Politecnico di Torino

Master's Degree Course in

Engineering and Management

Master's Degree Thesis

Effect of time of the day and environmental factors on creativity in engineering design

Supervisor

Prof. CANTAMESSA Marco

Advisor

Dr. COLOMBO Samuele

Author

PIGA Federico

Academic year 2021/2022

ABSTRACT

This study is part of a broader research, conducted by the Polytechnic of Turin in collaboration with the Department of Psychology of the University of Turin, and its goal is to find out the relationship between the engineering design processes and the external environment, through the study of neurophysiological signals that reflect the impact the factors analyzed have on the subjects' work, influencing their mental condition in terms of stress and creative attitude.

To this end, the research is divided into two chapters, after a first introductory one.

In the first one, a preexisting experiment (Colombo, et al., 2020), was taken up, from which data some ANOVAs were carried out to study the influences of the first external factor: the time of the day. The results explain that during the afternoon there are greater TRP (Task Related Power) values for all the waves, probably due to mental stress, that is increasing during the day, and to circadian rhythms.

The second one, through an approach from general to particular, aims to analyze first the structure of creative thinking, along a multidisciplinary horizon, and then go down to the specifics of the creative or innovative space. It concerns the study of those environmental variables that can influence creative work, from the analysis of the literature to the definition of an experiment. The most studied are *noise*, *temperature*, *lighting* and *colour*.

In general, previous studies agree especially about the temperature, that is ideal for workplaces around 21°C. In all the other factors the research is far from an overall concordant result: about the colours, the findings reflect the psychological meaning of each one, i.e. the red enhances alertness due to its correlation with errors and danger, and blue, connected with openness, encourages innovative thinking; then, the noise can be stressful but can support divergent thinking. Finally, the lighting is, at the same time, the most studied factor and the most interesting: the future experiment proposed is about that factor, to find confirmation to both the hypothesis that a dimly illuminated workplace has a positive influence on creativity in engineering design (Steidle & Werth, 2013) and that there is an optimal range of illumination around 300 – 440 lx, studying which variations imply an engineering design task.

TABLE OF CONTENTS

INTRODUCTION

BACKGROUND

The concept of creativity is generally recognized as a specific personal quality (Findlay & Lumsden, 1988), which aims to create something new and innovative (novel and valuable) (Shalley, 1991) (Woodman, Sawyer, & Griffin, 1993), both at the level of products and at the level of simple ideas or processes. In a rapidly developing world, creativity has become an important factor in many areas and accompanies the engineering work too, during the processes of idea generation and development in the realization of a product.

It is important to add that although creativity is often studied as an individual characteristic, it is increasingly sought after by organizations and companies, which not only seek this characteristic in their employees but, above all, try to cultivate it through suitable working environments that stimulate creative thinking.

This concept has been studied since 1926, when Graham Wallas published its book “The art of thought” (Wallas, 1926); he subdivided all the creative processes into four phases: *preparation*, *incubation*, *illumination* and *verification*.

- Preparation: A problem is identified and considered.
- Incubation: Conscious effort at creativity is not made; however, unconscious or subconscious attempts are applied.
- Illumination: The moment when a creative idea bursts into conscious awareness.
- Verification: The idea is consciously verified, evaluated, elaborated, and finally applied.

  (from (Daikoku, Fang, Hamada, Handa, & Nagai, 2021)*)*

These phases express the different typologies of human thinking, that vary from convergent to divergent (Guilford, 1967).

Convergent thinking focuses on reaching one well-defined solution to a problem and characterizes the logic and schematic tasks.

Divergent thinking, instead, is its opposite and aims to generate more ideas and to develop multiple solutions to a problem, in a creative horizon.

It is important to specify that these two types of thinking are not totally separate, in the practical world they coexist, and a lot of work needs a balance between them. In fact, going back to the Wallas' subdivision, it is possible to see that the four phases are characterized, each one, by a different type of thinking, and all together they compose a creative process, as can be an engineering design work. Preparation and verification need a practical view of the problem, that needs firstly to be structured and preliminarily defined (i.e., in a project management phase, it can be useful to create workflows or a project plan), and, lastly, the ideas must be verified and evaluated: so, these phases are driven by convergent thinking. In the middle incubation and verification needs divergent thinking, in a moment when the person must identify all the solutions to the problem, looking at it from multiple perspectives. These two phases compose the idea generation, a concept that will return in the second chapter of the present research as the phase during which the subjects had to think about their solutions.

Finally, each phase is characterized by its particular neurophysiological signals, in particular, the alpha power is particularly sensitive to creativity, as it increases during creative ideation, and during divergent thinking (Fink & Benedek, 2013) (Schwab, Benedek, Papousek, Weiss, & Fink, 2014).

OBJECTIVE

This thesis work is part of a broader research, conducted by the Polytechnic of Turin in collaboration with the Department of Psychology of the University of Turin, and its goal is to find out the relationship between the engineering design processes and the external environment, through the study of neurophysiological signals that reflect the impact the factors analysed have on the subjects' work, influencing their mental condition in terms of stress and creative attitude.

The first phase of this research, through two different ANOVAs on the data of a previous experiment run by Colombo et al. in 2020 (Colombo, et al., 2020), aims to find which are the neurophysiological correlation between subjects that perform the task during a different time of the day. In particular, the day was divided into morning (until 12 AM), lunchtime (12 AM – 2 PM), and afternoon (after 2 PM). That is matched with the analysis of other factors, such as the subjects' educational background (engineer or designer) and the type of solution they are thinking about (common or uncommon).

Each of these analyses was run for alpha, beta, gamma, delta and theta waves.

In the second phase, the main objective is to enlarge the research about the environmental effects on creativity, introducing other parameters: noise, temperature, lighting and colour. After a literature review about the factors, it is suggested an experiment to study the effect of lighting, and in particular of dim illumination, on creativity in engineering design.

METHODOLOGY

Given the particular structure of this study, deeply described in the next section, the methodology is divided into a statistical analysis, for the first part, and a review of the existing literature, for the second one, plus the definition of an experiment.

More precisely, the statistical analysis is conducted by two ANOVA, run by the programming language R, through the IDE RStudio. The data, organized in files .xlsx, was uploaded in specific tables in the IDE through the package "readxl", which permits to use the specific function read_excel(). Each table contains data of a particular wave, and on these the two 3-way ANOVA were run, through the function aov(), for each group of electrodes (pre-frontal, frontal, temporal, central, parietal, occipital) or for each hemisphere (left or right). Then, the Tukey post-hoc analyses about the time of the day were done with TukeyHSD(), and the boxplots through ggboxplot() from the package "ggpubr".

The review of the literature, on the other hand, was based on specific queries on the database Scopus, from Elsevier. In particular, two queries were used, created by an iterative procedure, where each one gradually completed itself on the basis of its results' keywords. Below, there are the two queries:

- TITLE-ABS-KEY (("creativity" OR "creative ideation" OR "creative space") AND ("Physical space" OR "physical work environment" OR "work environment" OR "workplace" OR "Innovation environment" OR "Innovative space" OR "environmental effects" OR "environmental settings") AND ("literature review"))

- TITLE-ABS-KEY ((("blue" OR "color" OR "color effect" OR "green" OR "red") OR ("darkness" OR "light" OR "light comfort" OR "light environment") OR ("temperature" OR "thermal discomfort" OR "warmth") OR ("noise")) AND (("EEG" OR "electrocardiogram" OR "electrocardiography" OR "electroencephalogram" OR "electroencephalography" OR "ECG" OR "eye tracking" OR "heart rate variability" OR "HRV" OR "eye tracker" OR "eye tracking" OR "functional magnetic resonance imaging" OR "fMRI") OR ("creative performances" OR "cognitive performances")) AND ("physical space" OR "physical work environment" OR "work environment" OR "workplace" OR "workspace" OR "physical environment" OR "innovation environment" OR "innovative space" OR "environmental effects"))

The first is regarding literature reviews, it gives 35 results, reduced to 2 main reviews: from Daikoku et al. (Daikoku, Fang, Hamada, Handa, & Nagai, 2021) and from Thoring et al. (Thoring, Desmet, Mueller, & Badke-Schaub, 2020). Other two useful reviews were found from their citations: one from Daikoku's (Dul, Ceylan, & Ferdinand, 2011) and one from Thoring's, (Meinel, Maier, Wagner, & Voigt, 2017).

The second query is structured to cover the greatest number of articles of interest. The keywords are encapsulated in 3 groups.

The first one includes all those words that refer to the environmental factors that are being studied. In this group, you can already find what are the factors of interest in the study of the environment, for example the color red, blue or green, or even the specific study of brightness through the phases of darkness.

The second group is instead divided into two subgroups, the first, larger, refers to the type of analysis of interest, or the study of neurophysiological signals. Therefore we find those that in the literature are the most studied signals: EEG, ECG, eye-tracking, HRV, and fMRI, along with their related measurement tools and derived keywords; the second subgroup, consisting only of the words "creative performances" and "cognitive performances", is useful to broaden the search to those articles that, despite they do not study the phenomena through specific neurophysiological tools, they involve a study based on their effect on creative and cognitive performances, for example through an external evaluation of the task chosen for the study, or through a specific questionnaire in which participants in the experiment can express their personal feelings about it.

The third and last group concludes the query by restricting the field of research to the study of environmental factors, or the work environment, bringing the focus of the query on studies as concrete as possible, with the aim of analyzing the external factors colour, noise, lighting and temperature in the workplace.

It is important to note that the number of results of this query is constantly increasing, 194 at the moment, reflecting the fact that research on this topic is alive and evolving.

STRUCTURE

The structure of this thesis is already introduced by the previous sections.

Specifically, it is divided into three chapters.

The first chapter describes the context of the research, helping the reader to familiarize with some concepts about the engineering design process and the neurophysiological signals.

The second chapter concerns the statistical analysis. It includes, after the introduction, a description of the previous evidence in the literature about the differences between people’s morning or afternoon attitudes, describing the phenomena of the chronotypes and the circadian rhythms; then, it is described the experiment (Colombo, et al., 2020) in a new section, to arrive at the core of the chapter, where are described the ANOVAs performed and are discussed the results.

The third chapter, instead, is divided into a first part that includes a literature review of each of the environmental factors studied (noise, temperature, lighting and colour), useful to understand on which results the literature agrees and about what is more interesting to proceed for the future research; and a second part that examines a proposed future experiment.

1. INITIAL CONTEXT

1.1. CREATIVITY AND CREATIVE THINKING IN ENGINEERING DESIGN

Before going specifically into the subject matter of this research, it is useful to clarify the context in which we are entering, defining and describing the process of engineering design and product development and its connections to creative thinking.

What is engineering design?

It is a process in a series of steps that engineers follow aiming to solve a product design problem. The steps, from Cantamessa and Montagna (Cantamessa & Montagna, 2016), are:

- **Product planning** → the initial phase of the process, during which the designer has the objective to give the first definition of the product, on the basis of the market's expectations and of the technological function needed. Briefly, it is the phase in which it is created the first design brief of the product, contextually to its market positioning, containing the user needs and requirements.
- **Conceptual design** → it is created a product concept, defining with more precision the technological solutions, starting to draft the technical specifications of the product.
- **System-level design** → that is the phase in which the designer creates the product architecture, the list of subsystems that make up the product and their reciprocal interfaces. At the same time, the develop or buy decisions about the product are made.
- **Detailed design** → at this point there are taken the decisions about materials and components, eventually reviewing the decision in the system-level design phase.
- **Prototyping and testing** → it is created a prototype of the product to be tested. The same can be done through virtual simulations, a progressively-

growing solution, due to its predictive power and low cost. In the case of physical prototyping, there can be created alpha, beta or pilot prototypes, depending on the testing phase the process is (preliminary, intermediate or final).

- **Process design** → processes that will permit to produce, distribute and serve the final product are defined.
- **Product launch and production** → in this final phase, the product is launched in the market, often through pilot lines that permit to test the product and prepare the machines for the full production.

As it is possible to see, these steps are a practical transposition, applied to engineering design, of the four phases of creative thinking described in the introduction (preparation, incubation, illumination and verification). The product planning phase is near to the preparation, in which the problem is identified and the designer starts to think about the possible solutions; then, there are all the design phases (conceptual, system-level, detailed and process), which represents the creation of the product, starting from the idea generation (incubation and verification) and designing all the features which are needed to a product to be launched in the market; finally, the phases of prototyping and launch are correlated to the verification, during which the creative idea, and so the product, is verified, evaluated and launched in the market.

For the purpose of that research, it is interesting to go deeper in the study of idea generation, i.e., the conceptual design phase.

This phase is the core of the product development process, since it is during this that the creative and innovative factors take the lead. In fact, after a first phase of study of the market and clarification of the problem, characterized by convergent thinking, the divergent one emerges.

The conceptual design phase, then, is usually described as an alternation between idea generation and idea evaluation, respectively a divergent and a convergent phase; the designer has to both think to produce new solutions and to evaluate the previous one, in order to choose the one that best fits the requirements.

With this objective, different methods of idea generation have been developed over time, each characterized by a different degree of structurization of creative thinking (the more it is structured the more is near to a convergent phase). Each method is equally valid, and during the creation of a product can be used even several, by one person, or, more frequently, by a working team, composed of people with different characteristics. The main ones are:

- **Brainstorming** → (Osborn, 1953) It requires participants of the working team to freely propose each other new ideas, without criticizing any of them. It is a totally unstructured method.
- **Scamper** → (Eberle, 1996) It is a complementary technique to brainstorming, as participants are required to suggest their ideas following the tips deriving from the word SCAMPER, acronym of "substitute", "combine", "adapt", "modify" (or "magnify", "mignify", "multiply"), "put to other use", "eliminate" and "reverse" (or "rearrange").
- **Wish and wonder & law-breaking** → it is a variant of brainstorming during which participants are required to totally lose their constraints, pretending to live in an ideal world with all the possibilities open.
- **Morphological analysis** → in this problem-solving technique, the initial problem is divided into parts, that represent the essential parameters that have to be analysed and solved. It is a semi-structured method.
- **TRIZ** → the more sophisticated method, from the Russian acronym of "theory of inventive problem solving". It is based on the theory that most of the problems, especially the most complex ones, include contradictory requirements, leading to the compromise that the improvement of a parameter is achieved at the expense of others, in a way that one of the requirements will not be satisfied. The only solution to this "paradox" is to think in an innovative way, analysing the problem and applying the TRIZ instruments, contained in the "contradictions matrix", a matrix that includes 40 generic principles that help the designer to abstract the problem and define a problem model that leads to the creative and concrete solution.

These methods will be re-proposed in chapter 3, i.e., in the definition of an experiment in which the subjects are required to solve engineering design problems with different methods: brainstorming, morphological analysis and TRIZ.

1.2. EVOLUTION OF THE SCIENCE OF DESIGN

Design processes are studied within the research field of Science of Design, since 1969, year in which the political scientist Herbert Simon published its book "The Sciences of the Artificial" (Simon, 1969). He was the first to suggest studying the design factors with respect to the cognitive human responses, understanding the artificial world.

Years of evolution of these studies lead to the protocol analyses: these types of studies sign the transition from a phase of pure observation of the subjects' outputs to more scientific and methodological research.

Protocol analysis consists in the direct observation of the subjects', trained to think aloud as they find the solution to a problem, with the goal to write a verbal protocol (Ericsson & Simon, 1984). This gives to researchers insights about the participants' cognitive processes, to make all the task activity the most explicit possible. It is a type of analysis common in cognitive psychology and cognitive science fields, but have the important limitation of being based only on the verbal output.

Specifically, the problem of a study based on the explication of the subjects' sensations is that it is a method that includes only signals arising from the sphere of consciousness, while it is known that a large part of our emotions and, eventually, predispositions, cannot be explicitly explained.

In this panorama, the researchers start to study human behaviour and the science of design using neurophysiological instruments, that give a more objective and scientific vision of the outputs, allowing access to the subconscious sphere and to distinguish in a clear way the various phases of reasoning and thinking that a subject goes through during a task procedure.

1.3. NEUROPHYSIOLOGICAL SIGNALS

Given this premise and clarified how the research of engineering design has evolved to reach the neurophysiology, it is useful to describe what are the possible analyses that can be conducted with this type of instruments, and what is their application and correlation to the research.

Both in the next chapter about the statistical analysis of the experiment run by Colombo et al. in 2020 (Colombo, et al., 2020), and in chapter 3, in the phase of definition of the experiment, will be proposed, but other types of signals were also included in the literature review phase, briefly described below.

- **EEG:** it consists in the detection of the electrical activity of the brain, through the measurement of its waves, that are usually classified by their frequency: gamma (> 30 Hz)**,** beta (12-30 Hz)**,** alpha (8-12 Hz)**,** theta (4-8 Hz)**,** delta (0.5-4 Hz). That waves characterized each one different phases of thinking; gamma ones, for example, are shown during short-term memory and beta during focusing tasks and states of high alertness and anxiety, so both of them are more aimed at convergent thinking; alpha, instead, characterized phases of life during which there are fewer inhibitions and constraints of thinking, so they are aimed to divergent thinking. Compared to fMRI, it offers a better temporal resolution
- **ECG:** this method is used to record the electrical activities correlated to the cardiac contractions, through the metric of the heart rate.
- **Eye-tracking:** it is a process that monitors eye movements to determine where, what and for how long the subject is looking.
- **fMRI:** it is used to measure brain activity by detecting changes in blood flow. Compared with the EEG, it offers a better spatial resolution.

The EEG is often used in experimental research, due to the advantages that have with respect to other possibilities: it only requires a quiet room and a low-invasive equipment, leading the subjects to sensations similar to reality, also thanks to the fact that EEG is more tolerant to subject movements; then, as a direct consequence, the instruments have lower costs compared to other solutions.

1.4. THE WORK ENVIRONMENT

Given these premises and entering more into the specifics of this research, it is appropriate to introduce the theme of the work environment, since it will be the core of the next chapters.

In a world increasingly focused on innovation, the working places have to follow this trend. As written before, creativity is year after year becoming more than a simple individual characteristic, the organizations have the objective to support the internal creativity, no longer defined by the single predetermined employee’s creative attitude, influencing and improving it through different methods at the individual, team and organizational level.

Recent studies (Meinel, Maier, Wagner, & Voigt, 2017) divide the components that influence creativity into two groups: the social work environment, composed by those social-organization factors such as the type of the job, the team fellowship or the nature of the leaders, and the physical work environment, the topic of this research.

In the study of the physical work environment, the elements that can influence creativity are often divided into tangible and intangible factors (Dul, Ceylan, & Ferdinand, 2011) (Meinel, Maier, Wagner, & Voigt, 2017). The first group is composed of elements as the furniture, the plants, the windows, the office equipment and all the decorative elements of the workplace; the second, analysed in chapter 3, includes the noise, the colours, the lighting and the temperature, as most studied factors.

2. STATISTICAL ANALYSIS

2.1. INTRODUCTION

The second chapter of this thesis is a statistical analysis of a previous experiment (Colombo, et al., 2020).

The experiment was run during the whole day, and the 40 participants ran the task (*Alternative Uses Task*) at different time, some of them in the morning, some of them in the afternoon. The analysis aims to introduce a new variable, the time of the day, to see if it is statistically significant as an independent factor, and in correlation with others, such as the background of the subjects, the condition common or uncommon of the task, or the hemisphere activation.

The literature gives interesting starting points for that research: the time of the day is a significant parameter in correlation to cognitive performances and neurophysiological activity; in fact, some studies confirm a time-dependency during task execution. It seems that there are differences in performing different type of tasks at different time of the day, and the existence of an EEG circadian rhythm can influence the measurements.

2.2. MORNING AND AFTERNOON EFFECTS

Looking more specifically at the differences between morning and afternoon, it is important to point out that they do not have a fixed and definite influence on every individual (Venkat, Sinha, Sinha, Ghate, & Pande, 2020), in fact, the chronotypes exist.

The chronotype is the characteristic of humans that indicates whether they are most active at a particular time of day, and the two most common are: 'lark', people who are most active in the morning and therefore prefer to wake up early to capitalise on this; and 'owl', who on the contrary are most active in the evening and prefer to fall asleep late.

The majority of people cannot be categorised into one type or the other, which is why we all have more or less the same habits, so we generally define a tendency towards a particular chronotype rather than a total belonging.

In the above-cited study, for example, chronotypes M, "morning" (lark), and E, "evening" (owl) are contrasted and their effects on cognitive measures and on EEG are investigated. The most significant results show a higher level of alpha and beta power in the parietal lobe during the evening for chronotype E, thus demonstrating the existence of a neurophysiological reaction to the personal tendency and a greater propensity towards creative work for chronotype E (Giampietro & Cavallera, 2007).

The effects of the chronotype are therefore directly linked to the mentioned circadian rhythms, which influence human performance in everyday activities. They refer to our biological rhythms, which can be circadian (one cycle per day), ultradian (more than one cycle per day), and infradian (less than one cycle per day).

These rhythms and variations are present in every function of our body, from body temperature to hormone secretion, or even from metabolic activity to the above-mentioned sleep-wake cycle; studying the cognitive performances it is interesting to note that the lowest level of cognitive performance is in the early morning time slot (07:00-10:00), then improves around noon (10:00-14:00), but there is a decline after lunch at 14:00-16:00. Performance improves again in the afternoon, reaching its highest level in the evening (16:00-22:00). Finally, they decline at night (22:00-04:00) and reach its lowest levels at dawn (04:00-07:00) (Valdez, Ramirez, & Garcia, 2012).

One of the most interesting effects of the circadian rhythm for our study is that concerning brain waves, which show a higher level during the afternoon hours for all frequencies, where the larger the frequency of the cerebral waves, the larger its diurnal maximum (Petersen & Harmon-Jones, 2009) (Cacot, Tesolin, & Sebban, 1995).

This circadian EEG rhythm is therefore reflected in the ability of individuals to perform better or worse a given task during the morning or afternoon, depending on what is its type: tasks of a more schematic and repetitive type are generally better to be performed in the morning, unlike tasks of a more creative type (Mackenberg, Broverman, & Vogel, 1974).

This first evidence stands as the starting point of the present research, from which it is possible to hypothesize a significant difference between brain levels during the morning or the afternoon, with a tendency to have higher values during the latter, in particular during the divergent thinking phase of the experiment.

2.3. DESCRIPTION OF THE EXPERIMENT

As it is in Fig. 2.3.1 in the next page, the experiment was run by 40 students, 28 males and 12 females, characterized by different backgrounds (engineers or designers).

During a day they perform a revised version of the Alternative Uses Task (Guilford, 1967), which requires the subjects to uncommon uses for everyday objects. The task was divided into 2 conditions, according to the experimental paradigm by (Jauk, Benedek M., & Neubauer, 2012): it is requested to the participants to find both a common use and an uncommon use for the objects, to analyze the two phases of the creative thinking, convergent and divergent.

The experiment was structured as follows (Fig. 2.3.2): 40 items were assigned randomly to one of the two conditions (common or uncommon), and each condition-phase consisted of 20 trials. Each trial starts with a blank screen for 5 seconds, as an inter-trial interval, then a fixation cross was shown in the centre of the screen for another 5 seconds, useful as a reference period. At this time the word appeared on the screen for 500 milliseconds, to start the idea generation phase, with another cross in the screen for 30 seconds. When the subjects wanted to present their ideas, they can press the spacebar, to access the next phase, where a balloon appear on the screen, and they could vocalize their solutions. After that, another spacebar press started the next trial.

When the first block ended, a 2-minute break preceded the start of the second one, structured as before.

At the end of the experiment, the participants were requested to answer a questionnaire.

The dependent variable was calculated as the Task Related Power (TRP): for each electrode, for each trial, for each subject, TRP was calculated as the difference between the power of the idea generation period and the corresponding reference period (Pfurtscheller & Lopes da Silva, 1999).

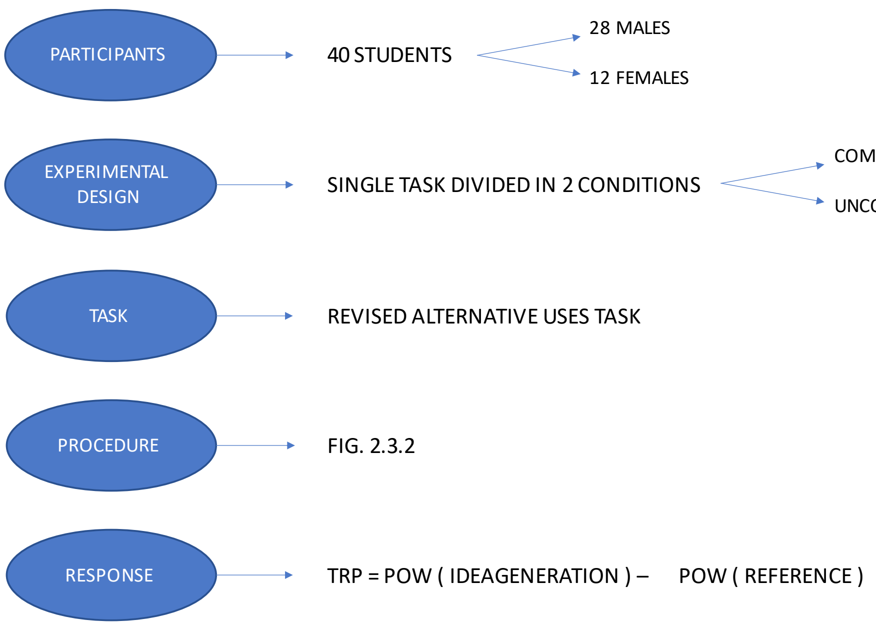

Fig. 2.3.1: Description of the experiment

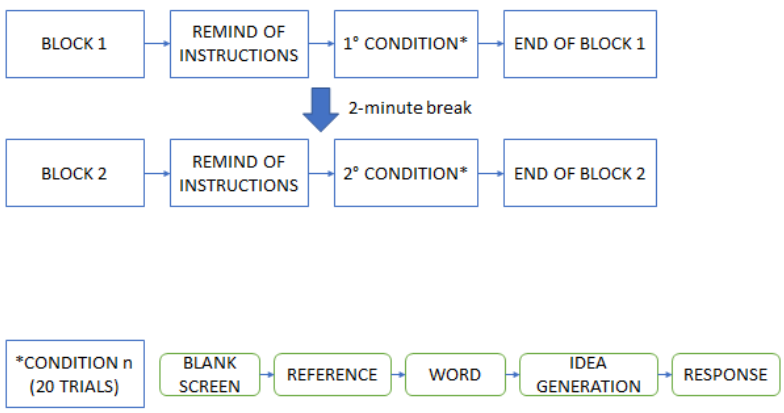

Fig. 2.3.2: Task procedure

2.4. ANOVAs

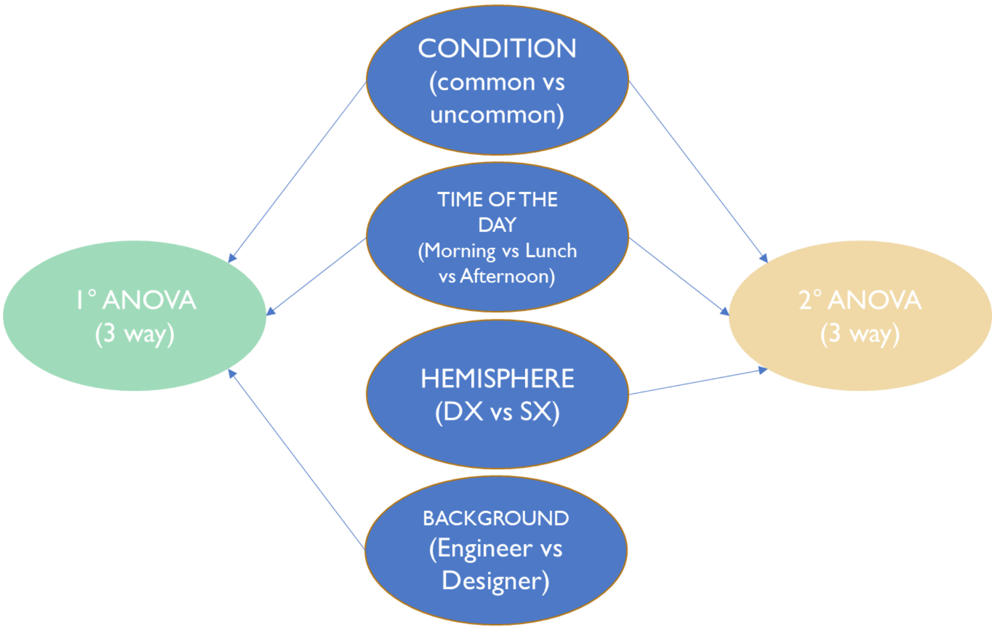

Fig. 2.4.1: ANOVAs' variables

The analysis was carried out by two different ANOVAs, as shown in Fig. 2.4.1.

The independent variable taken into consideration were: **condition** (*common* vs *uncommon*), **time of the day** (*morning* vs *lunchtime* vs *afternoon*) and **background** (*designer vs engineer*) in the 1st ANOVA; while in the 2nd one the **hemisphere** (*right* vs *left*) takes the place of the background.

For both the analysis the electrodes' TRPs were subdivided into groups (Fig. 2.4.2), by calculating the mean between the values. In the 1st ANOVA the subdivision was by lobes: **pre-frontal** (**FP**, from *Fp1* and *Fp2*), frontal (**F**, from *F7*, *F8*, *FT9*, *FT10*, *F3*, *Fz*, *F4*, *FC5*, *FC1*, *FC2* and *FC6*), **central** (**C**, from *C3*, *C4*, *CP5*, *CP1*, *CP2* and *CP6*), **temporal** (**T**, from *T7*, *T8*, *TP9* and *TP10*), **parietal** (**P**, from *P7*, *P8*, *P3*, *Pz* and *P4*) and **occipital** (**O**, from *O1*, *Oz* and *O2*); while in the 2nd ANOVA the subdivision was by hemisphere: **left** (**SX**, from all the odd-numbered electrodes) and **right** (**DX**, from all the even-numbered electrodes).

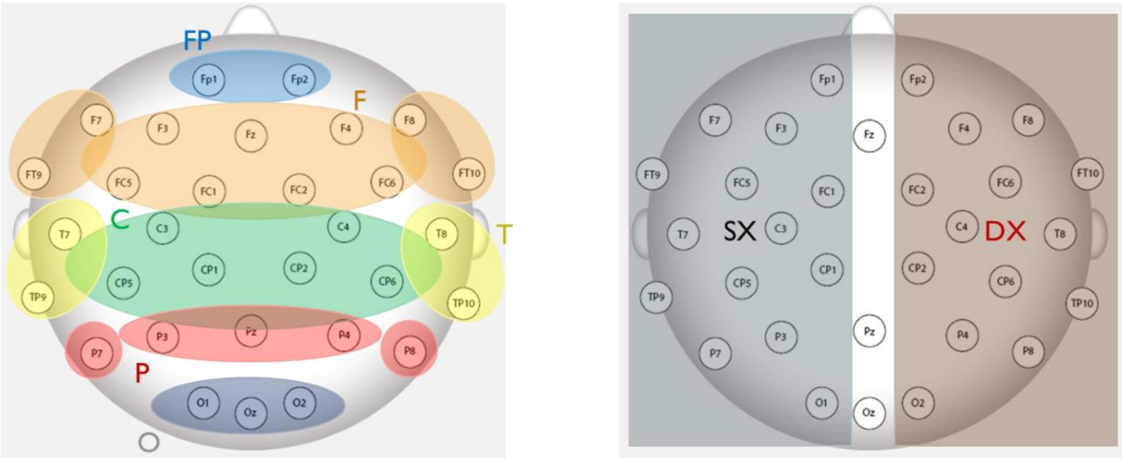

Fig. 2.4.2: Electrodes placement (according to the international 10-20 system) and subdivision for 1st and 2nd ANOVAs

It is important to add that while the second ANOVA takes into consideration all the 40 participants, in the first one there were removed 8 subjects, due to lack of data in terms of educational background.

2.5. RESULTS

The results are shown in the following pages, through tables that contain the resulting p-values of the respective analysis, where on the columns there are the independent variables (condition, time of the day and background, and their interactions), and on the line the type of wave, for all the groups of electrodes. The values are highlighted, to facilitate the reader with different green intensity, on the base of the significance of the result: the level of significance, following the suggestion of R, were divided into the following groups, identified with different shades of green, brighter the more the p-value is near to 0.

The groups are:

→ 0

→ 0.001

→ 0.01

→ 0.05

→ not significant (ns)

Starting from the 1st ANOVA, the results show that each independent variable has a significant effect on the subjects (Tab. 1.1):

- Condition → significant results for alpha, beta and gamma waves, for all electrodes except for the pre-frontal lobe about alpha waves.
- Time of the day → significant results for all the waves in all the lobes, except for the frontal lobe about beta waves.
- Background → significant results for all the waves in all the lobes, except for the parietal and the occipital lobes about beta waves.

The interaction effects for this first analysis (Tab. 1.2), instead, show 2 more significant interactions and 2 less significant. In fact, time of the day and background correlation is significant for all the waves in all the lobes, and the combined correlation between time of the day, condition, and background presents not significant results only in the occipital lobes about alpha and delta waves. On the other hand, the interaction between time of the day and condition shows only some scattered significant results, and the one between condition and background has significant results for beta and theta waves, and some other in delta and gamma 1, but with relatively high p-values.

The 2nd ANOVA (Tab. 1.3 and 1.4) adds to these first results some interesting points, first of all, it confirms the previous results about time of the day and condition, showing significant p-values in the same lobes and waves (except for gamma 2 in the time of the day analysis); then gives the information that the hemisphere is not a significant factor neither as independent (where there are significant p-values only for alpha and beta) nor in its interactions, that are all not significant.

In the next section, there will be a deeper analysis of these results, to understand which is the trend of these results, trying to answer with more precision the research questions, and to explain the effect of the considered factors.

	CONDITION						TIME OF THE DAY						BACKGROUND					
	FP	F	T	C	P	O	FP	F	T	C	P	O	FP	F	T	C	P	O
ALPHA	ns	0.003717	2.67e-05	2.44e-06	5.65e-05	0.00893	8.58e-09	1.37e-08	3.33e-07	1.34e-06	1.05e-05	6.97e-06	0.001453	0.000121	0.003979	0.02432	0.0414	0.00522
BETA	6.83e-07	2.25e-08	2.23e-06	9.71e-05	3.60e-08	2.31e-11	0.008808	ns	0.000126	0.05500	0.00730	0.003569	0.000340	0.000123	0.001891	0.00945	ns	ns
GAMMA 1	<2e-16	1.87°e-13	2.74e-16	2.32e-11	<2e-16	<2e-16	0.004891	0.01055	0.002481	0.000445	8.47e-05	0.000539	2.18e-05	2.50e-05	0.000209	8.65e-05	0.000102	6.82e-06
GAMMA 2	2.34e-16	2.65e-12	2.84e-15	3.61e-10	5.51e-15	1.71e-15	0.005468	0.039944	0.01439	0.00954	0.00268	0.030678	0.000461	0.000763	0.00135	0.00240	0.00238	0.000172
DELTA	ns	ns	ns	ns	ns	ns	2.52e-06	4.93e-07	0.00423	0.00033	0.00781	0.00837	5.12e-07	1.27e-06	1.54e-05	6.24e-08	3.37e-06	1.90e-05
THETA	ns	ns	ns	ns	ns	ns	0.000695	0.00014	5.56e-06	0.002199	8.89e-06	3.67e-07	9.86e-05	1.99e-05	1.68e-06	0.000562	0.000174	4.06e-05

Tab. 2.1: 1st ANOVA - p-values

	TOTD:CONDITION						TOTD:BACKGROUND						CONDITION:BACKGROUND						TOTD:CONDITION:BACKGROUND					
	FP	F	T	C	P	O	FP	F	T	C	P	O	FP	F	T	C	P	O	FP	F	T	C	P	O
ALPHA	ns	ns	ns	ns	ns	0.01184	0.000265	0.000682	0.000714	0.00127	3.43e-06	5.87e-09	ns	ns	ns	ns	ns	ns	0.000696	1.87e-05	0.000235	0.03233	0.0875	ns
BETA	ns	ns	0.009004	ns	0.07248	0.094671	0.018919	0.001339	0.062189	0.00164	0.00255	0.000168	0.000891	0.053513	0.000539	0.01206	0.002555	0.002786	9.05e-07	4.58e-07	6.35e-05	3.50e-06	1.33e-05	9.97e-05
GAMMA 1	0.095454	ns	ns	ns	0.074957	0.088445	0.000745	0.00326	0.018838	0.020051	0.005245	0.010037	0.035735	ns	ns	ns	ns	0.051934	0.000696	6.64e-05	0.000128	0.000108	0.001153	0.000705
GAMMA 2	ns	ns	ns	ns	ns	ns	0.007039	0.020433	0.08066	0.06837	0.01279	0.013064	ns	ns	ns	ns	ns	ns	0.000340	1.18e-05	1.35e-05	3.67e-06	2.62e-05	3.26e-05
DELTA	0.02303	0.05256	ns	ns	ns	ns	1.00e-06	7.00e-06	7.34e-07	3.20e-06	2.82e-06	7.48e-05	ns	0.08600	ns	0.03788	ns	ns	0.00137	0.00101	0.01195	0.02874	0.06887	ns
THETA	ns	ns	ns	ns	ns	ns	0.000933	2.17e-05	0.00010	0.000173	0.000782	0.000801	0.086918	0.05740	0.05537	0.028911	0.015563	0.029577	0.000126	9.52e-06	0.00369	0.003797	0.010237	0.010450

Tab. 2.2: 1st ANOVA - p-values (interactions)

	CONDITION	TIME OF THE DAY	HEMISPHERE
ALPHA	5.43e-07	2.64e-14	0.0170
BETA	1.41e-09	0.000876	0.009126
GAMMA 1	<2e-16	0.0175	not significant
GAMMA 2	<2e-16	not significant	not significant
DELTA	not significant	2.21e-07	not significant
THETA	not significant	0.000111	not significant

Tab. 2.3: 2nd ANOVA - p-values

	TOTD:CONDITION	TOTD:HEMISPHERE	CONDITION:HEMISPHERE	TOTD:CONDITION:HEMISPHERE
ALPHA	0.0478	not significant	not significant	not significant
BETA	0.005025	not significant	not significant	not significant
GAMMA 1	0.0862	not significant	not significant	not significant
GAMMA 2	not significant	not significant	not significant	not significant
DELTA	not significant	not significant	not significant	not significant
THETA	not significant	not significant	not significant	not significant

Tab. 2.4: 2nd ANOVA - p-values (interactions)

2.6. DISCUSSIONS

i. Time of the day

The first independent variable analyzed is the time of the day. All the 40 subjects were divided into 3 timeframes: morning (until 12 AM), lunchtime (12 AM – 2 PM) and Afternoon (after 2 PM). The 3 groups are composed of 17-13-10 subjects in the 2° ANOVA and 16-9-7 in the 1° ANOVA, where were deleted the subject with no precise information about their background, to include this factor in the study. The group was assigned using the time they filled the questionnaire minus 2 hours, which was the total duration of the experiment.

Looking at the results of the analysis, from the 1° ANOVA, there are significant p-values in all the waves. Performing a post hoc analysis on the variable with a Tukey HSD test, it appears that the main differences are between Morning-Afternoon and Lunch-Afternoon, and the plots show greater TRP values during Afternoon.

These results are confirmed, despite a not significant result for gamma 2 (that was the wave with less significant values in the 1° ANOVA too), also in the 2° ANOVA.

In the following pages are reported, as examples, the boxplots about the pre-frontal electrodes, to graphically see the effect described above.

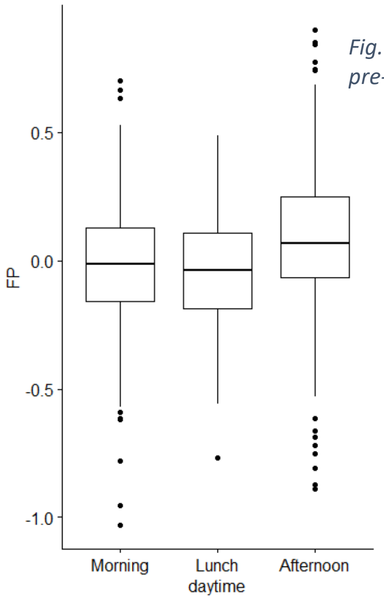

Fig. 2.6.1: Time of the day effect in pre-frontal lobe - Alpha

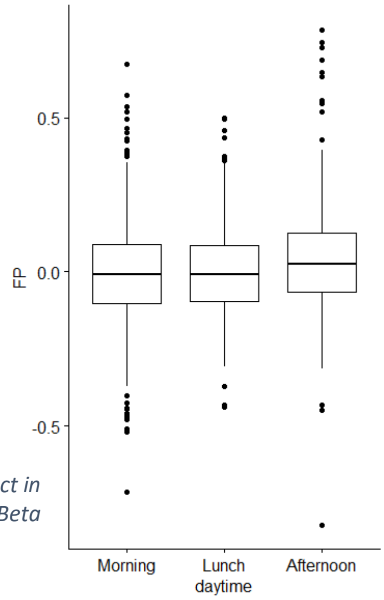

Fig. 2.6.2: Time of the day effect in pre-frontal lobe - Beta

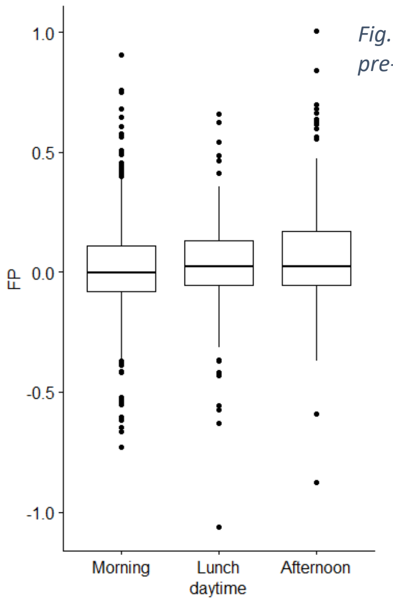

Fig. 2.6.3: Time of the day effect in pre-frontal lobe - Gamma 1

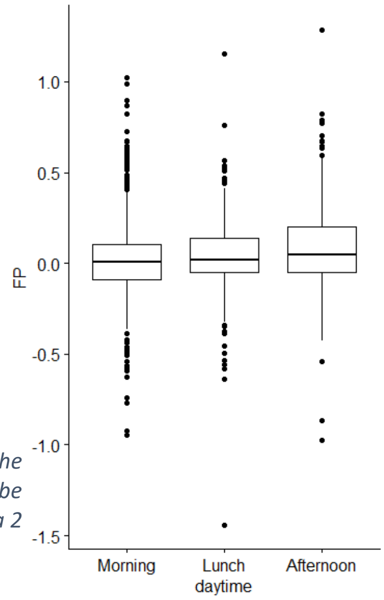

Fig. 2.6.4: Time of the day effect in pre-frontal lobe - Gamma 2

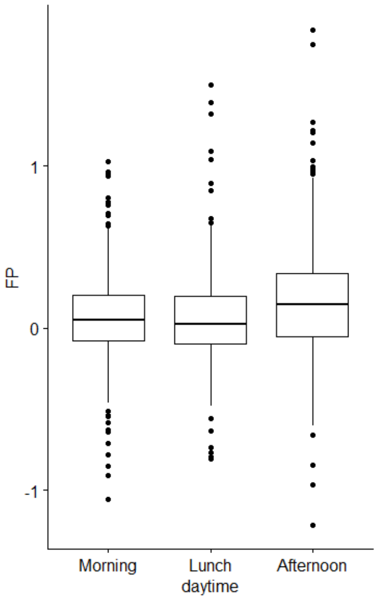

Fig. 2.6.5: Time of the day effect in pre-frontal lobe - Delta

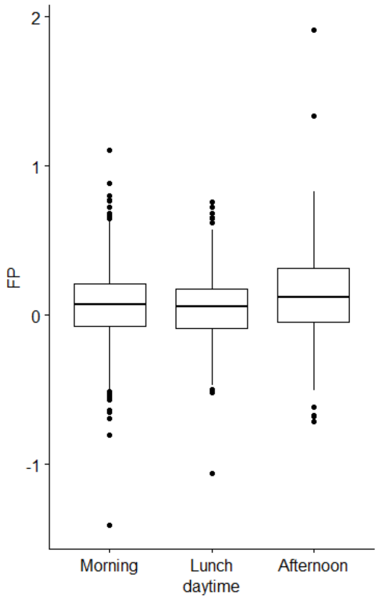

Fig. 2.6.6: Time of the day effect in pre-frontal lobe - Theta

As stated before, there are shown as examples only the pre-frontal electrodes, but all the others gave the same results.

That finding can be explained by what is described in section 1.2, through the effects of the circadian EEG rhythms, that show greater values during the afternoon. It can be hypothesized that the increasing mental stress and fatigue during the day, request both a greater cerebral activation and a greater effort to complete a task, reflecting in greater TRP values.

ii. Condition

The second variable analyzed is the condition. The experiment was based on a reviewed version of the «Alternative uses task», in which the subjects have to select a common use and an uncommon use for everyday objects. The two conditions are indicated by 0 (common) and 1 (uncommon).

The research gives confirm to the previous evidence in the literature of a greater alpha rhythm during divergent thinking activities, especially on the temporal, central and parietal lobes.

On the other hand, the beta and gamma rhythms follow a reverse trend, in all the lobes.

This confirmation is found again in the 2° ANOVA, where the electrodes are only divided by hemispheres.

Hence, here it is once again highlighted the positive correlation between alpha power and creativity (Fink & Benedek, 2013) (Schwab, Benedek, Papousek, Weiss, & Fink, 2014), with the addition of the negative correlation of beta and gamma power, giving the clue that, about these waves, a higher frequency is negatively linked with the divergent thinking.

Again, there are shown some boxplots. In this case, the temporal lobe is chosen, as it has the most significant p-values, but all the other lobes have the same trend.

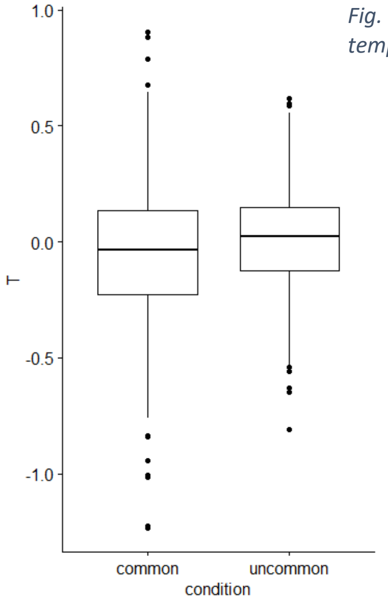

Fig. 2.6.7: Condition effect in temporal lobe – Alpha

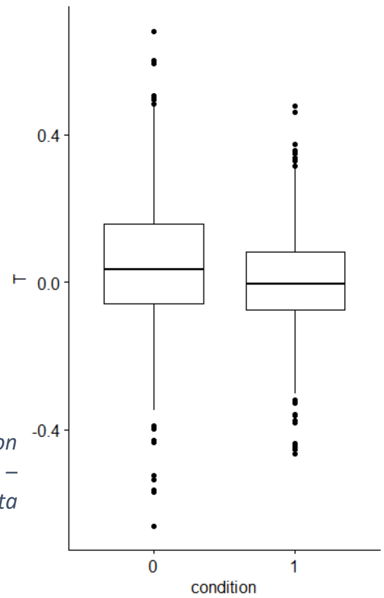

Fig. 2.6.8: Condition effect in temporal lobe – Beta

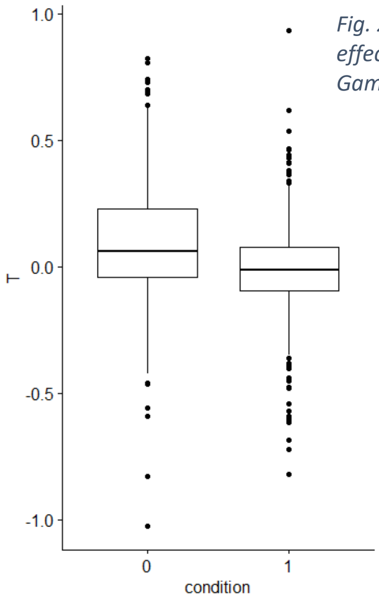

Fig. 2.6.9: Condition effect in temporal lobe – Gamma 1

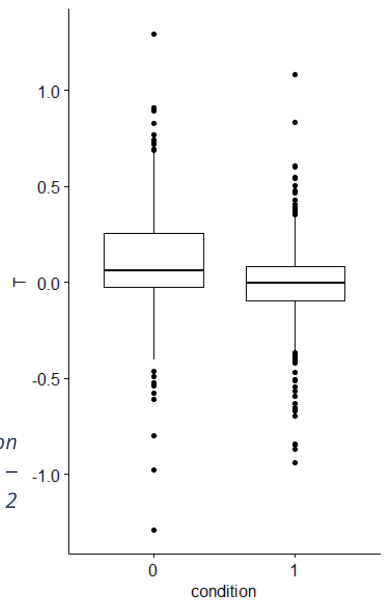

Fig. 2.6.10: Condition effect in temporal lobe – Gamma 2

iii. Hemisphere

The third discussion is about the hemisphere factor: it was studied in the 2° ANOVA as an independent variable, to see if there are some correlations only with respect to the type of cerebral waves.

The results are low significant, but there are, both for alpha and beta waves, greater TRP values of the right hemisphere, as it is possible to see in the following graphs.

That phenomenon is difficult to be explained, it is possible to conclude that performing a task there is greater activation of the right hemisphere, but it is not a totally significant result, as the p-values are quite high and there are no significant results in other waves. Then, in section (v.) about the interactions, it is confirmed that it is not a significant variable.

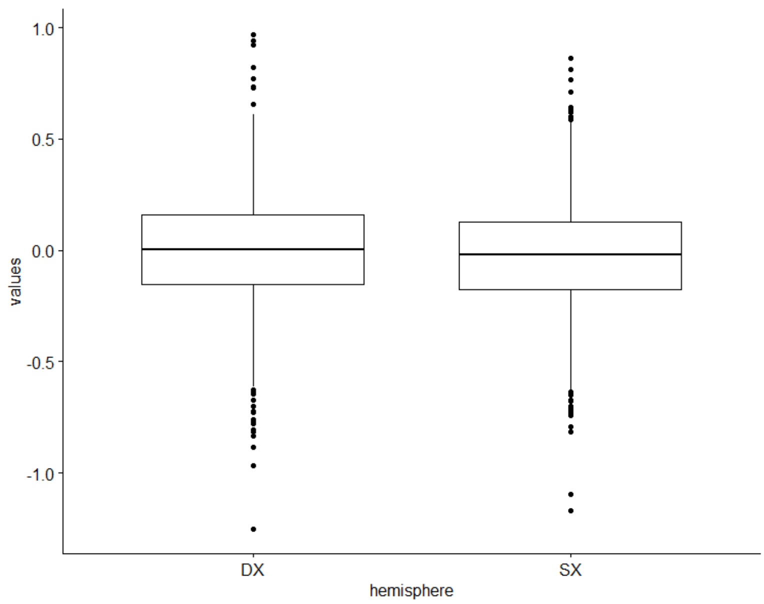

Fig. 2.6.11: Hemisphere effect – Alpha

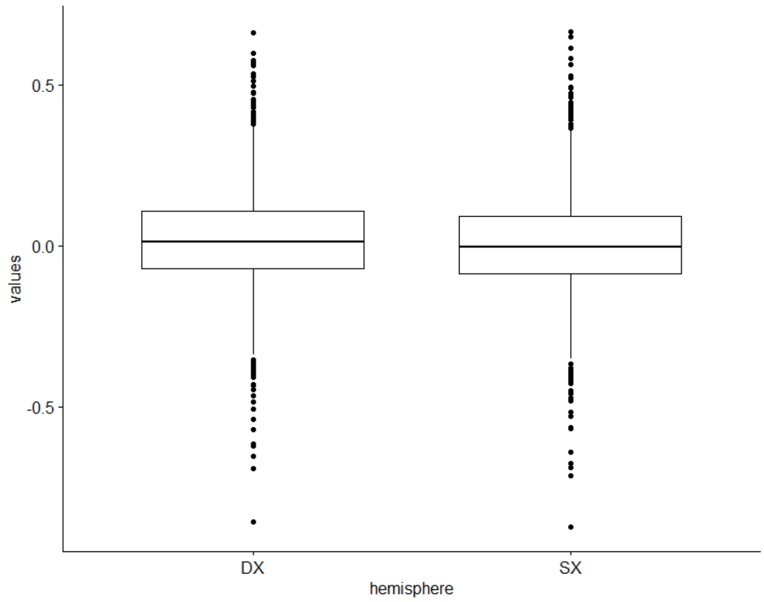

Fig. 2.6.12: Hemisphere effect – Beta

iv. Background

The last variable analyzed is the educational background. In particular, the subjects were divided between designers (15) and engineers (17).

The result is that it is a very significant parameter to study: except for the Parietal and the Occipital lobes during beta waves measurement, designers have greater TRP values.

That factor will be deepened with the interactions' effects, in which will be highlighted the greater time-of-the-day dependance and a greater activation during the convergent thinking phase, i.e., the convergent condition.

In the next pages, again, some boxplots as examples: there are selected the pre-frontal lobe graphs, but, as before, the other lobes follow the same tendency.

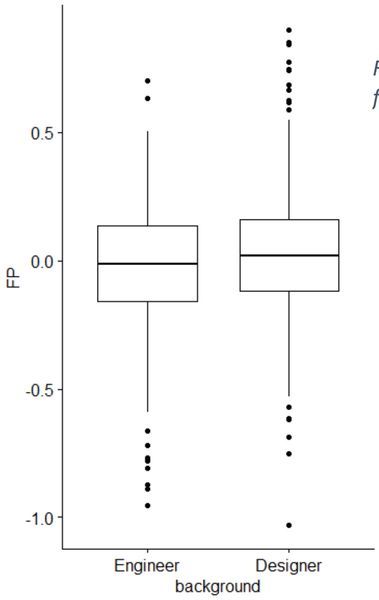

Fig. 2.6.13: Background effect in pre-frontal lobe - Alpha

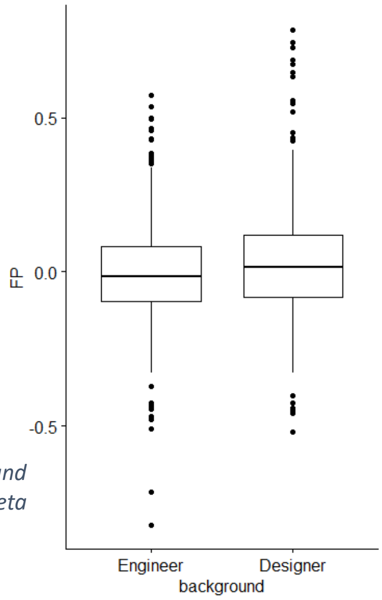

Fig. 2.6.14: Background effect in pre-frontal lobe - Beta

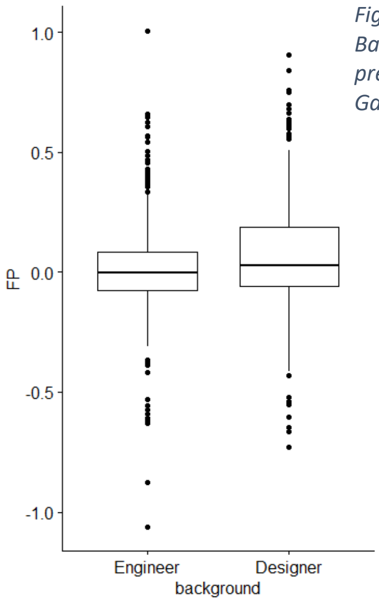

Fig. 2.6.15: Background effect in pre-frontal lobe - Gamma 1

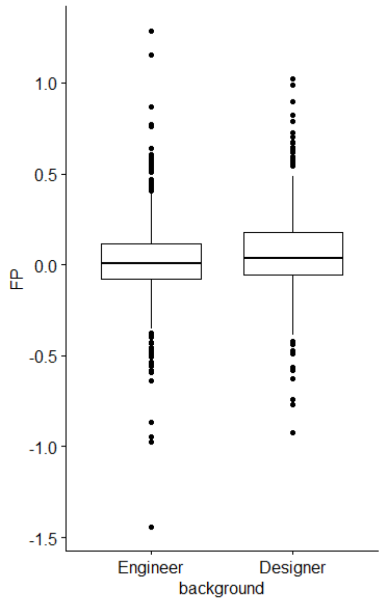

Fig. 2.6.16: Background effect in pre-frontal lobe - Gamma 2

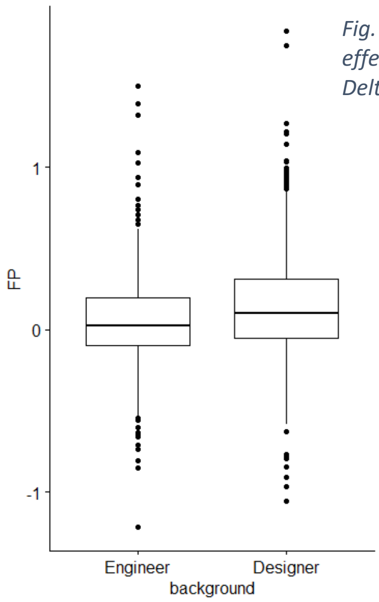

Fig. 2.6.17: Background effect in pre-frontal lobe - Delta

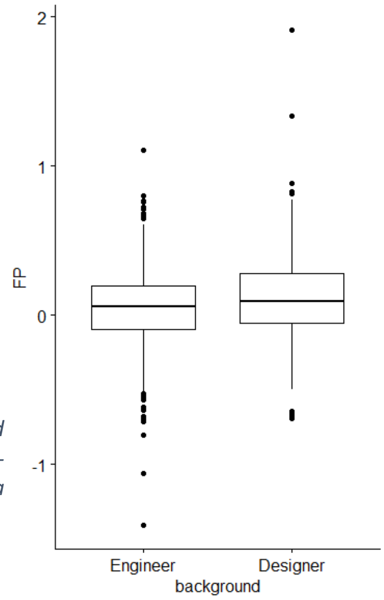

Fig. 2.6.18: Background effect in pre-frontal lobe - Theta

v. Interactions

The interactions between factors show significant results in the 1° ANOVA, while in the 2° only about time of the day and condition in alpha, beta and gamma 1 waves.

This first finding explains that the hemisphere is not a significant factor in relation with the others, thing that was confirmed from the study of the independent factor, which showed it as low significant.

The other less significant interactions are between time of the day - condition and condition - background.

About the first one, there are significant p-values in the occipital lobe for alpha, beta and gamma 1 in the 1st ANOVA, and in the 2nd ANOVA for the same waves, but with high values. The graphs shown in the next pages confirm that during the afternoon there are greater values for all the waves, especially during the uncommon condition for alpha (Fig. 2.6.19 – 2.6.22) and during the common condition for beta and gamma (Fig. 2.6.20 – 2.6.21 – 2.6.23). An exception to this is the value of the afternoon alpha wave during the common condition, which is higher than the respective uncommon.

About the second one, there are significant results in beta (Fig. 2.6.30 – 2.6.31) and theta (Fig. 2.6.32 – 2.6.33) above all, and then in gamma 1 and delta. Here it is evident how both in common and uncommon conditions designers have greater activation, but the main effect is in the common one, where there is a big difference between the two backgrounds.

Finally, the most significant interactions: between time of the day - background and between all the three independent variables.

In the interaction time of the day - background the graphs show higher values for designers in all the time frames, especially during the afternoon (Fig. 2.6.24 – 2.6.25 – 2.6.26 – 2.6.27 – 2.6.28 – 2.6.29). Even if also for engineers there is a greater activation during the afternoon, designers are more affected by this variable.

Then, in the last relationship, it is possible to see all these effects together (Fig. 2.6.34 – 2.6.35 – 2.6.36 – 2.6.37 – 2.6.38 – 2.6.39): the greater activation for designers during the common condition in the afternoon is the most evident, but in general, as stated before, designers are more affected by the time of the day and present higher values during the afternoon in both conditions. For engineers, this is less evident, and this effect is confirmed above all during the uncommon task, while during the common one there are contrasting results, with a reverse tendency.

In the next pages, some examples diagrams are shown.

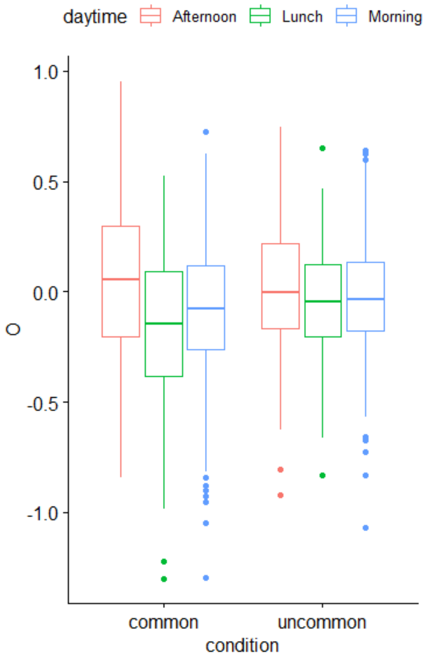

Fig. 2.6.19: Interaction effect time-of-the-day and condition in occipital lobe - Alpha

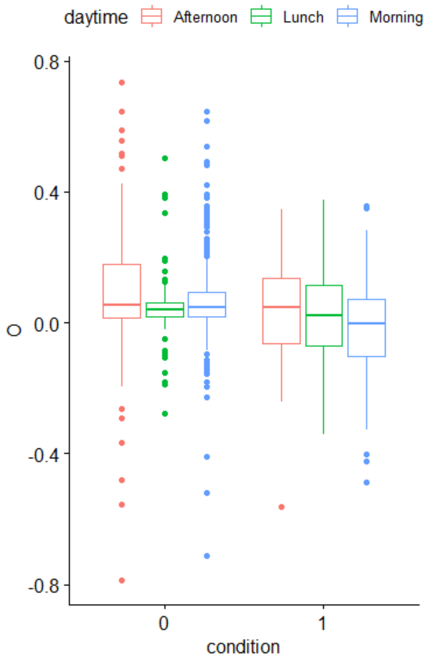

Fig. 2.6.20: Interaction effect time-of-the-day and condition in occipital lobe - Beta

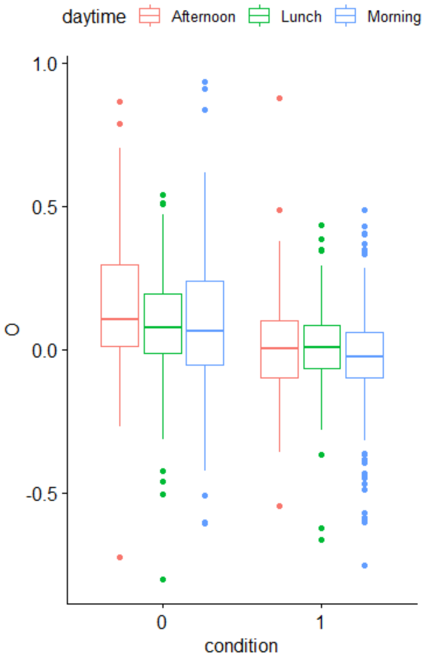

Fig. 2.6.21: Interaction effect time-of-the-day and condition in occipital lobe - Gamma 1

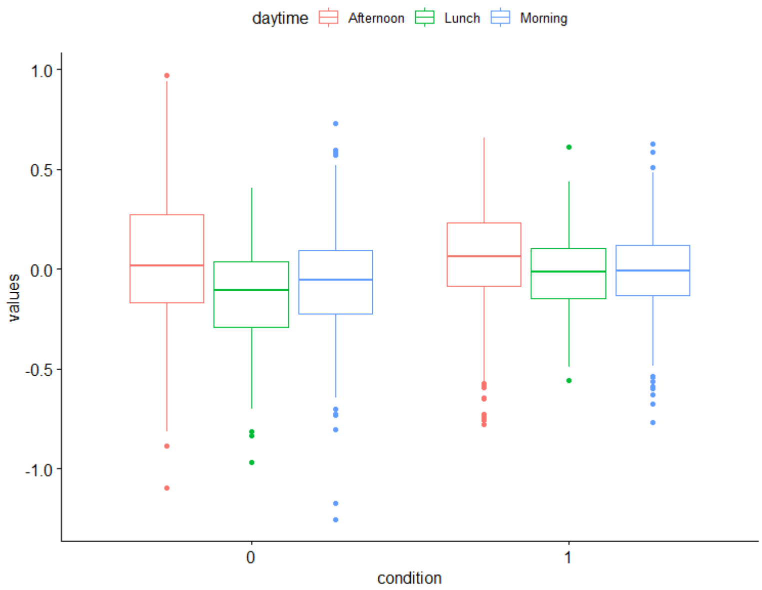

Fig. 2.6.22: Interaction effect time-of-the-day and condition - Alpha (2° ANOVA)

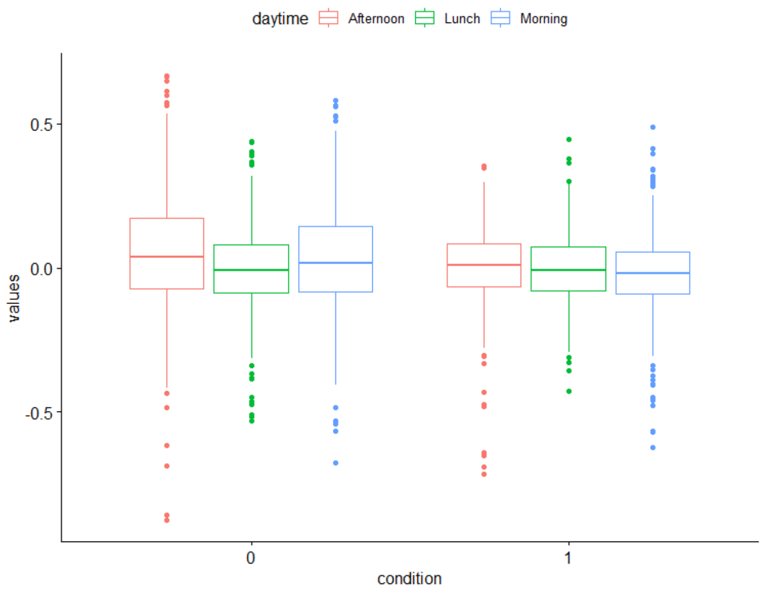

Fig. 2.6.23: Interaction effect time-of-the-day and condition - Beta (2° ANOVA)

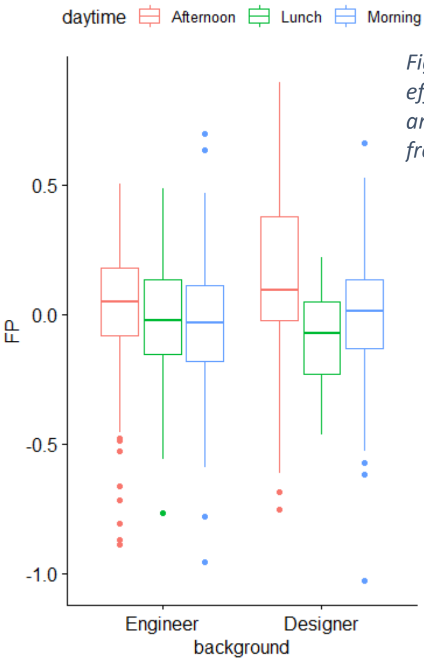

Fig. 2.6.24: Interaction effect time-of-the-day and background in pre-frontal lobe - Alpha

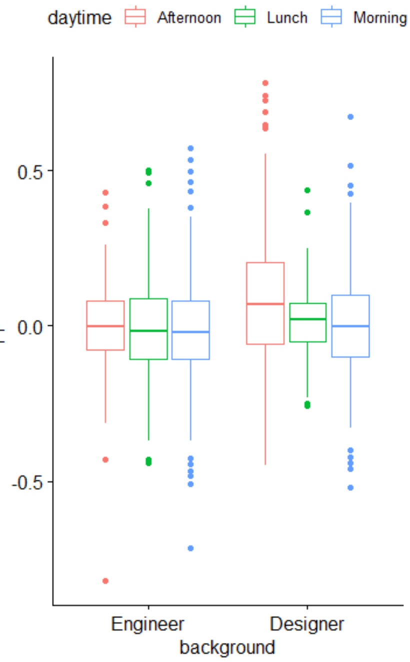

Fig. 2.6.25: Interaction effect time-of-the-day and background in pre-frontal lobe - Beta

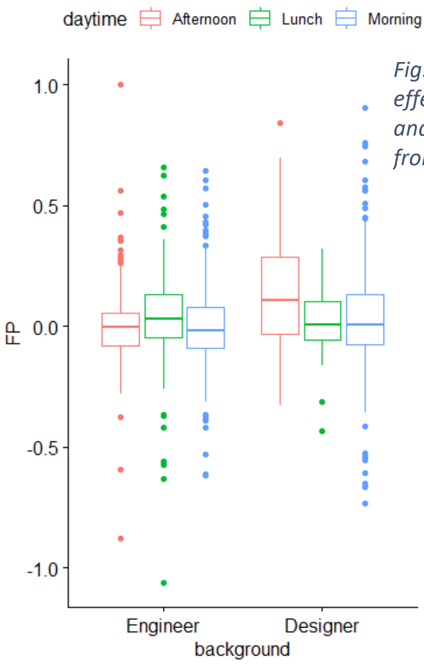

Fig. 2.6.26: Interaction effect time-of-the-day and background in pre-frontal lobe - Gamma 1

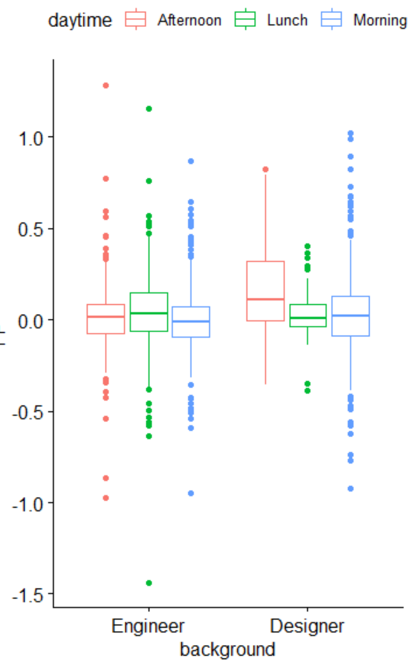

Fig. 2.6.27: Interaction effect time-of-the-day and background in pre-frontal lobe - Gamma 2

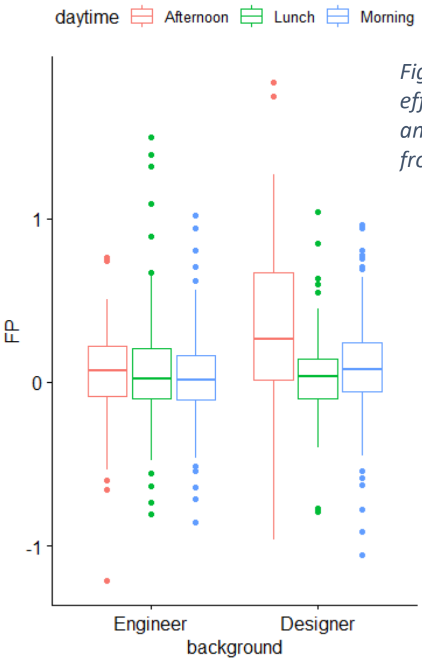

Fig. 2.6.28: Interaction effect time-of-the-day and background in pre-frontal lobe - Delta

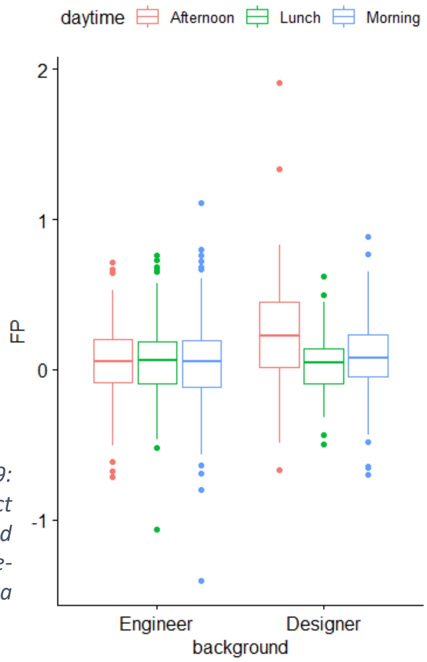

Fig. 2.6.29: Interaction effect time-of-the-day and background in pre-frontal lobe - Theta

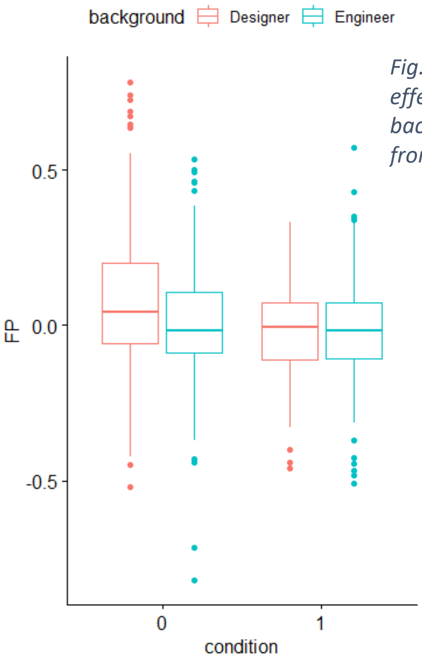

Fig. 2.6.30: Interaction effect condition and background in pre-frontal lobe - Beta

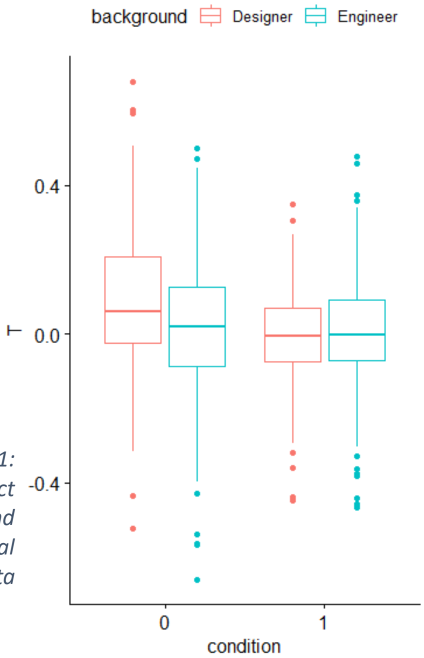

Fig. 2.6.31: Interaction effect condition and background in temporal lobe - Beta

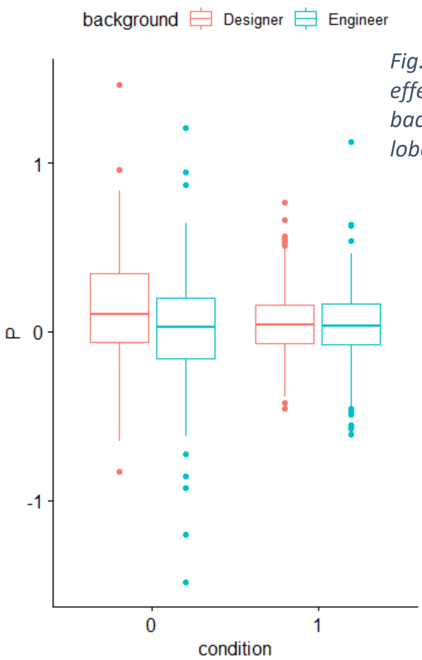

Fig. 2.6.32: Interaction effect condition and background in parietal lobe - Theta

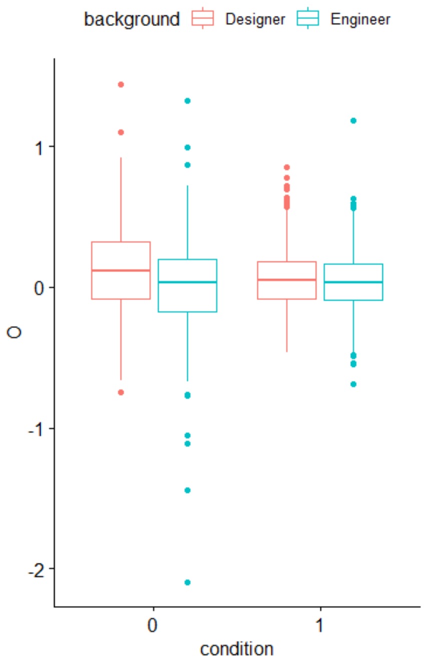

Fig. 2.6.33: Interaction effect condition and background in occipital lobe - Theta

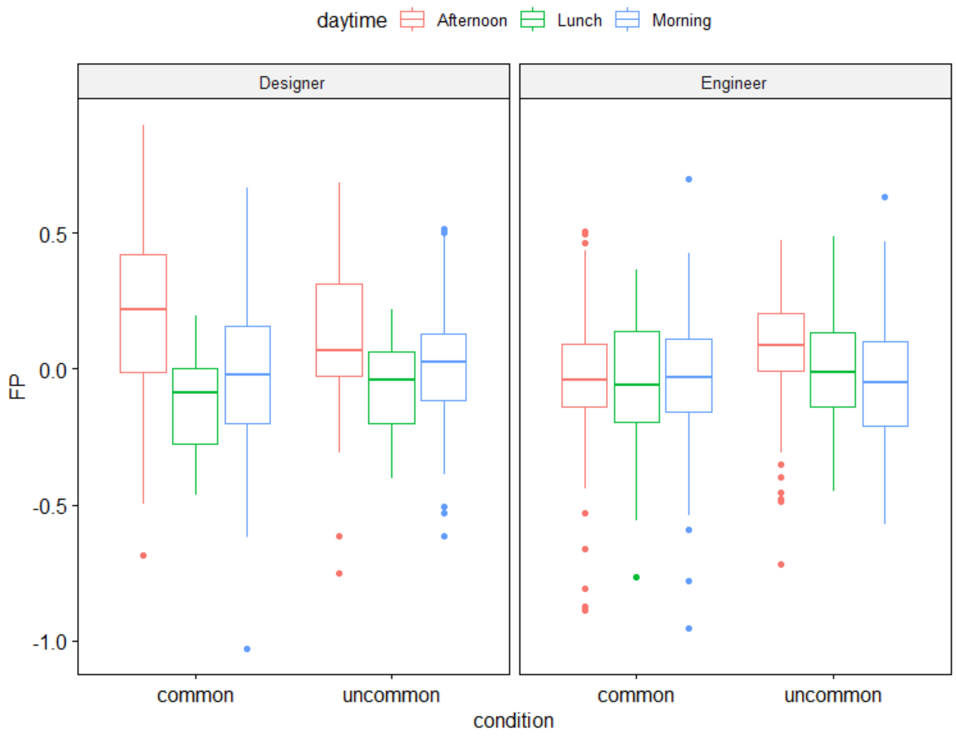

Fig. 2.6.34: Interaction effect time of the day, condition and background in pre-frontal lobe - Alpha

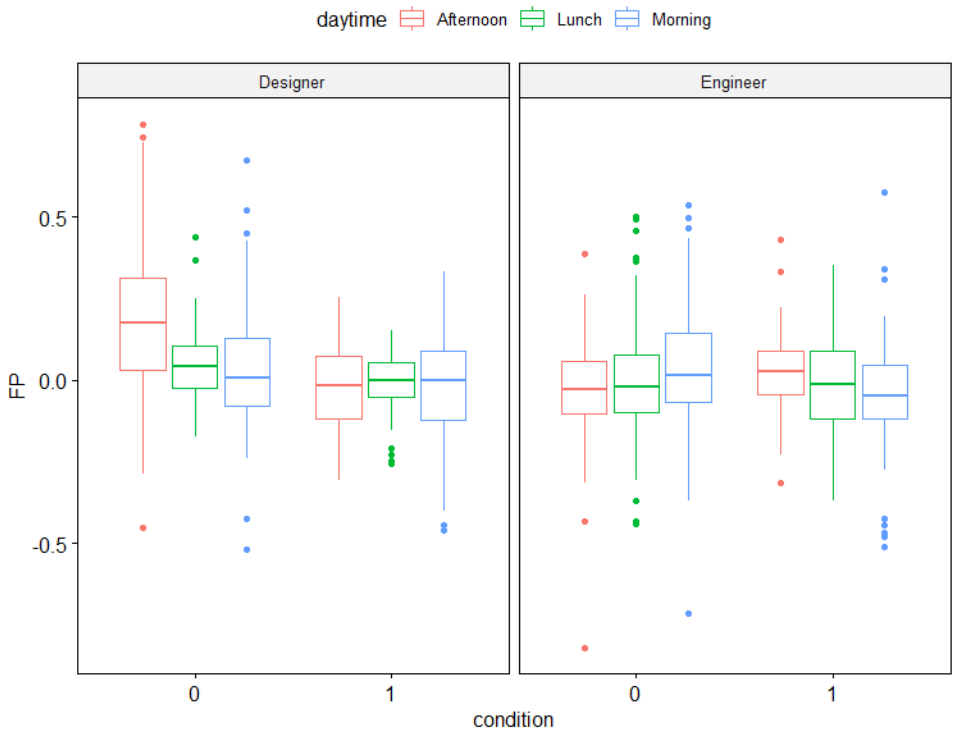

Fig. 2.6.35: Interaction effect time of the day, condition and background in pre-frontal lobe - Beta

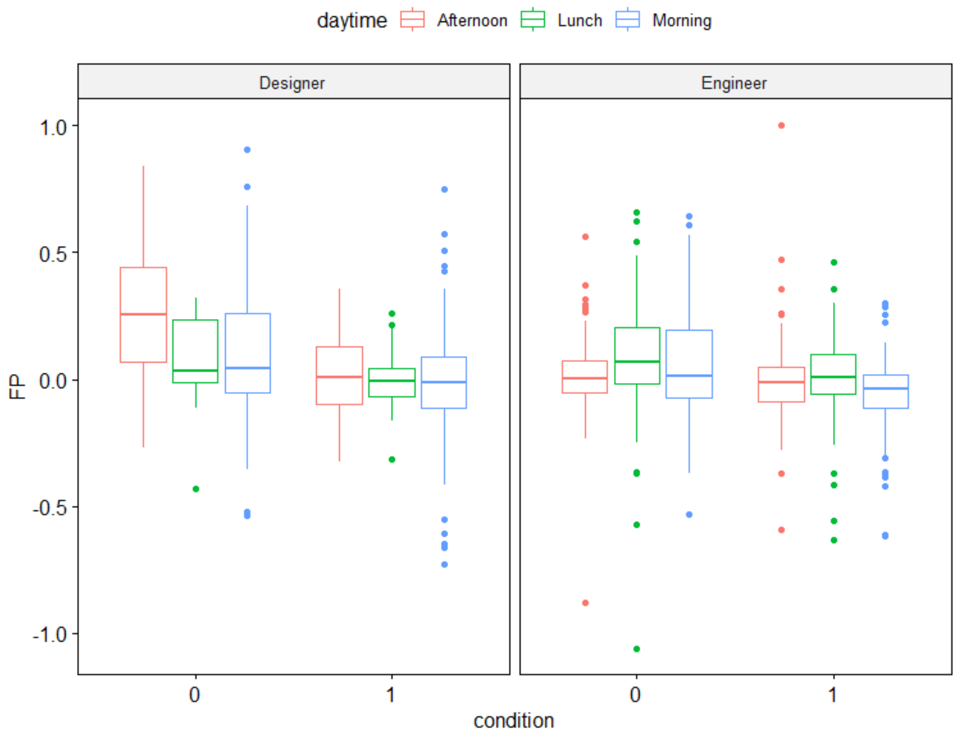

Fig. 2.6.36: Interaction effect time of the day, condition and background in pre-frontal lobe - Gamma 1

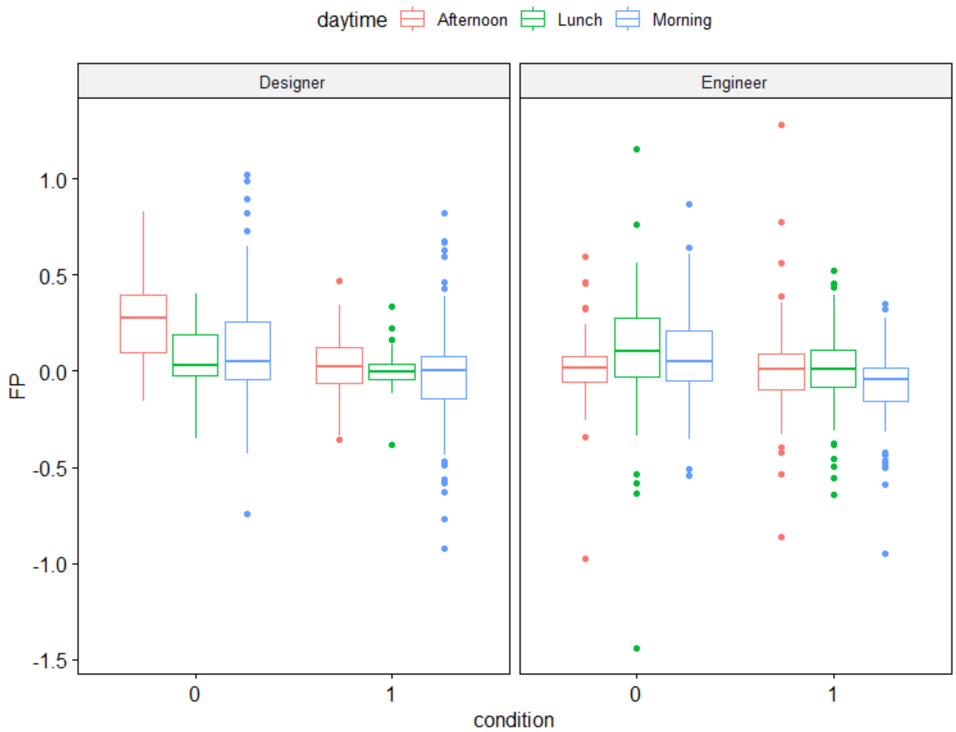

Fig. 2.6.37: Interaction effect time of the day, condition and background in pre-frontal lobe - Gamma 2

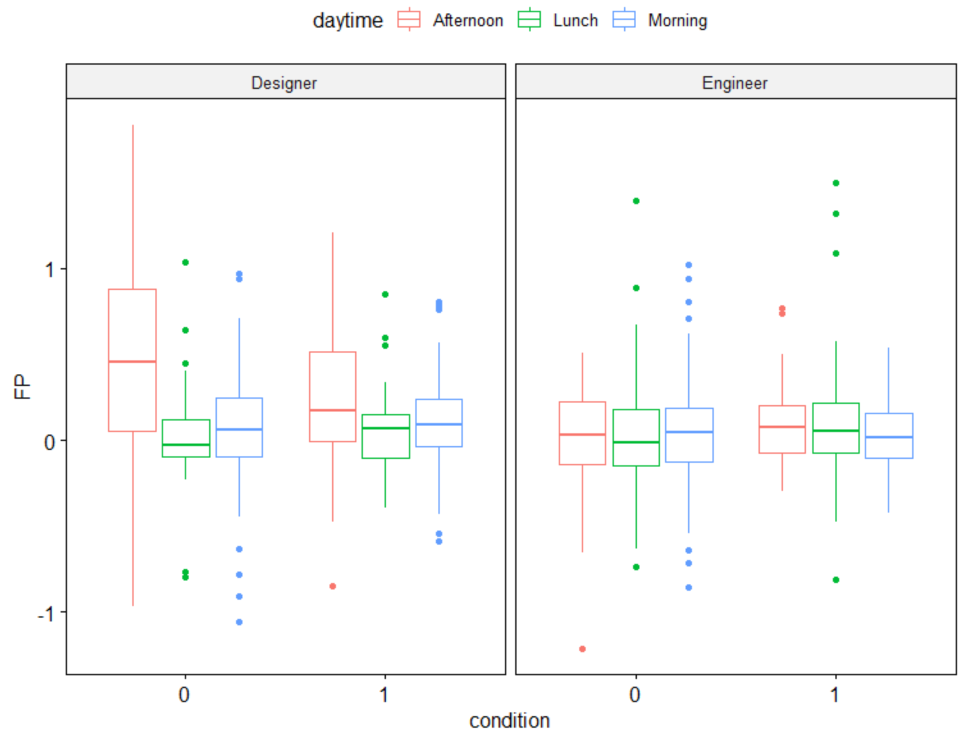

Fig. 2.6.38: Interaction effect time of the day, condition and background in pre-frontal lobe - Delta

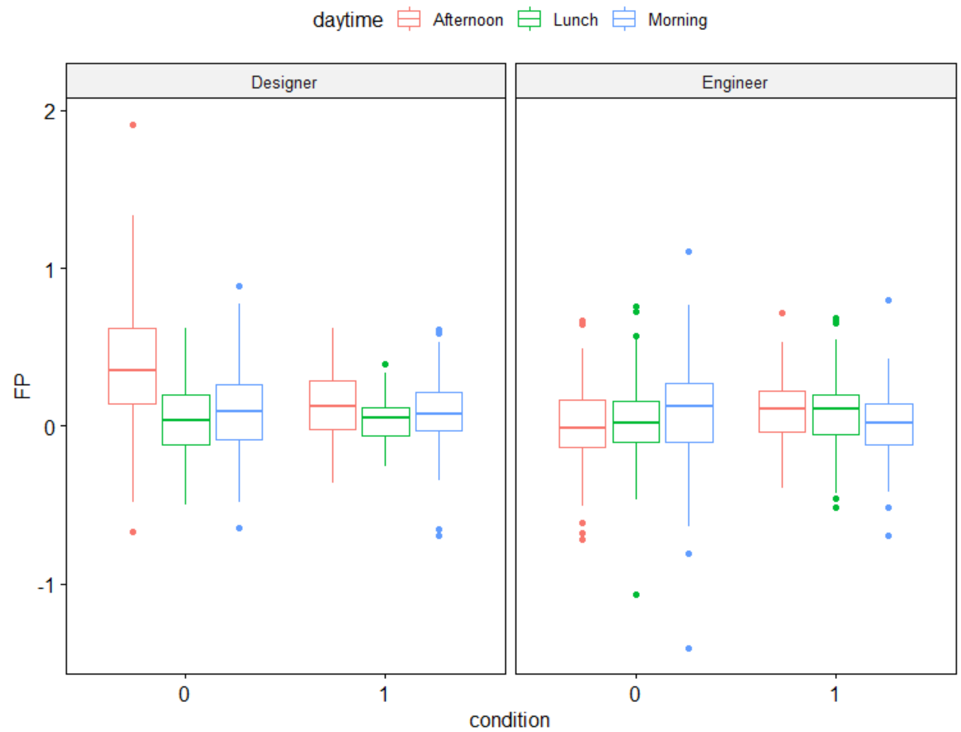

Fig. 2.6.39: Interaction effect time of the day, condition and background in pre-frontal lobe - Theta

2.7. CONCLUSION

The results discussed before, summarizing, have highlighted:

- **Hemisphere →** Is the less significant factor, the only notable results are that the right hemisphere presents greater TRP values about alpha and beta waves (with high p-values) and the total lack of significative interactions with other factors.
- **Background →** Designers have greater TRP values than engineers, and they are more time-dependent.
- **Time of the day →** TRP values are greater during the afternoon, for all the waves, probably because of mental fatigue, higher later in the day, or stress. In its interactions' effects, designers are more affected by this factor, especially in the common condition.
- **Condition →** During the common condition there are found higher values for beta and gamma waves, while during the uncommon one there are greater alpha values, confirming the previous studies in the literature.

Given that starting point, and to complete the discussion about the time of the day, it can be interesting to go deeper in the environmental dependencies of creative thinking in engineering design.

So, after the first finding that there are external variables that influence the engineering design work, as there are found greater TRP values during the afternoon, the study can go to the next step: there are other "external/intangible" factors that influence creativity?

3. ENVIRONMENTAL FACTORS

3.1. INTRODUCTION

This chapter aims to highlight the main effects of the environment on creativity, related to engineering design, through neurophysiological signals.

It starts from a general analysis of creative thinking, from Graham Wallas' book "The art of thought" (Wallas, 1926), which gave us the subdivision of creative thinking in 4 phases: *preparation* – *incubation* – *illumination* – *verification*. Then, the research becomes more specific, through further literature research about reviews on the topic and specific papers.

It emerges that environment plays a crucial role in creativity, and the most studies factors are **noise**, **lighting**, **colours** and **temperature**, as it is in the reviews from (Thoring, Desmet, Mueller, & Badke-Schaub, 2020) and (Meinel, Maier, Wagner, & Voigt, 2017).

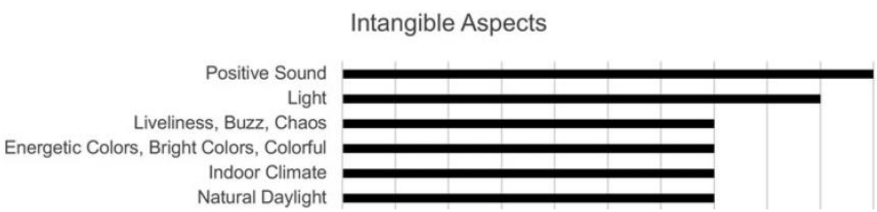

Fig. 3.1.1: Most studied aspects (Thoring, Desmet, Mueller, & Badke-Schaub, 2020)

Categories of the physical work environment	No. of studies
Office elements	**16**
Intangible office elements	*13*
Sound	9
Colors	9
Light	8
Temperature	5

Fig. 3.1.2: Most studied aspects (Meinel, Maier, Wagner, & Voigt, 2017)

Each factor has been studied through different methods (from the questionnaire to EEG) in different fields of research, reaching conclusions with similarities and differences.

3.2. ENVIRONMENTAL FACTORS

i. Noise

The current literature about noise is a lot segmented: the factor is studied in many fields.

In the engineering field the most relevant article are from (Horii, Yamamura, Katsumata, & Uchiyama, 2004), (Kawasaki, Karashima, & Saito, 2009) and (Cho, Hwang, & Choi, 2011).

Horii et al., through EEG, studied the physiological effects in response to particular types of sounds, in four different experiments in which participants were subjected to four different types of auditory stimuli: white noise, emergency bell, seven simple tons (2580, 4460, 6370, 8790, 11400, 14470, 18360 Hz), and two combinations of the latter (4460, 6370, 2580, 4460, 6370 Hz).

The results show that all sound impulses caused participants to experience a reduction in alpha wave rhythm, which as seen in the previous chapter is closely related to divergent thinking, and thus creativity.

The same result concerning white noise was found in the second experiment cited above (Kawasaki, Karashima, & Saito, 2009), which defines white noise as unpleasant, contrasting it with other positive sounds that, instead, support brain waves that foster creativity.

In the latest experiment from the engineering field, participants were exposed to 3 different noise samples, for five minutes, to see if a given frequency was more or less stressful. The results obtained show that low-frequency sounds are equally stressful compared to high-frequency sounds, and all these noises, therefore, induce a decrease in cognitive activities (measured by ECG).

Equally interesting are the studies coming from other fields of research, which, differently, aim to highlight the effects of noise on pure cognitive performance, in the performance of particular tasks. In fact, if on the one hand the first evidence shows how noise can be destructive to creativity, on the other hand, not all activities are equally creative, and these other experiments help to understand if and when it might be useful to be accompanied by noise.

In fact, noise produces an increase in the speed of carrying out the tasks, but reduces precision, so that it is better a low noise condition (compared to high noise) in memory tasks (Hygge & Knez, 2001).

Despite the results described above, there are some researches that, in turn, find the results that a high of noise enhances creativity, inducing overloading in the DMN, the default-mode network (Rondinoni, Amaro Jr, Cendes, dos Santos, & Salmon, 2013).

CONCLUSION	ARTICLE	METHOD	Field of Research
Increased noise-inducing distraction, which improves the construal level and abstract processing, enhance creativity	Mehta, Zhu, & Cheema, 2012	Questionnaire	Management and Social Sciences
White noise reduces the alpha rhythm	Horii et al., 2004 Kawasaki, Karashima, & Saito, 2009	EEG	Engineering
Low noise levels allowed networks to reach wider areas and allowed for higher oscillatory activity in the motor/auditory cortex, supplementary motor network, and frontal executive network	Rondinoni et al., 2013	fMRI	Neuroscience
High noise levels induced an overload in the DMN, connected to creative thinking	Rondinoni et al., 2013	DMN	Neuroscience
The stress induced by low frequency noise is as stressful as that induced by high frequency noise	Cho et al., 2011	ECG Eye-tracking	Engineering
Noise increases speed in tasks but reduces precision Better long-term recall in the low noise than in the high noise Better free recall in the low noise condition	Hygge and Knez, 2001	Task evaluation Questionnaire	Psychology

Tab. 3.1: Summary of articles about NOISE

ii. Lighting

The lighting of an environment is one of the most important factors to take into consideration, a good light setting plays a crucial role also in the work environment, leading to increase productivity and reduce mental stress.

That factor is often studied combined with the colour factor, in terms of its intensity and temperature. Below, there will be analysed some of the most interesting articles about lighting in the literature, again, the factor is studied in many fields and with different methods, but there are some contact points and similar results between the researches.

So, illumination is the primary attribute in designing the ideal work environment, and there are some preliminary indications, for example from the British Institute of Lighting Engineering, that recommends 500 lx for offices where typing is carried out occasionally and 750 lx for offices where design and typing are the daily routine. At the same time, in Japan, the ordinary offices are lightening in the range of 500 lx-750 lx, in a similar approach; and again, the International Commission of Illumination recommends a light intensity no less than 500 lx (Lu, et al., 2020).

Lu et al., in their experiment, analyse the effect of 5 levels of light intensity (75 lx, 100 lx, 200 lx, 300 lx, 500 lx) and 3 levels of light temperature (3000 K, 4000 K, 6000 K), by performing a subjective, a task, and a physiological evaluation. In particular, it is interesting to look at the graph in Fig. 3.4.1, where they plotted a comprehensive comfort zone on the base of the evaluations: on one hand, it appears that not always the physiological signals correspond to the individual preferences, but on the other hand, there is an intersection between the two zones.

The optimal range is between 300 lx and 450 lx with a light temperature of 3000 K, 250 lx – 450 lx with 6000 K, and 330 lx – 420 lx with 4000 K.

Finally, the task evaluation shows that a neutral colour temperature affects and improves the reading efficiency.

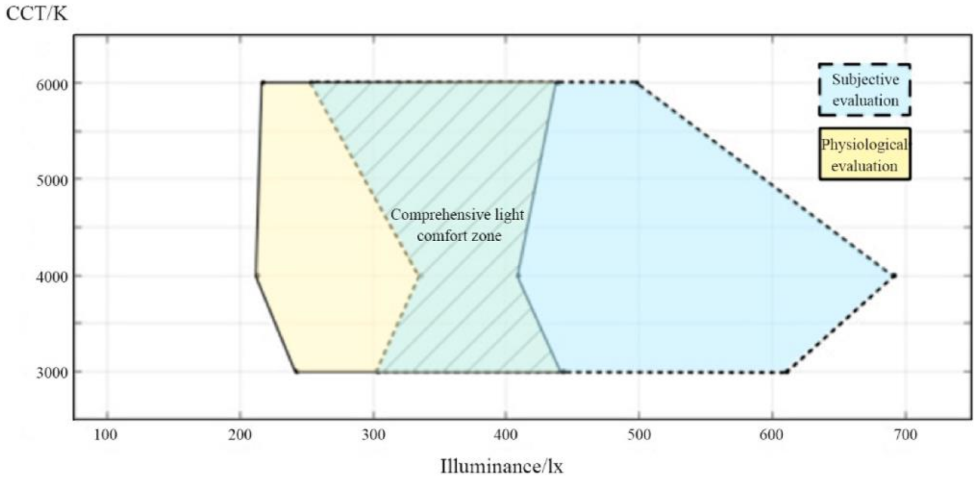

Fig. 3.2.1: Comprehensive light comfort zone from (Lu, et al., 2020)

Going through other task evaluation experiments, the most relevant results are that subjects perform better in terms of both long-term and short-term recall tasks with high intensity of light (1500 lx vs 300 lx) (Hygge & Knez, 2001), while high light temperature improves reaction times in tasks associated with sustained attention, but not in tasks associated with executive functions (Chellappa, et al., 2011).

From these studies, then, it appears how the institutional indications are confirmed, but it seems that physiologically our body performs better with lower intensity.

In the end, it is interesting that it can exist a positive correlation between this lower intensity and creativity, through a perception of freedom from constraints (Steidle & Werth, 2013). They studied the effects of dim illumination and darkness (1500 lx vs 500 lx vs 25 lx or 150 lx) in six different experiments, reaching that result.

In Tab. 2.3, on the next page, a summary is shown.

CONCLUSION	ARTICLE	METHOD	Field of Research
Darkness allowed freedom from constraints, which facilitated global and explorative processing style and, consequently, facilitated creativity	Steidle & Werth, 2013	Questionnaire	Psychology
Colour temperature affects the reading efficiency (neutral colour temperature). The physiological evaluation shows that illumination affects the response of the visual centre	Lu et al, 2020	Subjective evaluation Task evaluation EEG	Engineering
Better long-term recall and free recall in 1500 than in 300 lx	Hygge and Knez, 2001	Task evaluation Questionnaire	Psychology
Light at 6500K led to significantly faster reaction times in tasks associated with sustained attention but not in tasks associated with executive function	Chellappa et al., 2011	External evaluation	Multidisciplinary

Tab. 3.2: Summary of articles about LIGHTING

iii. Colour

In the previous section, the colour effect was partially described in its correlation with light, as light temperature, but this can be an important factor on its own too.

The colour psychology is a widespread phenomenon, famous examples are in the marketing field, where each colour can enhance some specific reactions in the public, helping the company or the person to express the core message of its product or brand: many colours have their specific related emotions correlation, such as red - excitement, orange - confidence, blue - loyalty, black - formality and so on.

In the creativity research, the most studied colours are blue and red, as they are primary colours and because of their length wave contraposition (long for red and short for blue). The studies about their influence on cognitive performances have contrasting results, some demonstrate increasing performances with red, some with blue, at the same time their effect depends on the task type and the task difficulty, making the research a lot scattered.

Mehta and Zhu (Mehta & Zhu, 2009) studied that the two colours can produce different reactions: on one hand, the red produces an avoidance motivation, making the subjects pay more attention to errors, due to its direct link to danger and errors in general, on the other side blue, in its correlation with openness and peace, encourages individuals to use innovative and creative strategies. So, in their experiment, red was better for detailed-oriented tasks and blue for creative tasks.

In that direction Xia et al. (Xia, Song, Wang, Tan, & Mo, 2016) add the factor of task difficulty in the research, obtaining similar results, that showed that red enhanced the performance on a simple detail-oriented task. However, blue improved the performance on a difficult detail-oriented task as well as on both simple and difficult creative tasks.

This finding is confirmed by neurophysiological states too, in fact, Yoto et al. (Yoto, Katsuura, Iwanaga, & Shimomura, 2007), in their EEG study, obtained greater alpha powers when subjects looked at the red paper than while they looked at the blue paper, indicating that red elicited an anxiety state, increasing attention.

Of course, and that is the last article described, blue and red are not the only colours that can influence creativity. There are four experiments that demonstrated that a prior brief glimpse of green prior facilitates creativity tasks (Lichtenfeld, Elliott, Maier, & Pekrun, 2012). They studied the green effect in contrast with white, gray, red and blue, finding confirms to the previous evidence too.

CONCLUSION	ARTICLE	METHOD	Field of research
Blue activates an approach motivation and enhances creative task performance; Red activates an avoidance motivation and enhances detail-oriented task performance	Mehta & Zhu, 2009	Task evaluation	Psychology
Red, compared to Blue, induces increased alpha oscillation and elicits an anxiety state, resulting in greater brain activity involved in perception and attention processes	Yoto et al., 2007	EEG	Anthropology
In four experiments it is demonstrated that a brief glimpse of green prior to engaging in a creativity task facilitates the creativity	Lichtenfeld et al., 2012	Questionnaire External evaluation	Psychology
Red enhanced the performance on a simple detail-oriented task. Blue improved the performance on a difficult detail-oriented task as well as on both simple and difficult creative tasks.	Xia et al., 2016	Task evaluation	Psychology

Tab. 3.3: Summary of articles about COLOUR

iv. Temperature

Finally, there is the temperature, the factor on whose results the literature agrees more. It is confirmed that for workspace, whatever the type of task is, a warm environment is suggested.

Each of the following research finds that result through different methods.

Lan et al. (Lan, Wargocki, Wyon, & Lian, 2011) proposed an experiment to measure the level of arterial oxygen saturation, that the higher it is, the better the performances are. In their experiment, they compared the reaction to a 22°C temperature to a 30°C one: the subjects had to perform a simulation of office work in both the conditions, and the arterial oxygen saturation was higher at 22°C.

Similar results were obtained by using EEG by Yao et al. (Yao, et al., 2009), in a comparison between four temperatures (21°C, 24°C, 26°C, 29°C): they obtained that alpha waves increased under neutral temperature (24°C-26°C), with a significant decrease as we move further from that range.

The already cited experiment by Hygge and Knez (Hygge & Knez, 2001), about the free recall tasks, arrived at the same conclusions, with a preference for 21°C compared to 27°C; and, finally, Kosonen and Tan (Kosonen & Tan, 2004) found a neutral predicted mean vote near to 21°C, giving a further confirmation to the fact that a warm or slightly cool workplace is better both for work in general and creativity tasks.

CONCLUSION	ARTICLE	METHOD	Field of Research
22°C is better than 30°C, higher arterial oxygen saturation	Lan et al., 2011	arterial oxygen saturation	Engineering
Global relative EEG powers of alpha waves were increased under thermally neutral (24-26°C) and slightly cool environments, as well as decreased in environments at > 29°C and < 21°C	Yao et al., 2009	EEG	Engineering
A PMV value of -0.21, which ranges from thermal neutral to slightly cool, allows optimal performance for thinking and typing tasks	Kosonen and Tan, 2004	Predicted Mean Vote	Engineering
Better free recall in 21°C than in 27°C	Hygge and Knez, 2001	Task evaluation Questionnaire	Psychology

Tab. 3.4: Summary of articles about TEMPERATURE

3.4. SUMMARY OF CONCLUSIONS

NOISE		LIGHTING / COLOUR		TEMPERATURE	
ENGINEERING	OTHER	ENGINEERING	OTHER	ENGINEERING	OTHER
• White noise → reduces alpha rythm → reduce creativity • Low noise is as stressful as high noise	• Low noise increases accuracy and memory in tasks • High noise increases speed and distraction → increases creativity	• Optimal range during work 300-440lx • Using light colour near 3000K or 6000K it is possible to decrease the illumination and stay in the optimal range • In turns, neutral colour temperature (4000K) increases reading efficiency	• High light intensity (1500lx) increases memory • High light temperature (>6000K) improves reaction times in tasks associated with sustained attention but not in tasks associated with executive function • Darkness (150lx) enhances creativity	• 22°C better than 30°C → better oxygen saturation → creativity • 24°C-26°C high alpha rythm → creativity • Better PMV value in warm and slightly cool temperature	Temperature near to 21°C improves memory
The research is a lot segmentated: in the engineering field noise is studied in its influence on the human body, but not specificly during work. On the other side it seems that an appropriate level of noise can enhance creativity.		The research by Lu et al. (2020) is the more complete in engineering field, and study the relations between colour and temperature of light during work. Even if in some research it is suggested to use high light intensity, it is confirmed that the best range during work is between 250lx and 500lx. It can be interesting to study if in creativity tasks that value can be lowered. The temperature of light maybe it is not an high-influence factor.		It is confirmed that a warm workplace it is better both for work in general and creativity tasks	

Tab. 3.5: Summary of conclusions

In the table above there are summarized all the findings discussed in the previous sections, to have a complete overview of the main results from the literature.

They are all divided between those from the engineering field and those from other fields, to obtain a first indication regarding which are the most studied factors in our field of interest and if the results are consistent compared to the other field's literature.

3.5. DESIGN OF THE EXPERIMENT

i. Introduction

Based on the results summarized in the previous section, some hypotheses about which could be the best experiment to do were made: with this objective were taken into account both any concordance or discordance in the literature, to identify which was the most promising field in which to find confirmation and at the same time deepen the previous results, and the technical feasibility of the experiment, in terms of instrumentation needed, recruitment of subjects and timing.

In that direction the experiment to be chosen should not have too many conditions to consider, so the first step was to exclude any study that concerns more than one of the factors described, to avoid going deeper in their correlation effects, for example, while on one hand the possibility to expand the experiment by Lan et al. (Lan, Wargocki, Wyon, & Lian, 2011) to the field of engineering design tasks was very interesting, on the other hand, that includes both the intensity and the temperature of the light, so that there were too many conditions to study.

Finally, the most promising experiment chosen was on the basis of the research run by Steidle and Werth (Steidle & Werth, 2013).

As written before, they ran six experiments with the result that darkness or dim illumination increases freedom from constraints, which in turn promotes creativity. To expand this research in our field of interest can be interesting to change the experiments focalizing on engineering design.

The hypothesis is that creativity as a large concept has the same application in all the domains, so the test is to switch from the psychological domain to the engineering one, with further confirmation by neurophysiological signals.

So, the proposed experiment deepens the study of darkness, trying to insert that environment setting in the other previous literature results about the illumination.

When and how can be useful to decrease the illumination?

ii. Description

The experiment is defined as follows:

20 engineers or engineering students will be divided into 2 different rooms, in which are set two different light intensities: 500 lx and 150 lx. The first level represents the ideal level of illumination recommended from the main global lighting institutes, as well as a value in line with the subjective evaluation done by Lan et al. (Lan, Wargocki, Wyon, & Lian, 2011), and just slightly higher than their comprehensive subjective-physiological range; while the second is the reference point for a dimly illuminated room, as in the experiment from Steidle and Werth (Steidle & Werth, 2013).

Despite it can be interesting to study the effect of a completely or partially dark room, this possibility was discarded to meet greater practical applicability of the results of the experiment, as it is not credible to create a work environment with too little lighting, even if only for safety reasons.

Finally, these two levels permit to study of the phenomena in a sufficiently complete way, without adding too many conditions. This setting is useful to two main objectives: first of all, it allows the focus of previous studies to shift to engineering design and creativity, thanks to the task described below; but, at the same time, it permits to find confirmation to previous literature results that have identified an optimal lighting setting, expanding the research with a more in-depth study of the darkness (intended as dim illumination) factor.

As mentioned above, to reach the goal to study lighting in the engineering design field, it is chosen the tasks already used by Shealy et al. in 2018 (Shealy, Gero, & Hu, 2018).

The subjects have to perform 3 different design tasks, in 3 different methods, varying in structuredness: brainstorming provides no predefined direction (unstructured); morphological analysis requires designers to decompose the problem into sub-functional components before offering solutions (semi-structured); TRIZ requires designers to think through both the problem and solution using a predefined knowledge base (structured).

The 3 design tasks are:

1. to assist the elderly with raising and lowering windows → Brainstorming
2. to design an alarm clock for the hearing impaired → Morphological analysis
3. to design a kitchen measuring tool for the blind → TRIZ

These tasks, then, allow us to study the convergent and divergent phases of thought, as structuredness is directly related to this concept. A more structured problem is closer to convergent thinking, a less structured one to divergent thinking.

Finally, the study will be done through EEG, in line with both the experiment analysed in chapter 2 (Colombo, et al., 2020) and with the one by Lan et al. (Lan, Wargocki, Wyon, & Lian, 2011).

The procedure is described through two swim-lane diagrams (Fig. 3.5.1 – 3.5.2), that highlight the main steps that the researcher and the subjects have to do.

Firstly, the researcher has to prepare the rooms and the instruments, while the subjects start to enter and complete their registration, then, after a precise description of the experiment, the lighting conditions are set and the experiment started.

Before going through the completion of the tasks, the subjects are requested to sign the consent to a GDPR form, then, the researcher help them to wear their EEG tracker.

After that, the subjects receive the paper with the design problems to solve, and some paper to take some notes and to brainstorm.

Then, it starts the relax phase of the experiment, which permits the subjects to familiarize themselves with the instrument and to the researcher to collect the resting values; then, the subjects start to solve the tasks. Between each task, there will be a break of 30 seconds, which is meant to bring cognitive function back to the general baseline level before the next task. The process of including a baseline cognitive measurement and rest period between each design is based on prior defined methods in neuroscience (Tak & Ye, 2014).

After the completion of all the tasks, the timer stops, and the experiment ends with the collection of the proposed solutions.

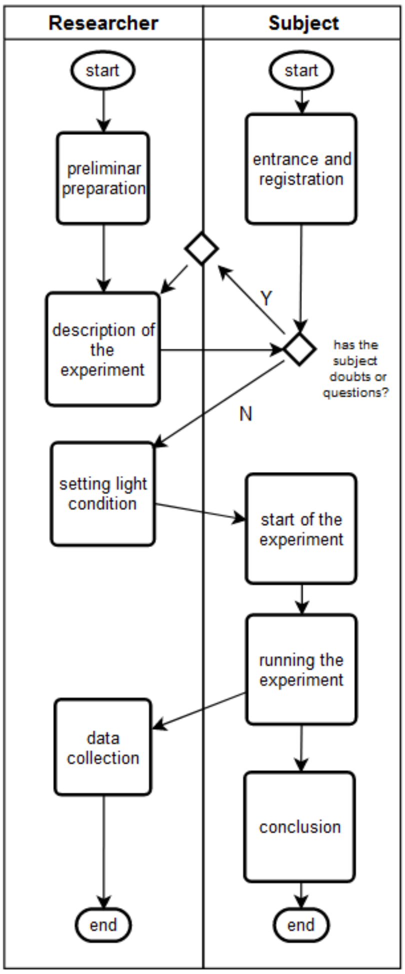

Fig. 3.5.2: Experimental chart

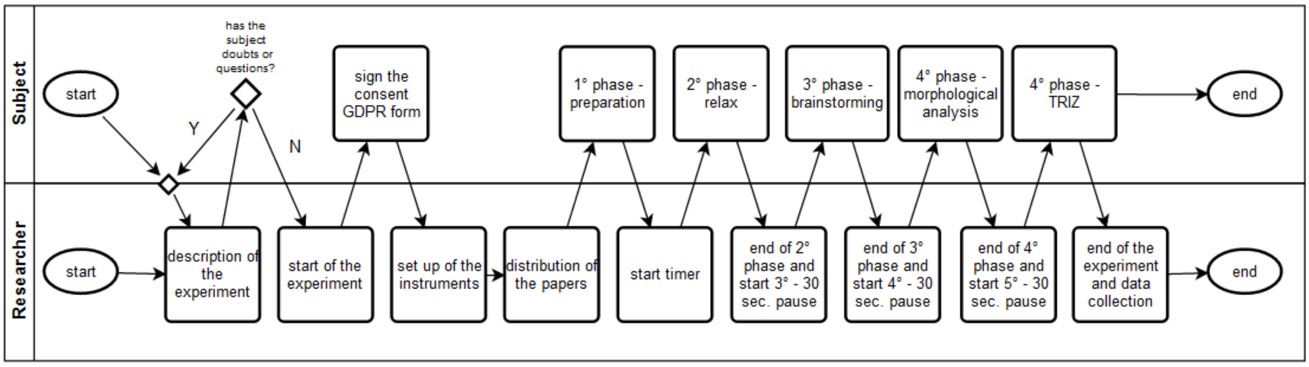

Fig. 3.5.1: Task procedure chart

4. CONCLUSION

To conclude this research, it is possible to highlight some salient points. Given the multidisciplinary nature of the study, which ranges from engineering to physiology and psychology, and the complexity of human thinking it is difficult to reach absolute results.

During every work and every task each one has to complete, subjective personal factors are involved, so a complete study of the phenomenon needs to take in consideration a lot of conditions, making it very complicated. The personal attitude plays a crucial role when the topic is the creativity and external factors and everyone reacts in different ways to different stimuli (for example, the chronotypes' phenomenon described in the second chapter), and that is reflected in the different results from the literature, between different fields or within the same one.

Given this premise, the scope of the work is reached, it is confirmed the time of the day influence on the work and its relationship with other factors, such as the background, partially confirms what is stated above about the different personal attitudes. At the same time, the research about other external factors is deepened, with a literature analysis and a proposal for an experiment, with scope to cover a sector that is only partially studied yet, i.e., the different influence of a different level of illumination on the work. The previous results only give a starting point about that darkness or dim illumination can enhance creativity, but this has never been studied more specifically in a real workplace or with engineering design application. The other research only aims to find which is the more comfortable lighting setting, without asking whether this has a different influence depending on the type of work.

The results discussed, then, are inserted as part of a broader collaboration project between Polytechnic of Turin and the Department of Psychology of the University of Turin, so that the research is not, therefore, to be placed as self-contained research, but within a wider panorama, which gradually aims to complete itself, with the ambitious goal of creating better and better ideal work environments.

4.1. LIMITS AND RECOMMENDATIONS FOR FUTURE RESEARCH

The limits of that research, partially described before, derive from its exploratory nature and its wide horizon. It is evident that there is not a clear goal to be crossed, that states the end of the research, but every step tends to clarify the precedents and expand the current horizons. Remaining on the theme of this thesis, the experiment in chapter 2 by itself offers a large variety of study options, from the data collected it is possible to run a lot of different analyses, with different parameters and interactions between them; at the same time, it can be an example for future research that want to study the phenomenon similarly, taking in considerations other variables and changing the subjects. The more parameters are added to the study the more it is close to being complete: for example, the study of the time of the day factor, not initially planned, and derived from the questionnaire time, can be deepened with a future study with a more balanced subdivision between those who complete the task in the morning and in the afternoon, perhaps defining and separating clearly the two timeframes. Another proposal can be to choose subjects with the same chronotype, to avoid this factor influencing the results.

The third chapter offers, in the same way, a lot of options for future research: the experiment proposed is a good starting point, but at the same time it can be interesting to include the factor of the light temperature, to confirm the experiment by Lu et al. (2020) (Lu, et al., 2020), that has as main focus the work efficiency on engineering design tasks; or to study other variables' effects, such as noise or temperature, even if only to confirm the previous results in our field of research.

Then, for the future, the study can be extended to other factors different from the "intangible" ones that are described in this research, for example the social and organizational factors, i.e. the teamwork effect, the type and complexity of the job, or the incentives that a worker can obtain, play a crucial role in the workplaces, and they can themselves influence creativity (Dul, Ceylan, & Ferdinand, 2011).

REFERENCES

Cacot, P., Tesolin, B., & Sebban, C. (1995). Diurnal variations of EEG power in healthy adults. *Electroencephalography and Clinical Neurophysiology, 94*, 305-312. doi:10.1016/0013-4694(94)00298-y

Cantamessa, M., & Montagna, F. (2016). *Management of Innovation and Product Development - Integrating Business and Technological Perspective.*

Chellappa, S., Steiner, R., Blattner, P., Oelhafen, P., Gotz, T., & Cajochen, C. (2011). Non-Visual Effects of Light on Melatonin, Alertness and Cognitive Performance: Can Blue-Enriched Light Keep Us Alert? *PLoS ONE, 6*(1). doi:10.1371/journal.pone.0016429

Cho, W., Hwang, S., & Choi, H. (2011). The relationship between pure-tone noise and human bio-signal response. *International Journal of Precision Engineering and Manufacturing, 12*(4), 727-731. doi:10.1007/s12541-011-0094-8

Colombo, S., Mazza, A., Montagna, F., Ricci, R., Dal Monte, O., & Cantamessa, M. (2020). Neurophysiological evidence in idea generation: differences between designers and engineers. *International Design Conference – Design 2020*. doi:10.1017/dsd.2020.161

Daikoku, T., Fang, Q., Hamada, T., Handa, Y., & Nagai, Y. (2021). Importance of environmental settings for the temporal dynamics. *Thinking Skills and Creativity, 41*. doi:10.1016/j.tsc.2021.100911

Dul, J., Ceylan, C., & Ferdinand, J. (2011). Knowledge workers' creativity and the role of the physical work environment. *Human Resource Management, 50*(6), 715-734. doi:10.1002/hrm.20454

Eberle, B. (1996). *Scamper: creative games and activities for imaginative development.* Waco: Prufrock Press.

Ericsson, K., & Simon, H. (1984). *Protocol analysis: Verbal reports as data.* The MIT Press.

Findlay, C., & Lumsden, C. (1988). The creative mind: toward an evolutionary theory of discovery and innovation. *Social and Biological Structures, 11*(1), 3-55. doi:10.1016/0140-1750(88)90025-5

Fink, A., & Benedek, M. (2013). EEG alpha power and creative ideation. *Neuroscience and Biobehavioral Reviews*. doi:10.1016/j.neubiorev.2012.12.002

Giampietro, M., & Cavallera, G. (2007). Morning and evening types and creative thinking. *Personality and Individual Differences, 42*, 453-463. doi:10.1016/j.paid.2006.06.027

Guilford, J. (1967). Creativity: yesterday, today and tomorrow. *The Journal of Creative Behavior, 1*, 3-14. doi:10.1002/J.2162-6057.1967.TB00002.X

Horii, A., Yamamura, C., Katsumata, T., & Uchiyama, A. (2004). Physiological response to unpleasant sounds. *Journal of International Society of Life Information Science, 22*(2), 536-544. doi:10.18936/islis.22.2_536

Hygge, S., & Knez, I. (2001). Effects of noise, heat and indoor lighting on cognitive performance and self-reported affect. *Journal of Environmental Psychology, 21*, 291-299. doi:10.18936/islis.22.2_536

Jauk, E., Benedek M., & Neubauer, A. (2012). Tackling creativity at its roots: evidence for different patterns of EEG alpha activity related to convergent and divergent modes of task processing. *International Journal of Psychophysiology, 84*(2), 219-225. doi:10.1016/j.ijpsycho.2012.02.012

Kawasaki, M., Karashima, M., & Saito, M. (2009). Effect of emotional changes induced by sounds on human frontal alpha-wave during verbal and non-verbal tasks. *Int. J. Biomedical Engineering and Technology, 2*(3), 191-201. doi:10.1504/IJBET.2009.024411

Kosonen, R., & Tan, F. (2004). Assessment of productivity loss in air-conditioned buildings using PMV index. *Energy and Buildings, 36*(10), 987-993. doi:10.1016/j.enbuild.2004.06.021

Lan, L., Wargocki, P., Wyon, D., & Lian, Z. (2011). Effects of thermal discomfort in an office on perceived air quality, SBS symptoms, physiological responses, and human performances. *Indoor Air, 21*, 376-390. doi:10.1111/j.1600-0668.2011.00714.x

Lichtenfeld, S., Elliott, A., Maier, M., & Pekrun, R. (2012). Fertile green: green facilitates creative performance. *Personality and Social Psychology Bulletin, 38*(6), 784-797. doi:10.1177/0146167212436611

Lu, M., Hu, S., Zhu, M., Liang, P., Xin, S., & Guan, H. (2020). Research on work efficiency and light comfort based on EEG evaluation method. *Building and Environment, 183*, 107-122. doi:10.1016/j.buildenv.2020.107122

Mackenberg, E., Broverman, D., & Vogel, W. (1974). Morning-to-afternoon changes in cognitive performances and in the electroencephalogram. *Journal of Educational Psychology, 66*(2), 238-246. doi:10.1037/h0036131

Mehta, R., & Zhu, R. (2009). Blue or red? Exploring the effect of color on cognitive task performances. *Science, 323*, 1226-1229. doi:10.1126/science.1169144

Meinel, M., Maier, L., Wagner, T., & Voigt, K.-I. (2017). Designing creativity-enhancing workspaces: a critical look at empirical evidence. *Journal of Technology and Innovation Management, 1*(1), 1-12.

Osborn, A. (1953). *Applied Imagination: principles and procedures of creative thinking.* New York: Scribner.

Petersen, C., & Harmon-Jones, E. (2009). Circadian and seasonal variability of resting frontal EEG asymmetry. *Biological Psychology, 80*, 315-320. doi:10.1016/j.biopsycho.2008.11.002

Pfurtscheller, G., & Lopes da Silva, F. (1999). Event-related EEG/MEG synchronization and desynchronization: basic principles. *Clinical Neurophysiology, 110*(11), 1842-1857. doi:10.1016/s1388-2457(99)00141-8

Rondinoni, C., Amaro Jr, E., Cendes, F., dos Santos, A., & Salmon, C. (2013). Effect of scanner acoustic background noise on strict resting-state fMRI. *Biomedical Science, 46*(4), 359-367. doi:10.1590/1414-431X20132799

Schwab, D., Benedek, M., Papousek, I., Weiss, E., & Fink, A. (2014). The time-course of EEG alpha power changes in creative ideation. *Frontiers in Human Neuroscience, 8*(310). doi:10.3389/fnhum.2014.00310

Shalley, C. (1991). Effects of productivity goals, creativity goals, and personal discretion on individual creativity. *Journal of Applied Psychology, 76*(2), 179-185. doi:10.1037/0021-9010.76.2.179

Shealy, T., Gero, J., & Hu, M. (2018). Patterns of cortical activation when using concept generation techniques of brainstorming, morphological analysis, and TRIZ. Quebec. doi:10.1115/DETC2018-86272

Simon, H. (1969). *The Science of the Artificial.* Cambridge: The MIT Press.

Steidle, A., & Werth, L. (2013). Freedom from constraints: darkness and dim illumination promote creativity. *Journal of Environmental Psychology, 35*, 67-80. doi:10.1016/j.jenvp.2013.05.003

Tak, S., & Ye, J. (2014). Statistical analysis of fNIRS data: a comprehensive review. *Neuroimage, 85*(1), 72-91. doi:10.1016/j.neuroimage.2013.06.016

Thoring, K., Desmet, P., Mueller, R., & Badke-Schaub, P. (2020). Spatial design factors associated with creative work: a systematic literature. *Artificial Intelligence for Engineering Design Analysis and Manufacturing*. doi:10.1017/S0890060420000232

Valdez, P., Ramirez, C., & Garcia, A. (2012). Circadian rhythms in cognitive performance: implications for neuropsychological assessment. *ChronoPhysiology and Therapy, 2*, 81-92. doi:10.2147/CPT.S32586

Venkat, N., Sinha, M., Sinha, R., Ghate, J., & Pande, B. (2020). Neuro-cognitive profile of morning and evening chronotypes at different times of day. *Annals of Neurosciences, 27*(3-4), 257-265. doi:10.1177/0972753121990280

Wallas, G. (1926). *The art of thought.*

Woodman, R., Sawyer, J., & Griffin, R. (1993). Toward a theory of organizational creativity. *Academy of Management Review, 18*(2), 293-321. doi:10.5465/AMR.1993.3997517

Xia, T., Song, L., Wang, T., Tan, L., & Mo, L. (2016). Exploring the effect of red and blue on cognitive task performances. *Frontiers in Psychology, 7*(784). doi:10.3389/fpsyg.2016.00784

Yao, Y., Lian, Z., Liu, W., Jiang, C., Liu, Y., & Lu, H. (2009). Heart rate variation and electroencephalograph-the potential physiological factors for thermal comfort study. *Indoor Air, 19*(2), 93-101. doi:10.1111/j.1600-0668.2008.00565.x

Yoto, A., Katsuura, T., Iwanaga, K., & Shimomura, Y. (2007). Effects of object color stimuli on human brain activities in perception and attention referred to EEG alpha band response. *Journal of Physiological Anthropology, 26*(3), 373-379. doi:10.2114/jpa2.26.373