufficiently powerful one (Cohen, 2017; Nunez, 2006). For these signals to be summed up, the cells must accomplish two conditions: first, they must be parallelly disposed; second, their dendrites depolarization must happen at the same time. This spatial-temporal coupling is fundamental: in fact, if neurons are oriented in a random fashion, their potential will cancel each other out, resulting in a neutral signal for the electrode; moreover, if the dendrites do not depolarize at the same time, their joint electrical field will not be powerful enough to be recorded (Jackson and Bolger, 2014).

Pyramidal neurons are the most relevant neurons for EEG - i.e. the neurons that produce the biggest electrical signal recorded by the electrodes (Nunez, 2006). Pyramidal neurons bodies are mostly in the III and V layers of the cortex, and their dendrites and axons leak into other layers, being perpendicularly oriented with respect to the cortex surface and parallel with each other. As the brain is folded into sulci and gyri, this implies that pyramidal cells can have different orientations with respect to the scalp, as shown in figure 7. This results in a very heterogeneous mixture of signals for each single electrode, which is anyway capable of capturing both tangential and radial neurons activities (Puce and Hamalainen, 2017; Jackson and Bolger, 2014).

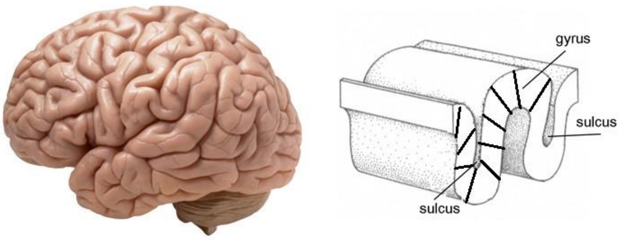


Figure 7 - Gyri and Sulci - University of Queensland, Queensland Brain Institute

When working with EEG, it is important to keep in mind that we are working on a *sensor space* and not on a *source space*: this means that what we observe is the signal recorded by an electrode, and not the electrical activity produced by a specific population of neurons (Puce and Hamalainen, 2017). It is also important to keep in mind that an EEG electrode is a very powerful sensor that is capable of detecting neuronal voltages, that happen in the order of units of microvolts (µV). So, an electrode is also capable of detecting almost any kind of electric activity around it. In the practice, unfortunately, it is impossible to record pure brain signals. This means that the EEG signal recording is a mixture of many electrical inputs. An EEG electrode thus can have many sources influencing its output. These sources can be both physiological sources or non-physiological sources. Physiological sources can be – beyond brain ones – muscular activity, cardiac activity or eye activity, for example. A non-physiological source can be, for example, the alternate current produced by the batteries of many devices.

When these non-brain electrical sources are recorded by an electrode, they produce a noise that affects and potentially covers the signals of interest, i.e. the brain signals. This noise is responsible of creating artefacts in the time course of the signal. Artefacts directly derive from non-brain sources and represent a serious issue to deal with when analyzing EEG data. Artefacts can be distinguished in physiological and non-physiological ones as well. The most common physiological artefacts are probably muscular, electromyography (EMG), artefacts and ocular, electro-oculography (EOG), artefacts.

2.3 Electromyography, Electro-oculography and Artifacts

EMG artefacts derive from electricity passing through the muscles when they are moved. The most commonly ones detected by EEG are those deriving from body movement, face/neck movements or glossokinetic activity – tongue movement. Muscular activity is easy to recognize in the EEG time course, as it displays as a very high-amplitude and high-frequency signal occurring (Figure 8).

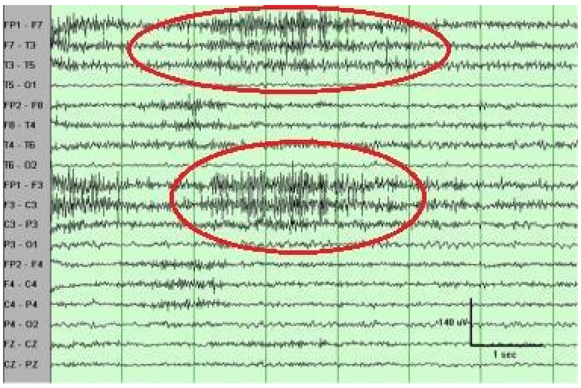


Figure 8- Muscular Activities in EEG - Benbadis, Lutsep et al.,2017

EOG artefacts usually produce very large artefacts as well, that can also be easily identified in the EEG time course. Usually it is possible to recognize blinks and horizontal/vertical eye movements just looking at the most antero-frontal electrodes. These artefacts produce alterations of the signal as shown in figure 9. The physiological nature of EOG artefacts is unclear, and many explications have been proposed. The most accepted ones are: (a) the eye is a dipole, being the cornea positively charged and the retina negatively charged: this causes a direct current source that affects closest electrodes when eyes are moving; (b) the eyelid is responsible of these artefacts as it has been demonstrated to be able affecting the voltage around the eyes even in absence of eyeball rotation (Croft and Barry, 2000).

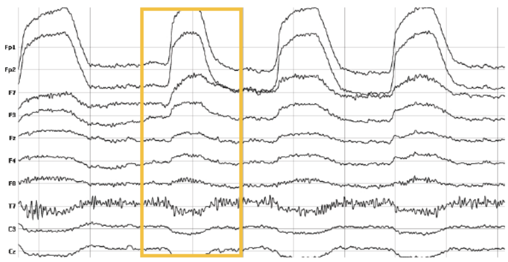


Figure 9 - The artefacts in EEG – iMotions, 2016

The main non-physiological artefact that can be encountered during EEG data acquisition is probably the one due to the electronic devices that are present in the laboratory: every electronic device produces a 50 Hz alternate current (in EU; 60 Hz in the USA) that constantly affects ongoing EEG time course. This is called *line noise* and can be easily removed through an online or offline band-stop (*notch*) filter that selectively removes 50 Hz components from the signal.

In an ideal EEG session, artefacts are absent. In real life many kinds of artefacts are always present. So, researchers always have to deal with them. Artefacts can be prevented while recording, for example by asking participants not to move or not to blink, but this is quite impossible during a session; moreover, when we ask participants not to move or not to blink, we could introduce something like a "*cognitive artefact*", as people will then pay attention to this instructions more than to the real task, and this can affect our data (Puce and Hamalainen, 2017).

2.3.1 Management of Artifacts

When it is not possible to prevent artefacts, dealing with them implies adopting some offline strategies. The easiest way is to visually inspect raw data and manually remove artefactual epochs. (Zeng et al., 2013; Puce and Hamalainen, 2017). This is of course a high time-demanding procedure, and it is not always possible to inspect all the data. So, many algorithms exist to help spotting artefacts. For example, for EOG artefacts, two categories of methods exist. The first is based on time domain regression methods: it consists in recording eye activity via electro-oculogram electrodes placed close to the eye during recording and then subtract their activity from the scalp electrode signals. A criticism of this approach is that the subtraction it operates is bidirectional, and some brain signal will be lost because EOG electrodes capture brain activity too (Zeng et al., 2013). The second category is based on the so-called *blind source separation* (BSS) methods: these methods can detect and separate from each other the original sources contributing to the mixture of signals recorded by each electrode. From this, it is possible to identify artefactual sources and remove them from the global signal (Zeng et al., 2013). BSS methods can be used for the removal of different kinds artefacts, and the most popular one is the Independent Component Analysis (Jung, 2000).

2.4 Electrodes

Electrodes are usually located on the head according to the international *10-20 coordinates system*. This is an internationally recognized pattern for identifying the precise 3-dimensional coordinates that describe the location of each electrode on the scalp. The name 10-20 refers to the proportion of distances between the electrodes and the anatomical references. The anatomical references are the *nasion* and the *inion* for the sagittal axis and the periauricular crests of helix (A1 and A2) for the coronal axis. The nasion refers to the middle point of the nasofrontal bridge, and the inion refers to the external occipital protuberance of the head (Jurcak et al., 2007). At the crossing point between the two lines described by these reference points stands Cz, the middle point of the scalp. So, the 10-20 system states that the distance from the reference point to the closest electrode (e.g. from A1 to T3) is the 10% of the relative axis length. Between the electrodes (e.g. between T3 and C3), instead, this distance is the 20% of the relative axis length.

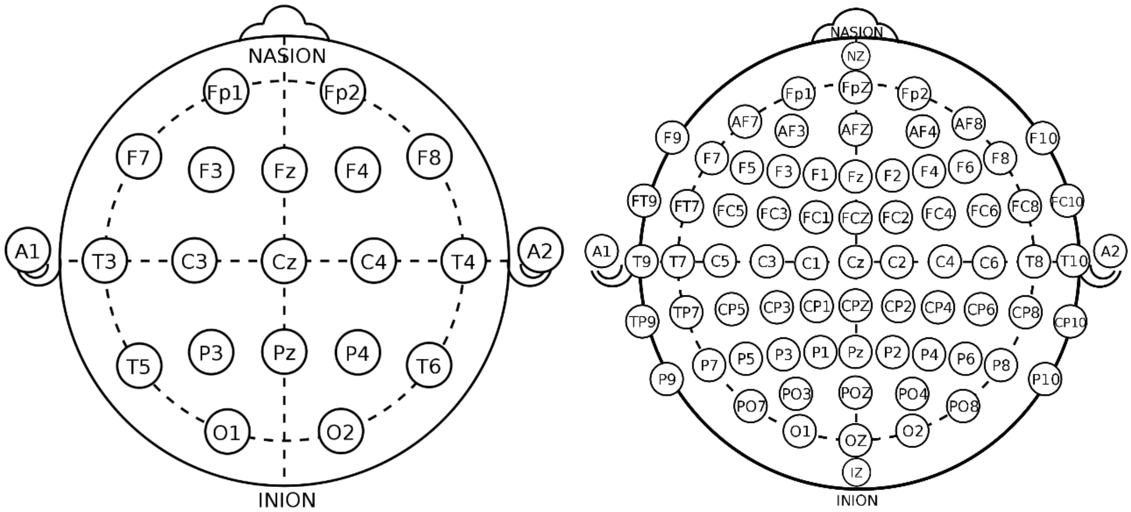


Figure 10 - Electrodes dispositions - ActiCHamp

From this system derives the nomenclature of the electrodes. An electrode name is composed of a letter and a number: the letter indicates the corresponding lobe or anatomic position (F = Frontal, C = Central, T = Temporal, O = Occipital, T = Temporal), while the number indicates the hemisphere (odd numbers for the left hemisphere, even numbers for the right hemisphere). Moreover, as shown in Fig, there could be two letters indicating the lobe (Fp = Frontopolar), while a z instead of a number is used to indicate the central sagittal line.

The 10-20 system was initially designed for 21 electrodes montages. When more electrodes are used, this system is modified into a 10-10 system or a 10-5 system, depending on the number of electrodes (Sharbrough, Lesser et al., 1991). The consistency of the nomenclature, anyway, must be guaranteed by three characteristics: (I) the letters used to indicate the location cannot be more than two; (II) the letters must derive from the underlying lobe or anatomical landmark; (III) the alphanumerical combination must define a specific electrode coordinate, with each letter appearing on only one coronal line and each number appearing on only one sagittal line - the “T” electrodes naming and numbering represent the only exception to this rule. (Sharbrough, Lesser et al., 1991).

Electrodes can be placed directly on the skin or in a cap that is worn by the subject. In order for them to work, active recording electrodes must have a reference electrode. This means that the signal given by an electrode is basically the difference between the voltage it records and the voltage that is recorded by another electrode, i.e. the reference electrode (Nunez, 2006). Thus, we need to set a reference for each electrode when we record EEG activity. Usually two kinds of reference montages are distinguished: bipolar montage and a common reference montage. In the bipolar montage each EEG channel is represented by the difference between two adjacent electrodes, so that each electrode functions both as an active recording one and as a reference for another one. In the common reference montage, instead, there is only one predefined reference electrode, and from each active electrode signal is subtracted the signal recorded by that reference electrode.

2.5 Reference Electrode

The problem here is where to put the reference electrode. Ideally, it should be in a totally neutral position at an infinite distance from the subject (Nunez, 2006).

Of course, this is impossible, so we have to choose a location, on subject's body, that is supposed to be the most neutral as possible. Most commonly used reference electrode locations are Cz, mastoids, ear lobes and nose. These are supposed to be the best places because, in theory, they do not receive any electrical signal from the brain and are relatively far from muscles too. It is important for the reference electrode not to receive brain signal, because if it does, that signal will be subtracted from the signal of each active electrode. An exception is represented by some special montages, i.e. the common average reference (CAR) and the Laplacian montages. The CAR uses the average voltage recorded from all the electrodes as a common reference; the Laplacian montages use, as a reference for each individual electrode, the average of the voltage recorded by the adjacent electrodes.

The result of the subtraction *active electrode – reference electrode* is a plot of the time course changes in voltage under the active electrode. These voltage fluctuations result in complex, non-stationary waves.

2.6 EEG Waves

An EEG wave is defined by five characteristics:

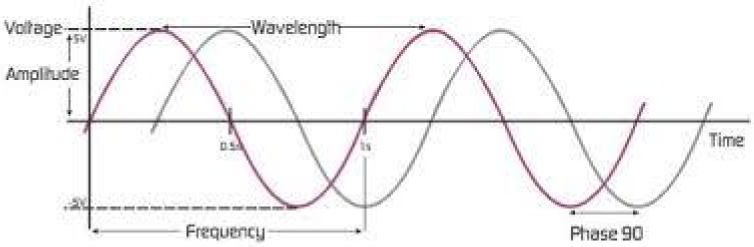
(i) *Frequency*: the number of cycles per second, measured in Hertz (Hz).

(ii) *Amplitude*: the "height" of the wave, i.e. the distance between the zero axes and the peak of the wave, expressed by the voltage measured in microvolts (µV).

(iii) *Phase*: the position of a time-point in a cycle, expressed in degrees or radians.

(iv) *Latency*: the temporal window in which the wave is recorded, usually expressed in milliseconds (ms).

(v) *Topography*: the anatomical location where the wave is recorded, usually given by the electrode(s) where it is recorded.



The EEG waves classification is most commonly done based on their frequency. Their amplitude can vary between 10 µV and 100 µV and is inversely proportional to the frequency (i.e. high frequencies show low amplitude, and vice versa). Their bounds are not well defined and can vary among individuals. Here is a brief list of the different EEG waves and their main characteristics in normal subjects (Freeman and Quiroga, 2013):

- *Gamma* (>30 Hz): are the less studied waves and seem to be related to some sensory and motor processes and to highly demanding cognitive tasks.
- *Beta* (12-30 Hz): are typically associated with normal cognitive functions in awake and aware people, such as attention and calculation. They are mostly present in frontal locations but can spread over the entire scalp during demanding cognitive tasks.
- *Alpha* (8-12 Hz): are normally present in awake individuals. They are most evident with closed eye or during relaxed and mentally inactive moments. Their topography tends to be more pronounced in occipital regions. They must not be confused with Mu waves, which have the same frequency but are typical over motor regions.
- *Theta* (4-8 Hz): are characteristic of deep sleep and deep meditation status. They have a very important role during childhood. Abnormalities in theta waves are associated with epilepsy.
- *Delta* (0.5-4 Hz): are also typical of deep sleep stages. If present in the awake adult, they can be associated with brain tumors.

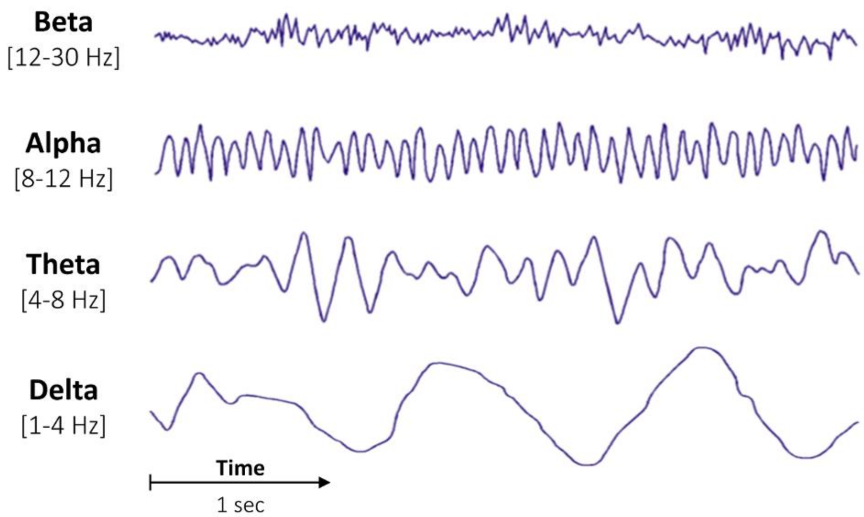


Figure 11 - Brain Waves - Diary to Doctror, University of Minnesota Rochester

2.7 Task Related Activities

When recorded during a specific task, the global EEG activity can be divided into three different (but not independent) types of activities that contribute to the global voltage changes that characterize these oscillations: evoked activity, induced activity and background activity (Kalcher and Pfurtscheller, 1995; Roach and Mathalon, 2008; Michalopoulos et al., 2011).

Evoked activity is the phase-locked activity produced by the brain in response to an external or internal event. When an electrical activity is phase-locked this means that the specific oscillations produced by the event tend to be consistent in phase across trials. Basically, immediately after the stimulus onset, the EEG signal shows the same phase angle in all trials (Mike X Cohen, confidential arguments).

It is possible to extract many kinds of information from phase synchrony. For example, it can be interesting to observe phase synchronization across different frequency bands and/or across different brain regions within the same frequency band (phase coherence). These kinds of activity can be used to get information about functional connectivity across different neural populations. Or, by averaging the signal across many trials it is possible to extract phase-locked activity during the first milliseconds after stimulus onset from the global EEG signal. This is the case of the *Event Related Potentials* (ERPs) (Michalopoulos et al., 2011). ERPs are voltage variations that are evoked by an event (hence, Event Related Potential) and that usually occur within the first 1000 milliseconds after the stimulus onset. Then, they are also strongly time-locked to the event. Moreover, ERPs are very weak variations -in the order of a few μV -, and so they are easily masked by the global background activity – in the order of tens of μV. This is why ERP studies usually need up to hundreds of trials for enhancing the signal-to-noise ratio: as many trials we have, as easier it is to extract the ERP through trial averaging.

The events that cause the ERPs can be external or internal. External events cause *exogenous* ERPs (or *early* ERPs): these represent the forced physiological response to physical stimuli coming from the environment. Exogenous ERPs are then dependent on the sensory modality in which the stimulus is presented and can be divided in *Auditory Evoked Potentials* (AEPs), *Visual Evoked Potentials* (VEPs) and so on. Internal events cause *endogenous* ERPs (or *late* ERPs): these reflect the physiological activity underlying a cognitive process. Thus, they are independent from the activated senses and can also be linked to movement tasks. Examples of endogenous ERPs are the P300, N400, contingent negativity variation (CNV), mismatch negativity (MMN) (Sur and Sinha, 2009). All the ERPs are composed of different components. A component is a positive (P) or a negative (N) deflection in the signal. Depending on when a component occurs, it has a time definition in its name (for example, N400 is a negative deflection that occurs after about 400 milliseconds from the event onset). Thus, it is clear why ERPs are phase-locked activities and are strictly time-locked to the event.

Induced activity, instead, is the non-phase locked activity, even if it is time-locked to an event. This means that the starting phase angle is not important when observing this activity. As consequence, the averaging in time of the signal does not give any clear information. Then, the EEG changes we observe are attributed to frequency changes in the ongoing activity (Pfurtscheller and Lopes da Silva, 1999) and cannot be studied through ERPs: in fact, the signal characteristic that is mostly extracted and analyzed in this case is the frequency.

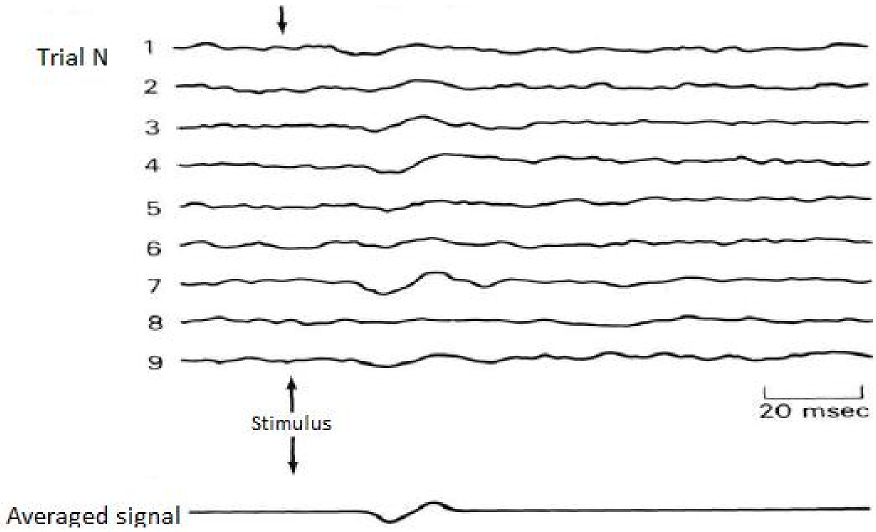


Figure 12 - EEG signals - Confidential material, University of Turin

This means that we need to take an EEG record time window and try to analyze it in terms of its frequencies: we have to move from the time domain to the frequency domain. The functional neurocognitive role that is attributed to the existence of the different neural oscillations is a double one: (a) they might help the dynamic information flow through different brain regions via a synchronization of the activity across different neural networks; (b) they might provide a precise clocking system for neural computation (Cohen, 2018).

2.8 Frequency Analysis

In frequency analysis we observe frequency changes related to an internal or external event or stimulus. This brings us to be interested in the observation of the behavior of the individual frequency bands of interest when it is related to that event. This behavior is a change in power (μV^2) and is often to as an *Event-Related Spectral Perturbation* (ERSP): "ERSP measures have been considered in relation to quantified changes (increase or decrease) in power of specific frequency bands relative to mean pre-stimulus power" (Michalopoulos et al., 2011). The increase in power is called Event-Related Synchronization (ERS), and the decrease in power is called Event-Related Desynchronization (ERD) (Pfurtscheller and Lopes da Silva, 1999; Michalopoulos et al., 2011; Roach and Mathalon, 2008). The underlying mechanism can be seen as an increase or decrease of synchrony of the neural populations, whose responsible physiological mechanisms are thought to depend on cell membrane properties, neural interconnection strength and neurotransmitters modulation. The power of a certain frequency appears to be directly proportional to the number of neurons showing that firing pattern (Pfurtscheller and Lopes da Silva, 1999).

Any actual EEG recording does not contain pure sine waves of a certain frequency but is rather composed of a mixture of different frequencies and results

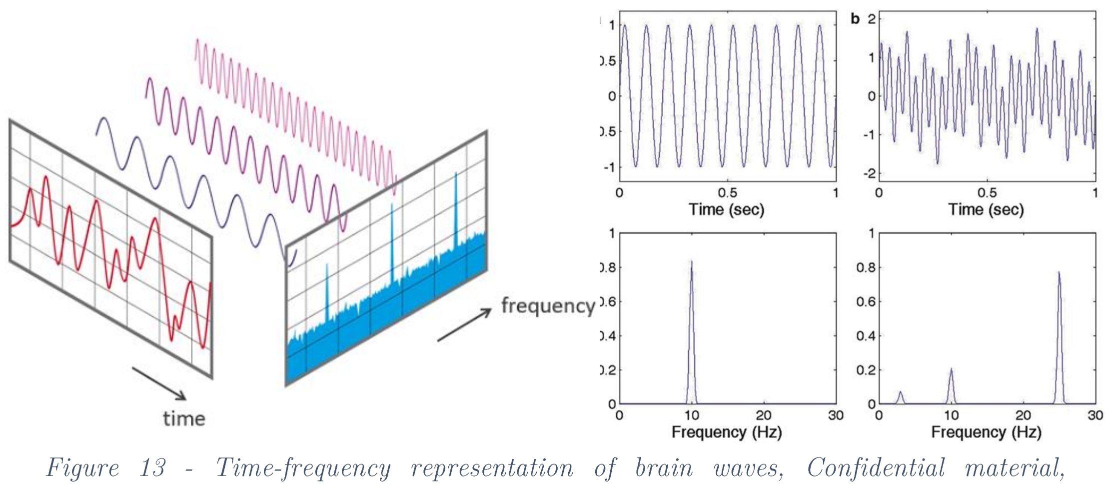


Figure 13 - Time-frequency representation of brain waves, Confidential material, University of Turin

in a complex and noisy time representation (Freeman and Quiroga, 2013). So, we need to decompose the complex EEG signal into his elementary components, i.e. into the elementary frequencies that define it. This is the basis of the *Fourier theorem*: it states that "*any signal can be represented as a combination of sine waves, each sine wave having its own frequency, phase and amplitude*" (Cohen, 2018).

The Fourier theorem allows having an ensemble of transformations that return the estimated "weight" (*density*) that each pure sine wave with a certain frequency has in the determination of the final EEG signal. The Fourier transform used with EEG signals is the discrete Fourier transform: this because the EEG actually gives a discrete signal -even if with a high sampling rate -, and it is not possible to apply a continuous Fourier transform to it. In 1965, Cooley and Tukey developed a much faster and computationally faster version of the *discrete Fourier transform*: the FFT. This is nowadays the most used algorithm in frequency analysis in many scientific fields (Freeman and Quiroga, 2013). The output of the FFT is a periodogram. A periodogram is an estimation of the power spectrum, that is the distribution of the power (μV^2) as a function of the frequency spectrum of the signal (Cohen, 2018). The periodogram is also called *Power Spectral Density* (PSD), as it gives an estimation of the variance of the signal, i.e. the probability (density) that each frequency bin shows for that specific sample.

2.8.1 Technical and Practical Issues

There are several practical issues when dealing with the frequency analysis.

First, it is not possible to detect any frequency: the maximum frequency we can detect is the half of the sampling frequency. This is known as the *Nyquist theorem*, and its logic is that at least two data points per cycle are needed. If this is not accomplished, there may multiple peaks within two data points, and so they are not captured by the EEG. This results in spurious low frequency components appearing in the periodogram: this phenomenon is called *aliasing* (Freeman and Quiroga, 2013).

Second, the discrete Fourier transform assumes that the signal is periodic, i.e. that it repeats itself infinitely in time. In real life, no record is infinite and also an EEG time window has a start and an end. Thus, a Fourier transform analyzes the finite signal as if it repeats over and over again, as if its last data point was immediately preceding the first data point. This is not a problem when a signal shows a perfectly integer number of cycles within the time window; but this is never the reality with EEG. The consequence of a mismatch between the first and the last data point is a discontinuity that will result in a frequency smearing in the periodogram. This phenomenon is called *leakage* (Freeman and Quiroga, 2013).

Third, EEG signals are non-stationary signals (Nunez, 2006; Cohen, 2018). A stationary signal is a signal whose statistical characteristics – mean, variance, frequency etc. – do not change over time. This is not the case of an EEG signal, because its frequency continuously changes over time (Cohen, 2018). This results in features that are meaningful but difficult to see in a power spectrum, mainly if the time window we analyze is long enough to contain a high number of changes in frequency. Thereby, the power spectrum will not show clear frequency peaks, will have a big variance and will thus be meaningless for interpretation. (Freeman and Quiroga, 2013).

2.8.2 Different Approaches to Solve Problems

To deal with the aforementioned issues several methods exist. We will briefly report the main ones. (I) Aliasing: it is possible to use an online *low pass anti-aliasing filter*, or just oversample the signal while recording and then filter it offline. Simply, it could be possible just to use a sampling rate that is at least the double of the higher frequency of interest (Freeman and Quiroga, 2013). (II) Leakage: this issue is coped by tapering the borders of the signal to zero through a window function. This process is called *windowing* and consists in multiplying the recorded signal with a predefined function that has zero values at its extremities. On one hand, this allows to have a zero value both at the beginning and at the end of the signal, bypassing the leakage effects. On the other hand, there is a loss of information resulting in decreased frequency resolution (Freeman and Quiroga, 2013). The most used window functions are the Hamming, Hanning and Blackman. (III) Non-stationarity: the most famous methods for dealing with EEG non-stationarity are based on averaging periodograms of shorter time windows: the original signal is split into multiple shorter segments, a periodogram is calculated for each of them and finally an average periodogram is computed (Freeman and Quiroga, 2013). This helps reducing the variance of the periodogram and is known as the Bartlett method. Better implementations of this method have been created and differentiate depending on settings such as segment length, segment overlapping, etc. A popular version is the Welch method, which overlaps and windows these segments (Freeman and Quiroga, 2013). A similar method is the *Short Time Fast Fourier* Transform (STFFT), mostly used in time-frequency domain, as it generates a 3-dimensional structure that allows to visualize frequency amplitude changes over time (Cohen, 2018).

2.9 Eye Tracking

The *eye tracker* is a device that is able to detect eyes activity. This can be, for example, the direction of the gaze, but also the number and rapidity of saccades, the blinking activity, pupil dilatation or the number and duration of fixations. Eye tracking is the recording of these activities and its translation in objective analyzable data. The existing devices for eye tracking are non-invasive and can be distinguished in screen-based, or *remote*, devices and head-mounted, or *mobile*, devices. Remote eye trackers usually consist of a little and portable stick that can be attached directly to the computer screen; head-mounted eye trackers consist of easily wearable glasses. In recent times, an eye tracking technology is being applied inside virtual reality headsets too. Anyway, any eye tracker device comprises two basic components: an infrared non-visible light source that is directed from the device towards the eyes and a camera capable of detecting the infrared light reflected by the cornea through the pupil – a phenomenon known as *pupil center corneal reflection* (PCCR). This simple mechanism allows the device to extrapolate all the aforementioned pieces of information, that are then sent to the computer via cable or wireless technologies and recorded on a compatible software (e.g. iMotions).

While remote devices are mostly employed for the observation of eye behavior on stationary environments with screen-based stimuli, portable devices are suitable for real or virtual dynamic environments. The problem associated with remote eye trackers is the constriction of the subject to a restricted area representing the eye trackers range – also called the *headbox*. Anyway, the headbox is usually large enough to allow the subject to feel free to move, and the eye calibration is based on head coordinates so that head movements do not affect the quality of the data.

2.9.1 Applications

Most of the times, eye tracking is used to analyze eye-related components of cognition (attention, learning, memory etc.) and emotion (arousal, affective involvement, avoidance behaviors, etc.). Eye data can reveal many neurophysiological aspects of human cognition and behavior and apply to several fields of study. For example, in cognitive neuroscience it is possible to study how visual attention is related to different environmental conditions, such as room luminosity, the presence of distracting cues and so on; or it is possible to observe how eye behavior is associated with the internal status of the subject, such as stress, relaxedness, or general arousal. The portability of the eye tracker makes it compatible with different sensors, such as EEG, EMG, GSR and so on, and thus allows to obtain more complete and complementary data. These data are then applicable to many environments. For example, it is possible to observe students' gaze during lessons and infer conclusions about their attentional level; to study eye behavior in patients with neuropsychological or psychiatric disorders (e.g. see Kortman and Nicholls (2016) for a feasibility study employing eye tracking glasses on patients with unilateral spatial neglect); to see how much a car driver pays attention to the big number of stimuli in front of him while driving. These are just examples.

Another research field in which eye tracking is proficiently used is marketing. Knowing where a customer points his gaze is a non-trivial issue. As gaze direction is a reliable marker of visual attention, one could be interested in knowing where people tend look when they have to choose between a set of different brands. So, for example, portable eye trackers are employed in real environments such as supermarkets to collect data about search behavior and environment navigation. Based on these data, many companies redirect marketing strategies in order to drive purchase choices: for example, they change the location of a product on a shelf, modify the shape and color of a package or re-design their advertisements. A related approach is used in web-designing. Eye tracker can give useful information about how to design a web page or where to locate the apps on a tablet screen.

Other fields using eye tracking are recently emerging. For example, it can be a useful tool in the developing of *Human Computer Interface* (HCI) and *Machine Learning*. Similarly, it is becoming a supply tool in videogaming. Gaming industry is using this technology both to improve their virtual worlds – through the study of cognitive and emotional behavior of the gamers - and to integrate eye activity in gameplay.

2.9.2 Metrics

Eye trackers data provide several kinds of metrics, giving different types of information. The most prominent data in eye tracking literature are about gaze points, fixations and saccades. A *gaze point* corresponds to a raw sample data. At a sampling rate of 25 Hz, for example, a gaze point represents 40 milliseconds. A *fixation* is represented by a series of gaze points close in space and time, and its average duration is about 100-300 milliseconds. Fixations can be quantified through the concept of *perceptual span*: the perceptual span is defined as the number of characters a person can recognize while reading, and it consists of about 17-19 letters. A *saccade* is a brief discrete movement happening between two gaze points or fixations. Saccades happens when the object targeting requires a speed higher than 30°/s. When this speed is lower, the eye movement is not discrete anymore, but smooth instead: this phenomenon is in fact called *smooth pursuit*.

Figure 14 - Gaze points and fixation with eye-tracker - iMotions, 2016

Another popular metric given by eye tracker data is the *heat map*: a static or dynamic colored scheme representing the distribution of visual attention based on the aggregation of gaze points and fixations (Figure 14). The heat map returns the original stimulus with an overlapping color scale ranging from red areas (the most gazed ones) to yellow-green areas (less gazed) to no color at all (not gazed at all).

More, it is possible to set different *areas of interest* (AOI) relative to the stimulus displayed in the visual field of the subject. An individual AOI will retain only the gaze information within its range, making it possible to differentiate various sub-spaces of the stimulus, run separate analyses and also compare the data across these sub-spaces.

To spot the salient elements of the stimulus in a more data-driven way, it is possible to observe and analyze *fixation sequences* (Figure 15). It is basically a spatiotemporal sequence of subject's fixations. As shown in fig., the spatial information is given by the position of the circles on the stimulus; the temporal information is given both by the numbers inside the circles (representing the temporal sequence of the fixations in ascending order) and the width of the circles (representing the temporal length of the respective fixation).

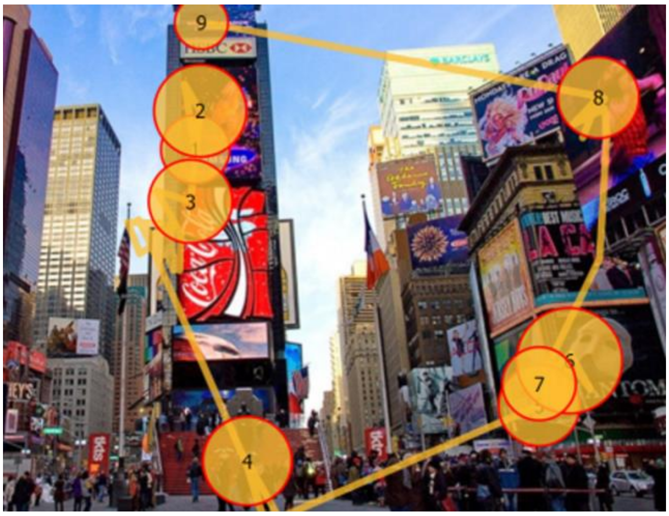


Figure 15 - Fixation sequences with eye-tracker - iMotions, 2016

Furthermore, it is possible to inspect how much time it takes for a subject to gaze a certain AOI after stimulus onset. This metric is called *time to first fixation* (TTFF). It can reveal a bottom-up attentional process telling us how much time it takes for the subject to gaze at a flashing light, for example. It can also reveal top-down features, for example recording after how much time the subject intentionally points his eyes in a certain direction or on a certain stimulus.

Finally, the eye tracker allows collecting data about more basic physiological events such as pupil size and dilatation, ocular vergence, blinking activity and distance to the screen. From these, it is possible to extrapolate information and interpret it in cognitive/emotional terms. For example: from pupil dilatation it is possible to take information about emotional arousal and cognitive workload; ocular vergence can give insights about concentration, as convergence increases with increasing focus on stimulus; blinking activity has been variously associated with attentional processes; an increasing/decreasing distance from screen can reveal an approach/avoidance behavior, respectively.

2.10 Electro-oculography

The *electro-oculogram* (EOG) devices are usually composed by two electrodes placed close to one eye to record the eye activities. If the eye tracker is focused on what, how much and how many times the subject is staring, the EOG is focused on the eye movements, because they are a problem during the EEG recording periods. It is caused by the interference of eye activities, those create electric signals, with brain activities. For this reason, usually it is necessary to record the eye activities with an EOG device, in order to clean the data of the EEG, in particular on the electrodes on the forehead. The major activity that causes the interference is the blinking, because its potential is very higher than the potential of the brain activities, so much that a blink could saturate the electrodes. The recording is based on the difference in potential between the cornea (positive) and the retina (negative) and is carried out using electrodes, placed on the external chant of the right eye and left, respectively 1 cm above and 1 cm below an ideal horizontal line passing through the eye.

There are two main ways, both placed close to one eye, to collect this data, using different type of electrodes: (I) EMG electrodes to collect the muscles movements those are activate during the blinking movements; (II) EEG electrodes to detect the pupil activities, because it is a dipole and its movement create an electric field.

The unique role of the EOG is to clean the data in the pre-processing activities. In the present study, according with literature and for the lack of a correct device, the experiment was structured without the use of the EOG. It is possible to clean the data without the EOG signals, but it is more onerous. The data of the present study are collected with the awareness and all the precautions in order to analyze them with the *independent component analysis* (ICA), to detect the blinking activities.

3. Literature Review

After the explanation and the understanding of the context, the starting point of the present work was a deep literature review regarding science of design, in particular the neuroscientific papers on creativity. The main documents those inspired this study were the Jauk, Benedeck and Neubauer, 2012 paper and A. Laspia master thesis, after them a long and deep web research and review of papers pertinent to this field. The intentions of the research and review were mainly two: (I) understand the state of the art in the context to identify a construct related to the design process to be investigated involving electroencephalography and eye tracking; (II) define how and why structure the data analysis with an overview on analysis of signals and deep neuroscientific knowledges. The fundamental of the literature in this field begins in 1950 with the first creativity construct proposed by Guilford, still used and accredited.

3.1 Creativity in Literature

The term *creativity* is often used in very different ways and therefore implies different meanings (Eysenck, 1993; 1995). The fundamental author in literature about the concept of creativity is Guilford, with the contraposition between divergent and convergent thinking. He postulated six criteria involved in divergent thinking: (I) sensitivity, (II) fluency, (III) flexibility, (IV) redefinition, (V) elaboration, (VI) originality. Moreover, Guilford's view on creativity as a trait implied not only divergent, but also convergent cognitive processes; especially when the individual is concerned with the evaluation of divergent productions (Guilford, 1966, as cited in Amelang et al., 2006). The processes where these two activities work together on one single action where creative people should be better able to move between them than less creative one.

According to Plucker and Renzulli (1999), there are five different approaches in the creativity research: psychometric, experimental, biographical, historiometric and biometric. There is good empirical evidence for this assumption to hold true. Neuroscientific studies (focusing mainly on EEG and fMRI) could show different patterns of cortical activity during creative ideation as compared to resting levels or convergent thinking tasks. Most of the previous studies used the alternative uses task to assess creative ability (Jauk, master thesis, 2011).

3.2 Measurements of Creativity

There are four categories of methods of creativity measurements: biographical methods, self-report measures, peer assessment measures and psychometric tests (Krampen, 1993). The present study is focused only on the psychometric measures and they can be subdivided into convergent and divergent measures. The convergent measures are more associable to intelligence test, because the related cognitive processes come into play in problem with a single one correct solution. Instead, the cognitive processes related to the divergent measures are in situation where there are more possible solutions (Krampen, 1993, cited by Jauk, 2011).

For instance, one task of the most used to assess the convergent activities is the *Remote Associates Test* (RAT), where participants are to find the missing link between different concepts (e. g. if the words are "*cream*", "*skate*" and "*water*" the correct answer is "*ice*"). For the divergent the most used is the *Alternative Uses Task* (AUT), where participants are required to find a novel application for an object of everyday use (e. g. if the object is "*brick*" some possible uses can be "*as a doorstop*" or "*to throw through a window*").

3.3 Overview on the Cognitive Neuroscience of Creativity

In the last decades, neuroscience has been developing and specializing in the study of many cognitive aspects of the human brain such as attention, memory, language and so on. This is not completely true for creativity. The reasons are various, but according to many, the main reason is that there has not been a standardized way in which it has been studied (Dietrich and Kanso, 2010) nor psychometrically defined and assessed (Arden et al., 2010), thus bringing to a "lack of consistency in how creativity is operationalized" (Sawyer, 2011). Moreover, studying creativity in a laboratory-controlled environment can be intrinsically tricky and maybe counterintuitive. Indeed, as Dietrich and Kanso (2010) say, we cannot just take an individual and ask him to be creative, nor we can control when an insight occurs. So, fully replicable controlled experimental paradigms are still needed: the reliability of the different methods seems not to have been fully achieved, while their validity depends on the method itself, meaning that each method is valid for some aspects of creativity but not for others. So, for example, different studies investigated divergent thinking, insight, creative/improvisational art, mind wandering and so on. In addition, each of these creativity aspects has been studied by means of multiple tasks, with different control conditions. Furthermore, different instruments have been used to see the creative brain, the aforementioned EEG, fMRI, PET, SPECT, fNIRS. Each of these tools gives different data about the brain, making it difficult to compare results among them. Finally, the data available in literature did not yield many solid empirical evidences for a specific brain region/pattern characterizing creative cognition. In light of this, nowadays it is a difficult goal to match all the variegated approaches, different methodologies and apparently inconsistent results to build a unitary neuropsychological construct of creativity. (Arden et al., 2010; Dietrich and Kanso, 2010; Sawyer, 2011). Nonetheless, first consistencies seemed to pop-out in recent years: divergent thinking paradigms helped addressing research through significative results. The debate is now shifting on the meaning of these results and on their interpretation.

3.4 Divergent Thinking in Literature

As pointed out in the previous sections, divergent thinking (DT) is the most popular conceptual proxy of creativity or, at least, it is a valid and reliable indicator of creative production. Furthermore, it is particularly adaptable for lab-controlled experimental settings. Thus, the work focuses on studies about divergent thinking: first, we will present a broad overview of brain correlates of DT, then we will specifically focus on EEG studies, with a detailed view on alpha oscillations.

As already stated, how the brain works during DT tasks is not clear. Neuroimaging results indicate that creative ideation can be related to a general decreased activity: the deactivation of particular areas would represent a top-down inhibition of task-unrelated stimuli, thus reflecting enhanced concentration and interior focusing. This process is at the base of Klimesch's inhibition-timing hypothesis (Klimesch et al., 2007), discussed later in this paragraph. There also seems to be a major involvement of *prefrontal cortex* (PFC), *anterior cingulate cortex* (ACC), both in the frontal lobe, and *temporoparietal* (TP) regions but these observations are not fully consistent across studies. The popular myth that right brain is more involved in creative processes is sometimes confirmed but, again, results are not that consistent through literature.

3.5 Neuroimaging Studies

According to Dietrich and Kanso (2010), neuroimaging results can be categorized into four main groups of findings about brain structures: *laterality*, PFC, TP regions and other brain structures. In general, brain hemispheres seem not to have a critical difference of activation while performing DT tasks: while some studies report about a right-sided specialization, few studies find no differences or, in a case, left hemisphere enhanced activation. More consistence has been found about the role of prefrontal areas: spacing from frontopolar regions to ventrolateral PFC and *premotor cortex* (PMC), a diffuse PFC activation seems to be highly involved in DT tasks, with different studies finding significative results about multiple frontal sub-regions. Carefulness is needed in interpreting these results because these areas (mainly dorsolateral and ventromedial PFCs) are also responsible for superior cognitive functions such as working memory and executive functions, and DT implies their engagement. The same situation can be drawn for results highlighting the role of temporoparietal regions. These have been found to be involved in DT in many studies, particularly in the right hemisphere; but, still, no clear conclusion can be outlined about their specific role. Finally, other results indicate a bunch of other areas engaged during DT tasks, such as hippocampus, visual cortex, anterior cingulate cortex and even thalamus (Dietrich and Kanso, 2010).

3.5.1 Event Related Potential (ERP)

EEG studies can focus on features about phase-locked or non-phase-locked activity. Phase-locked activity can be studied through ERPs or phase coherence across brain areas – phase coherence reflects synchronized activity across different neural networks. Phase-locked activity has been mostly studied in the domain of creative insight, and no ERP study exist about divergent thinking (Dietrich and Kanso, 2010). Phase coherence, instead, has been investigated in a few DT studies. But DT is mostly studied in terms of oscillations, focusing on frequency bands and their power and synchronization (Arden et al., 2010). The most studied phenomena are the power changes occurring during a DT task, in a particular frequency band: namely, event-related spectral perturbations, which can display an increase (*event-related synchronization*, ERS) or decrease (*event-related desynchronization*, ERD) in power with respect to a baseline activity. In this field, the most studied frequency band is the alpha, which ranges between 8 and 12 Hz. Moreover, the most consistent EEG results employing DT tasks are about alpha activity. Thus, alpha ERS and ERD will be the focus of the following discussion.

3.5.2 EEG Application

According to Dietrich and Kanso (2010), EEG studies on divergent thinking focused on three main aspects: (I) hemispheric lateralization, (II) changes in alpha frequency and (III) changes in other frequencies. Again, the right-brain dominance theory is not supported by an overall analysis of literature. Nor there is a consistent alternative theory and, according to the authors, "In sum, the EEG data on divergent thinking fail to substantiate the notion of lateralization in creativity for either cerebral hemisphere". The interest on alpha power changes raised after preliminary findings by Martindale and Hines (1975), who found that "creativity as measured by the remote associates test is connected with a tendency to exhibit differential amounts of alpha on different types of cognitive tasks, while creativity as measured by the alternate uses test is connected with a tendency to exhibit a high percentage of basal alpha on a variety of cognitive tasks". According to their original interpretation, this "makes psychological sense" because the increase of alpha frequencies is responsible for attentional defocusing, a necessary process for good performances – particularly in the AU test. Anyway, Dietrich and Kanso (2010) report contrasting findings about alpha synchronization. Some study report ERS, other studies ERD, but with a common feature: most of these patterns, even if contrasting, show up in frontal and/or temporoparietal regions. Finally, the data about all the other frequency bands follow a similar scheme: "they are spotty and contradictory".

3.6 Current State of the Art

If we look at the main reviews about neuroscience of creativity, the situation is unclear and somehow disappointing. According to Dietrich and Kanso (2010), "not a single currently circulating notion on the possible neural mechanisms underlying creative thinking survives close scrutiny". Similarly, Sawyer (2011) concludes that "creativity is not dependent on any particular mental process or brain region". Finally, Yoruk and Runco (2014) literally claim that their conclusions "just offered parallel those of Sawyer (2011) and Dietrich and Kanso (2010). When all of the findings are taken into account, it appears that both hemispheres are involved in DT, and DT is accompanied by both event-related increases and decreases in the neural activation". Anyway, all of them recognize the fact that this fragmentation can be due to (a) theoretical incongruencies about the meaning of creativity; (b) methodological discontinuities within and between different research groups; and (c) different interpretations about the meaning of the collected data. In line with this, Fink and Benedek (2012) claimed that "This diversity in defining and measuring creativity as well as the diversity of experimental procedures (e.g., stimuli, control conditions, timing, response mode, etc.) may well have contributed to the difficulties in identifying reliable and replicable brain correlates underlying creativity so far". Moreover, cognitive neuroscience underwent the study of creativity only in the last 20 years, thus it is a young research field which still needs to find its precise borders. The authors, in fact, called for the need of focusing research on very specific aspects, starting from a clear conceptual definition and going through a coherent analysis of specific brain patterns. According to them, the most prominent and promising neuroscientific results come from creative ideation tasks investigated through the analysis of alpha power changes: these data "have yielded a reliable and robust picture of some brain mechanisms underlying creativity, which may be among the most consistent findings in this field" (Fink and Benedek, 2012).

We now present our paper review, which focuses on the relationship between alpha power and creative ideation.

3.7 Methodological Review

3.7.1 Experiment Replication

This section focuses on the study by Jauk, Benedek and Neubauer (2012), as the present experiment study adopted a similar paradigm. It is important to highlight that a very useful document for the replication and all the correlated problems was the Alessandro Laspia's master thesis (2018). In that document, they already tried to replicate the Jauk, Benedeck and Neubauer (2012) and it made very effective to detect every obstacle in the procedure, design of experiment, etc.

There were some important differences between the first study and its first replication and it led to very different results, indeed in the A. Laspia's work there were no evident results in brain activities. For this reason, the present study has the aim to adjust all the main differences in order to identify if those differences were the reasons why the results changed.

Returning on the experiment of the paper this work wants to replicate, they employed an adapted version of the Alternative Uses Task, with two conditions: in one condition the subjects were asked to find highly uncommon (divergent) uses for the presented object; in the other condition they were asked to find highly common (convergent) uses. The procedure was the following: a fixation cross appeared on the screen for 5 seconds, representing the reference period; then, a letter indicated the instruction (common/uncommon) for the following item; next, the stimulus word appeared on the screen for a maximum of 30 seconds, and subjects had to think about the solution. This last represented the activation period. Before the experiment, the authors also assessed participants via creativity screenings, intelligence test, anxiety scale and personality inventory. Behavioral results indicate a main effect of the within-subjects factor condition (common vs uncommon), meaning that the paradigm works: in the uncommon condition, more original responses were generated. Here, they also found a significant main effect of the between-subjects factor "group" (high creative vs low creative subjects): highly creative subjects produced more original ideas. Regarding EEG analysis, alpha power was calculated by means of the *Task Related Potential* (TRP) method (Pfurtscheller and Lopes da Silva, 1999), according to the following formula for each electrode:

$$TRP = log(Power_{activation}) - log(Power_{reference})$$

TRP positive values thus indicate ERS (synchronization, increase in power compared to a reference period), while negative values indicate ERD (desynchronization, decrease in power compared to a reference period). A main effect "condition" was observed, with the uncommon condition showing lower decreases in alpha power than the common condition. An interaction condition*area indicated a significant power decrease from anterior to posterior regions. The between-subject factor group showed interaction with all the other factors (condition, area, hemisphere): highly creative subjects showed the strongest increase in alpha TRP in frontal regions, and lower creative individuals showed the strongest increased TRP over right posterior regions during the generation of uncommon ideas. Alpha sub-bands did not show significant differences, thus were aggregated. These results, in general, indicate a significant relationship between divergent thinking and increase in alpha power. Moreover, the authors used another task, the word association task (AS) in which participants were asked to find common vs uncommon associations for a given word. Interestingly, they found that the AUT, compared to the AS, induced stronger alpha activity.

3.7.2 Correlated Papers

In order to get a closer zoom, we reviewed 14 papers dealing with the alpha power changes in DT tasks. It was done to have a consciousness and reasonable argument to make the decision for each variable that could come into play (sample number, number of electrodes, task, etc.). These papers were studied with a very detailed approach and they are divided in the following groups: 9 of them employed the AUT (Jauk, Benedek and Neubauer, 2012; Benedek et al., 2014; Fink, Schwab and Papousek, 2011; Fink et al., 2009; Schwab et al., 2014; Camarda et al., 2018; Fink et al., 2006; Fink and Neubauer, 2008; Fink, Graif and Neubauer, 2009), 1 employed the *Torrance Tests of Creative Thinking*, TTCT (Grabner, Fink and

Neubauer, 2007), 1 employed the evaluation variant of the AUT (AUeT, Rataj, Nazareth and Van der Velde, 2018) and 4 employed different DT tasks: *Transportation problem*, *Plan-a-Day problem*, *Dialectic problem*, *Divergent Production problem* (Jausovec, 2000, exp. 1 and 2), *Creative problem* (Razumnikova, 2000) and RAT (Razumnikova, 2007). To be clear from the beginning, the first 11 experiments yielded results supporting the theory of increased alpha activity (*alpha ERS*) during divergent thinking tasks; Jausovec (2000) reported slightly contrasting results; Razoumnikova (2000; 2007) found exactly opposite results (*alpha ERD*). The latter were chosen because, to our knowledge, there is no EEG study employing the AUT which found such results. Tab. broadly resumes our review, taking into account only AUT tasks where possible, as many of these papers also employed other DT tasks. The present study discusses only AUT relevant results - where possible.

PAPER	APLHA POWER	SUBBAND (Upper & Lower)	AREA	HEMISPHERE
Jauk, Benedek and Neubauer, 2012	ERS	Both	Frontal, Parietal	NA
Benedek et al., 2014	ERS	NA	Posterior	Right
Fink, Schwab and Papousek, 2011	ERS	NA	Frontal	Right
Fink et al., 2009 (exp 1)	ERS	Both	Frontal	Right
Grabner, Fink and Neubauer, 2007	ERS	Both	Global	Right
Schwab et al., 2014	ERS	NA	Frontocentral, Posterior	Right
Camarda et al., 2018	ERS	NS	Frontal	Right
Fink et al., 2006	ERS	Both (Lower > Upper)	Centrotemporal, Centroparietal, Parietotemporal	Right
Rataj, Nazareth and Van der Velde, 2018	Reduced ERD ERD	Upper Lower	Parietoccipital Anterior	Right Left
Fink and Neubauer, 2008	ERS	Upper	Posterior	Right
Fink, Graif and Neubauer, 2009	ERS	Upper Lower	FrontoCentrotemporal Global	Right Right
Jausovec, 2000 (exp 1)	Reduced α-power	Both	Temporal	Right
Jausovec, 2000 (exp 2)	Increased α-power	Both	Global	Both
Razumnikova, 2000	ERD	Both	NA	NA
Razumnikova, 2007	ERD	Both	NA	NA

3.7.3 Experimental Paradigm

There are different tasks established to assess creativity. In literature, some of them are more used than others, in particular in research experiment with a similar aim of the present study.

To define the task, measures like the RAT demand predominantly insight, while others consist in a pure measure of divergent thinking, such as the AUT, in case of allowing different solutions. For the present study, such as the Jauk, Benedeck and Neubauer (2012) and A. Laspia's master thesis, it was defined a limited number of responses to $j = 1$. It allows to present a larger number of items in the same time, to see more same activities, making a more consistent statistical procedure. Another important reason is to reduce memory activities because, while thinking to more than one solution, the subject needs to remember what he has already thought. It is unknown if it could make a different brain path activity, rather than to find just a solution. While evaluation of divergent productions is one of the criteria postulated by Guilford, memorizing is not and can be regarded as a more intelligence-related cognitive function. It has been shown that sole maintenance in the verbal working memory induces alpha synchronization (Klimesch et al., 2007). The best-only instruction requires participants to maintain different solutions until they finally name the selected one (Jauk, 2011). The generation of more than one solution could also make some comparisons with previous solutions to auto-assess the answers, with less time, due to more potential stimuli, the participant has no time to wonder on it, because it is required to focus on a different problem. These considerations could complicate the interpretation of the results.

Other authors emphasize the view that alpha-synchronization increases as a function of task demands and reflects internal processing (Cooper, Croft, Dominey, Burgess, & Gruzelier, 2003) rather than pure working memory maintenance. Regarding the level of neuroscientific paradigms, the intended best-only - instruction would demand an event-related as opposed to a task-related paradigm because only one answer per trial is given (Jauk, 2011).

3.7.4 AUT Applications

Fink et al. (2006) adopted the AUT for the evaluation of training on DT. The task was employed, together with other tasks, in two time periods: before and after a 2 weeks training. EEG was recorded in both pre- and post- training. Regardless of the task or the time period, authors report only alpha power increases during the activation period with respect of the reference period. For the lower alpha band, the main factor area showed higher TRP in frontal and posterior regions, and an interaction area*hemisphere indicated higher TRP over centro-temporo-parietal areas of the right hemisphere. Moreover, the group participating to the training showed stronger TRP over frontal areas than the control group, and regardless of the task. For the upper alpha band, TRP was decreasing from frontal to posterior regions. These data indicate the AUT as an adequate DT tasks, and show that alpha activity increases during DT.

Fink and Neubauer (2008) adopted the AUT, together with other tasks, to investigate the relationship between extraversion and originality. For both alpha sub-bands, they found a general increase in alpha power from anterior to posterior regions. For the upper alpha band, higher power was observed in centro-temporo-parietal areas of the right hemisphere. Hemispheric differences were even bigger for the AUT. For the sake of completeness, it is interesting to note that extraverted individuals with higher scores in originality showed the highest level of alpha power.

Fink, Graif and Neubauer (2009) studied EEG activations of novice vs professional dancers. They employed the AUT, a waltz task and an improvisation task. With regard to the AUT, it showed to be the one with the most powerful ERS both in upper and lower alpha sub-bands, mainly in frontal and centro-temporal areas and over the right hemisphere. Interestingly, professional dancers showed more alpha synchronization on central and posterior regions than novice dancers in the AUT.

Fink et al. (2009) were the only authors, in this analysis, who studied DT by means of both EEG and fMRI, but this analysis shows only present EEG results (study 1). They employed four DT tasks, comprising the AUT. Overall, their results indicate that DT tasks enhance alpha synchronization. AUT better revealed to be creativity-related among the four tasks, and yielded significantly strong alpha synchronization, both in its upper and lower sub-bands. Furthermore, this was particularly true for frontal electrodes, and also for the right hemisphere for AUT compared to other tasks.

3.8 Previous Studies Summary

Fink, Schwab and Papousek (2011) adopted the AUT in three conditions – cognitive stimulation, affective stimulation and control – in order to investigate possible brain and behavioral differences different kinds of mental stimulation. They found, in general, strong increases in alpha synchronization during creative ideation in the AUT. In particular, alpha power strongly increased in frontal and frontopolar regions, while a little desynchronization was observed over temporal cortices. The factor hemisphere showed a main effect indicating the right hemisphere to show more alpha ERS than the left hemisphere. An interaction of the variables *hemisphere*area* indicated higher ERD recorded by central, parietal, temporal and occipital electrodes, while the right hemisphere showed a broad alpha ERS.

Schwab et al. (2014) run separate analysis on the data from Fink et al., 2011: they observed the time course of alpha power, analyzing data from the control group. To do this, they divided the 10 seconds response period in three consecutive and equivalent time segments. First, they confirmed anatomical results and found stronger ERS in frontocentral and posterior locations. Then, they found that the time course of alpha TRP followed a specific trend: in the first segment, alpha power increased; in the second segment, it decreased and desynchronized especially in left frontal, temporal and parietal areas; then, alpha power raised again, especially over the right hemisphere.

Benedek et al. (2014) investigated the effects of another kind of instruction set on the AUT and another DT task. Their paradigm is basically the same as Jauk, Benedek and Neubauer (2012), with the only difference that, in one condition of *Low Internal Processing* (LIP), the stimulus/word kept being visible on the screen, while in another condition of *High Internal Processing* (HIP) the stimulus/word was substituted with XXXX after 500 milliseconds. According to the authors, HIP condition should eliminate a bottom-up processing of the stimulus, which could interfere with ongoing mental processes. The results regarding the alpha power changes showed no statistically significant differences between the conditions in the AUT, but a tendency towards higher alpha TRP in the HIP condition ($p = 0.10$) was observed. Anyway, AUT induced higher alpha ERS in right posterior regions than in left hemisphere during creative ideation in both conditions.

Camarda et al. (2018) also employed AUT with a different procedural set and investigated alpha TRP time course. Objects were visually presented written on the screen, in a black-and-white picture format and acoustically by a voice. In one condition, the objects were shown together with their common use; in the control condition the objects were presented alone. Furthermore, this is the only available paper using high density EEG (256 channels) in DT literature. With regard to EEG results on AUT, the authors found a main effect ROI (frontal vs temporoparietal) indicating stronger alpha synchronization in frontal regions. A main effect laterality suggested higher alpha synchronization over the right hemisphere. As the authors run a time-frequency analysis, they were able to investigate also the time course of alpha activity: this analysis revealed a progressive desynchronization during time for subjects ideating fewer original responses, while more original ideation was accompanied by sustained synchronization.

Rataj, Nazareth and Van der Velde (2018) studied EEG activity during an evaluative version of the AUT, the *alternate uses evaluation task* (AUeT). Subjects, in fact, had to evaluate originality and functionality of preset items. Items were presented as pairs of words in rapid succession, being the first word an object and the second another word accordingly with three conditions: representing a common use for the object, an alternative use for it or just being an unrelated word. According to the authors, the assumption is that people create an internal representation of an objects when it is presented: to do this, access to and integration of semantic information is needed. This process is more demanding for uncommon uses than for common uses, thus it should be reflected in higher alpha activity when evaluating uncommon solutions. The authors run several analyses: on alpha frequency band, other frequencies and ERPs. ERP results reveal increased N400 amplitude during uncommon solutions evaluation compared to common solutions. Authors then focused on alpha ERDs within 400 and 1000 milliseconds after stimulus onset: results indicated reduced ERD (i.e., more power) in upper alpha sub-band over parieto-occipital regions, mainly on right hemisphere. Lower alpha sub-band showed increased ERD over frontal regions, with a left lateralization.

Grabner, Fink and Neubauer (2007) also investigated both phase-locked activity and alpha ERSP during DT tasks. They adopted two DT problems adapted from the TTCT, not including the AUT, and originality scores were given via a self-evaluation protocol. Globally, only alpha power increases from reference to activation period were found. Particularly, for lower alpha sub-band in right hemisphere, more original responses were accompanied by larger ERS than less original ones. Left hemisphere did not show any difference. In upper alpha sub-band, the main effect hemisphere indicated higher ERS in the right hemisphere. These patterns were also found regarding phase synchrony: for lower alpha sub-band, phase synchrony resulted to be bigger in right hemisphere for more original ideas, while the left hemisphere showed no differences; for the upper alpha sub-band, higher phase synchrony was higher in the right brain than in the left brain.

Jausovec (2000) studied EEG differences across four groups of individuals: gifted (high IQ and high creativity), intelligent (high IQ and average creativity), creative (average IQ and high creativity) and average (average IQ and average creativity). Subjects were administered intelligence tests (experiment 1) and creativity tests (experiment 2). He analyzed both frequency power and phase coherence data: we will report only power results. In experiment 1, subjects were asked to solve two intelligence-related problems: the *Transportation problem* (T) and the *Plan-a-Day problem* (P). As the same author states, "*both problems were classified as well-defined, calling for little or no creativity*". He found that alpha power seems to be more influenced by intelligence than by creativity levels. In particular, both lower and alpha sub-bands exhibited higher power in the gifted and intelligent groups compared to the creative and average ones; moreover, creative group showed less alpha power at the right temporal electrode (T6).

In experiment 2, different tasks were administered: The *Dialectic problem* (D) and the *Divergent Production problem* (DP). These are reported by the author as being creativity tasks and were divided in a writing part and a reading part, and in verbal form and visual form. Overall, results revealed higher alpha power for high creative subjects with respect to average creative ones, in both sub-bands and globally distributed over the scalp. Interestingly, the gifted group showed higher alpha power in right frontal electrode (F8) if compared to the other three groups.

Razoumnikova (2000) studied EEG activity in convergent (CT) vs divergent thinking (DT) through two tasks: a mental arithmetic task (convergent) and the divergent problem of measuring the length of a hundred poisoned snakes. She analyzed frequency power and phase coherence data for different frequency bands. Here only alpha power data are reported: results indicate a decrease in power for both upper and lower alpha sub-bands in both the CT and DT tasks with respect to an initial resting condition, and no differences between CT and DT emerged.

In another study, Razoumnikova (2007) employed a CT task (the *Simple Association Task*, SAT) vs a DT task (the *Remote Association Task*, RAT) to study verbal creativity. Again, she run the same kinds of analyses as in Razoumnikova (2000). We will only report results about alpha power. Globally, the author reported an increase in ERD for both upper and lower alpha sub-bands during the generation of divergent verbal associations compared to convergent verbal associations. This result is consistent with her previous study, and together with it represents the main evidence against a theory of increased alpha power during creative ideation. Interestingly, the author also found a positive correlation between lower alpha sub-band in the left hemisphere and originality scores.

3.9 The Results of the Review

The aim of this review is to try to focus on a narrow area of the current neurocognitive literature about creativity: EEG alpha power changes in divergent thinking tasks, with a closer zoom on the employment of the AUT as DT task. Still, getting into the individual experiments, a considerable methodological heterogeneity exists. For example, some of them assessed participants before the experiment via psychometric tests for creativity, intelligence, stress and so on, while some did not. Among those using psychometric assessment, different tests were employed. Then, differences in sample size can influence the statistical properties of the results. Additionally, EEG settings (number of electrodes, sampling rate, electrodes montage, artifact rejection methods and so on) vary from study to study.

Additionally, the experimental procedure is not always the same even within papers employing the AUT: the reference and activation periods duration vary from study to study; control conditions are multiple across studies; items can be presented via different intra- or inter- sensorial ways; et cetera. AUT is not always employed, or it can be employed in a production or evaluation version.

Analyses heterogeneity can also be seen: papers can differ in establishing a frequency bandwidth and/or in defining sub-bands borders, for example; electrodes aggregation can be different, then modifying the way of defining and framing topographical brain areas; comparisons can be done between or within subjects, between or within frequency bands, thus yielding results which take into account different parameters; and so on.

Anyway, focusing on specific aspects (i.e., alpha power in DT tasks) helped drawing a picture of the situation: in general, 12 of the 15 experiments reviewed found empirical evidences for an increase in alpha power during divergent thinking processes, one found a decrease in alpha power during intelligence tasks (Jausovec, 2000, exp. 1) and only two (Razoumnikova 2000; 2007) found contrasting results indicating alpha power decreases during a DT task. A closer view on the papers supporting alpha ERS reveals that most of the times the right hemisphere seems to play a major role in this neurophysiological process, while results about the areas/lobes seem not to indicate a specific topographical specialization. The subdivision in sub-bands also does not yield a clear conclusion on their role: some studies identify specific roles for upper- and lower- alpha; other studies found no significant differences; further studies do not even divide the alpha frequency band in sub-bands.

Regarding the contrasting findings, it must be noted that the two latter studies (Razoumnikova 2000; 2007) drastically differ from others in their methodological approach: namely, the employed DT tasks (e.g. DP and RAT) were different from the majority of the other studies and only a pre-experiment long duration resting period was used as reference period to be contrasted to the activation periods. As the same author noticed, the RAT is a highly demanding task, and the "decrease of the alpha power during the RAT may be related to intellectual subcomponent of problem solving namely intellectual difficulty of the verbal creative task" (Razoumnikova, 2007, p. 101). Also, it is interesting to note that, in the same study, phase coherence results indicated a functional decoupling of frontal areas in lower alpha sub-band, thus indicating a defocused attention. In fact, lower alpha sub-band is thought to reflect attentional demands, while upper alpha seems to be more related to semantic processing.

Beyond all possible interpretations, the overall situation seems to be promising and points towards the use of the AUT for the study of divergent thinking and towards the analysis of EEG alpha activity. We think that it is very important to restrict the field of study in a narrow but precise frame: this is the only way by which it is possible to find consistent preliminary results, thus giving the opportunity to a relatively young field of study like this to be able to rise and develop in future. When basic knowledge will be solid, research will be expandable, and interpretations will be clearer.

In this review the mere electrophysiological results yielded by the studies are reported, without getting deep into their interpretations. In the next paragraph, the characteristics of alpha waves are reported and their interpretations in the creativity field so far, with considerations regarding the review.

3.10 The Alpha Waves

3.10.1 Alpha Waves History

The alpha rhythm was the first to be observed in the very first EEG studies by Berger in the ‘20s and ‘30s. He found that a 10 Hz activity could be observed at occipital regions as soon as a subject closed his eyes. This activity disappeared when the subject opened the eyes. Later on, studies deeply investigated this frequency band, and empirical findings made evident that alpha activity was reduced over a brain region involved in a motor or sensory task. Thus, it became clear that a desynchronization of the alpha frequencies (ERD) reflected cortical activation. Further studies found that alpha activity was instead more pronounced (ERS) over those cortical areas not involved in the task. This led to the so-called *idling hypothesis*, which states that alpha activity is characteristic of resting neural populations (Pfurtscheller et al., 1996). For instance, it can be seen over the motor cortex ipsilateral to the moving arm in a movement task (Pfurtscheller and Lopes da Silva, 1999); or it can be seen over the visual cortex ipsilateral to a lateralized presented stimulus. The idling hypothesis is no more accepted or, at least, just considered a partial explanation of the role of alpha frequencies in the brain because it interprets its role as a mere obligatory response to a stimulus. In fact, more recent studies yielded evidences for a more cognitive role of alpha activity.

3.10.2 ERD vs ERS

The starting point is, as Klimesch (2012) says, that “The most general observation is that brain regions that are activated during a task exhibit ERD, whereas regions associated with task irrelevant and potentially interfering processes exhibit ERS”. And this is true when different tasks involve different sensory areas (e.g., if an acoustic stimulus is presented alpha ERS occurs over visual areas and ERD over auditory areas), different processing modes (e.g., ventral vs dorsal stream) or different hemispheres (left vs right). But when a bimodal visuo-auditory stimulus is presented, alpha power is larger on occipital cortex if the attention is oriented to the auditory part; alpha power is larger over parietal areas if the ventral stream is engaged; and if a bilateral cue is presented, alpha power is higher on the hemisphere ipsilateral to the side of the stimulus to which attention is oriented (Klimesch, 2012). These findings clearly demonstrate that alpha activity is related to a top-down attentional control.

In their review, Klimesch and colleagues (2007) also report a set of findings for a cognitive involvement of alpha power. For instance, alpha ERD was found to happen even when a subject closes his eyes even in a dark room and so without visual stimulation: this would reflect a top-down decision. The authors also report that alpha ERS has been selectively seen in tasks requiring the withhold of a learned response. For example, ERS have been observed during retention of items in a memory go-no-go task, with increasing power for increasing number of items to be remembered; the same is true for a motor inhibition task, in which the authors also assessed cortical excitability via *transcranial magnetic stimulation* (TMS) and found that the *motor evoked potential* (MEP) was reduced over the same motor areas displaying alpha ERS in the EEG during movement inhibition.

3.10.3 Top-Down Control

Again, in another review, Fink and Benedek (2013) report numerous results from different studies indicating alpha synchronization over areas exerting a top-down control. For example, a study found increased alpha activity over parieto-occipital sites in relation to increased memory workload and interpreted this result as a sensory inhibition of external inputs potentially disturbing the working memory processing in frontal areas. Another reported study observed stronger alpha power during an internally driven mental imagination task compared to an externally sensory-driven task, with alpha power increasing in function of the increase of the task demand. According to the authors, these and other results bring evidences about the cognitive top-down mental role of the alpha activity: as they state, "*it seems that alpha synchronization is particularly sensitive to sensory inhibition or internal processing demands*".

3.10.4 The Role in Creative Tasks

From this overview, it seems clear that the alpha waves are engaged in a number of cognitive processes, such as memory and attention; it can be argued that their activity might reflect attentional processes, mainly when these are internally-directed, probably because alpha rhythm is proven to be involved in a sort of gating activity which inhibits external influences over the ongoing mental activity. These two processes – top-down stimuli shielding and internally directed attention - might be the core of the relationship between alpha activity and creative ideation. The first author conceptualizing these observations in the field of creativity was Martindale: according to him, free-associative primary processes, critical in creative ideation, should happen during relaxed states, i.e. during low cortical arousal. This is the case of enhanced alpha activity, which reflect an inhibitory activity. He observed the association alpha power-creativity in his preliminary studies. So, he drove the interpretation of increased alpha power during creative processes through a *low-arousal* hypothesis. Let's now see recent findings about this ensemble of interpretations.

According to Benedek (2018), the top-down/bottom-up interplay is the base for any kind of cognitive activity, and "*we can further distinguish between externally directed attention and internally directed attention: while external attention refers* *to a focus on sensory information, internal attention refers to a focus on self-generated mental representations*". These two processes are continuously competing, and even involve different brain mechanisms. The second one, internal attention, has been quite neglected by recent cognitive neuroscience even if it has been suggested that humans spend up to the 50% of their awake time engaged in thought that are totally detached from the external world. During this time, thoughts are usually directed towards past memories or future planning – in this sense, it could be interesting to investigate where the default mode network proposed by M. Bar could take place in creative thinking (e.g. Kühn et al., [2013] investigated it through a structural MRI study in which the AUT was used to assess creativity). Anyway, these stimulus-independent thoughts can be spontaneous and self-rising or oriented towards a specific mental item, i.e. goal-directed. Spontaneous thoughts run free and are typical of events such as mind wandering. Goal-directed thoughts are instead intentionally addressed and controlled and are typical of idea generation. Thus, internally directed attention – which is related to increased alpha activity - might play a fundamental role in creative ideation: "*Being fully engaged with internal cognitive processes, and not distracted by external interference, may enable the generation of more elaborate and vivid mental representations, which may ultimately result in more creative ideas […] alpha activity appears to serve as a sensitive indicator of transient changes in the internal focus over time, and the actual level of internal focus may predict the outcome of creative thought […] the consistent association between creativity and alpha activity can be explained by central role of internal attention for creative thought.*".

3.11 Previous Results and Interpretations

These explanations are consistent with the conclusions that can be drawn from a broad overview on the interpretations given by the papers analyzed in this review.

For example, Benedek et al. (2014) found alpha power increases in right parietal cortex only in the experimental conditions involving a focused internally-directed attention. They interpreted this observation integrating it to results from other studies investigating phase-locked EEG activity and fMRI data and gave this explanation: alpha activity over the *right temporo-parietal junction* (rTPJ) reflects the inhibition of the ventral attentional system, involved in the detection of relevant external stimuli. Its inhibition is caused by a top-down control exerted by prefrontal regions, which in fact are functionally connected with rTPJ. This mechanism prevents re-orienting the attention to irrelevant stimuli and, in divergent thinking, it "*may help to stay fully focused on internal processes such as retrieval from semantic and episodic memory during the performance of mental simulations and the construction of mental images*". In particular, according to the authors, the AUT is the task that is mostly internal focus demanding because it requires retrieval of uses from episodic memory, mental manipulation of the objects and imagery creation – this process is enhanced by the shielding of the stimulus during the idea generation period. These mental actions are the most sensitive to external stimuli, thus alpha activity may be used as an indicator of the depth of the mental elaboration and thus "*represent a valid indicator of a cognitive process specific for creative cognition*".

This seems to be confirmed also by the evaluative version of the AUT proposed by Rataj and colleagues (2018), who found reduced alpha ERD over right parieto-occipital regions during the evaluation of uncommon uses compared to common uses. This result was interpreted as the underlying activity of a mental imagery process based on semantic associations needed in the creation of conceptual re-representations of the proposed objects in the context of an uncommon use, thus reflecting internally-directed goal-driven cognition.

Accordingly, Jauk, Benedek and Neubauer (2012) compared the generation of common vs uncommon uses: they found higher alpha TRPs (i.e. bigger ERS or smaller ERD) during the ideation of novel uses for the objects in the AUT. According to them, this observation yields support for an effective specific role of alpha activity in divergent thinking "*rather than other processes elicited by other general task characteristics of creative ideation tasks*". In the same study, the authors investigated possible individual differences, on behavioral performance and EEG patterns, between high creative and low creative subjects as assessed before the experiment. With regard to EEG alpha activity, they found different activation patterns: on one hand, they observed that highly creative people show more differences in convergent vs divergent processing in frontal alpha power than low creative people – who just showed little variance. It must be said that their paradigm required a continuous switch between convergent and divergent ideation, and the differences in frontal activity might be due to the different ability in switching between different modes and maybe reflecting differences in frontal flexibility. On the other hand, low creative subjects showed higher alpha synchronization at centro-parieto-occipital regions during divergent ideation. So, according to the authors, low creative people seem to rely less on top-down strategies (prefrontal activation) and pursue loose semantic memory association processes – involving parietal activity.

Similarly, Camarda et al. (2018) analyzed the differences among subjects generating high vs low original ideas. They observed that people with high remoteness (i.e. originality) scores maintained a sustained alpha synchronization along time both in frontal and temporo-parietal regions, while subjects with lower remoteness scores showed a decrease in frontal alpha in time. They interpreted this result as indicating a higher top-down frontal executive control for people ideating creative ideas.

The alpha TRP time-course in high vs low originality performers was also investigated by Schwab et and colleagues (2014). In general, they observed a u-shaped pattern of alpha synchronization in time, meaning that ERS is initially strong, then decreases in a second moment and successively re-increases again. This pattern was accompanied by an increasing hemispheric lateralization: the left hemisphere showed a constant TRP decline over time, while the right hemisphere followed the u-shaped pattern. The authors interpreted this pattern as characterizing a 3-phases creative thinking process: the initial hemispheric coherence represents the memory retrieval of common ideas; in the second phase, the occurring lateralization might indicate passage from memory retrieval to a more creative or imaginative process, based on specific memory search inside semantic networks; the last phase could represent the mental imagery based on simulation for the new uses generated. The last phase is the most sensitive to external distracting influences and could be accompanied by the strongest alpha activity which functions as a task-shielding process. Interestingly, this whole process was more pronounced in subject with high originality scores, and the difference with low original subjects was even bigger in later time intervals: high original subjects showed in fact an earlier lateralization and stronger alpha ERS over right lobes. The authors assumed that "*ideas of high quality require the same neural circuits and mechanisms than less original ideas, but probably in a more efficient manner*", thus leading to more elaborate ideas which, as consequence, are rated as more original.

A similar neurophysiological pattern was found by Fink et al (2009), suggesting that higher originality scores are accompanied by a more pronounced hemispheric lateralization: the right brain of more original subjects showed higher alpha ERS over central and parieto-occipital areas. Moreover, independently of the originality score, a general pronounced frontal alpha ERS was found. The frontal critical role was confirmed by their fMRI study too (in the same paper), and the authors interpreted it as fundamental location for top-down executive control over the ongoing task.

In line with these observations, Grabner et al. (2007) found higher alpha ERS and phase synchrony for more original responses as compared to less original ones. In particular, the right hemisphere showed higher ERS than left hemisphere, and phase synchrony appeared to be stronger over anterior right areas. According to them, these findings yield further support to the idea that frontal areas are involved in cognitive control during divergent semantic processes, and that the right hemisphere is involved in more primary, holistic and free-associative semantic operations.

Jausovec (2000) divided his sample in four groups and investigated individual differences in alpha power and phase coherence during creative tasks. The different groups were: gifted (high IQ and high creativity), intelligent (high IQ and average creativity), creative (average IQ and high creativity) and average (average IQ and average creativity). During divergent production, high creative individuals (i.e., gifted and creative) showed stronger alpha power than low creative ones, with the gifted group showing the highest level of alpha activity over right frontal areas and right parietal areas. Moreover, phase coherence data revealed that creative people displayed a bigger cooperation between different brain areas than gifted ones, in particular among distant networks both at an inter- and intra-hemispheric scale. According to the author, this might indicate that intelligence may negatively influence the creative ideation process by involving more specialized networks that are relevant for intelligence-related problems but not for creativity-related ones, thus resulting in worse performances; on the contrary, creativity seems to rely on a broader pattern of activation among different areas.

Individual differences were also investigated from different points of view. For instance, taking into account the level expertise in a certain field: Fink et al. (2009) found that professional dancers exhibit higher alpha ERS over frontal and right posterior parietal regions than novice dancer when they are engaged in improvisation dance and also while generating original uses for everyday objects. Or, with regard to personality traits, Fink and Neubauer (2008) investigated the relationship between creativity and extraversion: they observed that the highest alpha synchronization was exhibited by extraverted individuals creating the most original ideas, while the lowest level of alpha activity was found in introverted individuals generating the lowest original ideas. Finally, the papers we review did not investigate gender differences, but anyway little studies in literature did it and the results are contrasting: in fact, as Yoruk and Runco claim in their 2014 review, "*we cannot conclude that there is a particular way of thinking for males or females when working on a DT task*".

Divergent-thinking-related EEG alpha activity also seems to be influenced by different kinds of interventions. A *2-weeks training* on divergent thinking was found to enhance the amount of frontal alpha ERS in the post-training with respect to the pre-training period (Fink et al, 2006); Fink et al. (2011) observed that a mental (cognitive or affective) stimulation just before the trials enhanced the alpha TRP in frontal sites if compared to a control (no stimulation) condition. The cognitive stimulation consisted in exposing the subject to original uses generated by other people in the AUT: the increase of alpha synchronization over the frontal lobes in this condition was interpreted as reflecting the heightened internal attention level after the presentation of external bottom-up stimuli, which could potentially interfere with the ongoing mental representations.

Altogether, the reported findings and discussions seem to highlight some specific recurrent mechanisms and emerging facts. Strong alpha activity is generally associated with internally-directed attention, inhibition of external distracting stimuli and memory retrieval. These processes are involved in several cognitive abilities; nonetheless, they also represent key features for creative ideation: even if they cannot be assumed as sufficient, they still seem to be necessary for it. In detail, a recurring lateralization of alpha activity during creative tasks is most of the times observed, and a broad topographical overview seems to indicate the major involvement of frontal, parietal and occipital regions. Occipital alpha activity is usually indicating inhibition of the visual system as a consequence of external stimuli shielding. Frontal alpha is generally associated with two main mechanisms. First, frontal alpha activity during creativity tasks is referred to reflect the top-down inhibition of external distracting stimuli or internal interfering thoughts, meaning that the control played by executive functions is crucial for the effectiveness of the creative ideation. Second, frontal lobes display higher alpha power during tasks requiring high internal processing demands and an enhanced internally-oriented attention; this is mainly observed in studies comparing responses to external vs internal stimuli. This results particularly evident in idea generation tasks such as the AUT, as an external stimulus is presented at the beginning, and then it is all depending on mental work – e.g. memory, mental imagery, mental manipulation, semantical recombination and associations. Parietal alpha activity during creative ideation has largely been observed: it is most of the times peculiar of the right hemisphere and has prevalently been associated with memory retrieval and semantical elaboration of ideas. Right parietal alpha activity seems to be more creativity-specific than frontal alpha, and the right hemisphere is thought to be involved in more primary, free-associative processes reflecting a parallel information processing. As Fink and Benedek (2012) report, these observations have been similarly replicated by fMRI studies which showed decreased right parietal activity during creative tasks. Anyway, parietal alpha activity is reported to be under the influence of frontal lobes: as their functional coupling has been proven by phase synchronization data, most of the papers suggest that frontal areas exert a top-down control over parietal regions, again reflecting the central role of the executive functions. Other authors link the right parietal activity attenuation to the inhibition of the ventral attentional network proposed by Corbetta and Shulman (2002), which involves connections between the right temporo-parietal cortex and the right inferior frontal cortex: these regions are thought to be responsible for the bottom-up (re)orienting attention to external stimuli. Inhibiting this network prevents other networks activity from being disrupted by unnecessary information. Interestingly, the same model proposes a dorsal attentional network that bilaterally involves the superior parietal lobes and the dorsal frontal cortices and is responsible for top-down goal-directed attentional orienting, both for exogenous and endogenous stimuli. Thus, right parietal alpha synchronization may reflect an enhanced state of internally-directed attention towards a mental item, which might contribute to facilitate those memory-related functions that are essential for semantic (re)representations and mental manipulations of an object – crucial in creative ideation.

To conclude, it is worthy to report the results of a recent study by Lustenberger and colleagues (2015) who investigated the role of alpha activity in creative ideation through a brain stimulation paradigm. They used the *transcranial Alternate Current Stimulation* (tACS) to directly enhance alpha waves in frontal lobes. They administered a 10 Hz alternate current over F3 and F4 scalp location for 30 minutes during the execution of figural DT tasks from the Torrance Test for Creative Thinking (TTCT). The results indicate that 10-Hz brain stimulation generally improves the creative performance in a global way, as the effect was evident for the Creativity Index but not on its sub-scales singularly taken. As the author claim, "*This finding represents the first direct evidence for a functional role of alpha oscillations in creative ideation*".

4. The Experiment

4.1 Experimental Paradigm and Features

4.1.1 Sample Size

To define the *sample size*, starting from the previous studies was fundamental to understand how to structure this variable. The sample size is one of the main reasons that could affect the statistical power of the study. This reason is strenghten both by the precedent studies and by the Laspia's thesis. The formers because almost all the studies used a relatively high number of participants, the latter because using a small number there were no results. Of course, it is not the only reason why there were no results, but it could be a very important lack.

The analyzed studies show a number of participants as shown in the figure 16, where the x-axis is the grouping of the numbers of participants in four ranges and the y-axis is the number of papers with the number of participants in that

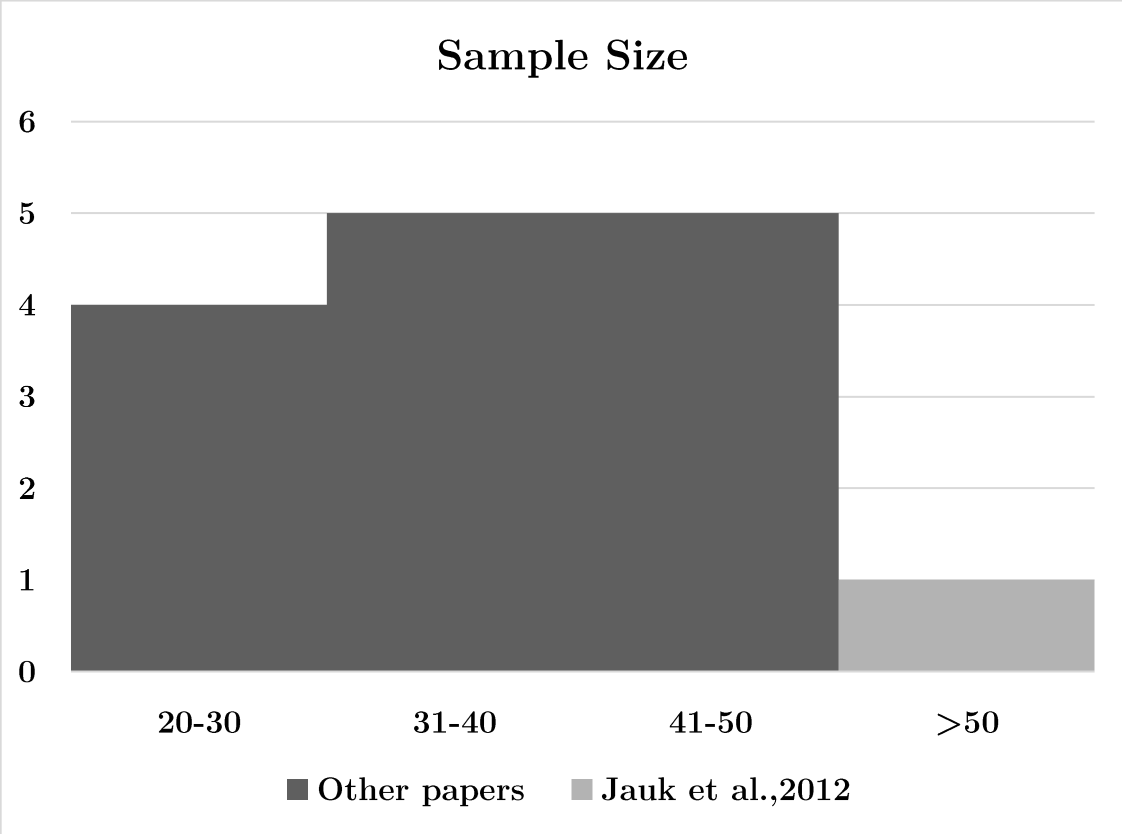


Figure 16 - Sample sizes

range. The numbers are clearly superior to A. Laspia's thesis, where there were fourteen participants. Most of the papers have between 30 and 50 participants, in particular Jauk, Benedeck and Neubauer (2012) is the only one with more than 50 (they had 55 participants). The average, the mode and standard deviation are respectively 39, 45, 11.

To be sure about the necessary hypotheses for a robust statistical inference, it is important to have a high sample size (at least 30 participants), in order to assume the sample statistical distribution as normal. In addition, having a high number of participants allows to obtain more data and then the possibility to make further detailed analyses (e. g. dividing the sample in different subgroups: high vs low creative, older vs younger, etc.). The only disadvantage is that the time for data recording and analysis will increase. Given these issues and evaluating participants' disposability, it was necessary to recruit a sample between 30 and 40 subjects, obtaining 40 participants.

4.1.1.1 Gender Differences

It is an open point from the previous studies to understand if there are any significant differences in cognitive performance in task related to divergent thinking related to the choice of the gender of the participants. Some of them found gender effects, such as Razumnikova (2004), who found a higher topographic expansion of lower alpha desynchronization in creative women as compared to men during the performance *snake-problem*. The author interprets this finding in terms of different patterns of hemispheric organization in females and males (Jauk, 2011). In the study by Fink and Neubauer (2006), differential effects of sex were also found in interaction with the examined hemisphere and topographic area, suggesting that males displayed higher task-related power in the alpha band in posterior regions of the right hemisphere during creative ideation. Furthermore, an interaction was found in the reference period in the way that females displayed stronger alpha power in posterior right-hemispheric regions, suggesting that gender differences were not induced by the experimental task but reflect a rather habitual phenomenon (Jauk, 2011).

It is important to say that Razumnikova (2004) used a particular task that is not used so much in literature and significantly different from the AUT and it could be a very strong assumption to say that those results could be the same in a different task. Indeed, in several other studies the variable of gender is judged as unimportant variable and the sample is a mix of females and males.

This ambiguity of the previous studies points to the necessity of either (a) statistical control of gender differences or (b) the limitation of the sample to one gender (Jauk, 2011). For the present study, both options were chosen in order to avoid loss of statistical power due with just a small sample size and to have enough participants of one gender (male), to make the experimental design more robust: it was decided to have about forty participants with a bigger number of males (about thirty) and the others females to have the possibilities to investigate the gender differences too. As result, it was obtained forty participants, twenty-height males and twelve females.

4.1.2 Number of Electrodes

The *number of electrodes* is another important variable because of the spatial resolution and the output data are strictly relate to this variable. The analyzed studies show also a number of electrodes clearly superior to A.Laspia's thesis (9). The most used number of electrodes is indeed 33. The lowest number of electrodes we found in our review is 16, that is anyway almost the double of those used by Laspia. A higher number of electrodes is necessary for two main reasons: (i) it allows a better quality of the data and thus a better signal-to-noise ratio; (ii) it certainly allows a better spatial resolution.

Furthermore, a number of electrodes that approaches the most used ones in literatrure (e.g. 33) better allows a direct comparison between our study and the previous ones. Finally, in order to run the ICA algorithm, the thumb rule we found in litreraturе is to have the biggest number of electrodes possible, anyway at least 20. The *average* of the number of electrodes is 28 electrodes (excluding the Camarda's research because it represents an outlier with 256 electrodes, thus it changes the average to 42), the mode is 33 electrodes and the standard deviation is 12 (also here Camarda's study was excluded, it changes the standard deviation to 58). For the present study, it was necessary to adapt all these consideration with the instruments availability and the standards of the tools, thus the coiche was to use 32 electrodes on the head and 1 electrode as reference, for a total of 33 electrodes.

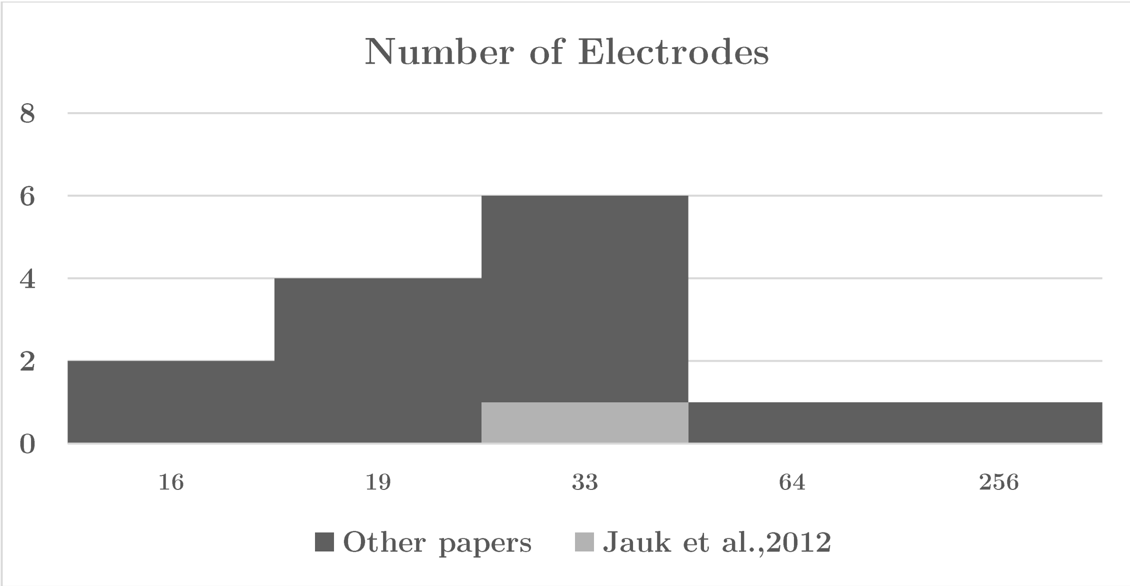


Figure 17 - Number of Electrodes

4.1.2.1 Reference Electrode

Usually in EEG study there are some different places for the reference (mastoid, nose, vertex,…). In the previous AUT papers, most of them set it on the nose. The tip of the nose is clearly free from brain electrical signals and is cosidered as one of the most muscolar artifacts free location. In the Laspia's thesis it was set on the mastoids, due to the constrains of the EEG cap used. It is interesting to note that the ear lobes reference was used by Razumnikova's and Jausovec's experiments, i. e. those who did not find alpha power in DTT. The result of this consideration is to adopt the reference on the nose, for the present work.

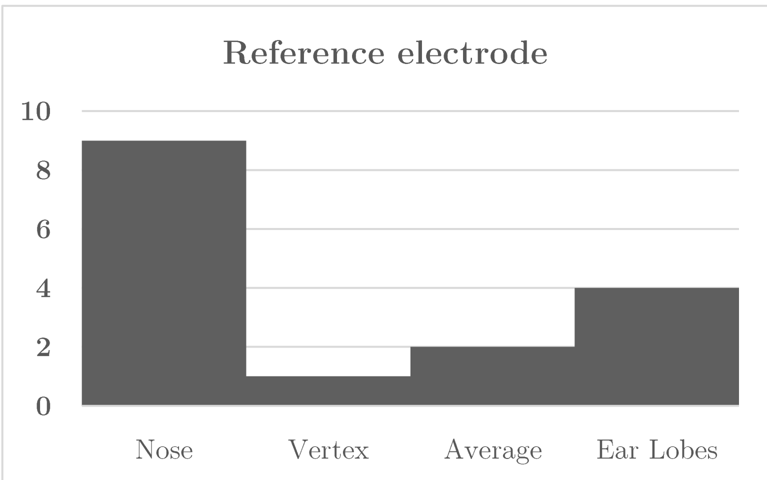


Figure 18 - Positions of Reference Electrodes

4.1.2.2 Impedance

The neuroscientific studies require to keep electrodes impedences below 5 kOhm, as a golden standard. In Laspia's thesis they were kept below 40 kOhm without any specifications and it could have affected the quality of data and then probably the results. Of course the lower the impedance, the better the signal. In the present study to be in line with the most of the literature in this research branch, the impedance was kept below 5 kOhm.

4.1.2.3 EOG

The EOG electrodes were not used in the present work. It is due to: (i) the apposite device was not available for the research with the used EEG device; (ii) EOG would not bring substantially more information about blinking than running the *Independent Component Analysis* (ICA) to the signals recorded by the scalp electrodes.

4.2 Materials and Methods

4.2.1 Participants

In this study, we recruited 40 healthy volunteers. All the participants were students at the Lulea Technology University (Sweden), attending different courses. The sample is composed of 28 males and 12 females from different nationalities. All the participants had no declared neurological disorder. Some of them had visual deficits and wore glasses or contact lenses. Before the experiment, all the participants were informed about the intents and the risks of the study and signed a consent form. At the end of the experiment, all the participants have been rewarded with some gadget from the LTU Shop.

4.2.2 Experimental Design

The design of the experiment is based on a single task, divided into two conditions. The task is a revised adaptation of the Alternative Uses Task (AUT) used by Jauk, Benedek and Neubauer (2012). The AUT requires to the subjects to find uncommon uses for everyday objects. The task was performed under two conditions: Common vs Uncommon. In the *uncommon* condition, the subject has to find a highly uncommon/original use for the presented object. In the *common* condition, the subject has to find a highly common use for the presented object. For example, if the object is "glasses", a common way of using it could be "to read better" and an uncommon way of using it could be "to start a fire".

4.2.3 The Task - Alternative Uses Task (AUT)

The task is the Alternative Uses Task (AUT), the same as Laspia, Montagna and Torlind (2018) and Jauk, Benedek and Neubauer, (2012). The AUT is, in creativity literature, the most used task for the evaluation of divergent thinking. It has been created by Joy Paul Guilford (1967) and has been for the first time used in an EEG study by Martindale and Hines in 1975. Since, it has been variously used, adjusted and interpreted. In literature, its validity in assessing creativity/divergent thinking is recognized to be good and satisfactory, and its reliability has been proven to be strong.

The AUT consists in asking the subject to find uncommon/unusual uses for everyday objects. Typically, the subjects' responses are evaluated in terms of fluency (number of ideas), flexibility (number of different categories of ideas) and novelty (originality of ideas). The aforementioned studies – and many others – only assessed "novelty" (i.e. Originality) as behavioral dependent variable, together with neurophysiological measurements. Furthermore, they adjusted the task by adding the “common” condition against the “uncommon” condition as independent variable, in order to distinguish and assess convergent and divergent thinking, respectively. In both these studies, they administered a total of 20 items, randomized across the two conditions (Common vs Uncommon). The presentation of the two conditions was randomized too, so that each item was preceded by the “common” or “uncommon” instruction. Thus, the two conditions were not separated into two different blocks.

Starting from these studies, we adjusted this task as follows: a total of 40 different items were randomly assigned to the condition “common” or “uncommon” (20 items per condition). Each condition consists in a block of 20 consecutive trials, where the subject has to find common or uncommon uses for a certain item/object. Each subject undergoes both the conditions. The order of appearance of the two blocks/conditions was counterbalanced across subjects. Subjects were randomly assigned to the group that starts with the common or uncommon block/condition.

4.2.4 Procedure

The task is divided in two blocks, one for the “common” condition and one for “uncommon” condition. Each block consists of 20 trials, for a total of 40 trials. At the beginning of the first block some slides are presented to explain if the block is “common” or “uncommon”: the first slide just says: “Block 1”, for 5 seconds; the second slide shows the instructions for the subject to continue and when he is ready to start he has to press the space bar. After the space bar is pressed the third slide is shown for 10 seconds on the screen. It only shows the instruction “common” or “uncommon”. Then the trial sequence starts (figure 19).

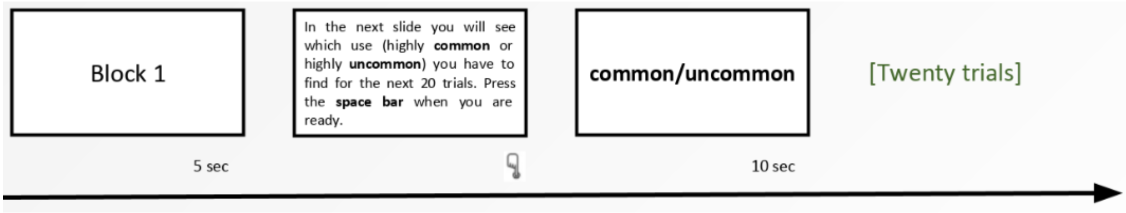


Figure 19 - Start of the experiment with Block 1

The trial starts with a blank screen displayed for 5 seconds, and Its aim is to separate the trial from the previous one, representing the inter trial interval. A fixation cross is then presented in the center of the screen for another 5 seconds, representing the reference period. Subsequently, the stimulus/word appears in the center of the screen for 500 milliseconds. Then, a fixation cross – identical to the reference period one - again appears in the center of the screen for a maximum of

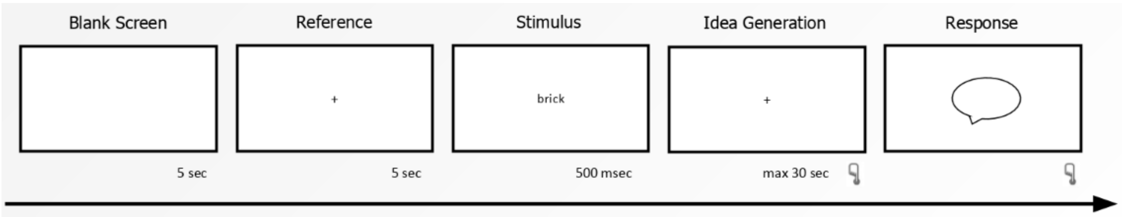


Figure 20 - Task trial session

30 seconds, representing the idea generation period. The subject is instructed to press the spacebar as soon as he wants to vocalize his idea. After the subject presses the spacebar, a speech balloon appears on the screen, indicating that the idea can be vocalized. The subject then presses the spacebar again, and next trial starts (Figure 20).

After the first block ends, with the last trial, a 5 seconds slide informs the subject that the block has ended. Then a 2-minutes pause allows the subject to rest and reset the mind from the previous “common”/ “uncommon” instruction. Next, an acoustic signal is presented 3 seconds before the block 2 starts, in order to capture subject’s attention. The acoustic signal is followed by a 3-seconds count-down from 3 to 0 (Fig.). Then a slide saying “Block 2” is presented for 5 seconds, followed by the slide with the instructions for the next block. When the subject is ready, he presses the spacebar and the next slide - “common” or “uncommon” - appears for 10 seconds. Then the task continues with the next 20 trials (figure 21).

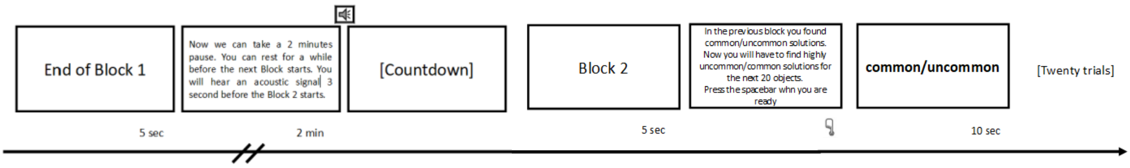


Figure 21 - Inter-block pause of two minutes and start of block 2

Note that if the first block was, for example, the “common” one, at the beginning of the second block the subject already knows that the second block will be the “uncommon” one (and vice versa). This was said to the subject both in the instructions before the experiment and also before the beginning of the second block.

In addition, in order to investigate possible global activity changes in brain oscillations due to a prolonged divergent (uncommon) or convergent (common) mindset, additional longer reference periods were added. Each of them was represented by a 30 seconds slide in which the subject is instructed to gaze at a black cross in the middle of the screen. The reference periods were 3: the first was presented immediately before the beginning of the first block; the second one was presented immediately after the end of the first block; the third was presented immediately after the end of the second block.

At the end of the experiment, the subjects were presented with two brief questionnaires, in order to collect additional qualitative data. The first questionnaire consisted of an open-ended question, written on the screen as follows:

“*What are the mental strategies that you adopted while thinking on the uncommon uses that you found for the objects? Try to explain it in a minute, keeping in mind that there is no correct answer and feel free to say whatever you want.*”

The subjcts answered vocally and their answers were transcribed by the experimenters.

The second questionnaire consisted of six brief multiple choice questions, and they were administered via an apposite doodle which collected the answers. The six questions were the following:

1. *Did you feel stressed in answering?*

   [Answer on a Likert scale ranging from 1 ”very relaxed” to 5 ”very stressed”]
2. *If you had more time (e.g. 1 minute or more), do you think your answers would be more creative?*

   [Answers: YES; NO; OTHER]
3. *Before finding an uncommon use, did you first think about the common uses of the objects?* [Answers: YES; NO; OTHER]
4. *Was it the first time you thought about these solutions?*

   [Answers: YES; NO, I had already thought about all of them; OTHER]
5. *If yes, in which percentage?*

   [Answers: 0-20; 21-40; 41-60; 61-80; 80-100]
6. *Did you answer with the first uncommon use that popped up in your mind?*

   [Answers: YES (0%-20%); YES (21%-40%); YES (41%-60%); YES (61%-80%); YES (81%-100%), NO, I found other solutions for all the objects]

4.2.5 Items

The total of the items was 40, with 20 items per condition. The items were randomly assigned to the common or uncommon condition by the software (iMotions 7.2) and could never be repeated nor within nor between the conditions. Thus, each one of the 40 items could appear only once during the experiment, and only in one of the two blocks/conditions.

Within the 40 chosen items, 18 items were taken from Jauk, Benedek and Neubauer (2012) and Benedek, Schickel, Jauk, Fink and Neubauer (2014), 2 items were taken from Schwab, Benedek, Papousek, Weissand and Fink (2014), 1 item was taken from Fink, Grabner, Benedek and Neubauer (2006), 4 items were taken from Vartanian, Martindale and Matthews (2009), 2 items were taken from Fink, Graif and Neubauer (209) and 2 items were taken from Gilhooly, Fioratou, Anthony and Winn (2007) [Appendix]. The resting 11 items were subjectively selected by us based on common agreement among all the staff. These items are: net, sponge, needle, scissors, comb, mirror, fork, paperclip, guitar, coin, bra.

The original version of the experiment by Jauk et al. (2012) was conducted in Austria, so that the mother tongue of the participants was German, and the items were presented in German. The maintaining of the mother tongue of the participants in the presentation of the items is crucial if we want to avoid any intervenient effect due to translation. Thus, we translated all the items in the mother tongues of all the participants. The total of the languages across the participants was 8, including Swedish, English, Italian, French, Spanish, Portuguese, German and Romanian. Translations of all the items are available in the appendix.

Vase	**Can**	**Basket**	**Bed**	**Book**	**Ball**	**Pot**	**Ring**
Helmet	**Tent**	**Rag**	**Axe**	**Tyre**	**Trousers**	**Bread**	**Stick**
Coffin	**Magnifier**	**Net***	**Colander**	**Shoe**	**Toothpaste**	**Pillow**	**Hammer**
Window	**Umbrella**	**Sock**	**Hanger**	**Gun**	**Sponge***	**Lamp**	**Needle***
Scissors*	**Comb***	**Mirror***	**Fork***	**Paperclip***	**Guitar***	**Coin***	**Bra***

Figure 22 - Items

4.3 Apparatus and Instruments

4.3.1 EEG

The Electroencephalogram (EEG) device used is the BrainVision ActiCHamp (developed by BrainProducts GmbH, Germany) with a 32 electrodes splitter box connected to the ActiCap. We applied 31 electrodes on the scalp according to the International 10-20 system (figure 23, green locations). One electrode was placed on the tip of the nose and served as the reference electrode. The ground electrode was placed on the forehead, in Fpz position. No EOG electrodes were used. All the electrodes impedances were kept below the 5 kΩ, with the exception of three subjects, whose impedances were anyway below the 12 kΩ and had a maximum variation range of 5 kΩ. All the recordings were sampled at a 500 Hz frequency, and no online filter was used.

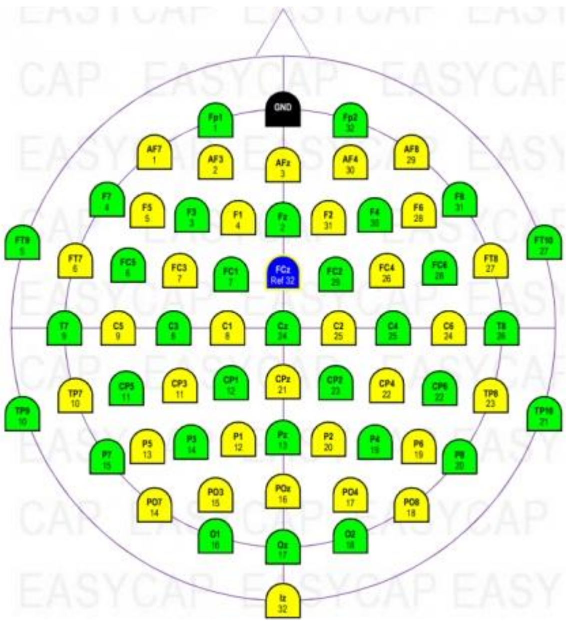


Figure 23 - Electrode Positions

Note that the ActiCap conformation allows to freely move the electrodes among the various plugs in the cap. So, we used the electrode originally designed for Cz as reference, and put it on the tip of the nose, leaving the Cz position electrode-free. Furthermore, in the default configuration of the ActiCap, as shown in Fig, FCz is indicated as the reference electrode location. We simply ignored that location, that must be considered electrode-free as well.

4.3.2 Eye-Tracker

The device used for ocular data acquisition is a Tobii X2-30 Eye Tracker Compact Edition (Tobii). It can record ocular screen-based data about gaze direction, saccades, fixations and blinking at a sampling frequency of 30 Hz. The device was installed just above the screen, on its lower border, and required the subject to be at a 60 cm distance from the screen, which is the distance to which the subjects were placed. Some of the subjects wore contact lenses or glasses: these could affect the eye tracker calibration in about the half of the times.

4.3.3 Cameras

We employed two Logitech c920 cameras by Logitech, both having a 30 Hz sampling rate. The first camera was placed on the upper side of the screen, being the one recording subjects' face and expressions, while the second one was placed on the right side of the subject, being the environment camera, which recordings were used to control eventual excessive body movements by the subjects, that could affect other sensors data.

4.3.4 Software

The software used for data recording was iMotions 7.2 (the latest version at the date). It was chosen mainly because of it is able to record data from many different sensors at the same time. Moreover, iMotions can be used, while recording, to administer the task, so that it can synchronize the acquired data with the administration of the task. In fact, it allowed an easy synchronization of many sensors (EEG, Eye-tracker, cameras), in order to collect a various amount of data. It was very important for us to synchronize the EEG data with the video recorded by the cameras, in order to improve the artifact inspections at best. iMotions also provided an easy implementation of the stimuli sequence and their automatic randomization across and within the blocks. With regard to the EEG recording, iMotions automatically splits the entire EEG time course in subsequent epochs, based on the slide changing on the screen: its precision is guaranteed by the use of a photodiode. Another useful feature is also that it allows to export data in .txt files, so it is easy to convert them in any other type and directly imported in MATLAB for the analysis.

Conclusions

The neuroscientific approach to design process is growing in interest in last years, as a complementary tool to the traditional protocol analysis, in the science of design. Despite the research is going in this direction, this research branch is still in an embryonic phase. Thus, there are not enough studies to define the real potential and limits of the research in the indicated field. The basis of the increasing use of the neurophysiological devices is due to their possibility to empower the set of research questions, allowing to obtain unbiased results without the subjective components of the researchers and subjects. In line with the previous observations, the ambition of the present work is to identify cognitive and physiological activities related to design process with the support of EEG and eye tracker.

The choices of the instrument and design paradigm for this project are made in order to validate and reinforce the results of the previous studies. The attempt of the replication of the Jauk, Benedeck and Neubauer (2012) experiment was adjusted with the resources and capabilities of the research groups. The multidisciplinary environment required to analyze literature in different fields of research, such as neuroscience, design and signal analysis and processing. A rigorous methodology was defined according with the literature, in particular the previous studies related to detect cognitive creative processes. The design of the experiment is a single task, divided in two conditions: the alternative uses task in the common and uncommon conditions. The procedure is the main difference from Jauk, Benedeck and Neubauer (2012) with the distinction of the two conditions in two blocks of stimuli, one for the common and one for the uncommon. The order of the two blocks is randomized in order to avoid any bias due to the participants' mind set. After the presentation of the first block, as common or uncommon, twenty trials started in that condition. Each trial is presented as a series of five slides: (i) a blank screen for five seconds, (ii) a reference cross in the middle of the screen for five seconds, (iii) the stimulus for half a second, (iv) a reference cross again for a maximum of thirty seconds, as the idea generation period, and (v) a speech balloon to vocalize the solution. Subsequently to the first twenty trials, a two-minutes pause is taken and then the second block starts. To collect more behavioral data, at the end of the experimental session a brief questionnaire is administered. The procedure is supported by the EEG and eye tracker devices. In relation to the Jauk, Benedeck and Neubauer (2012), they used twenty items, for the present study twenty more items were selected. For the selection, first all the other papers with alternative uses task were analyzed, but only few of them presented some examples of the used items. For this reason, some of the items were selected to complete the necessary with a semantic approach.

Some details of the method used in the present study are different from the previous paradigms, but they were validated for the neurophysiological aspect with the support of the neuroscience department of University of Turin and for the signal analysis with the support of the biomedical engineering department of the Polytechnic of Turin.

For the large amount of work the present work does not include the data analysis. The results will be focused on the frequency bands analysis. The algorithm to analyze the data is being processed because of some discrepancies between the neuropsychological literature and the biomedical engineering approach. In order to define a correct solution for both aspects it was necessary to take more time than expected. Regardless this, the results anticipated are high brain activities in the right parieto-occipital area, during the most creative idea generation, generally related to the uncommon condition. It could be possible to define any significant differences between the high creative and low creative people.

For further study, it is important to highlight the problem that could be related to the alternative uses task in a design process: because of its features, the task could lead the participant to high memory retrieval, trying to remember uncommon situation where they used those objects. One hint to avoid, or reduce, this problem could be the modification of the task presenting the objects in pairs, asking to define useful solutions to use them together in an uncommon way. Another import issue that could be modify is the “laboratory” condition: the EEG is one of the less invasive neuroimaging techniques, but the task and the long set up process could make the participants stressed. As it is known, the stress can make distortions in the results, for this reason the experiment was presented as a creative test, to highlight the recreational part of the activity.

The present study, even if it has the important limitation to not have the results of the data analysis, improve to the neurophysiological design research branch through to provide a framework and a solid structure to the research questions related and useful insights to achieve further experiments.

Appendix

The present section has the aim to report many details about the present study to show the whole work done. In the present appendix further materials are reported regarding the participants and the experiment in detail.

A.1 Participants

Forty participants took part to the study, as volunteers. In the sample, all the participants were students at Luleå Technology University and they were 11 females and 29 males, with a heterogeneous background in Engineering and belonging to heterogenous years of their course 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, with the support of mother tongue people, in order not to involve the translation cognitive process in the analysis.

Subjects	Gender	Age	Nationality	Mother Tongue	Corse of study	Year of Study	Handed ness	Poor Eyesight	Neurological Disorder
Subject 1	FEMALE	23	Italian	Italian	Materials Engineering	5th	RIGHT	NO	NO
Subject 2	MALE	25	Italian	Italian	Automation Engineering	5th	RIGHT	NO	NO
Subject 3	MALE	23	Italian	Italian	Material Science	5th	RIGHT	GLASSES	NO
Subject 4	MALE	23	Swedish	Swedish	Civil Technical Design	1st	RIGHT	NO	NO
Subject 5	MALE	26	Syrian	English	Advance Materials Engineering	4th	RIGHT	GLASSES	NO
Subject 6	MALE	20	Swedish	Swedish	Physics and Electrical Engineering	1st	RIGHT	NO	NO
Subject 7	MALE	23	Portuguese	Portuguese	Maintenance Engineering	4th	RIGHT	GLASSES	NO
Subject 8	FEMALE	21	German	German	Business Engineering	4th	RIGHT	GLASSES	NO
Subject 9	MALE	24	Italian	Italian	Materials Engineering	5th	RIGHT	GLASSES	NO
Subject 10	MALE	24	Swedish	Swedish	Industrial Design Engineering	4th	RIGHT	GLASSES	NO
Subject 11	MALE	27	Swedish	Swedish	Industrial Design Engineering	3rd	RIGHT	LENS	NO
Subject 12	FEMALE	23	Swedish	Swedish	Industrial Design Engineering	3rd	RIGHT	LENS	NO
Subject 13	FEMALE	21	French	French	Mechanical Engineering	4th	RIGHT	GLASSES	NO
Subject 14	MALE	24	Swedish	Swedish	Industrial economy engineering	3rd	RIGHT	NO	NO
Subject 15	MALE	20	Swedish	Swedish	Engineering Physics	2nd	LEFT	NO	NO
Subject 16	MALE	28	Swedish	Swedish	Technical Design	3rd	RIGHT	NO	NO
Subject 17	MALE	26	Brazilian	Portuguese	Material Science and Engineering	4th	RIGHT	NO	NO
Subject 18	FEMALE	26	Spanish	Spanish	Advance Materials Engineering	4th	RIGHT	NO	NO
Subject 19	MALE	24	Austrian	German	Chemistry Engineering	5th	RIGHT	NO	NO
Subject 20	MALE	24	German	German	Material Engineering	4th	RIGHT	NO	NO
Subject 21	MALE	22	Spanish	Spanish	Mechanical Engineering	4th	RIGHT	LENS	NO
Subject 22	MALE	20	Swedish	Swedish	Computer Science	1st	RIGHT	NO	NO
Subject 23	MALE	25	German	German	Mechanical Engineering	5th	RIGHT	GLASSES	NO
Subject 24	FEMALE	19	Swedish	Swedish	Civil Architecture	1st	RIGHT	LENS	NO
Subject 25	MALE	25	Swedish	Swedish	Industrial Design Engineering	3rd	RIGHT	GLASSES	NO
Subject 26	MALE	23	Swedish	Swedish	Industrial Design Engineering	3rd	RIGHT	NO	NO
Subject 27	MALE	23	Swedish	Swedish	Industrial Design Engineering	3rd	RIGHT	GLASSES	NO
Subject 28	MALE	21	French	French	Computer Science	4th	RIGHT	NO	NO
Subject 29	FEMALE	27	Swedish	Swedish	Industrial Engineering	5th	RIGHT	NO	NO
Subject 30	MALE	22	Swedish	Swedish	Mechanical Engineering	2nd	RIGHT	NO	NO
Subject 31	FEMALE	23	Swedish	Swedish	Technical Design	4th	RIGHT	LENS	NO
Subject 32	FEMALE	21	Swedish	Swedish	Industrial Design Engineering	3rd	RIGHT	NO	NO
Subject 33	MALE	27	Swedish	Swedish	Industrial Design Engineering	4th	RIGHT	GLASSES	NO
Subject 34	MALE	21	Swedish	Swedish	Technical Design	3rd	RIGHT	GLASSES	NO
Subject 35	MALE	32	Swedish	Swedish	Technical Design	4th	RIGHT	NO	NO
Subject 36	FEMALE	31	Swedish	Swedish	Industrial Design Engineering	5th	RIGHT	GLASSES	NO
Subject 37	MALE	22	Swedish	Swedish	Technical Design	3rd	LEFT	GLASSES	NO
Subject 38	FEMALE	19	Romanian	Romanian	Computer Science	2nd	LEFT	GLASSES	NO
Subject 39	MALE	25	Spanish	Spanish	Mechanical Engineering	5th	RIGHT	NO	NO
Subject 40	MALE	22	French	French	Material Science	5th	RIGHT	NO	NO

Figure 24 - Subjects' data

A.1.1 Some Numbers about Participants

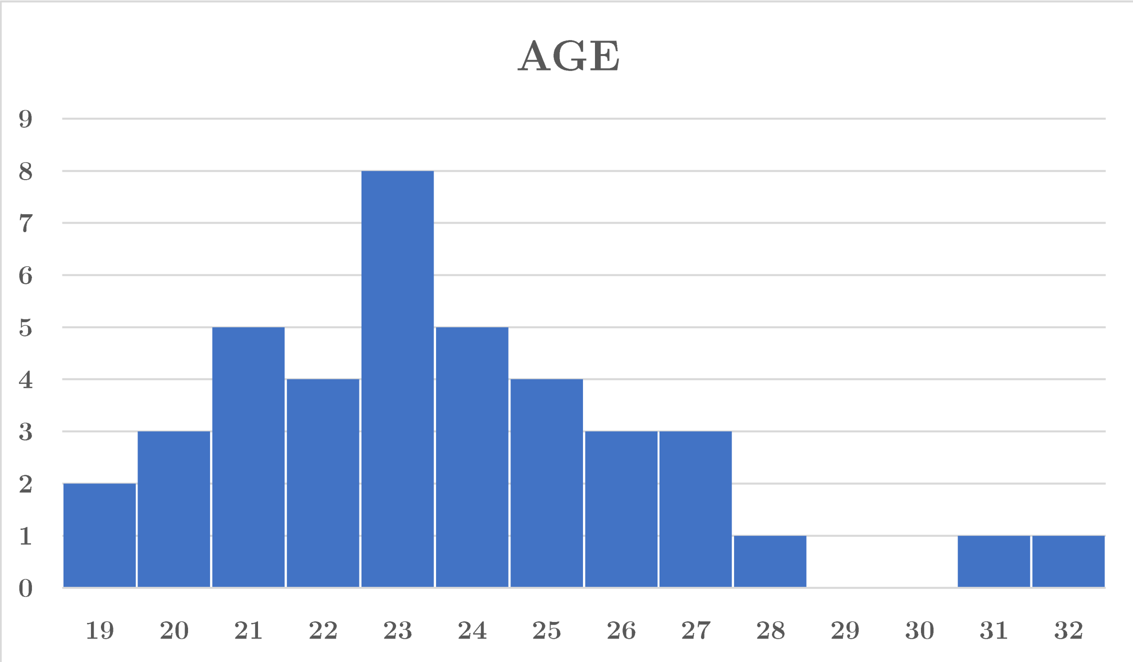


Figure 25 - Subjects' Age

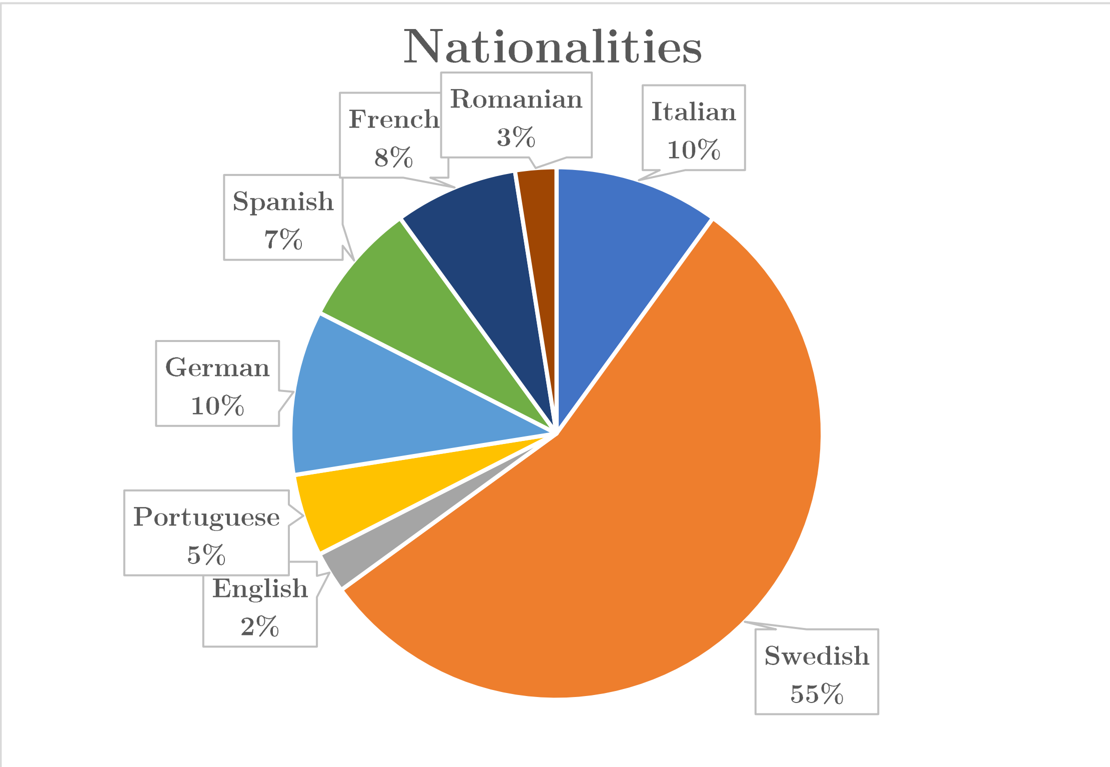


Figure 26 - Subjects' mother tongue

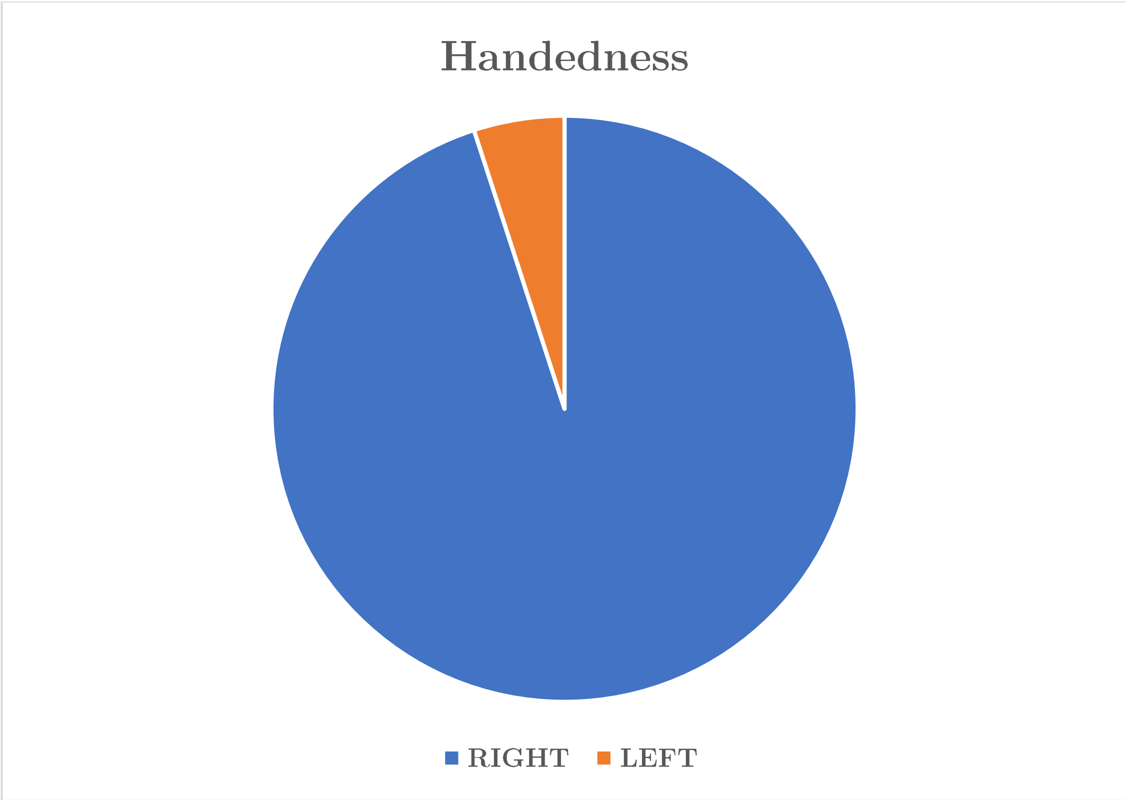


Figure 27 - Subjects' Handedness

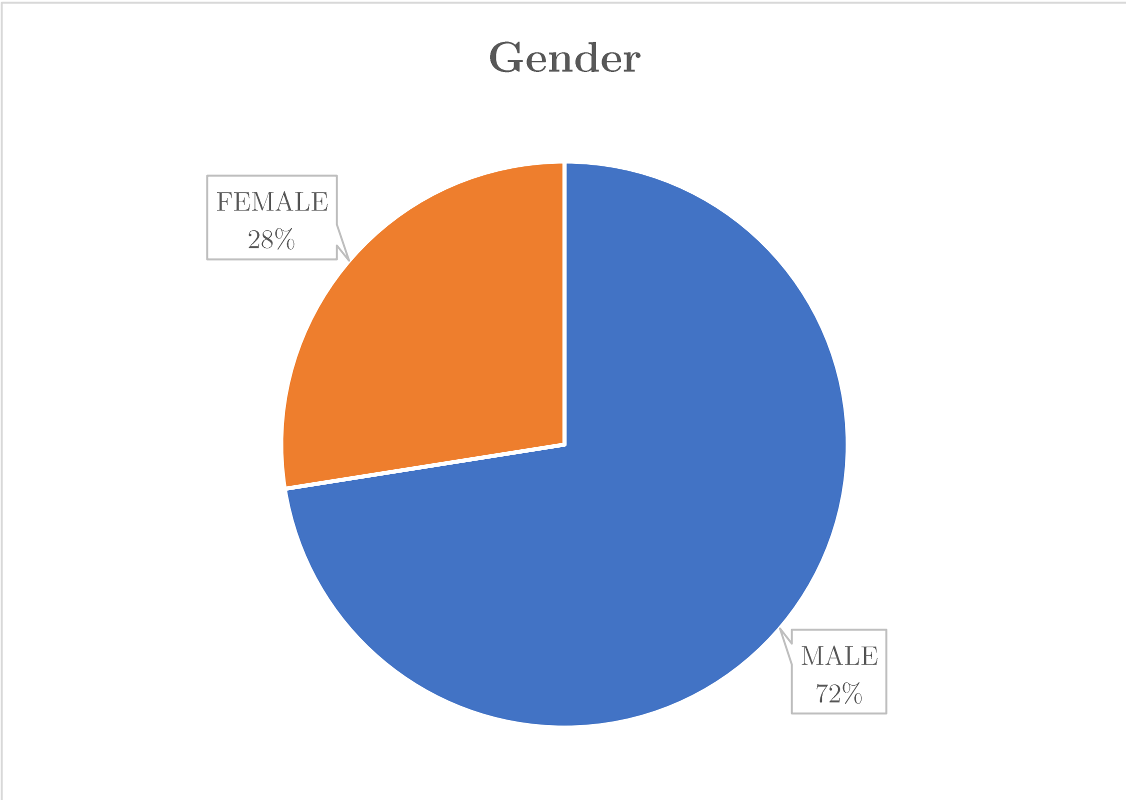


Figure 28 - Subjects' Gender

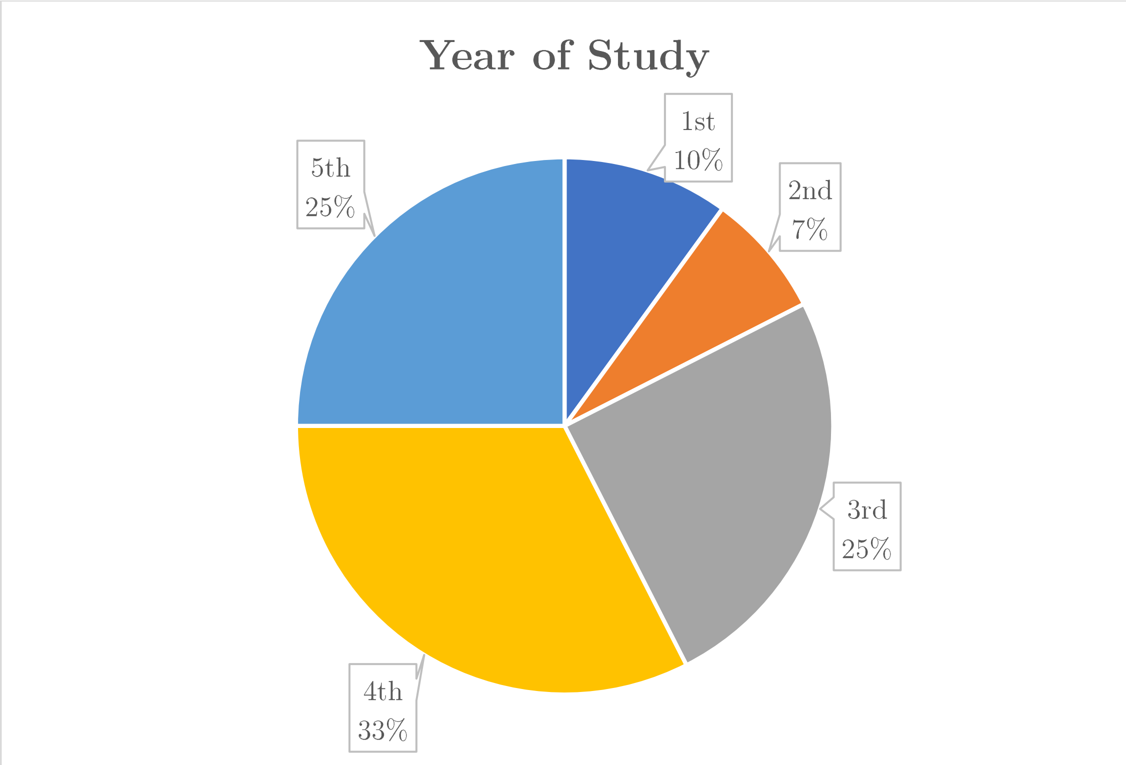


Figure 29 - Subjects' Year of Study (University)

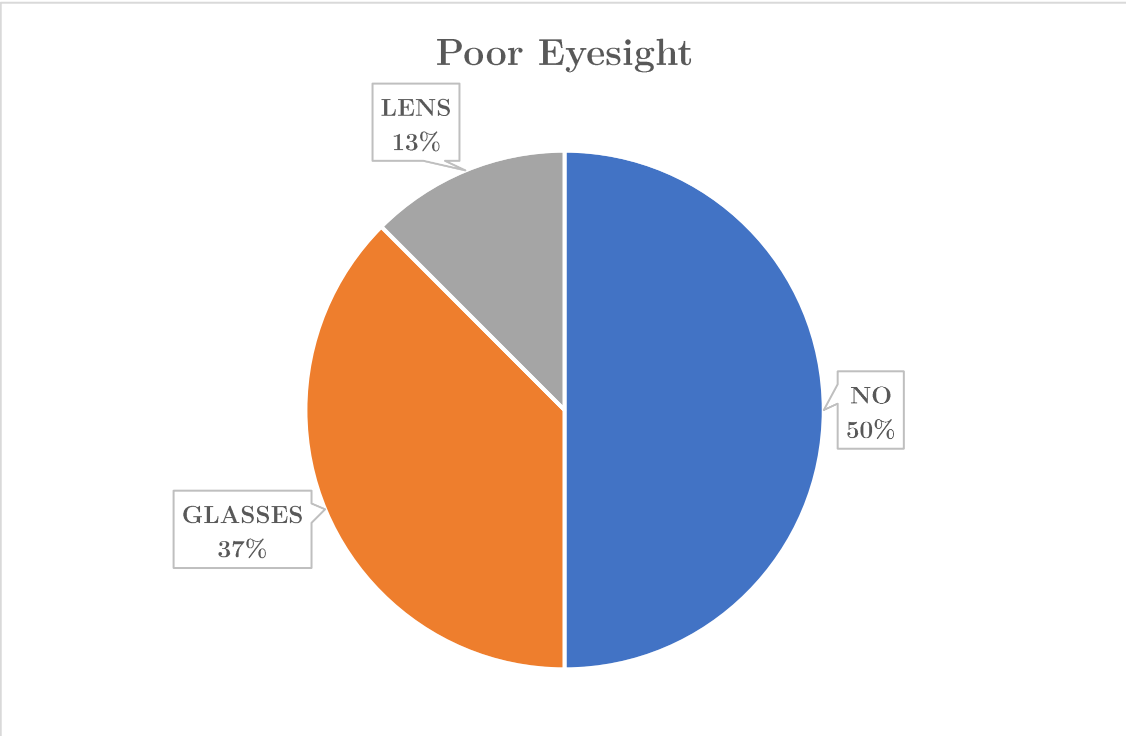


Figure 30 - Subjects' Poor Eyesight

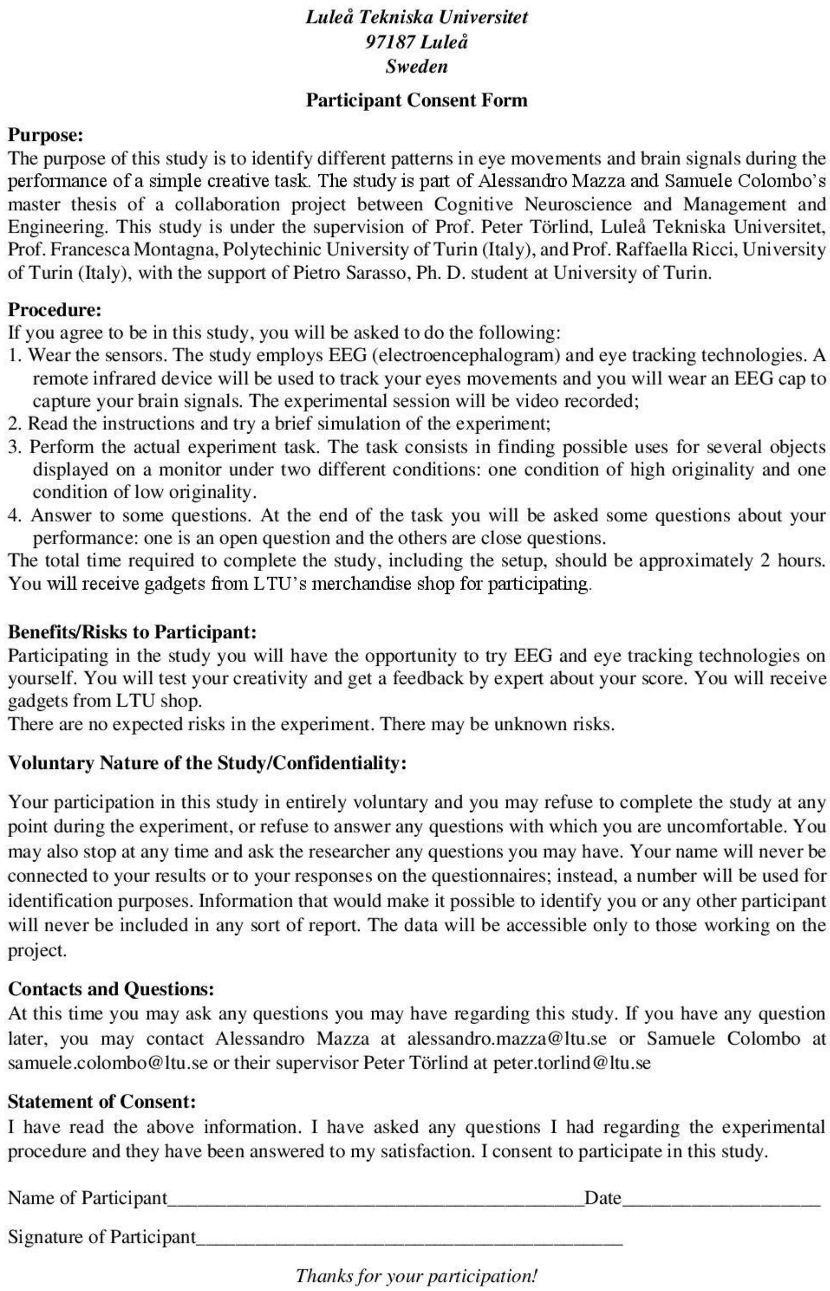
A.2 Recruiting Volunteers

For the recruitment of the participants, the professors' support was fundamental, allowing to present the project to their students during their lessons. In particular, the Professor Peter Törlind gave some incentives to his students to participate. In addition, we structured the following flyer. It was made with the intent to recruit more people, presenting the test as a game to win over the students. Indeed, after the originality assessment that will be done by external raters the most original participant will get an extra-prize.

Figure 31 - Flyer to recruit subjects

A.3 Consent Form (GDRP)

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 Mazza and Samuele Colombo's master thesis of a collaboration project between Cognitive Neuroscience and Management and Engineering. This study is under the supervision of Prof. Peter Törlind, Luleå Tekniska Universitet, Prof. Francesca Montagna, Polytechinic University of Turin (Italy), and Prof. Raffaella Ricci, University of Turin (Italy), with the support of Pietro Sarasso, Ph. D. student at University of Turin.

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 you will wear an EEG cap to capture your brain signals. The experimental session will be video recorded;
2. Read the instructions and try a brief simulation of the experiment;
3. Perform the actual experiment 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.
4. Answer to some questions. At the end of the task you will be asked some questions about your performance: one is an open question and the others are close questions.

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

Benefits/Risks to Participant:
Participating in the study you will have the opportunity to try EEG and eye tracking technologies on yourself. You will test your creativity and get a feedback by expert about your score. You will receive 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 in 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 any question later, you may contact Alessandro Mazza at alessandro.mazza@ltu.se or Samuele Colombo at samuele.colombo@ltu.se or their 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__________________

Signature of Participant____________________________________

Thanks for your participation!

Figure 32 - GDRP

A.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 Sterile swabs with alcohol;
    - o Cotton swabs;
    - o Shampoo, towels and hairdryer;
    - o Latex gloves;
    - 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, mother tongue).

- ☐ The experimental stimuli sequence has been prepared in all the mother tongues requested:
  - Randomization has been completed for the size of the sample;
  - .csv file and images have been loaded on iMotions.
- ☐ The coupling and the right configuration between computer and recording devices is tested:
  - EEG;
  - Eye tracking;
  - Cameras.
- ☐ The instructions have been tested:
- ☐ The experimental stimuli sequence has been tested with two external volunteers;
- ☐ EEG amplifier has been charged during the night;
- ☐ Laptop has been charged during the night.

Setup

- ☐ Materials for the experiment have been collected:
  - EEG conductivity gel;
  - Alcohol, latex gloves, napkins, swabs and cotton swabs;
  - Scissors, pins;
  - 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 please do not disturb" 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;
  - Cameras.
- ☐ Subject's head size is measured and the right cap is worn to the subject;
- ☐ Laptop for transcription of the responses is ready.

The Experiment

- ☐ The subject has signed the consent form;
- ☐ The subject has confirmed 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 signed:
  - Nasion-inion distance;
  - Ear-Ear (Crests of Helix) distance.
- ☐ On the forehead and the tip of the nose, where the EEG sensors will be placed, have been wiped down using an alcohol swab;
- ☐ The EEG cap has been placed on the subject's head:
  - The cap is centred;
  - The strap is not resting on the subject's ears;

- The cap is tied;

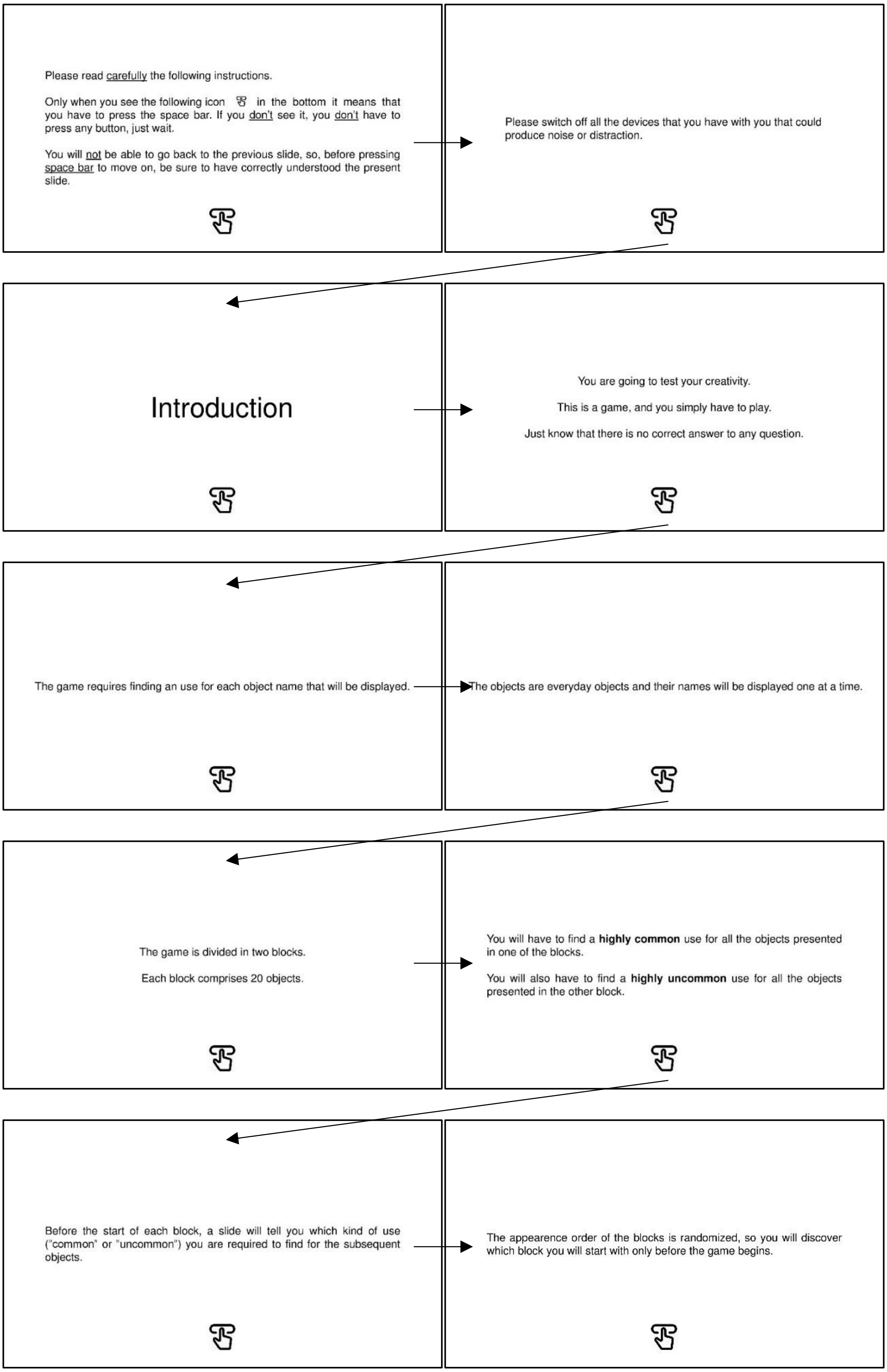
- ◻ Some entrainment videos have been set-up to avoid the subject's boredom;
- ◻ The electrodes holes have been adjusted on the subject's head;
- ◻ The first layer of conductive gel was placed with cotton swabs, with a circle movement to remove as much as possible the hair from the position of the electrodes;
- ◻ Electrodes have been placed in the right positions on the scalp;
- ◻ Reference electrode have been applied to the tip of the nose;
- ◻ The electrodes have been plugged into the amplifier;
- ◻ The participant has been questioned about the comfort:
    - In case of discomfort individual strip arms have been loosened.
- ◻ The impedance has been checked on iMotions software;
- ◻ The electrodes with impedance above 5 kΩ have been adjusted with syringes with flat needles to add more conductive gel;
- ◻ The subject has been positioned at the right distance from the monitor (60 cm);
- ◻ 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;
- ☐ 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);
- ☐ Shampoo, towels and hairdryer has been procured to the subject to wash the head and hair close to the laboratory;
- ☐ Participant has received the gadget and has been thanked.

After the Experiment

- ☐ EEG cap has been cleaned and disinfected;
- ☐ Electrodes has been cleaned and disinfected;
- ☐ Electrodes has been left to dry;
- ☐ 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.5 Instructions Presentation



The two blocks are separated by a 2 minutes pause.

The randomization of the two blocks means that you will have only one of the two following possibilities:

1. if you start with the "common" Block, then the second will be the "uncommon" Block;

2. if you start with the "uncommon" Block, then the second will be the "common" Block.

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

key

If you are in the "**common**" block, then you could think that a highly common way in which you could use a key is "to open a door".

Instead, if you are in the "**uncommon**" block, then you could think that a highly uncommon way in which you could use a key is "as a little saw".

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".

<u>Remember</u>: if you are in the "uncommon" condition you have to think the most original use you can think of.

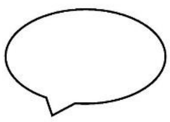
Do not necessarily stop at the first idea that pops up in your mind.

Keep in mind: the word will be displayed in your mother tongue, and it will stay on the screen for half a second.

Don't worry! This is a long enough time for you to read it and keep it in mind.

After the word is displayed, you have 30 seconds to find the common/uncommon use.
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.

If you do not find a translation that satisfies you, you can express your idea in your mother tongue and in the end of the experiment you will explain it to the researchers.

Please note: the idea generation period and the vocalizing period are different phases.

It is very important for us that while you are thinking about your solution, you do not worry about translating it.

After you press the space bar you can take all the time you need to translate and verbalize your idea.

We are not assessing your English, thus for the game it is better a good solution in your mother tongue, than a good translation of a bad solution.

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.

Please avoid even any little movement that could affect 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 cross while you think, but you have to keep your eyes inside the screen's perimeter.

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.

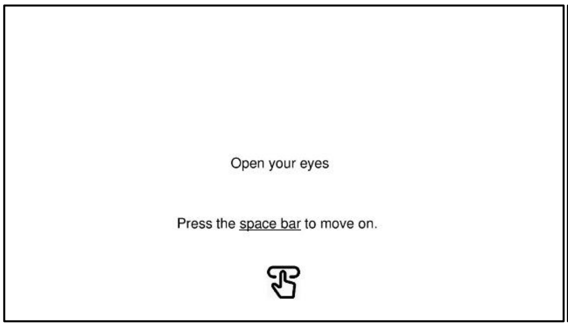
After this slide, a white screen will be displayed.
Please, look at the white screen for one minute until you see the next instruction.

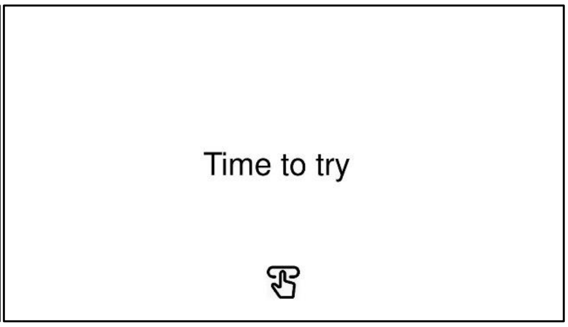
Press the space bar when you are ready

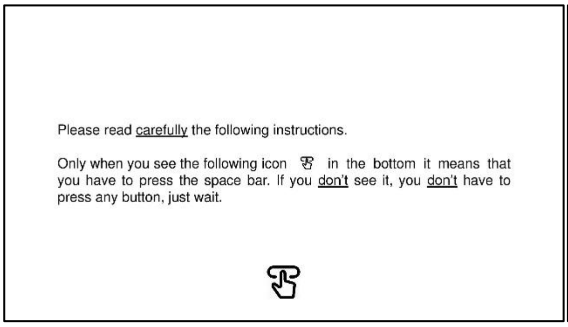
Please, now for one minute you have to stay with closed eyes.
You can open your eyes only when you will hear an acoustic signal.

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

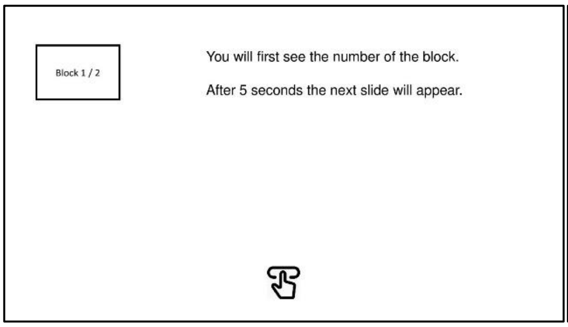
Resting for a minute

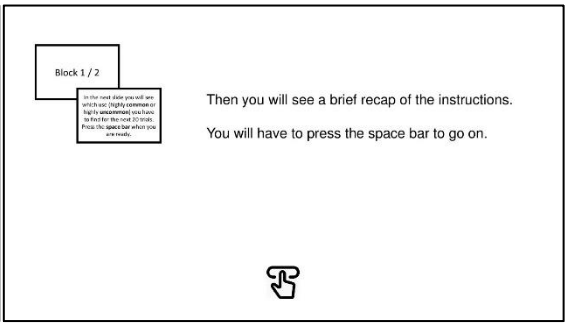

Open your eyes
Press the space bar to move on.

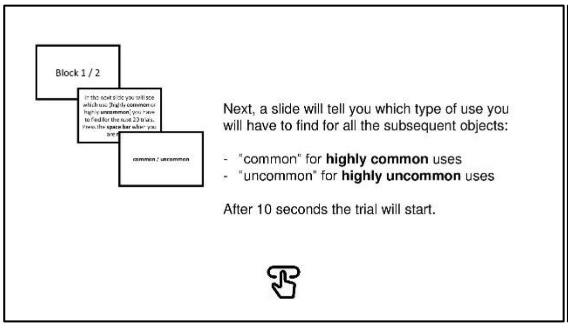

Time to try

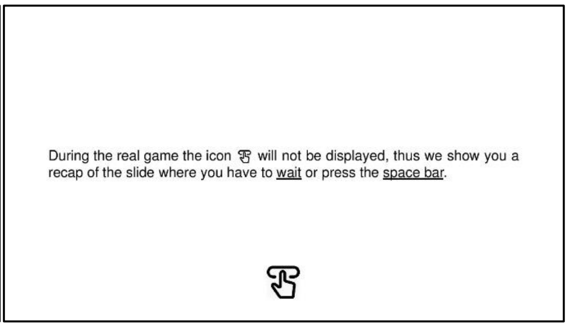

Please read carefully the following instructions.
Only when you see the following icon in the bottom it means that you have to press the space bar. If you don't see it, you don't have to press any button, just wait.

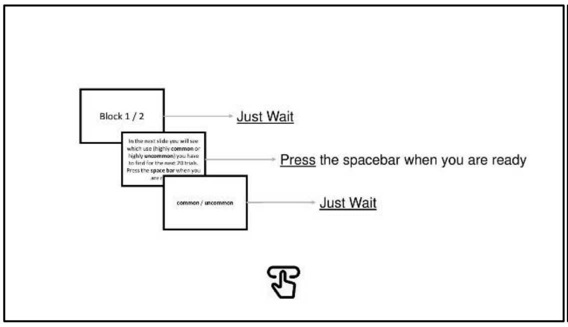

You are going to try how to play.

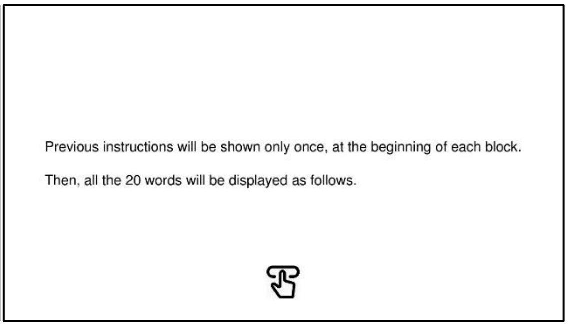

Block 1 / 2
You will first see the number of the block.
After 5 seconds the next slide will appear.

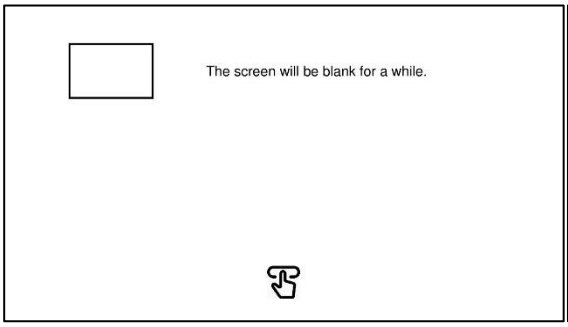

Block 1 / 2
Then you will see a brief recap of the instructions.
You will have to press the space bar to go on.

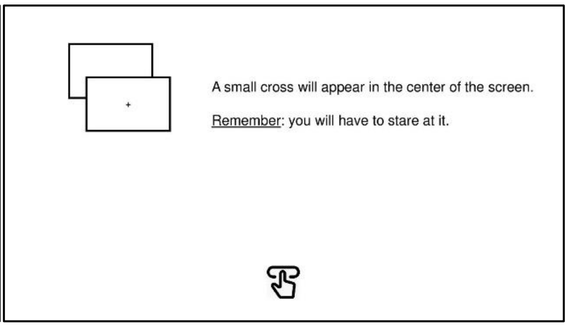

Block 1 / 2
common / uncommon
Next, a slide will tell you which type of use you will have to find for all the subsequent objects:
- "common" for **highly common** uses
- "uncommon" for **highly uncommon** uses
After 10 seconds the trial will start.

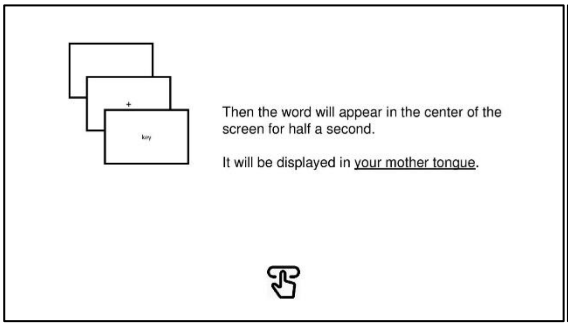

During the real game the icon will not be displayed, thus we show you a recap of the slide where you have to wait or press the space bar.

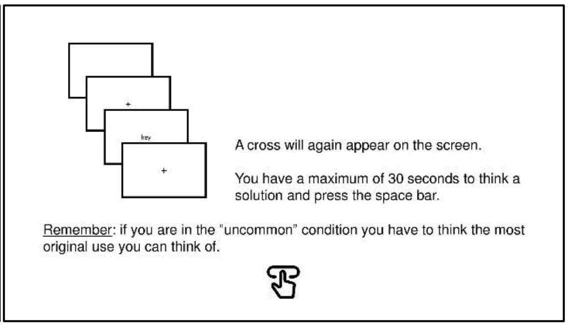

Block 1 / 2
Just Wait
Press the spacebar when you are ready
common / uncommon
Just Wait

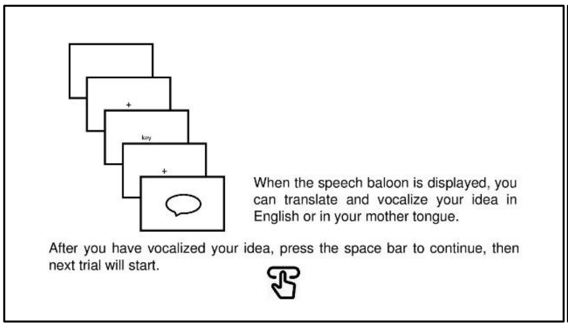

Previous instructions will be shown only once, at the beginning of each block.
Then, all the 20 words will be displayed as follows.

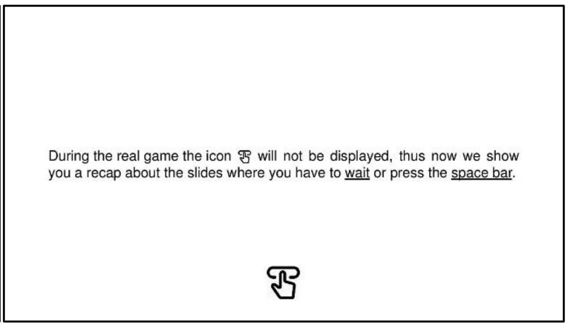

The screen will be blank for a while.

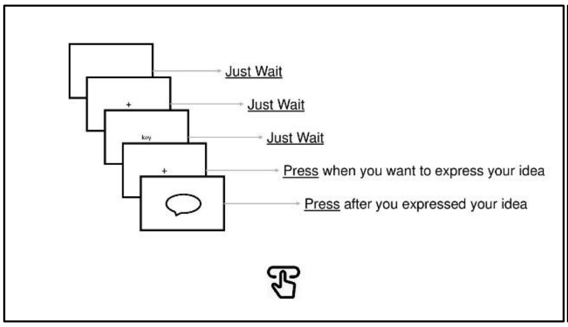

+
A small cross will appear in the center of the screen.
Remember: you will have to stare at it.


+
key
Then the word will appear in the center of the screen for half a second.
It will be displayed in your mother tongue.

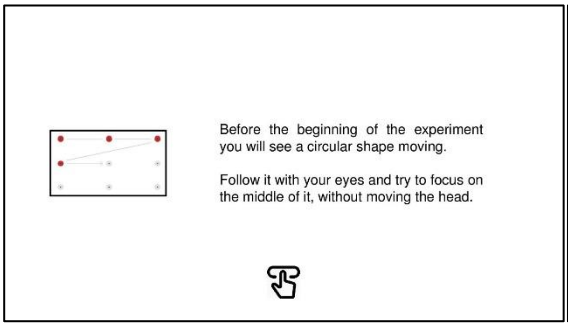

+
key
+
A cross will again appear on the screen.
You have a maximum of 30 seconds to think a solution and press the space bar.
Remember: if you are in the "uncommon" condition you have to think the most original use you can think of.

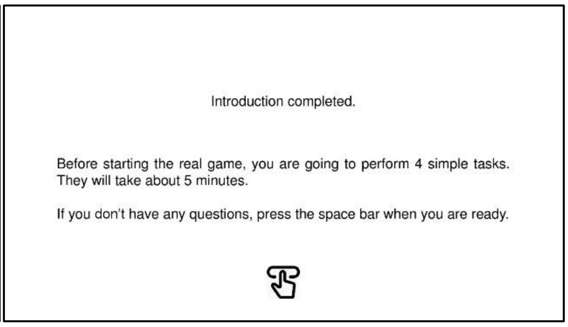

+
key
+
When the speech baloon is displayed, you can translate and vocalize your idea in English or in your mother tongue.
After you have vocalized your idea, press the space bar to continue, then next trial will start.


During the real game the icon will not be displayed, thus now we show you a recap about the slides where you have to wait or press the space bar.


Just Wait
+
Just Wait
key
Just Wait
+
Press when you want to express your idea
Press after you expressed your idea


The game will take about 30 minutes.


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 the head.


Introduction completed.
Before starting the real game, you are going to perform 4 simple tasks. They will take about 5 minutes.
If you don't have any questions, press the space bar when you are ready.

Find a comfortable position.

It is better for the sensors if you don't need to look at the space bar: the arms should lie on the table and one hand should be close to the space bar so that you have to move only fingers to press it.

Remember:
- You don't have to talk during the experiment, except when you see the speech baloon, after that you have pressed the space bar;
- You don't have to move and you should also avoid smaller movements;
- You don't have to look away from the screen;
- You can express your solution also in your mother tongue, if you can't find the proper translation.

Now we are going to test if you understood everything with a brief simulation.

The objects in the simulation will be written in English

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

Block 1

In the next slide you will see which use (highly **common** or highly **uncommon**) you have to find for the next 20 trials.

Press the **space bar** when you are ready.

common

table

+

+

skateboard

+

End of Block 1.

Pause.

Remember:
- in the real experiment you will have two minutes of pause and Block 2 will begin automatically after a 3 seconds count down;
- in the real experiment the sequence of the two blocks (common and uncommon) is randomized.

Press the space bar once to start Block 2.

Block 2

In the previous block you found common uses for the objects.

In the next block you will have to find **uncommon** uses for the following objects.

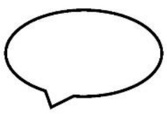
Press the space bar when you are ready.

uncommon

+

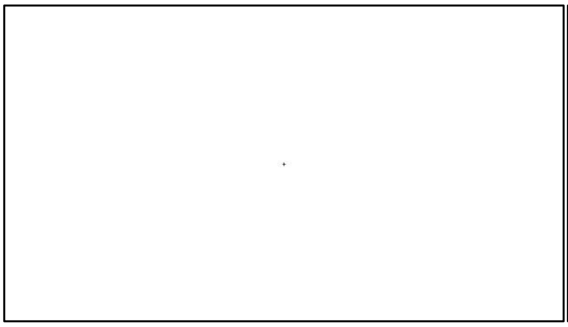
brick

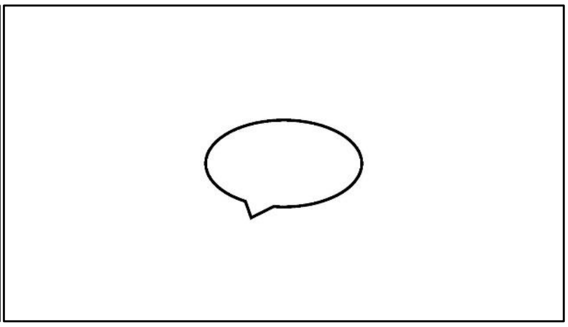
+



+

glasses





A.6 Translation of the items

The heterogeneity of the sample required to translate the items into all the mother tongue of the participants. It was necessary to avoid all the translation cognitive processes and to reduce at minimum different activities from the aim of the task. To translate the words, researchers exploit their network of mother tongue people, with a consecutive analysis of the use, the meaning and the frequency of the words.

Number	English	Italian	French	Swedish	Romanian	German	Spanish	Portuguese
1	axe	ascia	hache	yxa	topor	beil	hacha	machado
2	ball	palla	balle	boll	minge	ball	pelota	bola
3	basket	cesto	panier	korg	coş	korb	cesto	cesto
4	bed	letto	lit	säng	pat	bett	cama	cama
5	book	libro	livre	bok	carte	buch	libro	livro
6	bra	reggiseno	soutien-gorge	behå	sutien	bustenhalter	sujetador	sutiã
7	bread	pane	pain	bröd	pâine	brot	pan	pão
8	can	lattina	canette	burk	doză	dose	lata	lata
9	coffin	bara	cercueil	kista	sicriu	sarg	ataúd	caixão
10	coin	moneta	pièce	mynt	monedă	munze	moneda	moeda
11	colander	scolapasta	passoire	durkslag	strecurătoare	sieb	colador	coador
12	comb	pettine	peigne	harbroste	pieptene	kamm	peine	pente
13	fork	forchetta	fourchette	gaffel	furculiță	gabel	tenedor	garfo
14	guitar	chitarra	guitare	gitarr	chitară	gitarre	guitarra	violão
15	gun	pistola	pistolet	pistol	pistol	pistole	pistola	pistola
16	hammer	martello	marteau	hammare	ciocan	hammer	martillo	martelo
17	hanger	gruccia	cintre	galge	umeraş	kleiderbugel	percha	cabide
18	helmet	casco	casque	hjälm	cască	helm	casco	capacete
19	lamp	lampada	lampe	lampa	lampă	lampe	lámpara	luminária
20	magnifier	lente d'ingrandimento	loupe	förstoringsglas	lupa	lupe	lupa	lupa
21	mirror	specchio	miroir	spegel	oglindă	spiegel	espejo	espelho
22	needle	ago	aiguille	synal	ac de cusut	nadel	aguja	agulha
23	net	rete	filet	nät	plasă	netz	red	rede
24	paperclip	graffetta	trombone	gem	agrafă de birou	büroklammer	clip	clipe
25	pillow	cuscino	oreiller	kudde	pernă	kissen	almohada	travesseiro
26	pot	pentola	casserole	gryta	oală	topf	olla	panela
27	rag	panno	chiffon	trasa	pânză	tuch	trapo	trapo
28	ring	anello	bague	ring	inel	ring	anillo	anel
29	scissors	forbici	ciseaux	sax	foarfece	schere	tijera	tesoura
30	shoe	scarpa	chaussure	sko	pantof	schuh	zapato	sapato
31	sock	calza	chaussette	strumpa	şosetă	socke	media	meia
32	sponge	spugna	éponge	svamp	burete	schwamm	esponja	esponja
33	stick	bastone	bâton	pinne	băț	stab	bastón	pau
34	tent	tenda	tente	tält	cort	zelt	tienda de campaña	barraca
35	toothpaste	dentifricio	dentifrice	tandkräm	pastă de dinți	zahnpasta	dentífrico	dentifrício
36	trousers	pantaloni	pantalon	byxor	pantaloni	hose	pantalones	calças
37	tyre	pneumatico	pneumatique	däck	pneu	reifen	neumático	pneu
38	umbrella	ombrello	parapluie	paraply	umbrelă	regenschirm	paraguas	guarda-chuva
39	vase	vaso	vase	vas	vază	vase	jarrón	vaso
40	window	finestra	fenêtre	fönster	fereastră	fenster	ventana	janela

A.7 Answers

Here are reported the behavioral answers of the validated thirty-eight participants, because the answers of two participants (subject 4 and subject 38) are not collected because of some troubles with the software. Several answers were given after the thirty seconds limit of idea generation period, other answers were not found by participants: they are highlighted with the red background of the cells referred to those items. The way to manage those answers is being processed.

The data related to the questionnaire, in particular about the mental strategy, are reported as they are collected, without any modification, to not effect them.

Subject 1

Block	Trial Nr	Object	Answer	Response time (s)
u	24	axe	To cut the meat	
u	33	ball	As a rolling pin to make pasta	26,5
c	7	basket	To pick up things as fruits	16,1
c	14	bed	To sleep	1,9
u	29	book	As an ornament	7,6
c	19	bra	To hold the breast of people who have it	12,7
c	13	bread	To eat it	1,5
u	40	can	You can split it in two halves and make a chandelier	14
u	35	coffin	As a wardrobe	10,4
c	20	coin	To pay	2,6
u	38	colander	You can use it to make spaghetti, pushing the dough inside it	17,9
u	30	comb	-	
c	17	fork	To eat	6,4
c	3	guitar	To play music	6,4
u	22	gun	-	
u	31	hammer	To open nuts	17,8
c	4	hanger	To hang your coat	
c	6	helmet	To protect your head in case of bike accident	8
u	26	lamp	As a lanyard pendant, for example for necklaces	17,4
c	18	magnifier	To watch something small	3
u	25	mirror	To tan better than usual	14,8
c	9	needle	To sew	9,4
c	11	net	To go fishing	10,5
c	5	paperclip	To keep papers together	
u	27	pillow	As a door blocker	30
c	12	pot	To cook	1,2
u	28	rag	-	
u	23	ring	To draw circles	15,9
c	16	scissors	To cut paper	2,4
c	15	shoe	To walk	8,6
c	8	sock	To protect your foot from cold when you put the shoes	12,6
c	10	sponge	To wash the dishes	3,2
c	1	stick	To do trekking in mountains	8,8
c	2	tent	To cover the windows	
u	34	toothpaste	As a glue	
u	36	trousers	As a scarf	15,6
u	37	tyre	-	
u	32	umbrella	As a crutch	
u	21	vase	To put fishes inside it and use it as a fish tank	19,3
u	39	window	Use its handle as a hanger for clothes, when it is open	30 + 4
Mental strategies			I was thinking about the object, its dimensions, its shape and then its common use. Then I tried to find another use for it, based on its shape. I thought about "what I use it for", or "how I used it in an uncommon way before"	

Subject 2

Block	Trial Nr	Object	Answer	Response time (s)
u	40	axe	as a bottle opener	7,6
u	23	ball	to splash water	3,2
c	12	basket	for the laundry	6,1
u	34	bed	as a barrier	9,4
c	15	book	to read it	0,7
u	32	bra	as earmuffs	6,4
u	38	bread	as a stick	4
u	37	can	as a weapon	6,4
u	35	coffin	as a bed	4,3
c	9	coin	to pay	1,5
c	3	colander	to drain pasta	1,9
c	14	comb	to comb your hair	
u	39	fork	as a barbecue grill	30 + 6
u	33	guitar	as a piece of decor	14,8
c	8	gun	to shoot	0,7
u	25	hammer	to hit somebody	-
c	11	hanger	-	-
u	36	helmet	as a vessel	2,9
u	26	lamp	as a vase to keep flowers in	17,4
u	21	magnifier	to light a fire	-
c	1	mirror	to see yourself reflected in it	3,9
c	2	needle	to sew	2,8
c	5	net	to fish	1,1
u	31	paperclip	as a pin	6,3
u	28	pillow	use it for shimming something	9,3
u	29	pot	as a hat	3,8
c	6	rag	to dry things	1,3
c	17	ring	for wedding	0,7
c	20	scissors	to cut paper	1,3
u	27	shoe	as a dog bowl	2,1
u	30	sock	as a condom	2,5
u	24	sponge	use it as a trap for animals: make an animal eat it to make it die	7,1
c	13	stick	to play with the dog	3,9
c	19	tent	to repair from the sun	4,8
c	4	toothpaste	to wash your teeth	0,8
c	16	trousers	to dress up	0,4
c	18	tyre	for car road holding	1,6
u	22	umbrella	to hit somebody	1,7
c	7	vase	to keep plants in it	0,8
c	10	window	to ventilate the room	1,3
Mental strategies			The uncommon answers came up in my mind either because I had already experienced them personally or because I saw those kinds of uses somewhere. I think that a 60% of my answers did not reflect actual creativity but was just memory retrieval of something.	

Subject 3

Block	Trial Nr	Object	Answer	Response time (s)
u	40	axe	to play a game where you have to throw it as far as you can	25,2
u	38	ball	to make noise making it explode	30 + 1
c	6	basket	to put fruit inside it	10,3
c	11	bed	to sleep	3,3
u	37	book	to make many paper airplanes	10
c	20	bra	to hold breasts	11,1
c	4	bread	to make a sandwich	6,2
c	9	can	to put a drink inside it	6,5
c	5	coffin	to bury dead people	7,6
c	18	coin	to pay	6,8
u	24	colander	as a hat	12,5
u	27	comb	to play music	20,2
c	15	fork	to eat	3,6
c	14	guitar	to play music	3,7
c	17	gun	to shoot	4,1
u	35	hammer	to open a bottle	30
u	36	hanger	to threaten someone	30 + 2
u	39	helmet	wear it to commit a robbery	28,1
u	30	lamp	to do shadow puppetry	12,8
c	19	magnifier	to better read words written on a piece of paper	4,2
c	8	mirror	to comb	5,4
c	10	needle	to make an injection	5,7
c	3	net	to fish	4,9
c	13	paperclip	to keep papers together	6,4
u	29	pillow	to pretend having santa's belly	23
u	32	pot	to build a drum	12,8
c	1	rag	to wipe the dishes	9,8
u	28	ring	to do magic tricks	21,2
u	22	scissors	to engrave your initials on wood	23,7
u	34	shoe	to simulate a cellphone	15,6
u	23	sock	to put candies inside it	1,4
c	7	sponge	to wash dishes	4,6
u	25	stick	to take a ball stuck on a tree	15,7
u	33	tent	to hide yourself while playing hide-and-seek	15,9
u	21	toothpaste	put it on somebody's face while sleeping as a joke	14,7
c	12	trousers	to dress up	6
c	2	tyre	to set it up on a car	8,5
c	16	umbrella	to protect from the rain	5,1
u	26	vase	break the bottom and use it as a bracelet	15,5
u	31	window	to use it as a mirror to watch yourself	30
Mental strategies			The uncommon answers came up in my mind either because I had already experienced them personally or because I saw those kinds of uses somewhere. I think that a 60% of my answers did not reflect actual creativity but was just memory retrieval of something.	

Subject 5

Block	Trial Nr	Object	Answer	Response time (s)
u	36	axe	lifting weight	14,4
c	5	ball	to do sports	4,2
c	4	basket	put stuff in like fruits	6,9
c	16	bed	sleep on it	1,4
c	12	book	read it	2,2
u	38	bra	throw water baloons	3,9
c	11	bread	eat it	2
u	21	can	store letters inside as time capsule, bury it in the ground and then take it ten years later	-
c	18	coffin	for the eternal sleep	3,2
c	8	coin	to pay	6,2
c	13	colander	to note a date?	10,9
u	32	comb	you can rub it fastly in your hair and create static electricity	12,4
c	20	fork	eat spaghetti	2,3
c	3	guitar	play music	2,2
u	26	gun	as a sex toy	29,4
c	1	hammer	to break stuff	4
c	10	hanger	hang clothes	1,6
c	17	helmet	protect your head	1,3
c	15	lamp	light	3,8
c	19	magnifier	make small objects bigger	3,3
u	37	mirror	on the top of the bed and watch yourself on sex	27
u	35	needle	to make holes in something to build a narghilè	17,4
u	33	net	as a weapon if you put rocks in	27,5
u	30	paperclip	put it on your nose if something smells bad	14,6
u	39	pillow	use a bunch of them to build a fortress	14,5
c	2	pot	for cooking	3,1
u	40	rag	as a parachute	20,4
u	25	ring	with a small stick you can make a game and try to throw the ring in it	21,9
c	14	scissors	cut paper	2,8
u	22	shoe	instead of an hammer, use it with nail	8,1
u	24	sock	put some rocks in it and use it as weapon	11,2
c	9	sponge	soak up water	6,3
c	7	stick	to lean on it	12,4
u	31	tent	to use it as a coverer if you have one tent more	15,9
u	27	toothpaste	use it as a prank, mix it with the onion to make a cream for your face	9,2
u	34	trousers	cut all the trousers and make round bracelets	26,7
u	28	tyre	roll on it as in a circus	18,7
c	6	umbrella	protect from rain or sun	3,4
u	23	vase	break it and use it as puzzle	9,3
u	29	window	if it is raining, you can go by the window and make yourself a video to look dramatic	-
Mental strategies			The uncommon answers came up in my mind either because I had already experienced them personally or because I saw those kinds of uses somewhere. I think that a 60% of my answers did not reflect actual creativity but was just memory retrieval of something.	

Subject 6

Block	Trial Nr	Object	Answer	Response time (s)
c	33	axe	to chop wood	1,4
c	24	ball	to play football	4,9
u	3	basket	skateboard	20,4
c	37	bed	to sleep	1,4
u	15	book	in a fire place	23,1
c	32	bra	to hold your brests	19,3
u	20	bread	to throw away	26,8
u	4	can	to build a wall	19,9
c	27	coffin	to bury someone	7,1
u	7	coin	to throw it	14,8
u	18	colander	as a helmet	3,4
u	14	comb	when you want curly hair	25,9
c	38	fork	to eat with	3,5
u	11	guitar	as a weapon	7,3
u	5	gun	when you are nice to someone	12,6
u	12	hammer	to break things	11,3
c	34	hanger	to hang up your clothes	1,7
u	1	helmet	cooking food	8,4
c	23	lamp	to light up a room	5,9
u	17	magnifier	to start a fire	17,3
u	13	mirror	to look at others	17,8
c	28	needle	to stitch someone up	4,9
c	29	net	to catch fhises	7,9
c	36	paperclip	to hold paper together	5,2
u	9	pillow	when you are not trying to sleep	8,8
c	21	pot	when you are cooking	7,3
c	26	rag	when you need to clean something	3,9
c	31	ring	propose to someone	4,8
c	35	scissors	to open something	5,9
c	22	shoe	when you are going outside	6,1
u	19	sock	store things in	9,8
u	6	sponge	to have a pick nick	14,7
c	30	stick	to make a dog fetch	18,9
c	25	tent	when you are camping	2,1
u	8	toothpaste	as a lotion	18,7
c	39	trousers	to wear when you are going outside	6,2
u	10	tyre	to roll down from a hill	10,9
u	2	umbrella	when it's sun outside	3,2
u	16	vase	use it as a saw	22,2
c	40	window	to getting light into the house	20,3
Mental Strategy			First thinking about something you use the object for, and then thinking on the opposite and something useful	

Subject 7

Block	Trial Nr	Object	Answer	Response time (s)
u	39	axe	to cut my nails	6,1
c	2	ball	play football	2,2
u	38	basket	to bring my books to school	9,3
u	23	bed	to put clothes on it	4,6
c	4	book	to read	3,8
c	7	bra	women use it for the breasts	7,4
u	36	bread	to plug holes	9,8
u	31	can	to dig a hole	13,9
c	5	coffin	to put someone that is dead	6,3
u	27	coin	to draw circles	13,8
c	20	colander	NO ANSWER	-
c	19	comb	to comb	5,5
c	18	fork	it is an instrument to help eating	10,2
u	22	guitar	to decorate	5,2
c	12	gun	to kill	4,8
c	14	hammer	to beat	7
c	3	hanger	put jackets on	4,4
u	35	helmet	put water inside and drink it later	7,1
c	10	lamp	to give light	-
u	29	magnifier	to make a fire	8
c	17	mirror	to see ourselves	3,6
u	28	needle	to write	11,1
c	11	net	to protect from the exterior, to divide	8,7
c	16	paperclip	to put papers together	4,8
c	9	pillow	to put the head on when you go to sleep	-
u	26	pot	as drums	5,4
u	30	rag	as a courtain	14,3
c	6	ring	put it on the finger	3,5
u	37	scissors	to open holes in the floor	20,1
c	15	shoe	to put in your foot	4,6
u	25	sock	to filter liquid from solids	6,3
c	8	sponge	clean dishes	3,7
c	13	stick	to beat	3,4
u	32	tent	as an hospital to make surgery in a dirty place	25,6
u	21	toothpaste	clean the computer screen	18
u	24	trousers	to clean surfaces, like a table	9,9
u	34	tyre	to build a house	7,7
c	1	umbrella	protect from rain	10,5
u	40	vase	as a helmet on my head	11,1
u	33	window	as a blackboard	12,7
Mental Strategies			I tried to find idiot uses for the objects, uses that I would never do	

Subject 8

Block	Trial Nr	Object	Answer	Response time (s)
c	38	axe	to cut with	2,1
u	20	ball	to sit on	30+2
u	14	basket	as a bathtub	11,5
c	30	bed	for sleeping	2,2
u	8	book	as toilet paper	6,9
c	31	bra	to wear it	0,7
u	9	bread	let it dry and use it as a weapon	13,4
c	39	can	to store	3,1
u	11	coffin	as a bag to put skies	22,6
u	10	coin	as a key	19,8
c	21	colander	to sift	20
c	25	comb	to brush the hair	3,2
c	24	fork	for eating	1,4
c	36	guitar	to make music	2,3
c	26	gun	to kill people	1,7
u	12	hammer	as nutcracker	18,2
c	28	hanger	to put clothes on	4,7
u	5	helmet	as plant pot	30+1
u	16	lamp	as a heater	15
u	15	magnifier	to burn things	14,8
u	18	mirror	to cut things	13,6
u	1	needle	to pop the bubbles under your feet	30+1
c	40	net	for fishing	2,9
c	37	paperclip	to fix paper together	2,6
u	3	pillow	to use the pillowcase for decoration	28,4
u	2	pot	a game with also a spoon where you have to find the pot based on other people's instructions	30+1
c	32	rag	as a scarf	5,4
c	34	ring	??	
c	23	scissors	to cut things	1,7
u	17	shoe	as a flower pot	25,9
u	6	sock	as a glove	30+1
u	19	sponge	to grow cress (a plant)	7,7
u	13	stick	as a magic wand	17,5
c	35	tent	for camping	2,6
c	27	toothpaste	to brush the teeth	2,3
c	22	trousers	to wear it	7,3
c	33	tyre	for biking	6,5
c	29	umbrella	to protect from the rain	1,8
u	7	vase	for eating as a cup or a bowl	30+1
u	4	window	to grow plants (with the light)	30+1
Mental Strategy			thinking about the most uncommon way I have used this object in my life	

Subject 9

Block	Trial Nr	Object	Answer	Response time (s)
c	12	axe	to chop wood	3,8
u	40	ball	as a life-saving floater, not to drown in the sea	
u	23	basket	to play basketball with friends	15,7
c	16	bed	to sleep in the night	6
u	32	book	burn it and make a fire	30+1
c	6	bra	to hold breasts	9,5
c	2	bread	to have a snack	13,3
u	30	can	as decoration for christmas tree	13,2
c	7	coffin	to put dead people inside	7,9
c	19	coin	to pay	4,9
u	28	colander	as a helmet	19,4
u	36	comb	break it into several pieces and use them as components for other things	
u	38	fork	as a bottle opener	8
u	24	guitar	as a self-defence weapon	23
c	9	gun	to shoot	5,7
u	29	hammer	as a coat hanger if you fix it to the wall	22,4
u	22	hanger	to open a lockbox	
u	35	helmet	as a fruit basket	19,5
c	17	lamp	to be able to see in the dark	5,5
u	33	magnifier	to start a fire	14,9
c	1	mirror	to make up in the morning	9,9
c	8	needle	to sew clothes	13
u	26	net	if you take two posts, you can build a goal for playing football	16,2
c	3	paperclip	to put documents together	6,6
c	4	pillow	to lay your head when you sleep	5,9
c	14	pot	to cook pasta	5,8
c	11	rag	to wipe dishes	6,1
u	39	ring	you can sell it and take the money	14,9
c	13	scissors	to cut paper	4,4
u	31	shoe	to hide money inside	19,1
c	10	sock	to shelter from cold	8,8
c	20	sponge	to wash dishes	6,8
u	21	stick	to help blind people walking	26,3
u	27	tent	turn it into a carnival dress	17,2
u	34	toothpaste	as a glue	17,7
c	18	trousers	to hang out	10
c	5	tyre	device for a car	16,5
c	15	umbrella	to repair from rain	2,6
u	25	vase	as a bottle of water	30+0
u	37	window	as a surfboard	30+1
Mental Strategy			First, I thought about the normal use fo the objects, then I tried to go out of reality. I just tried to go off the grid	

Subject 10

Block	Trial Nr	Object	Answer	Response time (s)
u	16	axe	to start a fire, as you can chop wood and make sparks	14,2
c	28	ball	to kick it or throw it	4
c	27	basket	put fruits in	1,3
u	15	bed	as a shelter in war times	12,1
c	37	book	to store informations	
u	9	bra	have it on your head and pretend having a horn	9,3
c	22	bread	to eat	3,4
u	12	can	stack many of them to build a tower	11,9
u	14	coffin	to build a boat	19,2
u	17	coin	put it on your eyes to protect from sun	13
u	11	colander	as a sledge	13
c	31	comb	to make your hair straighter	4,4
c	32	fork	to grab food with	4,1
c	40	guitar	to play music	1,5
c	35	gun	to shoot someone	2,4
u	10	hammer	as a coat hanger if you fix it in a wall	18,4
c	26	hanger	to hang clothes	1,8
u	5	helmet	as a shield	12,1
c	36	lamp	to light something	3,6
c	21	magnifier	to magnify things	3,3
u	13	mirror	use it to trick other people and make them think that you are coming from another direction	9,6
c	25	needle	to sew clothes	2,7
u	6	net	use it like a baloon if you plug the holes and inflate it	23
u	4	paperclip	as a lock mechanism	7,3
c	38	pillow	make your head more comfortable	4,4
u	19	pot	as a helmet	20,7
u	20	rag	if it is white, wave it for peace	7,4
u	8	ring	to draw circles	13
u	2	scissor	to make a hole in a baloon	16,4
c	30	shoe	to protect feet	3,9
u	7	sock	as a boxing glove	6,6
u	3	sponge	with a very big one, to absorbe all the water in a lake	10,3
c	23	stick	no answer	
c	39	tent	as a portable house while travelling	5,5
c	34	toothpaste	to brush teeth	3,3
c	24	trousers	wear on your legs	2,7
u	18	tyre	sit inside it and roll down a hill	11,6
c	33	umbrella	to protect from rain	3,2
u	1	vase	scatter a window	6,9
c	29	window	to look out or in	2,6
Mental strategy			First thought about the shape of the object and then tried to figure it out in different environments.	

Subject 11

Block	Trial Nr	Object	Answer	Response time (s)
c	23	axe	to chop wood	1,8
u	4	ball	remove the air from inside and use it as a bag	17,5
u	7	basket	to dig a hole	16,8
c	29	bed	to sleep in it	1,5
c	40	book	to read it	1,4
u	3	bra	as a sail	5,4
c	31	bread	eat it	3,2
u	2	can	use as an amplifier for your phone	10,8
u	12	coin	to scrape away something from a surface	24
u	14	colander	as a helmet	5,7
c	33	comb	comb your head	1,4
c	34	fork	eat with it	3,3
u	5	guitar	remove the strings and use it to put plants in it	15,4
c	25	gun	to shoot someone	3,1
c	24	hammer	to punch nails with it	4
c	22	hanger	to hang your shirt on it	2,5
u	8	helm	use it as knee-cap	6
c	38	kista	to store stuff in it	
c	36	lamp	to turn it on	6
u	10	magnifier	to start a fire with	11,7
c	27	needle	to sew	3,2
u	17	net	to hang stuff in it	20,3
u	6	paperclip	unfold it and use it to clean the charger plug of the phone	12,3
c	30	pillow	use it under your head	8,2
c	28	pot	cook food in it	3,5
u	16	rag	put it on the wall	17,6
u	18	ring	as a candle holder for a small candle	15
u	20	scissors	to calculate angles, as a goniometer	10,1
c	26	shoe	wear it on your feet	1,8
u	13	sock	use it as a glove	14,4
c	39	spegel	to look at yourself	2,4
u	15	sponge	to store needles in it	10,8
c	32	stick	as walking stick	6,2
c	35	tent	sleep in it	4,6
c	37	toothpaste	put on your toothbrush	4,1
u	1	trousers	wear it on your head	10,1
c	21	tyre	as a tyre	6,4
u	11	umbrella	to collect water with using it on the contrary	9,2
u	9	vase	to store things	27,8
u	19	window	use it as a door	5,5
Mental strategy			I first thought about the shape of the object and then try to compare it with different shapes and sizes.	

Subject 12

Block	Trial Nr	Object	Answer	Response time (s)
u	35	axe	to sleep with it	16,4
u	40	ball	roll over it and go somewhere	16,2
c	9	basket	put things in	2,8
u	33	bed	as backrest	19,6
c	12	book	read it	0,9
u	26	bra	fix it to the wall and use it as coat hanger	15
c	16	bread	eat it	0,6
c	17	can	to store stuff in it	2,5
c	13	coffin	to bury dead people	5,9
c	10	coin	pay with	1,5
u	25	colander	wear it on your head	6,3
c	3	comb	brush your hair	2,2
c	14	fork	eat with it	1,9
c	15	guitar	play music	0,8
u	29	gun	to dig a hole with	11,8
c	6	hammer	hammer	3,4
c	4	hanger	hang clothes on	1,9
u	37	helmet	wear it on your foot	5
c	18	lamp	light on	
u	21	magnifier	no answer	
u	31	mirror	sit on it	4,4
u	28	needle	to cut with	8,1
u	39	net	as a tent where to sleep	3,6
c	8	paperclip	no answer	
u	22	pillow	wear it	4,6
u	24	pot	have stuff in it	5,3
c	20	rag	to clean something	0,9
c	2	ring	have it on the finger	4,3
c	1	scissors	cut paper	
u	38	shoe	no answer	
c	5	sock	have it on your foot	3,6
u	36	sponge	no answer	
u	34	stick	to build with	4,8
u	32	tent	as a parachute	4,7
c	19	toothpaste	brush your teeth	2
c	11	trousers	wear it	3,1
u	30	tyre	sit on it and sledge in the snow	6,4
c	7	umbrella	keep you from the rain	2,8
u	23	vase	bring it with you	5,3
u	27	window	no answer	
Mental strategy			No particular strategy.	

Subject 13

Block	Trial Nr	Object	Answer	Response time (s)
c	13	axe	to cut trees	1,6
c	2	ball	play football	7,4
c	5	basket	carry your shopping	4,4
u	24	bed	use it as a trampoline	19,4
c	20	book	to read it	1,2
u	25	bra	to do a slingshot	5
u	39	bread	to hit someone with it	12,8
c	18	can	to drink a soda	3,6
c	19	coffin	to put dead people in it	3,9
u	29	coin	as a spinning top	16,4
u	33	colander	use it as a helmet	11,5
c	3	comb	brush your hair	1,3
u	35	fork	to brush your hair	10,6
u	22	guitar	use the wood of the guitar to make a fire	16,9
u	40	gun	use it as a hammer	20
c	15	hammer	to push a nail when you build something	7
c	12	hanger	to hang your clothes	4
c	14	helmet	no answer	
c	1	lamp	to read during the night	8
u	36	magnifier	make a fire and burn little animals	8,2
u	26	mirror	break it and use it as a weapon	11,5
c	9	needle	to sew clothes	9,3
c	11	net	to catch fishes	2,6
u	37	paperclip	to open a lock	6,6
c	7	pillow	sleep on it	1,9
u	28	pot	as a small boat for animals	12,5
u	32	rag	to dress a small doll	12,7
u	38	ring	as fashion accessory for your snake	27,4
u	27	scissors	you can use it to make a figurine pretending the shades to be the legs	20,6
u	21	shoe	to hit someone	6,6
c	16	sock	to wear on your shoes	1,8
u	23	sponge	to empty out a swimming pool	6,9
c	4	stick	to throw it to the dog	3,3
u	34	tent	as a kite	30+3
c	6	toothpaste	brush your teeth with	1,3
c	8	trousers	to wear	3,7
u	31	tyre	to burn, to fuel a fire	12,8
c	10	umbrella	use it when it's raining	1,7
c	17	vase	put some flowers in it	1,1
u	30	window	use the glass as a magnifier for the sun and start a fire	16,2
Mental strategy			I just tried to figure out a use starting from a mental image of the object and then to see if it could work.	

Subject 14

Block	Trial Nr	Object	Answer	Response time (s)
u	12	axe	as cheese grater	19,3
u	6	ball	cut a hole in it and use it as a container	12,8
u	3	basket	lamp shade	8,7
u	4	bed	for isolation	5,9
u	5	book	like a leg or something to stay on it	22,9
c	39	bra	hold up breasts	8,7
u	15	bread	as an absorbent	11,5
u	2	can	container for rasperberry pies	10
u	17	coffin	as a model for kid's car	15,4
c	30	coin	pay with	2,5
u	19	colander	transporting swing wear	17,9
c	34	comb	untangle your hair	3,6
c	36	fork	transport food into your mouth	3,9
c	38	guitar	play music	3,4
c	29	gun	shoot to things	5,1
c	24	hammer	remove nails	4,1
c	28	hanger	hang clothes on	1,7
u	9	helmet	strenghten to your shoes to do something	29,4
c	31	lamp	light up an area	4,2
u	18	magnifier	as a lid for canister	18,9
c	35	mirror	watch yourself from another angle	9,5
c	32	needle	repair stuff	2,4
u	13	net	for making a pattern	21,3
c	37	paperclip	hold up a large amount of papers	5,6
c	23	pillow	rest your head on	2,5
u	7	pot	for storage	30+3
u	11	rag	cut it in small pieces and use them as chess pieces	30+1
u	8	ring	melting it down and use it for something else	24,3
c	33	scissors	cut paper	4,6
c	21	shoe	for walking	2,8
c	27	sock	warm your feet	1,9
u	16	stick	to draw on the sand	9
u	20	svamp	answer lost	20,6
u	10	tent	use it as a sail	10,4
c	22	toothpaste	brush your teeth	3,7
u	14	trousers	use the material to design walls	30+1
c	40	tyre	put it on a vehicle	7,6
c	26	umbrella	protect you from rain	1,7
u	1	vase	crack it and use it as art	13,1
c	25	window	look through	1,9
Mental strategy			I know other people use objects for other uses, mainly in design. I tried to keep my mind blank, and avoid thinking about the common use.	

Subject 15

Block	Trial Nr	Object	Answer	Response time (s)
c	6	axe	to cut wood	2,1
c	15	ball	to play with	1,2
u	22	ball	no answer	
u	37	basket	to clean clothes with	30+1
c	13	bed	sleep in	5,1
u	35	bed	use it like a tent	30+1
u	27	book	use it like a rock to throw	20,8
c	7	bra	to hold breasts	3,3
c	5	bread	to eat	1,2
u	29	can	no answer	
c	12	coffin	put a treasure	2,9
c	14	coin	to pay with	1,4
u	36	colander	use it like a spoon	30+1
u	32	comb	use it like a fork	8,5
u	31	fork	use it like a spoon	5,9
u	24	gun	as a head scratcher	21,9
c	8	hammer	to pick down nails	4,7
u	23	hanger	as a tool to scrape stuff	11,5
c	2	helmet	protect your head	2,2
c	19	lamp	turn on light	2,2
u	21	magnifier	to scrape off ice on a window	29,8
u	28	mirror	use it like a knife by breaking it	6,9
u	26	needle	to clean small holes	30+2
u	40	net	use it as a sledge	30+1
c	18	paperclip	to pin down paper	
u	33	pillow	no answer	
u	34	pot	use it like a hat	30+1
c	3	rag	clean the table	1,8
c	17	ring	to put on a finger	2
c	9	scissors	to cut papers	0,8
u	38	shoe	as a transporter for insects	30+1
c	10	sock	keep feet warm	1,5
u	30	sponge	to use as shoes	15,2
c	11	stick	throw it to a dog	3,3
c	16	toothpaste	to clean your teeth	1,6
c	20	trousers	to warm your legs up	2,1
c	4	tyre	use it on a bike or a car	5,5
u	25	umbrella	no answer	
c	1	vase	put flowers in	2,4
u	39	window	to scrape off ice from another window	30+1
Mental strategy			I tried to figure out something very uncommon and making sure not to say anything absurd. Tried to go over the most common uses that came up in my mind first.	

Subject 16

Block	Trial Nr	Object	Answer	Response time (s)
u	10	axe	unclear	30+6
c	25	ball	play with it	0,7
c	23	basket	to collect apples	2,3
u	7	bed	as a boat	30+2
u	6	book	you can make a frame with the cover and the wings with the pages	30+2
u	20	bra	i could make it with rubber, put siphons on it so people can use it as condom as well	30+1
c	24	bread	eat it	1,1
u	16	can	I could flatten it and ingrave a passport in it and travel around the world	30+2
c	22	coffin	to store stuff	1,2
u	8	coin	you can melt it down in multiple pieces and make many little swords for dwarves	30+1
u	12	colander	to rub your back	30+1
c	27	comb	brush your hair with	0,6
c	36	fork	eat with it	1
u	17	guitar	to hit people's butt with it	30+1
u	15	gun	I could make one with a very dense pasta, so i could choose if to shoot with it or eat it	30+1
c	32	hammer	build houses	0,4
c	29	hanger	hang stuff	0,5
u	9	helmet	you can cut in in a half-moon shape, make it look like a calzone and make fool people eat metal	30+1
u	19	lamp	i could increase the voltage of it, throw it in the sea and make a barbecue with dead fish	30+1
c	33	magnifier	magnify things	0,4
u	4	mirror	you can make an ever dark room with many of them	30+2
u	14	needle	stretch it really thin and far and put it between two speakers to communicate with Moscow	15,5
u	2	net	make clothing out of it	30+1
c	37	paperclip	put in your hair	1
c	31	pillow	sleep on it	0,7
u	13	pot	not clear	30+1
u	1	rag	make it very tense in a very single point and make a black hole	30+1
u	5	ring	cut it in very tiny pieces and make a small Eiffel tower	30+2
c	39	scissors	cut hair	0,7
c	26	shoe	wear it	0,6
c	28	sock	wear it	0,4
u	18	sponge	if mushrooms were the first life-form on the planet, now everything would look like mushrooms	30+1
c	38	stick	build a house	1,6
c	35	tent	camp with it	1
u	11	toothpaste	you can take all the toothpaste tube out, make it low-density and make a soft and nice pillow	30+1
u	3	trousers	you could stretch it really really long and thin and then you can make a catapult	30+1
c	34	tyre	use it on the car	0,7
c	40	umbrella	protect you against rain	1,2
c	30	vase	put a flower in	0,5
c	21	window	to look through	1,5
Mental strategy			I just thought to have fun and let the creativity run	

Subject 17

Block	Trial Nr	Object	Answer	Response time (s)
u	35	axe	to cut cheese	4,8
u	32	ball	as a sink	12,6
u	39	basket	as a tent for camping	14,6
c	1	bed	to sleep on it	5,1
c	20	book	read a story	2
u	31	bra	as a hat	10,2
u	23	bread	to stop a door	4
u	30	can	as a pencilcase	12
c	12	coffin	to bury somebody	4,1
u	22	coin	as a cork for a bottle	7,2
c	10	colander	to filter coffee	4,9
c	13	comb	to comb your head	4,1
u	21	fork	to comb a dog	8
c	8	guitar	to play music	2,8
c	2	gun	shoot something	5,5
c	9	hammer	to fix a painting on the wall	6
u	34	hanger	to scratch your back	8,8
u	36	helmet	as a vase for flowers	5,8
c	16	lamp	no answer	-
c	18	magnifier	to better see something	2,5
u	28	mirror	as a carpet	15,5
u	26	needle	to clean your nose	10,6
c	7	net	to fish	7,7
c	11	paperclip	put papers together	4,6
c	5	pillow	lay your head on it	5,7
u	38	pot	as a bathtub to have shower	16,7
c	14	rag	to clean the floor	5
c	19	ring	put it on your finger	2,4
u	37	scissors	as a homemade gun	25,3
u	27	shoe	to grow a fish inside it	6,7
u	33	sock	to filter coffee	10,4
u	40	sponge	to dry a little lake	6,5
u	24	stick	as an outrigger	17,9
c	17	tent	live inside it	7,4
c	15	toothpaste	no answer	-
c	3	trousers	to keep warm	5,8
c	4	tyre	put it on cars	8,1
u	29	umbrella	as a dish to have dinner	4,8
u	25	vase	to bake a cake	9,4
c	6	window	to look outside	5,6
Mental strategy			I tried to visualize the object, think of a natural or normal way to use it based on its shape and then think it in a different way.	

Subject 18

Block	Trial Nr	Object	Answer	Response time (s)
u	38	axe	destroy your wooden house	11,6
u	26	ball	hit somebody	10
c	4	basket	carry fruits	2,1
u	32	bed	jump on it	11,6
c	19	book	to read	1,9
c	18	bra	bfeel more comfortable	2,1
u	28	bread	put a soup on it	17,7
c	5	can	keep drinks in it	1,8
u	30	coffin	keep wine in it	8
c	7	coin	pay a product	1,2
c	20	colander	to filter juice	3,8
c	10	comb	brush your hair	1,8
u	31	fork	brush your heair	5,3
c	6	guitar	play music	1,7
c	14	gun	kill somebody	1,7
u	29	hammer	kill mosquitos	23,5
c	11	hanger	hang clothes	1,6
c	9	helmet	save your life	2,3
u	24	lamp	hang clothes on it	9,6
c	16	magnifier	magnifier	1,9
c	3	mirror	look at yourself	3,1
u	27	needle	take food and bring it in your mouth	9,3
u	37	net	as a collar for a doctor's cloth	21
u	40	paperclip	throw it when you are angry	8,7
u	21	pillow	make a pillow fight	5,3
u	35	pot	boil water	20,3
c	15	rag	clean a table	2
c	1	ring	put it on your finger	3,1
c	2	scissors	cut paper	0,8
c	8	shoe	wear it on	1,7
u	39	sock	put it on your face and go robbing a bank	4
c	12	sponge	have shower	2
u	22	stick	unlock a ole to put something in it	5,9
u	36	tent	as umbrella for kids	8,1
u	25	toothpaste	clean metal things	6
u	33	trousers	keep stuff in it	18,3
u	23	tyre	make a swing to play with kids	11,9
c	17	umbrella	avoid to get wet when it rains	4,3
c	13	vase	put flowers in	1,7
u	34	window	make paintings on the glass	10,4
Mental strategy			I just pictured stuff in my mind, its shape. Then i thought about the common use and try to get something more uncommon.	

Subject 19

Block	Trial Nr	Object	Answer	Response time (s)
u	18	axe	open a can of beer	17,4
u	3	ball	to get an apple from a high tree	20,2
c	31	basket	use it for shopping	3,9
u	17	bed	use it as a playground for something	15,2
c	30	book	read it	1,7
c	40	bra	to put things on top	10,8
u	4	bread	build shoes out of it	7,6
u	8	can	play flunky ball, a german game	15,1
c	37	coffin	put dead people inside	1,4
u	11	coin	keep doors open	9,9
u	16	colander	as a hat	7,7
u	2	comb	to clean things	15,2
c	25	fork	to eat	0,5
c	38	guitar	play music	1,3
u	9	gun	keep people safe	23,3
c	28	hammer	put a nail into something	2,1
c	21	hanger	hang clothes on it	2,4
c	29	helmet	protect your head	1
u	6	lamp	give light signals to your friends	26,3
u	20	magnifier	start a fire	13,4
c	24	mirror	look at yourself	1
u	14	needle	seek it in a haystack	9,1
u	19	net	catch air	15,8
c	36	paperclip	put papers together	2,5
u	15	pillow	no answer	
u	1	pot	as a hat	6,7
u	12	rag	fly on it as a magic carpet	16,6
u	10	ring	act like Gollum with it	11,4
u	13	scissors	to cut a lawn	10,3
u	7	shoe	decorate electric wires in the city	16,3
c	33	sock	wear it	4,3
c	26	sponge	wash dishes	1
c	39	stick	use it for hiking	5,8
c	35	tent	to camp	1,1
c	27	toothpaste	brush your teeth	0,9
u	5	trousers	fill it with water	10,1
c	34	tyre	to drive	3,2
c	22	umbrella	use it against rain	1,4
c	23	vase	put flowers in it	0,7
c	32	window	open it to let some fresh air in the house	5,4
Mental strategy			Sometimes i tried to think about stories i heard when i was a child, or uses i've already done in my life.	

Subject 20

Block	Trial Nr	Object	Answer	Response time (s)
u	19	axe	use its tip as a ruler	15,3
c	22	ball	play football	1,4
u	3	basket	as an umbrella over your head	8
c	32	bed	to sleep in	1,5
u	16	book	to hide things in	7,5
u	6	bra	put it over your eyes to protect them	5,8
c	27	bread	make a sandwich	3,7
u	10	can	to call someone with	7,1
c	39	coffin	put dead people in it	1,2
c	33	coin	to pay with	1,5
u	9	colander	make water pass though it and use it as if it was the head of the shower pipe	11,7
c	30	comb	comb your hair	4,4
u	7	fork	to gid a hole	13
c	38	guitar	play music with it	1,9
u	12	gun	to make your bag heavier	27,5
u	11	hammer	use it as a weight	10
c	21	hanger	hang clothes on	1,9
c	34	helmet	to protect your head	1,3
c	25	lamp	to light up a room	2,1
c	40	magnifier	to focus something	1,3
c	23	mirror	to build laser	10,2
u	15	needle	use it as a compass	6,8
c	28	net	catch something with	3,6
c	37	paperclip	to clip papers	2,3
c	31	pillow	put your head on to rest	6,8
c	24	pot	put plants in it	4
u	14	rag	as sunglasses	6,1
c	36	ring	for wedding	5,4
c	26	scissors	to cut paper	2,2
u	4	shoe	to drink from, as a glass	7,5
u	5	sock	as a filter	5,5
c	29	sponge	to absorb something	2,2
u	13	stick	make two people hold it and round it, and use it as a jump-rope	9,5
c	35	tent	take it out in the nature and sleep in it	5,1
u	8	toothpaste	put it on your skin and use it as a cream	11,1
u	18	trousers	use it as a flag on a pale, to see the direction of the wind	12,8
u	2	tyre	to work out	5,8
u	20	umbrella	use it to fly if there is a strong wind	15,3
u	17	vase	put ashes of dead people in it	14
u	1	window	shake it and use it as a fan	7
Mental strategy			First, i thought of the common use of the objects, and then tried to change what is possible to do with those things. Sometimes i remembered uses i had already seen from previous experiences.	

Subject 21

Block	Trial Nr	Object	Answer	Response time (s)
c	21	axe	to keep a door open	17,6
c	13	ball	play football	1,2
c	9	basket	to place stuff in it	1,6
c	20	bed	to sleep	0,6
c	14	book	to read	0,6
u	25	bra	take the metallic part and put it on a cable as connector	14
c	17	bread	to eat	0,8
u	23	can	cut the bottom, put some food on the other side and use it in the water to catch fishes	30+1
u	26	coffin	use it as a shelter from raining	17,5
u	27	coin	break it: it is something really strange to do	13,8
u	34	colander	put it close to a light inside a room to make a cool party	17,2
u	29	comb	use its teeth to remove the snot from your nose	10,4
c	18	fork	to eat	0,7
u	28	guitar	no answer	
u	33	gun	to fish	25,5
u	36	hammer	to make a pan flat again	4,3
c	7	hanger	to hang your clothes	1
c	19	helmet	to protect yourself	0,9
c	3	lamp	make light	1,1
u	24	magnifier	no answer	
u	40	mirror	to allow more sunlight inside your house reflecting it and focusing it	14,2
u	35	needle	put many of them in your car tyres so you have winter tyres	13,8
c	10	net	to take fishes from the sea	1,7
c	2	paperclip	put papers down it	3,5
u	30	pillow	open it, take the feathers inside and throw them on somebody after you had washed him with water in order to make the feathers stuck to him	30+1
u	31	pot	make a hole in the bottom of it, change its shape and make a funnel	17,1
u	37	rag	to do a costume	30+1
u	39	ring	as a can opener	18,4
c	5	scissors	cut papers	1,1
c	1	shoe	wear it	1,7
c	12	sock	wear it	2,3
c	15	sponge	to wash yourself	0,8
u	32	stick	replace your christmas tree at the base	21,7
c	16	tent	sleep in the mountains	0,8
u	22	toothpaste	you can use it to discolour yor t-shirt	30+2
c	4	trousers	to protect from cold	1,8
c	11	tyre	put it on a car	0,9
c	6	umbrella	prevent yourself from rain	1,1
u	38	vase	brake it in a lot of pieces and fix them to the wall as decoration	18,8
c	8	window	to have light inside your house	1,2
Mental strategy			I thought about things i did before or to things that i saw. Not a real strategy.	

Subject 22

Block	Trial Nr	Object	Answer	Response time (s)
u	14	axe	to kill someone	18,6
c	31	ball	play football	0,7
u	3	basket	as a hat	3,1
u	19	bed	to jump on it	20
u	16	book	hide stuff into it	6,5
c	28	bra	as underwear	0,9
u	1	bread	not valid	-
u	13	can	no answer	-
u	2	coffin	use it as a boat	5,4
c	22	coin	to pay	0,8
c	32	colander	no answer	-
c	35	comb	brush your hair	1,9
u	12	fork	use it for eating soup	18,4
u	20	guitar	smash it	2,2
c	33	gun	shoot someone	0,8
u	9	hammer	no answer	-
c	39	hanger	put clothes on	-
c	25	helmet	to protect your skull	0,6
c	21	lamp	see into the dark	1,1
c	40	magnifier	see small things	2,3
c	23	mirror	to see yourself	0,7
c	34	needle	to sew	2
u	18	net	to trap someone	12,3
c	36	paperclip	stick papers	2,1
u	4	pillow	as boxing gloves	11,7
u	7	pot	as a helmet	9,6
u	10	rag	sew many together to make clothes	30+1
c	24	ring	for wedding	1
u	15	scissors	to sharpen knives	18,4
u	5	shoe	put it on your hands and walk on hands	25,9
c	29	sock	wear on the foot	1,1
c	26	sponge	to eat	1,1
c	38	stick	beat someone	3
c	30	tent	to live outside	0,8
u	17	toothpaste	to clean CDs and repair stripes they have	5
u	11	trousers	use it for a scarecrow	8,5
c	37	tyre	put it on your car	1,7
u	6	umbrella	use it for fishing in the sea	19,2
u	8	vase	no answer	-
c	27	window	to look outside	0,7
Mental strategy			I tried to find an uncommon solution that many people could agree with, meaning that they can know it.	

Subject 23

Block	Trial Nr	Object	Answer	Response time (s)
u	31	axe	cuttin tools and searching others	8,1
u	24	ball	for shine marble again	11,6
c	5	basket	put things into it	2,1
u	27	bed	put it outside and use it as soft landing for forniture when moving house	13,3
c	17	book	read it	1,8
u	40	bra	keep your ears warm, putting it on them	4,7
u	21	bread	push it into people face	9,5
u	25	can	use it for baseball	7,7
c	9	coffin	put dead people in it	4,7
c	1	coin	for payment	3,6
c	20	colander	filter something	10,8
u	26	comb	use it as a fork	9,2
c	3	fork	for eating	5,7
u	33	guitar	slam it on people's face if they got my nerves	4,6
c	18	gun	shoot something	4,4
c	4	hammer	put in nails	4,4
c	11	hanger	hang your clothes on	6,3
c	19	helmet	protect my head	3,9
u	38	lamp	put it outside and attract mosquitos	6
c	2	magnifier	magnify things	3,9
u	34	mirror	to pop my eyes with a laser	17,3
u	22	needle	to pop my pimples	10,6
u	35	net	to filter really thick things	3,6
c	10	paperclip	attach paper together	5,9
u	23	pillow	for pillow fight	14
u	39	pot	as a helmet	3,6
c	15	rag	clean stuff	5,6
u	36	ring	as a separator for machine parts	14,4
c	6	scissors	cut things	1,7
c	16	shoe	put my feet into it	7,3
c	8	sock	put my feet in it	4,4
u	32	sponge	drink from it if it is full of water	6,3
c	13	stick	put things on top of it	18
u	30	tent	use it as submarine	10,7
u	28	toothpaste	dry your hair with it	4,6
c	14	trousers	put it over my legs	5,9
u	37	tyre	as a fast transportation for downhill	7,1
u	29	umbrella	use it as a boat	2,6
c	7	vase	put flowers in it	2,6
c	12	window	make the apartment lighter	5,4
Mental strategy			Most of the times i took the first thing that popped up in my mind, changing it in a more funny way, also considering that it should be useful.	

Subject 24

Block	Trial Nr	Object	Answer	Response time (s)
u	30	axe	use it as a weight	16,6
c	7	ball	play with	1,9
c	9	basket	carry things in	1,5
u	27	bed	remove the legs and go sledging on it	6,6
u	38	book	fold pages in different shapes and make origami	2,9
c	14	bra	keep your breasts in place	2,1
u	39	bread	mesh it up, combine with other ingredients and make a cake	16
c	2	can	store something	4,3
u	32	coffin	break it, take little pieces and build a little chair	15,2
c	8	coin	pay with	1,4
c	6	colander	strain pasta	2,8
u	25	comb	brush your cat	18,2
c	12	fork	eat with	1
c	5	guitar	play a song	1,6
c	1	gun	shoot somebody	2
u	40	hammer	cut each part and make a ring out of it	13,8
u	36	hanger	cut it apart and make a piece of art	11,5
c	18	helmet	protect your head	1,5
u	23	lamp	deconstruct it and use it as a hat	13,1
c	3	magnifier	see something small	2,6
c	4	mirror	see yourself	1
u	24	needle	put a bunch of them on a wire and make jewelery	7,5
u	22	net	put your belongings in it	13,7
c	10	paperclip	keep papers together	2,1
c	20	pillow	rest your head on	1,9
u	34	pot	as a drum	10,3
u	35	rag	cut it into pieces for weaving it into a carpet	11,3
u	21	ring	make a sort of armor with a lot of them	11,8
c	16	scissors	to cut things	1,7
u	26	shoe	as a door stopper	10,8
c	17	sock	keep feet warm	0,9
c	15	sponge	to eat	1,8
u	28	stick	make wall decoration	13,9
c	11	tent	sleep in	1,4
c	13	toothpaste	clean your teeth	1,6
u	31	trousers	cut it into strips and use it to wash your plants when you are away	7,8
c	19	tyre	put on your car	1,4
u	37	umbrella	turn it around and use it to gather water	10,9
u	29	vase	break it and make a mosaic	6,7
u	33	window	break it and use it as a weapon	7,5
Mental strategy			Just tried to think about what other people already did. Almost only based on instinct.	

Subject 25

Block	Trial Nr	Object	Answer	Response time (s)
c	14	axe	cut a tree	1,2
u	26	ball	roll over it and use it for transportation	15,4
u	31	basket	as a helmet	9,3
u	28	bed	as a sailing boat	11,7
c	8	book	to read	0,9
u	36	bra	as a fishing net	13,6
u	32	bread	as a projectile	9
u	40	can	use four of them as wheels for something	24
u	24	coffin	as a pet's house	15,3
c	11	coin	to pay with	2,6
c	10	colander	to eat rice	2,2
c	2	comb	brush your hair	1
u	37	fork	to scratch your back	20,8
u	38	guitar	as a pot co mix ingredients	20,3
u	22	gun	as a vase	6,7
u	23	hammer	as a wine opener	5,7
c	19	hanger	hang your clothes on it	0,9
c	20	helmet	protect your head	0,9
u	35	lamp	as a baseball bat	17,7
c	13	magnifier	see small things	1,8
c	15	mirror	see yourself	0,7
u	27	needle	not clear	14,7
u	25	net	to get a six-pack, drawing abdominals on your belly	15,2
u	34	paperclip	no answer	
c	5	pillow	rest your head on	1,4
c	7	pot	to cook	1,1
u	33	rag	to make a facade of a house with many rags	21,9
c	12	ring	wear it as accessory	2,9
u	39	scissors	as shade sharpener	30+1
u	29	shoe	to open wine	17,8
c	17	sock	warm your feet	0,9
c	6	sponge	eat	2,6
c	4	stick	play with the dog	4,6
c	18	tent	to get shelter outside	1,5
u	21	toothpaste	to stay at home from school	6
c	16	trousers	wear it as accessory	3,8
u	30	tyre	as a bed	29,8
c	9	umbrella	protect from rain	1,6
c	1	vas	put flowers in	4,6
c	3	window	get light into the house	1,3
Mental strategy			I was thinking about uncommon uses i have seen before and tried to come up with something better.	

Subject 26

Block	Trial Nr	Object	Answer	Response time (s)
c	39	axe	collect fire wood	5
u	11	ball	compromise a car starting	14
u	14	basket	as a discus to throw	29,1
c	29	bed	to sleep in	0,8
u	16	book	as a fly-swatter	14,4
c	21	bra	to hold your breasts	3,9
c	40	bread	to eat	2,5
u	4	can	to repair a muffler	9,6
c	30	coffin	to put things in	7,8
c	27	coin	pay with it	1,1
u	8	colander	as a hat or helmet	6,8
u	6	comb	scratch your back	10
u	12	fork	to change a tyre of a bicycle	17,6
c	32	guitar	play music	0,9
c	33	gun	shoot with	2,5
u	17	hammer	to hold things in place	12,8
c	25	hanger	hang your clothes on	3,2
c	31	helmet	wear it for safety reasons	4,8
c	37	lamp	light up a room	3,3
u	13	magnifier	overwhelm a flash light	24,8
u	10	mirror	reflect sunlight in people's eyes	23,6
c	22	needle	to hold fabric in place	7
u	2	net	as a pantyhose	20,2
u	5	paperclip	pick a lock	7,4
c	26	pillow	sleep comfortable	1,9
u	19	pot	play freesbee with its lid	11,6
u	7	rag	make a puppet	11,4
c	36	ring	wear it for safety reasons	4,7
u	20	scissors	divide it in two parts and use it as a knife	12,6
u	3	shoe	open a bottle of wine or champagne	8,1
u	1	sock	filter liquids	6,8
c	35	sponge	to clean with	4
c	34	stick	use it as a coat hanger	16,4
u	15	tent	as a storage area	13,1
u	18	toothpaste	to fill holes in dry walls	16
u	9	trousers	as a hat or helmet	16,5
c	24	tyre	inflate it and put it on yor bicycle	5,3
c	38	umbrella	keep yourself dry from the rain	2,8
c	23	vase	put flowers in	2,4
c	28	window	to look through	0,7
Mental strategy			I just followed my own experiences with the objects, or some memory form videos.	

Subject 27

Block	Trial Nr	Object	Answer	Response time (s)
u	18	axe	to put butter on a sandwich	30+7
u	14	ball	as a chair	30+4
u	2	basket	no answer	
c	24	bed	sleep in	2
u	11	book	to stand on, so you can reach higher	30+6
c	22	bra	contain breast	3,3
u	4	bread	to paint with	30+2
c	25	can	keep food in it	7,2
c	32	coffin	laying when you are dead	3
u	5	coin	write on the snow	30+3
u	13	colander	no answer	
c	33	comb	brush your hair	2,5
c	38	fork	eat food eith it	2,8
c	35	guitar	play music	3,4
c	30	gun	to hurt with	5,5
u	19	hammer	to dig a hole	30+3
c	39	hanger	hang your jacket	5,1
c	29	helmet	protect you	3,9
c	27	lamp	light up a room	6,3
u	16	magnifier	not valid	
c	37	mirror	see yourself	3
u	12	needle	if it is a very big one, you can use it as a sword	30+3
c	23	net	to fish	5,6
c	21	paperclip	hold papers together	5,7
u	17	pillow	if it is a big one, can use it as a bag	30+5
c	28	pot	cook food	5,2
u	20	rag	put it on a stick and use it to wipe the floor	30+6
c	31	ring	as accessory	5,3
u	8	scissors	as a compass to create circles	30+3
u	1	shoe	to get water out of a boat	30+3
c	34	sock	keep feet warm	5,6
u	10	sponge	use it as isolation	30+7
u	7	stick	no answer	
u	3	tent	to make clothes	30+6
c	36	toothpaste	brush your teeth	3
c	26	trousers	not to be naked	10
u	15	tyre	as an excersive tool, for workout	30+3
u	9	umbrella	protect you from the dirt of your bike	
u	6	vase	drink from	30+2
c	40	window	see outside of the house	7,1
Mental strategy			First i thought about the common use of the object, and then i spent time trying to find other multiple uses, compare them and try not to stuck on the first one that i thought.	

Subject 28

Block	Trial Nr	Object	Answer	Response time (s)
u	38	axe	to do a very inappropriate cosplay being a serial killer with an axe	15,3
u	32	ball	try standing on it	30+1
c	19	basket	put something in it	6,5
c	14	bed	to sleep	1,8
u	33	book	to rise the leg of a table	10,8
c	12	bra	keep the breasts to reduce back stress	14,8
u	34	bread	make a dessert with rough bread	20,1
u	35	can	as an ashtrayer	16,7
u	36	coffin	sleep in it for one night	23,7
c	15	coin	to buy something	24,3
c	6	colander	to drain pasta	14,5
u	26	comb	weapon for prisoners in jail	23,5
u	30	fork	use it as a catapult in food battles	8,9
c	13	guitar	to look cool with the ladies	2,9
u	40	gun	slice it into many parts to study its mechanisms	24
c	8	hammer	fix a nail in the wall	20,1
c	7	hanger	hang clothes on it	12,1
u	37	helmet	put it on the head with a friend and play slamming each other	30+3
u	31	lamp	stylish decoration	30+4
c	17	magnifier	to be able to see small things	8
u	22	mirror	create artistical light reflections	20,6
c	5	needle	to sew some clothes	3,9
u	24	net	use it as a trampoline	12,6
c	11	paperclip	keep several papers together	10,1
u	29	pillow	choke someone with it	23,5
u	28	pot	play music as a drum	13,7
u	27	rag	cover a hole with it	26,9
u	25	ring	play a very precise ring-toss game	27,5
u	23	scissors	force open a rusty door lock	30+2
c	10	shoe	isolate your feet from the ground	30+4
c	9	sock	keep your feet warm	15,6
c	1	sponge	wash dishes	14,8
c	2	stick	help you walking in the forest	18
u	39	tent	no answer	
u	21	toothpaste	fix a scratched CD with it	5,5
c	16	trousers	walk on the street without feeling cold to the legs	14,2
c	20	tyre	not valid	
c	18	umbrella	keep you from being wet when it rains	9,5
c	4	vase	put flowers in	5,6
c	3	window	watch outside your house and get the best temperature	24,2
Mental strategy			I literally asked to my self "what can i do with this? is it too common?". And then talk to myself in this way, like two people having a conversation.	

Subject 29

Block	Trial Nr	Object	Answer	Response time (s)
u	19	axe		
c	33	ball	play with	1,3
c	32	basket	carry stuff with	3,5
u	3	bed	to use as a sofa	30+5
c	22	bed	sleep on it	1,1
u	9	book	to make stable an unstable table	30+5
c	29	bra	to wear	2,1
u	16	bread	to cut it in slices, put them together as a soft matrass and sleep comfortable on it	30+2
c	28	can	keep stuff in it	2,8
c	24	coffin	bury someone in it	3,7
c	38	coin	to pay with	2,1
u	11	colander	as a helmet	3,3
c	31	comb	to comb your hair with it	1,5
u	20	fork	to brush your hair	30+2
c	25	guitar	play music	1
c	37	gun	shoot with it	1,3
c	30	hammer	to hammer a nail	1,6
u	14	hanger	to use the hook to try to grasp things	30+2
u	10	helmet	as a bag to carry stuff	14,6
c	34	lamp	light up so you can see	2,3
u	8	magnifier	use it by the window to see what the neighbours do	22,1
u	12	mirror	as a desk where to study	9,3
c	23	needle	sew clothes	1,4
c	21	net	to catch fishes	5,7
c	27	paperclip	tu clip papers	2,8
c	39	pot	to eat with	1,9
u	15	rag	use as a cloth under some flowers	30+4
c	36	ring	wear it on your finger	2,7
u	4	scissors	to scratch your back	30+2
u	7	shoe	to drink from as a glass	13,7
c	35	sock	wear it on your foot	1,8
u	13	sponge	you can squash it to fill a hole so that the liquid does not run out	14,5
c	40	stick	to play with dogs	13,1
u	2	tent	no answer	
c	26	toothpaste	use it on your toothbrusher	1,8
u	5	trousers	not valid	
u	1	tyre	work out with it	30+3
u	6	umbrella	use as a shelf to put stuff on	30+2
u	17	vase	use it to take out the water from a canoa that is drawning	14,9
u	18	window	to hide behind it	30
Mental strategy			It was about getting inspired by the word. I was thinking about the material and what happens when i put it upside-down, or placed it in another environment	

Subject 30

Block	Trial Nr	Object	Answer	Response time (s)
c	32	axe	chop trees	1,4
c	35	ball	play football	1,3
c	24	basket	put fruits in it	1,5
u	16	bed	build a cottage	17,7
c	33	book	to read	0,9
c	29	bra	hold up breasts	2,2
c	22	bread	make a sandwich	2
u	6	can	play music	16,6
u	18	coffin	for hiding when playing hide-and-seek	11,2
c	26	coin	to pay something	1,6
u	4	colander	to spread sugar on the cake	13,5
u	5	comb	to play music, as a guitar picker	7,1
c	23	fork	to eat with	1,5
c	21	guitar	play music	1,4
c	31	gun	kill someone	2,6
c	34	hammer	to hit nails	2,5
u	10	hanger	to popen locks	14,2
c	28	helmet	protect your head	2
u	14	lamp	to play tennis, as a racquet	26,8
u	3	magnifier	not clear	10,8
u	11	mirror	to cut things	15,3
u	1	needle	to build a compass	17,5
c	39	net	to fish	2,8
c	36	paperclip	keep papers together	1,4
u	20	pillow	go down a hill on it during the winter	13,4
u	13	pot	to build a sand castle	14,5
c	38	rag	clean in your house	2,1
c	40	ring	symbolize a wedding	1,4
u	17	scissors	not clear	15,6
u	7	shoe	open a wine bottle	7,3
u	19	sock	make a ball sticky to throw it on a velcro	6
u	9	sponge	to clean water	15,5
u	2	stick	to build an elevator	15,8
c	37	tent	sleep outside in nature	0,8
u	12	toothpaste	polish metal	13,3
u	8	trousers	to build a structure	8,3
c	25	tyre	put it on a car	3,4
c	30	umbrella	protect you from rain	3,3
c	27	vase	put flowers	0,8
u	15	window	to shave your hair	11,2
Mental strategy			I tried to think how the objects look like and what are their physical properties.	

Subject 31

Block	Trial Nr	Object	Answer	Response time (s)
u	9	axe	you can throw it in to the door and use it as a handle	13,2
c	21	ball	play football	3
c	33	basket	put fruits in it	2,5
u	11	bed	you can put a couple of beds against the wall and so you can have your karate room where to train karate against the wall	9,9
u	7	book	you can put two books by the door so if your house is awash you can walk on them	13,6
c	38	bra	to feel comfortable	3
c	37	bread	eat it	2,4
u	5	can	no answer	
c	26	coffin	to store dead bodies	4,3
c	23	coin	to pay	3,9
u	17	colander	when you colour you hair you can put a colander over it so you have it of different colours	
c	39	comb	comb your hair	1,3
c	34	fork	bring food to your mouth	3,7
u	3	guitar	you can put it over a couple of books and use it as a table, and put guacamole inside the hole of the guitar	10,7
c	24	gun	to shoot people	1,9
c	30	hammer	put nails in the wall	5,1
c	27	hanger	to hang your clothes	1,3
u	14	helmet	put two of them under your feet and train to find your balance	11,2
u	8	lamp	you can put a picture over the light, then a paper over the picture and so you can trace the picture there	24,2
u	13	magnifier	you can put a photo behind it and it would look very weird, and could be a cool thing to put on the wall	19,5
c	29	mirror	to look yourself in your outfit in the morning	2,6
u	6	needle	if you have a very very small flower that cannot stay up, you can use the needle to help it stayng up	15,5
c	25	net	to keep flies away	2,8
u	2	paperclip	you can put a couple of them on the curtains to keep them open	11,3
c	35	pillow	rest your head on	1,5
u	16	pot	you can put your teddy bear in it and pretend that it is its space ship	30+2
u	19	rag	as a curtain for a door that has a very very small window	30+2
u	18	ring	take two rings, put a plastic foil on them and make your own glasses	9,1
c	28	scissors	cut things	2,2
u	10	shoe	you can put some sauce in it or some cous cous	12,3
u	15	sock	if you sew together hundreds of socks you can have your cool curtain	17,7
c	31	sponge	clean your kitchen	3,3
u	1	stick	if you have a dress that is too long, you can put the stick in it and swirl it around to make the dress shorter	18,9
c	22	tent	to sleep in it when you are on adventures	3,7
c	32	toothpaste	to clean your teeth	2,3

u	20	trousers	when there is the hurricane coming you can tie together two pairs of pants and tie them to your furniture, so it will not fly away	17,7
u	4	tyre	you can put two tyres one over each other and have a chair to put outside	30+2
c	36	umbrella	protect you from rain	2,2
u	12	vase	use it as a very very large drinking cup to use when you have a giant friend that comes to your house	22,1
c	40	window	to see what is going on outside	3,4
Mental strategy			I tried to think as less as possible of the common use. I tried to see it just as a pure object and try to put it in some context by creating a mental picture of it	

Subject 32

Block	Trial Nr	Object	Answer	Response time (s)
u	8	axe	as a weight to put somewhere	17
c	23	ball	play sports	3,6
u	3	bed	no answer	
c	30	book	read it	3,6
u	2	bra	to throw things, as a little catapult	16,1
c	25	bread	to eat	3,5
c	26	can	keep things in it	5,8
u	20	coffin	as fire wood	13,2
c	37	coffin	keep dead people in it	4,6
c	29	coin	to buy stuff	2,9
u	11	colander	to sort different kinds of liquids	30+1
c	38	comb	brush your head	4,2
u	4	fork	to comb your hair	20
u	15	guitar	you can live in it if it is a giant one	8,3
c	36	gun	shoot people	3,7
c	39	hammer	build stuff with nails too	4,7
c	40	hanger	hang up your clothes	3,4
u	9	helmet	as a basket	11
u	1	lamp	to catch different types of bugs	27
c	21	magnifier	look really small stuff	6,8
u	17	mirror	to scare other people and animals	18,7
c	24	needle	sew and make clothes	3
c	28	net	catch fishes or other animals	5,5
u	6	paperclip	not clear	5,3
u	7	pillow	as a protection gear	14
u	13	pot	as a helmet	7,3
c	33	rag	clean up different surfaces	4,6
u	10	ring	as a little weapon	15,5
u	14	scissors	eat with it, as a fork	17,9
c	34	shoe	wear it on your feet	3,9
c	27	sock	wear on your foot	4,1
u	18	sponge	as a shelter for little animals	15,2
u	16	stick	make tools out of it	30+2
u	12	tent	hang it to a tree to avoid having things on the ground	30+3
c	22	toothpaste	brush yor teeth	3
u	5	trousers	as a part of a sail on a boat	19,2
c	31	tyre	put on a vehicle to make it move forward	7,6
c	32	umbrella	protect yourself from rain	3,5
u	19	vase	as a stepping tool	25,4
c	35	window	get light in your room	3,4
Mental strategy			I thought to have the object in my hand and figure out what could I do with it. Also thought about the common use, and then try to think the opposite.	

Subject 33

Block	Trial Nr	Object	Answer	Response time (s)
u	40	axe	as a beard trimmer	27,4
c	15	ball	kick it	3,2
u	25	basket	as elbow protection	15,2
u	38	bed	as a raft	11,5
c	4	book	to read	2
c	14	bra	keep breasts in a good shape	8,3
c	3	bread	eat it	2,4
u	26	can	as a diving mask	22,6
c	17	coffin	store dead bodies	9,6
u	31	coin	as a little freesbee	14,7
c	8	colander	colander	7
c	5	comb	brushing hair	4,1
u	34	fork	to comb your hair	4,3
c	13	guitar	play music	2,6
c	6	gun	for shooting	2
u	32	hammer	as a walking sticj	9,3
c	1	hanger	hanging clothes	4,4
u	39	helmet	as a salad bowl	7,9
c	10	lamp	read a book	4,8
u	24	magnifier	as a hammer	16,9
c	7	mirror	look at yourself	10,7
u	33	needle	as a tooth-pick	13,2
u	35	net	as a rain jacket if the drops are very very big	16,8
u	30	paperclip	as a guitar pick	11,8
c	2	pillow	for the head to rest	2,9
u	22	pot	as a helmet	2,7
c	16	rag	wipe a table	3,8
u	29	ring	as a spaghetti holder	24,7
c	20	scissors	cut paper	1,9
c	19	shoe	protect your feet	2,5
u	23	sock	as a wallet	6,8
u	36	sponge	as a pillow	11,6
c	9	stick	point at things	7,2
u	21	tent	as a boat	3,6
c	12	toothpaste	brush your teeth	2,5
u	27	trousers	for carrying oranges	10,1
u	37	tyre	as a chair	16,2
c	11	umbrella	shelter from rain	2,7
u	28	vase	to store coins	10,9
c	18	window	see the sun	6,3
Mental strategy			I first thought of the most common use, then something similar or figure out something crazy based on the shape of the object.	

Subject 34

Block	Trial Nr	Object	Answer	Response time (s)
u	11	axe	as a precision cutter	10
u	17	ball	empty the ball and make a bag	8,7
c	32	basket	contain things and food	3,8
c	30	bed	sleep on it	2,7
c	40	book	to read things	1,4
c	29	bra	to hold breasts	6,4
c	23	bread	bake it and eat it	2,5
c	28	can	drink from it	4,2
u	7	coffin	sleep into it as a little bedroom	11
u	4	coin	stuck many under your shoes to get high heels	7,6
u	14	colander	use it on your head	6,5
c	38	comb	fix your head to look good	6,2
c	39	fork	to eat	3,2
c	31	guitar	play it to make music	3,2
c	27	gun	to defend yourself	4,1
u	16	hammer	for some kind of massage for your neck	23,9
u	8	hanger	use it as a sort of hook	11,5
c	36	helmet	to protect your head	2,3
c	35	lamp	to get light	3
u	1	magnifier	as a viewfinder on a gun	8,7
c	22	mirror	look at yourself	2
u	12	needle	use many needles for making massages	18,4
u	20	net	as a warrior cape	8,3
u	3	paperclip	as an earring	4,3
c	21	pillow	lay your head on it	2,8
u	2	pot	as a hat	4,9
u	13	rag	use it to fix your hair as a comb	6,3
c	24	ring	give it to your wife	6,2
u	10	scissors	use it in some sort of machine part	15,4
c	34	shoe	on your feet to walk	3,6
c	33	sock	on your feet to make them warm	3,5
u	9	sponge	not valid	4,7
c	25	stick	not valid	-
u	6	tent	break it and use it as clothes	4
c	26	toothpaste	brush your teeth	3,5
u	19	trousers	to dress the upper body, for your arms	19,5
u	5	tyre	as a sledge to go down the hill	17,9
u	18	umbrella	use many to make a tent	5,2
u	15	vase	stand on it in front of an audience	15,7
c	37	window	look out from your room	2,9
Mental strategy			For some of them I thought about the common use before getting the uncommon use.	

Subject 35

Block	Trial Nr	Object	Answer	Response time (s)
u	31	axe	to fix a dent	30+3
u	32	ball	as a boxing bag	30+2
u	22	basket	shield from the rain	21,1
u	27	bed	rescue cats	30+2
c	15	book	read it	0,6
u	40	bra	as a slingshot	30+2
u	25	bread	for insulation of walls	30+2
c	19	can	store something	1,4
c	5	coffin	get buried in	1,6
c	8	coin	buy something	0,7
u	38	colander	to look for gold in the ground	30+2
u	29	comb	for little gardening	30+4
c	6	fork	eat your food	0,6
c	2	guitar	play a song	0,8
u	34	gun	as a musical instrument	30+4
c	13	hammer	hammer a nail	2,1
c	3	hanger	put your clothing on it	1,4
u	36	helmet	for sledging down a hill	30+2
u	33	lamp	make a terrarian	30+1
c	17	magnifier	magnify something	2
c	18	mirror	do your make-up	2
c	12	needle	sew and fix something	2,2
u	23	net	building a shelter	14,2
u	28	paperclip	pick a lock	30+1
c	16	pillow	rest your head on	1
c	9	pot	cook food	1,4
c	10	rag	clean your table	1,2
u	35	ring	as a sink	30+3
c	4	scissors	cut a paper	1,2
u	39	scissors	no answer	-
u	30	shoe	to raise a table	30+2
c	20	sock	keep your feet warm	1,2
c	7	sponge	eat it	1,1
c	11	stick	for fencing	1,3
c	14	tent	go camping	1,6
u	37	tent	for isolation from something	30+3
u	24	tyre	as a heavy bag	18,7
u	26	umbrella	to gather water if you turn it upside-down	30+2
c	1	vase	put a flower in	1,6
u	21	window	creating tools	15,4
Mental strategy			I tried to think for analogies, trying to find other things these objects are used for or things I had already seen. Also tried to see if I got stuck into a first idea, and try not to get stuck there, but go for other solutions. But the pressure of the time did not let me it so good. I also asked to my self "What if..." like what if it was big, small, upside-down and so on. Hence try to get my momentum.	

Subject 36

Block	Trial Nr	Object	Answer	Response time (s)
c	3	axe	chop wood	13,1
u	30	ball	no answer	
c	4	basket	put mushrooms in it	8,7
c	6	bed	have a good night sleeping	10,7
c	20	book	read it	1,5
c	16	bra	wear it	4
c	19	bread	eat for breakfast	4
c	2	can	open it	4,2
c	5	coffin	bury people	13,5
u	36	coin	wear a lot of coins in your clothes and see if you get a sound when you are dancing	18,8
u	40	colander	put it on your head and use hair colour, so that you colour just some parts of your hair	11,1
c	13	comb	brush your hair	2,1
c	7	fork	take a piece of food and bring it to your mouth	15,7
u	22	guitar	keep the strings and use them to make a barbecue grill in the summer	25,5
u	34	gun	recycle it and borrow it	18,8
u	38	hammer	put some in different corners of the house, hang some stuff on them and make nice decorations	30+3
c	10	hanger	hang clothes	8,4
u	27	helmet	as a solid basket to bring and protect eggs	18,6
c	14	lamp	turn on the light	8,7
u	26	magnifier	use it like glasses for dogs	27,5
c	9	mirror	see yourself	8,4
u	32	needle	for acupuncture	9,3
c	15	net	fishing	7,7
u	35	paperclip	take many colourful ones, bring them to a party and put one on each glass, so everybody can recognize his own glass	17,1
c	1	pillow	sleep on	5,5
c	12	pot	make a nice warm dinner	7,9
c	8	rag	clean the table	5,1
u	33	ring	build a beautiful shiny castle with many of them	23,5
c	18	scissors	cut paper	5,2
u	24	shoe	put many in the fresh cement, so when it dries you will have a nice path done in your garden	30+5
u	28	sock	take a lot of coloured socks, sew them and make your nice pigiama	18,5
u	25	sponge	take many many of them and make a nice playground, like for jumping	30+2
u	29	stick	take two sticks ora a giant one if you want to hang a very giant hat or jacket	23,5
c	17	tent	sleep outside in the nature	6,4
u	37	toothpaste	for a pedicure foot strapping	28
u	31	trousers	as a car seat	30+4
u	21	tyre	swing it around your belly, as a hoola-hoop	12,1
c	11	umbrella	protect from rain	4,4
u	23	vase	use it for brewery	30+15
u	39	window	as a cool transparent surfboard	11,9
Mental strategy			I tried to make a mental picture of the objects and see them in other situations.	

Subject 37

Block	Trial Nr	Object	Answer	Response time (s)
c	21	axe	chop wood	1
u	12	ball	have it on my back and roll it iof I have back troubles	1,5
u	10	basket	unfold its interlacement and make a rope	7,8
c	22	bed	sleep in it	0,2
u	17	book	use it in place of legs of my couch	21,4
c	26	bra	hold breasts	1,4
u	4	bread	I could use a sharp one as a knife or a shade	22,1
u	20	can	as a guide to draw circles	11,5
u	15	coffin	as an entrance for a secret tunnel	16,4
u	5	coin	throw it to confirm the 50-50 chance	10,4
c	23	colander	make pasta	1,2
u	9	comb	as a knife in prison	11,4
c	24	fork	to eat	1,7
c	36	gitarr	play some music	0,5
u	19	gun	as a trigger for a light that is too far away	13,5
c	34	hammer	to hit nails	0,7
c	39	hanger	put your clothes on	1
c	28	helmet	protect my head	0,8
c	33	lamp	to have light	0,6
u	18	magnifier	to start a fire	5,8
c	40	mirror	look at yourself	0,8
u	16	needle	to extract an electronic pen that is broken from the PC	4,1
c	30	net	to fish	0,7
u	1	paperclip	to pick a lock	14,1
u	3	pillow	as an extra bag for small stuff when I'm sitting in the car	11,5
u	6	pot	wear it as a helmet	20,3
c	32	rag	to wipe surfaces	0,8
c	31	ring	for wedding	1,7
c	35	scissors	cut papers	0,6
c	25	shoe	protect your feet	1,1
c	37	sock	warm your feet	0,5
c	27	sponge	to clean	0,7
u	11	stick	to set a broken leg	9,9
u	8	tent	inflate it with hydrogen and use it as a baloon	10,6
u	7	toothpaste	as a glue	2,1
c	38	trousers	wear it as a helmet	1,1
u	13	tyre	cut it and use it to transport water	12,6
u	2	umbrella	I could use it to retrieve something from the water, as a hook	10,7
c	29	vase	put flowers in	0,6
u	14	window	put it in place of the floor to be able to see below	27,7
Mental strategy			I tried to move away from the first most obvious ideas. Pictured the objects in different environments and use my imagination to see what I could do with it.	

Subject 39

Block	Trial Nr	Object	Answer	Response time (s)
c	13	axe	cut wood	1,4
u	24	ball	call someone through the window, hitting the window with the ball	20,2
c	6	basket	put mushrooms	3,8
c	2	bed	to sleep	2,3
c	9	book	to read	0,8
u	27	bra	no answer	
c	18	bread	make a sandwich	2,2
c	12	can	storage for drinks	2,5
c	19	coffin	to bury someone	1,6
u	32	coin	to play a drinking game	27
c	17	colander	to eat pasta	2
u	35	comb	no answer	
c	10	fork	to eat	0,9
c	3	guitar	play a song	2,7
c	11	gun	shoot someone	1,7
u	39	hammer	play music with it	15
c	4	hanger	put the clothes on	4,4
u	21	helmet	get it into a fight	13,4
u	22	lamp	to hide money	19,2
c	14	magnifier	to read	1,1
u	31	mirror	as a security on lasers	11,4
c	15	needle	to make an injection	2,2
u	26	net	as decoration in a house	24,5
c	7	paperclip	hold paper	2,9
u	38	pillow	to shout without making noise	16,1
u	40	pot	use it as a helmet	2,9
u	30	rag	to cover a wound in an accident	11,1
c	1	ring	ask for a marriage	6,8
u	29	scissors	to measure angles	13,8
u	28	shoe	pretend it is a telephone	16,8
u	25	sock	to store the balls when you play bingo	9,2
u	33	sponge	to make abstract painting	6,9
c	16	stick	to walk	1,7
u	23	tent	to cover the bike when it is raining	16,1
u	37	toothpaste	put on somebody's eye while he sleeps	23,2
c	8	trousers	to dress	2,4
c	20	tyre	put it on a car	3,2
u	36	umbrella	to hypnotize someone	13,3
c	5	vase	put flowers in	2,2
u	34	window	to visit a girl without her parents knowing it	30+2
Mental strategy			I thought about strange uses I saw in my life	

Subject 40

Block	Trial Nr	Object	Answer	Response time (s)
c	5	axe	cut wood	2,5
u	30	ball	to distract the attention of a viewer	30+4
u	24	basket	as a hat to protect from sun	22,7
c	18	bed	to sleep	1,3
c	16	book	to tell a story	1
u	39	bra	to build a scale or something to escape	12,2
c	9	bread	to eat	2,2
c	12	can	drink something	1,6
u	35	coffin	to make a fire	28
c	10	coin	to pay something	5,1
c	1	colander	to drain water	5,8
u	28	comb	to play guitar	29,5
c	6	fork	to eat	2,1
u	25	guitar	break it on somebody's head	26,1
c	11	gun	kill someone	1,5
c	8	hammer	for bricolage	1,9
u	29	hanger	to start a fire or make a hole	30
u	38	helmet	as a recipient to put water inside	18,9
u	40	lamp	to cook something over its heat	30+14
u	27	magnifier	start a fire	10,2
u	21	mirror	to kill somebody	18,3
c	19	needle	to sew something	1,3
u	34	net	create a cloth or a t-shirt	25,9
c	2	paperclip	put paper together	6,6
u	26	pillow	to stifle, make somebody suffocating	25,8
c	15	pot	to cook something	1,3
c	20	rag	to wipe or clean something	0,9
u	36	ring	use it as a placement to put a napkin inside	16,7
c	14	scissors	cut things	1,3
u	22	shoe	no answer	
c	13	sock	protect your feet from cold	4,5
u	23	sponge	to create a building with many of them	22,3
u	33	stick	dance and do a performance with it	17,5
c	4	tent	for camping	2
c	7	toothpaste	brush your teeth	1,1
u	31	trousers	create a stair with many of them	5,2
u	37	tyre	put many many of them one over another and build a house	21,3
u	32	umbrella	protect you from the sun	30+2
c	17	vase	put flowers in it	1,8
c	3	window	have more light in the room	5,1
Mental strategy			I tried to think another situation, like for surviving for example. Or maybe try to move the object around to interact with other things. Something like that.	

A.8 Common and Uncommon Distribution

The numbers of times those the stimuli are repeated in each block is reported to show the randomization method is efficient.

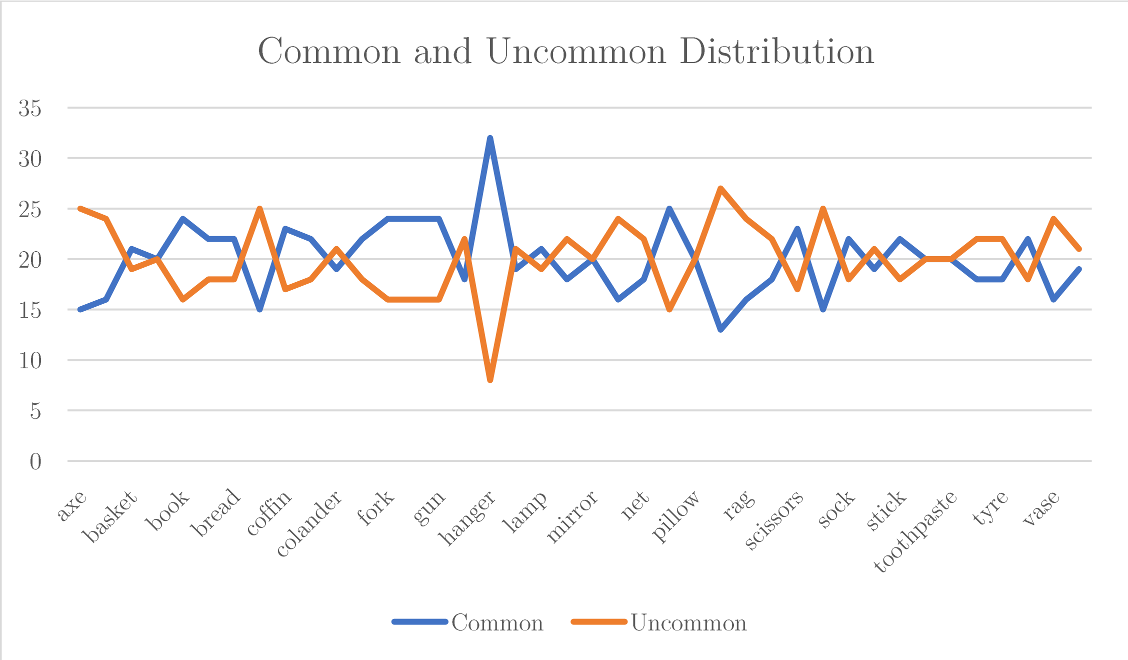


Figure 33 - Common and Uncommon Distribution of the stimuli

As shown in the table X, the distribution of the stimuli, between common and uncommon block, is equiparable. The casual distribution between them is efficient, with the exception of the "*hanger*", that represent an outlier. The standard deviation represented in table X demonsts that it is a solid casual distribution.

Table 1 - Average and Standard Deviation of the distribution of the stimuli

	Number of Common	**Number of Uncommon**
Average	**20,025**	**19,975**
St. Deviation	**3,5248**	**3,5248**

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