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Time of Day and Background: How They Affect Designers Neurophysiological and Behavioural Performance in Divergent Thinking

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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 it focuses on Engineering Design, aiming at understanding not only the influence of external and human factors but also the relationship between the behavioural and the neurophysiological response.

Engineering Design can be considered as a technical activity whose goal is to come up with a solution that will turn out to be effective in practice. Given its human and social nature, the attention to Design and Creativity, which is one of the most important features of the whole process, has been progressively grown among researchers. It is, indeed, this perspective on Engineering Design that drove scholars to observe and study the cognitive processes behind it and that justifies the analyses carried out in the present work.

The neurophysiological data were taken from a pre-existing experiment (Colombo, et al., 2020) while behavioural data relating to participants performances in terms of novelty and quality were gathered starting from the evaluation of the subjects' verbal answers, performed by 4 raters that followed specific assessment rules, according to Literature.

Focusing on the behavioural response, some ANOVAs have been carried out to investigate its relationships with daytime, participants educational background and neurophysiological signals.

It was also deepened through further statistical studies how daytime, and background can influence subjects' response time and how together with two other factors, the participants stress level and the strategy adopted during the experiment, can affect the neurophysiological response.

Significant results were obtained, for example, considering the time of the day in correlation with participants performances in terms of quality and novelty and regarding stress, daytime, and background in relation to neurophysiological signals.

Moreover, it was observed that different kinds of performances reflect distinct patterns in brain activity.

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Introduction

Background

Design still holds great importance among scholars although the study of its process, following a scientific approach, can be traced back to Simon Herbert and, precisely, to his well-known book “The science of the Artificial”, published in 1969.
For many years Design has been considered as a problem-solving activity (Alexander, 1964; Simon 1969), or as a coevolution of the Design problem and the relating solution space (Schön, 1992). Many perspectives on Design have been following each other though the past years, but it is because of the most recent standpoint that considers Design as a human and social activity if the attention given to the field has been growing ever since (Gero & Kannengiesser, 2004).
Scholars, thus, have started focusing their studies on the designers’ cognitive processes to better understand how to support them during these activities, boost pedagogy and improve the outcomes of Design itself (Gero & Milovanovic, 2020).
Since the beginning, Design Cognition has been explored by adopting empirical approaches, usually referred as Protocol Analysis or rather the evaluation of sketches, reports and words expressed by participants during the design activity (Hay et al., 2017).
However, these techniques completely ignore tacit aspects of designers which are unpredictable and regulated also by emotions. (Balters & Steinert, 2017).
In the last decades, to unfold designers’ subconsciousness sphere, a progressive adoption of a neurophysiological approach has been made within the research field, complementary to Protocol Analysis, also given the greater availability of biometric tools.
Nevertheless, literature is still in an early stage with an explorative and descriptive approach to the phenomena, providing fragmented or, sometimes, contradictory results.
The present thesis is part of a broader research, conducted by the Politecnico di Torino in collaboration with the Department of Psychology of Università degli Studi di Torino and the Technological University of Luleå.

Purpose of the research

The present work has as objective to deepen the analysis, already conducted by Piga (2022) in his master thesis about the time of day influence on Design cognitive processes. Moreover, this thesis aims to carry on the research project of Candusso (2019) who aimed at developing a proper design to compute the statistical analyses on the data gathered during the previous experiment and identifying the criteria to evaluate the subjects ‘performances in terms of creativity.

Thereby, the present thesis aims at bridging the neurophysiological, psychological and the behavioural response trying to understand if different performances in terms of creativity can be reflected into distinct cognitive activations during the design task.

It is also present the attempt to shed light on the influence that behavioural, external and personal factors can exerted on the idea generation process.
In particular, the project has the goal to understand if behavioural aspects, or rather the stress level felt by participants and the strategy adopted to perform the task, can generate peculiar neurocognitive patterns and/or affect performances in terms of creativity, also in correlation with educational background and daytime.
Finally, it is questioned if the time spent to generate ideas during the task can be somehow affected by the educational background and the time of day.

Methodology

The methodology for the present work started with a brief literature review carried out to explore the general context and the future directions of research.

As already pointed it out, literature is still in early phase and it is difficult to identify a clear direction of research. However, among the main goals have been recognised the aim of studying the Design processes by neurophysiological means in order to gain objective data allowing the comparability of results and the goal of understanding the key variables, such as the variety of stimuli, the stress level and the educational background, that can influence the cognitive processes during the Design task.

Candusso (2019) analysed the neurophysiological data gathered during the experiment by developing a design for the statistical investigations and identified the proper criteria for the Idea Creativity evaluation.
Piga (2022), on the other hand, through the analysis of the neurophysiological signals gathered, explored the influence of the time of day on the cognitive processes which characterise idea generation activity.

The literature review was conducted thanks to Elsevier's Scopus abstract and citation database, specifically through the following query:

- TITLE- ABS- KEY ("Design Cognition") AND ("Industrial Design" OR "Engineering Design") AND ("Design Thinking" OR "Idea generation" OR "Creative Thinking") AND ("EEG" OR "Electroencephalography" OR "Electroencephalogram" OR "ECG" OR "Electrocardiogram" OR "Electrocardiography" OR "HRV" OR "fMRI" OR "Functional magnetic resonance imaging" OR "fNIRS" OR "Functional near infrared spectroscopy")

This specific query was built by taking into consideration the general domain and the particular field of interest in the first part, by addressing the biometric devices employed to study Design together with their respective most common acronyms in the last part. Among the 77 results provided by it, three reviews in particular were acknowledged as the most explaining: Gero & Milanovic (2020), Hay, Cash & McKilligal (2020), Borgianni & Maccioni (2020). Moreover, starting from some previous thesis works, other interesting and useful sources were identified following a snowballing process with the aim of understanding the importance of the idea evaluation and of those factors able to influence people's cognitive processes such as daytime.

The methodology then moved on the data collected during the experiment that are both neurophysiological and behavioural. About the neurophysiology, for the data acquisition were employed the EEG 32 channel 10-20system and Tobii© X2-30 Eye Tracker Compact Edition with 30 Hz sampling frequency. Moreover, at the end of the task, a quick questionnaire was administered. In particular, the stress level (High, Low) was inferred starting from answers given by subjects on a 5 point-Likert scale and the strategy adopted to perform the task.

In order to carry out and gather the evaluations of the behavioural aspects, the present work exploit the methodology developed by Candusso (2019). It allows to evaluate the participants answers in terms of originality, paradigm relatedness, feasibility and effectiveness.

Finally, the statistical analysis was carried out by employing R programming language and RStudio as the Integrated Development Environment (IDE). The Analysis of Variance (ANOVA) was the statistical test adopted and organised as follows:

- 3-way ANOVA (2*2*2; Stress; Background; Daytime) with the TRPs of each brain wave as dependent variables.
- 3-way ANOVA (2*2*2*; Stress; Background; Daytime) with evaluations of the verbal responses given by participants as dependent variables.
- 2-way ANOVA (2*3; background; daytime) with the response time as dependent variable.
- 2-way ANOVA (2*3; background; daytime) with evaluations of the verbal responses given by participants as dependent variables.
- 2-way ANOVA (2*2; Strategy; Daytime) with the TRPs of each brain as dependent variables.
- 2-way ANOVA (2*2; Strategy; Background) with the TRPs of each brain as dependent variables.

- 2-way ANOVA (2*2; Strategy; Stress) with the TRPs of each brain as dependent variables
- 2-way ANOVA (2*2; Strategy; Daytime) with evaluations of the verbal responses given by participants as dependent variables.
- 2-way ANOVA (2*2; Strategy; Background) with evaluations of the verbal responses given by participants as dependent variables.
- 2-way ANOVA (2*2; Strategy; Stress) with evaluations of the verbal responses given by participants as dependent variables.
- One way ANOVA taking the evaluations of the verbal responses given by participants as dependent variables and each time one of the following factors: daytime, background, stress.
- One way ANOVA taking TRPs of each brain wave as dependent variables and strategy as factor.
- One way ANOVA taking the TRPs of each brain wave as dependent variables and the evaluations of verbal responses as factors.

On the neurophysiological signals, the analyses were conducted on their power, based on the main clusters of frequency (alpha, beta, gamma 1, gamma 2, delta, theta) and for each group of electrodes (pre-frontal, frontal, temporal, central, parietal, occipital). The analyses based on performance metrics (originality, paradigm relatedness, feasibility, and effectiveness) were run for each of them.

Document structure

The document is organised in four chapters, introduction and conclusions excluded.

The first chapter focuses on the context in which the present research fits in order to make clearer to the reader the main features of the Engineering Design and the neurophysiological approach followed to explore its cognitive processes.

The second chapter is represented by a brief literature review that aims at understanding the importance of the idea evaluation process and its main challenges together with the influence that daytime can exerted on cognitive performances with reference to the concepts of chronotype and biological rhythms.

The third chapter is centred around the data collecting activity. In particular, it is described the procedure of the experiment previously designed and carried out to gather the neurophysiological data and the evaluation method which was followed to perform and collect the assessments in terms of creativity with reference to the verbal responses given by participants.

The fourth and last chapter aims at presenting the statistical analysis and its results. In particular, the first part is dedicated to the description of the dependent variables and all the factors included in the analyses. The second part focuses on describing the actual outcomes of the ANOVAs that were carried out.

1 General Context

1.1 Product Development Process

Engineering design is part of a broader process, known as Product Development, which is worth describing in order to better understand the general context of the present thesis.

Product Development cannot always be predefined, especially if the innovation degree of its outcome is remarkably high, although it is possible to identify few general phases as the ones shortly described below (Cantamessa & Montagna, 2016):

-Product Planning: the aim of this highly inter functional initial phase is to come up with a rough description of the product, starting from identifying implicit and explicit market needs and seizing possible technological opportunities.

The so-called "product brief" makes possible the positioning among competitors and it also allows the definition of the cost and the business case which will turn into an actual operation plan during the steps ahead. User needs and user requirements definition also belong to this stage.

-Conceptual Design: this phase ends up defining a new product concept from the already gathered user requirements by initially generating a large number of technical solutions and then, according to the selected innovation level, by choosing only one specific option that will represent the start for the following design stages.

-System level design: this stage is characterised by few choices that will lead to the definition of the product architecture. In particular, it will be set the carryover level, how much to be taken from the previous product version, and it will also be decided which subsystems are to be developed from scratch and which, instead, can be chosen from pre-existing ones, provided by the firm itself or by competitors.

In the end, the firm will be engaged in make, buy and development decisions and it will focus the attention on the systems belonging to the entire product lifecycle.

-Detailed Design: this stage deals with the choice of materials and components aiming at meeting the desired product specifications. During this phase, decisions taken at system level will eventually be discussed again.

-Prototyping and testing: it is an important and most of the times compulsory stage because of existing regulations asking the final product to have specific certifications, only obtainable by running a series of tests on prototypes. Nowadays, the whole process can be performed in parallel with the detailed design phase in a cheaper and faster way thanks to the virtual simulation that counts on virtual prototypes, instead of the physical ones.

-Process Design: this stage is characterised by the detailed design of all the processes involved during the production, distribution and service phases of the final product.

-Product launch and production: this last phase deals with the combination of resources and processes that will be involved during the final product launch.
In particular, at this stage the pace of production is decided, normally slower at the beginning in order to be able to make the proper adjustments before reaching the nominal rhythm.

1.2 Creativity in Engineering Design

Creativity is necessary to pursue innovation and to reach long term success which is why it is fundamental for both organizations and individuals to study the processes that can lead to creative solutions-ideas (Howard et al., 2008).
However, a single and clear definition of creativity hasn't been provided yet.
Some scholars link creativity to people's personality interpreting it as a human aspect (Daikoku et al., 2021). According to this perspective, creative people are characterised by the ability of producing numerous ideas (ideational fluency) which will turn out to

be both unique-original (degree of novelty) and different from each other (flexible thinking).
Creativity is most often associated to the to the generation of novel, useful and valuable ideas and to the definition of solutions (Fink et al., 2010). This is why it is considered as one of the main aspects of Design process, strongly based on idea generation.
Creativity is, indeed, among the most investigated Design's feature as testified, for example, by Laura Hay, Philip Cash and Seda McKilligan's review, according to which the 71% of papers examined focused on "Conceptual and Creative Design" (Hay et al., 2020).
Creative stages of Design are the trickiest to study because of the heterogenous definitions of creativity and the great number of cognitive processes involved (Colombo et al., 2020).
Guilford was the first scholar to identify two main constructs that characterise idea generation, therefore creativity itself: divergent and convergent thinking (Guilford, 1956).
The former usually refers to ill form problems or rather problems that do not contemplate a single solution. The ultimate goal is, indeed, to generate a great number of possible solutions thinking freely without following any specific path.
Convergent thinking, instead, can be interpret more like a "concrete- specific thinking" (Daikoku et al., 2021) whose aim is to organise and screen the ideas produced though divergent thinking.
Even though the just mentioned processes appear to be opposite at first, they are usually implemented together as complementary stages to reach creativity.

1.3 Conceptual Design and idea generation

Empirical studies mostly focus on Conceptual Design among Design processes. The reason can be traced back to the strong connection it presents with creativity.

Conceptual design includes three phases. Once the design problem is defined (problem definition), a technical solution space is generated in order to develop new concepts starting from the user requirements (concept generation). Afterwards a screening phase takes place aiming at choosing a single idea among the ones previously produced. (Concept screening and selection) (Cantamessa & Montagna, 2016). The process already described reflects, indeed, what Warr and O' Neill reported in their work as the generic creative process, represented in the figure below. (Warr & O'Neill, 2005).

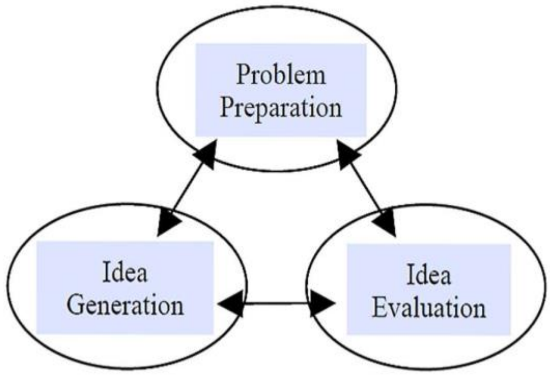

Figure 1:Generic creative process (Warr & O'Neill, 2005)

Therefore, given this solid connection to creativity, Conceptual design is usually described as a cycle of divergent and convergent thinking phases following the perspective according to which Design activities do not happen in sequence (Steinert & Jablokow, nd).

To support the idea generation phase and make the production of new concepts easier, different kinds of methods were developed by scholars.
Among the most common ones, it is possible to mention the following (Cantamessa & Montagna, 2016):

- Brainstorming: a group of people, usually lead by a facilitator, generate and share to each other a large number of ideas, working all together.
- SCAMPER: method that follows brainstorming principles and that involves a series of predefined categories to which ideas generated need to belong.
- TRIZ: the aim is overcoming the contradictions existing between a system and its environment or within systems components, generating new concepts by reducing human involvement referring to the technical system.

- Synectics: it consists of producing new ideas using metaphors and analogies.
- Wish and wonder & Law-breaking: people are asked to think without any constraint and ideas are produced imagining operating in an ideal world.

Literature suggests different ways of classifying the idea generation methods.
One of the most famous categorizations has been developed by Kudrowitz who proposed to split idea generation methods in structured and unstructured or ill form ones, according to the problem type they have to face. The former usually provide well defined objectives and contemplate a single, sometimes optimal solution. The latter, instead, cannot be described specifying every aspect and does not see only one possible way to solve the problem. (Kudrowitz & Wallace, 2012)
It is important to highlight that structured methods are usually employed once the idea-concept has been already chosen, further in the Design process, and that they are more likely to produce useful ideas. Free-form methods, on the other hand, are taken into consideration especially during the beginning of the Design process, given their tendency to generate more creative ideas. (Chulvi et al., 2012)

According to Shah classification, it is also possible to group idea generation methods into two macro categories: Intuitive and Logical methods. The former revolve around the stimulation of the human unconscious thinking processes while the latter show a more rational nature based on analysing the problem by employing engineering concepts together with pre-used solutions or resolution approaches. (Shah et al., 2020)

1.4 Protocol studies vs neurophysiological approach

In Literature it is common to read about three main paradigmatic approaches to study Design thinking and its characteristics (Design reasoning, processes, Design fixation, Design creativity…): Design Cognition, Design Physiology and Design Neurocognition.
Design Cognition has been taken the lead among the other approaches since designers' cognitive activity caught the attention of scholars (Gero & Milovanovic, 2020).

It focuses on measuring designers' cognitive behaviours especially through protocol analysis: the "think aloud method" has been borrowed from the psychological field. According to this research method, designers are asked to talk out loud while engaged in the design process as researchers collect insights relating to their thinking process and consequently to their cognitive behaviour.

Nowadays, however, few limitations of this method have been recognised. The process of verbalization, for example, could interfere with the design process itself altering the underlying thinking process. In addition to this, designers will rarely be able to verbalize all their thoughts and this is why some usually remain unexplored (Coley et al., 2007).

To sum up, Protocol Analysis leaves behind designers 'tacit aspects which are unpredictable and regulated by emotions. (Balters & Steinert, 2017). Thus, to capture and analyse the sphere of the subconsciousness designers and neuroscientists started to collaborate and neurophysiological tools have been progressively involved in the investigation of designer's cognition. These kinds of instruments also ensure to collect measures in a standard impersonal manner, something that wasn't possible by using Protocol Analysis (Teplan, 2002).

1.5 Biometric instruments

It is worth, at this point, describing the biometric tools that lately have been employed by scholars to carry out their studies, according to the two approaches, physiological and neurophysiological, that recently have been progressively adopted, in parallel with Protocol Analysis.

1.5.1 Design physiology

Design physiology, for example, uses different kinds of sensors in order to capture somatic changes, registered in response to the emotions felt during the design process (Balters & Steinert, 2017):

- Eye Tracker: It helps monitoring eye movements and pupil dilation when it is important to study the subject's level of comprehension, his cognitive load and the duration of his fixation.

- Electrodermal activity (EDA): It consists of a group of sensors that look at the activation of sweat glands, especially for palmar and plantar surfaces. Most of the times it is employed to study emotions such as stress, joy, fear, and the subjects' attention level.

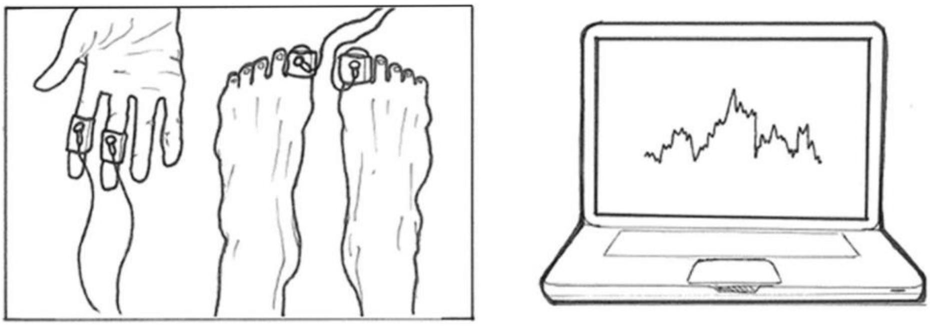

Figure 2: Galvanic skin response measurement (Balters & Steinert, 2017)

- ECG and Heart rate variability (HRV): it observes signals originated from changes in the interval between two heart beats (heart contraction). It is usually employed to study design creativity and measure the stress level during the process.

1.5.2 Design neurocognition

Design neurocognition, on the other hand, focuses on investigating the possible links between cognitive processes and mental activity. Before mentioning the most common instruments, it could be useful to briefly report the major areas of the cerebrum and the functions they host.

1.5.2.1 Brain areas

The cerebral cortex is commonly divided into two hemispheres and each one is commonly split in four lobes: frontal, parietal, temporal and occipital.

The frontal lobe carries high level regulation functions such as emotional controlling, planning, reasoning and problem solving, and it is also responsible for voluntary movement.

The parietal area hosts functions related to sensory information; touch, temperature and pain can be mentioned as examples.

Similarly, the temporal lobe includes areas responsible for the same processing type. In this case, the capability to hear, recognise language and building memories are all involved.

To conclude, the occipital lobe is known as the greatest visual processing spot in the brain (Rif-Queensland Brain Institute).

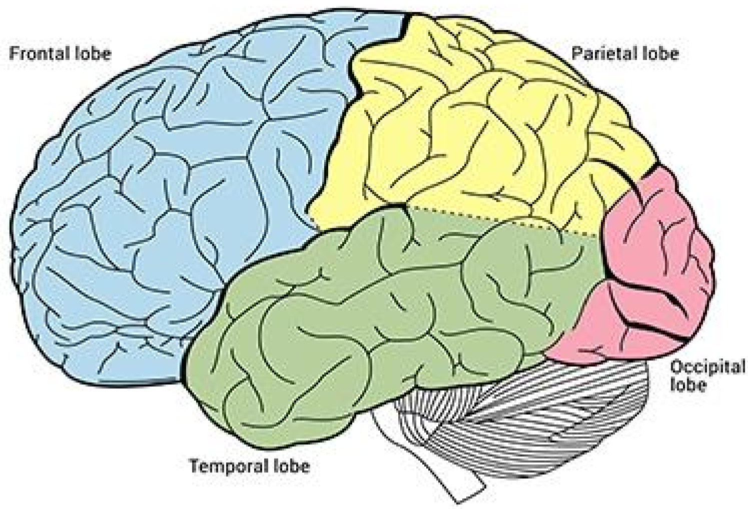

Figure 3: Brain lobes (Queensland Brain Institute)

Going back to the biometric tools employed to study brain activity, the following instruments are described to provide some examples:

-EEG: it detects the electrical brain activity looking at the neural communication via electrodes placed on the subject's scalp. Its temporal resolution is very high while its spatial one is poor. The neurophysiological signals are commonly classified according to the main clusters of frequency (Sawant & Zahra, 2010):

- Gamma (> 30 Hz): usually related to motor and sensory activity. Gamma waves are also commonly linked to highly demanding tasks.
- Beta (13-30 Hz): associated with mental activity when awake.
- Alpha (8-13 Hz): occur when subjects are awake, but in a relaxed and quite status.
- Theta (4-7 Hz): frequently related to deep sleep stages and childhood. Sometimes they are also associated to stress conditions.
- Delta (below 3.5 Hz): correlated to deep sleep stages, childhood, and neurological disorders-diseases.

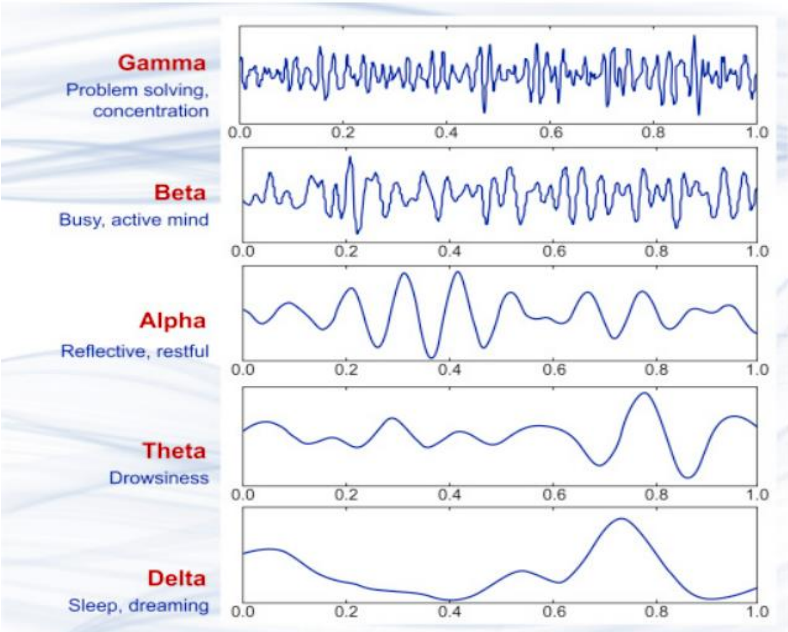

Figure 4: Brain waves representation (Abhang et al., 2016)

Figure 5: Example of a Dry EEG

EEG is commonly recognised in Literature as the most employed biometrical tool because of high temporal resolution, comparability of results and usability. It is, in fact, one of the least invasive tools and it allows subjects with more freedom during the experiment, not influencing results in a substantial way. It is also cheaper and easier to use comparing to other devices. (Rif-Bridging the gap between designers and engineers).

-fMRI: it recognises changes in the brain activity observing variations in the blood oxygen level. Comparing this tool to EEG it shows a lower temporal resolution, but a higher spatial one.

-Functional near infrared spectroscopy (fNIRS): it observes the light reflected to the sensor when a ray of light is faced towards the brain: the light reflected represents a higher presence of blood oxygen in all the areas activated in the brain.

2 Literature review

2.1 Idea evaluation

Given that being able to produce “good” ideas is crucial for innovation to thrive and for managerial problem-solving skills to develop (Dean et al., 2006), researchers have been committed to investigate the idea generation field focusing their attention on defining when to consider ideas good, how to evaluate them in order to improve the idea generation methods employed, already described back in chapter 1.

In psychology an idea is acknowledged as creative if it is novel, in fact, fluency and novelty are thought to be the most important features to measure the idea generation ability.

In Engineering Design this is not completely true: it is necessary for new concepts to be novel, but they must satisfy the intended functions to desired specifications as well. “Design is goal oriented. A designer’s success is judged by how well his/her design meets desired goals and how well he/she has identified the alternative ways of achieving those goals.” (Shah et al., 2003)

According to these two different points of view, idea evaluation methods can be classified in:

-Novelty based- methods: ideas can be considered creative if they are novel-original.

-Attribute-based methods: in order to be defined creative, ideas must be original, but also useful, feasible, as a matter of fact they need to be high quality ideas.

However, even if quality and novelty are the main constructs to be taken into consideration while attempting to measure idea generation outcomes, no standard evaluation procedure has emerged yet.

Indeed, according to Dean literature review of 90 articles published from 1990 to 2005, almost all the studies in Literature rarely adopted the same metrics to evaluate ideas.

At this purpose, the figure below (fig.6) shows few of the previous and most important research works in the idea evaluation field, highlighting the different dimensions of creativity chosen by each scholar.

Study	Summary	Products in review	Dimensions of creativity				
Dean *et al.* (2006)	Review of 90 constructs for idea evaluation	Ideas (e.g. increase tourism in Tucson)	Novelty (originality, paradigm relatedness)	Workability (acceptability, implementability)	Relevance (applicability, effectiveness)	Specificity (implicational explicitness, completeness and clarity)	
Besemer and O'Quin (1986, 1999)[a]	Objective metric for creative product evaluation	Artefacts (chairs)	Novelty (surprising, original)	Resolution (logical, useful, valuable, understandable)	Elaboration and synthesis (organic, well-crafted, elegant)		
Shah and Vargas-Hernandez (2000, 2003)	Evaluation of mechanical engineering designs	Artefacts and ideas (mechanical devices)	Novelty (unusual)	Quality (meets specifications)	Variety (explored solution space)	Quantity	
Horn and Salvendy (2006, 2009)[a]	Consumer-based assessment of product creativity	Artefacts (chairs and lamps)	Novelty (frequency, rarity)	Importance (relevance, significance)	Affect (appeal, desire, attraction, delight, stimulation, etc.)		
Amabile (1982)[b]	Subjective assessment method of creativity	Artefacts (artwork and poetry)	Creativity (as determined by appropriate judges)	Creativity Cluster (novel material use, novel idea, effort, detail, etc.)	Technical cluster (technical goodness, organisation, neatness, etc.)	Aesthetic judgment (liking, aesthetic appeal, would you display it?)	
Christiaans (2002)[b]	Creativity as one metric of design review	Artefacts (cabinets and telephone booths)	Creativity (as determined by appropriate judges)	Technical quality	Attractiveness	Interest	Goodness of example

[a]In these studies, each of the dimensions are made up of many sub-dimensions in the form of bipolar adjective scales.
[b]In these studies, the assessment dimensions in addition to 'creativity' do not determine creativity, but were used to find correlations with creativity.

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Figure 6: Creativity dimensions according to the main studies related to the idea evaluation process (Kudrowitz & Wallace, 2012)

The reason why research is still so fragmented can be traced back to the main challenges that scholars must face to evaluate the output of an idea generation process (Dean et al., 2006):

- It is necessary to define a reliable way to assess each idea. This is a difficult task to perform considering the large number of ideas commonly involved in idea-generation studies (from several hundred to more than a thousand).

- Ratings of individual ideas have to be combined into an overall score.
- There is no unique interpretation of the constructs employed to evaluate ideas.

2.2 Daytime

Among the factors that can affect human cognitive performances, researchers include the time of day.
Humans are, indeed, influenced by the so-called biological rhythms which can be listed into circadian, ultradian and infradian depending on how many cycles occur per day, respectively one, more and less than one.
These biological oscillations can be identified in many human aspects such as the body temperature, the nervous system, cardiac and metabolic activity etc.
In healthy adults, on average, the level of cognitive performance is low early in the morning, then it improves at noon, excepting for a small drop after lunchtime to rise again in the afternoon reaching its highest level in the evening (Valdez et al., 2012).

From a neurophysiological point of view, some studies highlight that brain power usually reaches its peak during afternoon, considering that the diurnal maximum is linked to the wave frequency, in particular, higher it is the frequency, later the diurnal maximum will occur (Cacot et al., 1995)

It is also worth mentioning that circadian rhythms influence task performances according to the nature of the task itself. Precisely, repetitive tasks are better accomplished during the morning. The reason can be probably traced back in the growing fatigue during the day that translates into a more effective performance of "creative- perceptual restructuring tasks" during the afternoon (Vogel et al., 1974).

When speaking of time-dependency it must be introduced the concept of chronotype because it influences, together with age, the circadian rhythms and, thus, people's habits and cognitive performances during the day.

Depending on their sleep-wake cycle, people can be associated to three different circadian typologies. There are psychometric screening tools which can help everyone discovering his chronotype, but, usually, everyone who prefers morning hours is considered to be a “lark” or a “morning type”, on the contrary who favours night hours belongs to the “owl” family or “night type”. There is also who stays in the in between, thus, being classified as the “intermediate type”. The latter, actually, it is the most common chronotype while larks or owls are much more difficult to meet (Venkat et al., 2020).

3 Data collecting

3.1 Description of the experiment

The neurophysiological data considered for the statistical analyses that will be deepened in the next pages were taken from a pre-existing experiment (Colombo et al., 2020).
The instruments adopted during the experiment to were EEG 32 channel 10-20system and Tobii© X2-30 Eye Tracker Compact Edition with 30 Hz sampling frequency.

The task which was requested participants to perform was inspired by Jauk experiment, a revised version of the most famous in Literature: the AUT (Alternative Uses Task) developed by Guilford in 1967. It can be classified as an ill form generation method because subjects were not forced to respect any particular constraint, exception made for the common and uncommon condition. Participants were, indeed, asked to provide common and uncommon, but still useful uses for everyday objects in order to evaluate respectively the convergent and the divergent thinking.
The experiment was proposed to 40 students, 11 females and 29 males, belonging to different backgrounds: 23 engineers and 17 designers.

As depicted in the figure nr. 7., the experiment followed the procedure described below.
40 objects, divided into two 20 items blocks based on the condition (common, uncommon), were presented randomly to each participant. Moreover, the number of subjects that started the experiment with the common block was balanced with the

ones who started by looking at the uncommon block. Participants were randomly assigned to the group that initiated with the common or uncommon condition.

Each subject pressed the spacebar when ready to begin. The experiment started by specifying the block number and giving some instructions. On the screen appeared the condition name for 10 seconds and between each trial was shown a blank screen for 5 seconds and a fixation cross for other 5 seconds to represent the reference period. Afterwards the stimulus (item in written form) was displayed for 500 milliseconds, followed by another fixation cross for the total duration of the idea generation period, 30 seconds. Participants were allowed to press the spacebar and record the verbal answer as soon as they felt ready and press it again to proceed with the next trial.

Between the two session, common and uncommon blocks, subjects had a 2-minute break. The second block followed the same procedure.

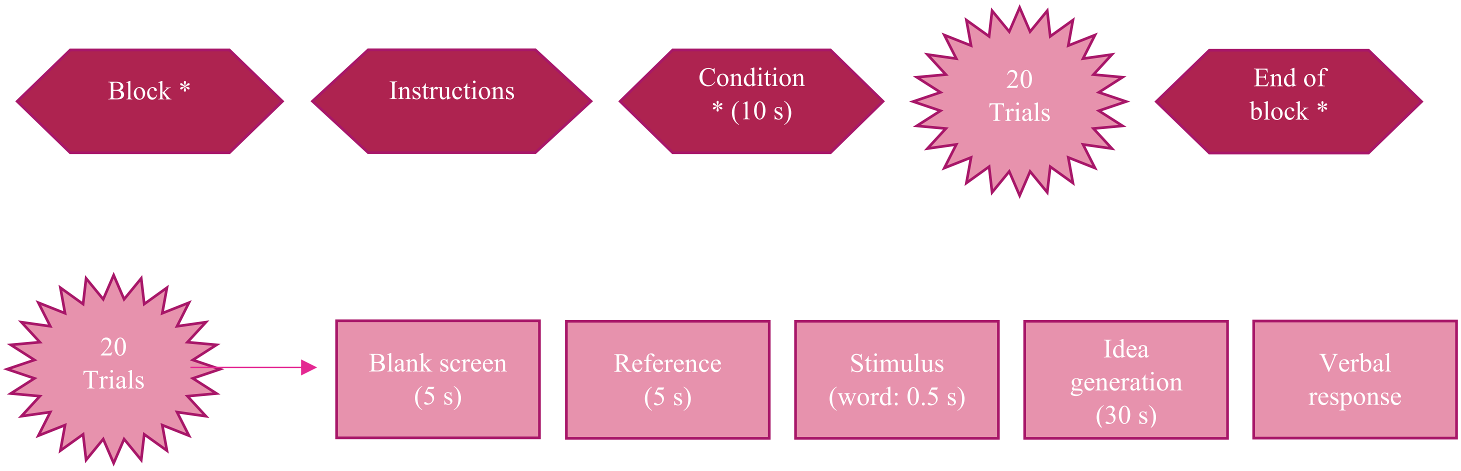

Figure 7: Experiment procedure

3.2 Evaluations of verbal responses

To serve the purpose of this research project it was necessary to evaluate the verbal responses given by subjects during the experiment.

To this end, the method proposed by Candusso (2019) in his master thesis was adopted to carry out the evaluation phase.
Based on Dean's study, two macro criteria have been chosen as constructs of evaluation and two dimensions per each were defined in order to achieve higher inter-rater reliability, as shown in table nr. 1.

Macro criterion	Dimension	Definition (Dean et al., 2006)
Novelty	Originality	"The degree to which the idea is not only rare, but is also ingenious, imaginative or surprising"
	Paradigm Relatedness	"The degree to which an idea is paradigm preserving (PP) or paradigm modifying (PM). PM ideas are sometimes radical or transformational"
Quality	Effectiveness	"The degree to which the idea will solve the problem without regard for feasibility"
	Feasibility	"An idea is feasible if it can be easily implemented and does not violate known constraints"

Table 1: Creativity criteria and dimensions adopted for verbal responses' evaluations

Four students served as raters, given the low degree of innovation that characterised the items employed during the experiment (everyday objects) and because two or more raters were necessary to reach good results reliability. Literature claims, indeed, that the level of experience requested for judges is strictly related to the innovation degree of products (O'Quin et al., 1999). In addition to this, it is worth mentioning that it is minimal the difference between experts and non-experts in rating design creativity (Amabile, 1982; Christiaans,2002).

However, it is essential for all raters to share the same background, information and that is why they must be supported by clear guidelines during the assessment phase. Hence, the anchor tables developed by Dean were borrowed and provided to judges to guide them during the evaluation, specifically during the scoring phase. The anchor tables employed by judges for their assessments can be found in the appendix.

Each verbal response was evaluated by raters in relation to each metric (originality, paradigm relatedness, feasibility, effectiveness) on a 4-point Likert scale through an Excel sheet, organized as shown in figure 8. Judges expressed their assessments for every dimension by putting an “x” in the cell associated to the value they thought to be the most pertinent.

OBJECT	Object															
Answer	Originality				Paradigm Relatedness				Feasibility				Effectiveness			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
idea 1	x				x						x			x		
idea 2			x					x		x						x

Figure 8: Idea evaluation Excel sheet (Candusso, 2019)

As an example, relating to idea 1 the evaluation for each metric is:

- Originality – 1
- Paradigm Relatedness – 1
- Feasibility – 3
- Effectiveness – 2

To verify the statistical reliability of raters’ evaluations, several Cronbach’s alpha tests have been carried out, in particular, one per each metric adopted. The results were all positive with alpha values never below 80%, meaning that the data gathered showed internal consistency and high reliability.

4 Statistical analysis

4.1 Introduction

Different kinds of ANOVAs were carried out, as shown in the table 2. The dependent variables occupy the rows, while the columns indicate the type of ANOVA. In each cell it is possible to observe which factors were included in the specific statistical test considered.

	One-way ANOVA	Two-way ANOVA	Three-way ANOVA
Performance metric	Daytime; Background; Strategy; Stress	Daytime*Background; Strategy*Daytime; Strategy*Stress; Strategy*Background	Stress*Background*Daytime
Brain waves	Performance metric; Strategy	Strategy*Daytime; Strategy*Stress; Strategy*Background	Stress*Background*Daytime
Response time		Daytime*Background	

Table 2: Statistical analysis: ANOVAs carried out

The results of the analyses, deepened in the next sections, will be shown by representing the p-values obtained through specific tables, organised as follows:

-rows: dependent variables or factors

-columns: dependent variables or factors

-cell: p-values

The p- values will be highlighted in three different shades of green according to the significance level:

- 0
- 0.001
- 0.01
- Not significant (NS)

The total number of subjects included in the analyses changed according to which factor was considered, as it will be explained in the next pages. In general, the responses were gathered for 38 participants due to collecting issues for two of them among the overall number of 40 subjects.

4.1.1 Dependent variables

Three dependent variables were analysed: performance metrics, brain waves, response time.

Data related to participants performances in terms of novelty and quality were taken from the evaluation process already described in chapter 3. In particular, each participant response received a score for each metric, obtained as the average evaluation expressed by raters. It is also important to specify that the four judges' assessments were available only for 20 stimuli out of 40, therefore, the total number of responses included in the analyses is inferior when referring to the study of participants performances compared to the dataset adopted while investigating brain activity.

With reference to the neurophysiological signals, the analyses were conducted on their power, based on the main clusters of frequency (alpha, beta, gamma 1, gamma 2, delta, theta) while electrodes were divided into 6 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).

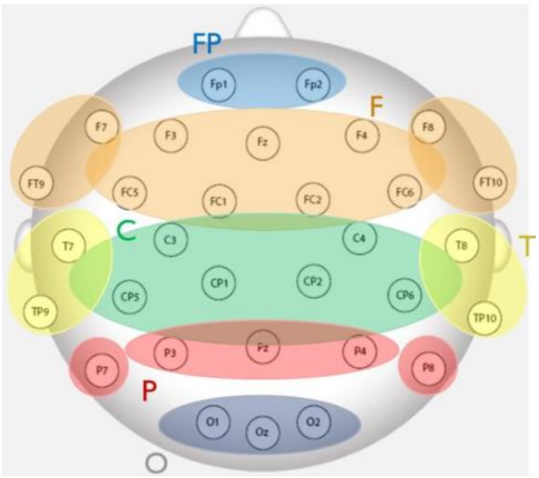

Figure 9: Electrodes placement (according to the international 10-20 system)

Response time represents the amount of time spent by each participant to generate the idea for every trial. Practically, it can be seen as the time between the sight of the stimulus (the word of the object) and the spacebar press by the subject after completing the task.

4.1.2 Factors

Background: it is used to represent the different cultural framework of participants who belong to the Design or the Engineering field. It is important to underline that for eight subjects it was not possible to trace back their educational background, thus, the dataset adopted every time the factor was included in the analyses was made up of 32 subjects instead of 38.

Daytime: the importance that Literature awards to the time of the day relating to cognitive studies has already been discussed in chapter 2.
Two different versions of daytime were employed to carry out the statistical analysis. The first one consists of dividing the day in three distinct moments: Morning (Until 12 AM), Lunch (from 12 AM to 2 PM) and Afternoon (after 2 PM).
The second approach adopted split the day in just two periods: Morning (until 12 AM) and Afternoon (after 12 AM). The latter point of view was used when the effect of daytime on participants performances and brain waves was investigated in correlation with other two factors (stress level and strategy) to balance the number of participants and responses considered for each condition.

Performance metrics: they were considered as factors in the attempt to discover possible patterns between the behavioural and the neurophysiological response.
In order to carry out the analysis, they needed to be turned from continuous variables into factors.
To this end, for each metric two different clusters ("High", "Low") were created by taking the average evaluation as reference. For example, if originality registered an

average value of 2, according to raters evaluation, all the responses that scored a higher value were associated to the “High” category, otherwise to the second one.

Stress: it is part of the behavioural factors that can affect cognitive processes behind design tasks.
The participants stress level was measured, right after the experiment, on a 5-point Likert scale when subjects were called to fill out a short questionnaire.
As well as it has already been explained for metrics, in order to conduct the statistical analyses, stress was divided in two groups representing a high and a low stress level. The reference value, in this case, corresponded to the average answer given by respondents. Once again, for example, if the subject indicated a higher number compared to the average value when assessing his/her stress level he/she would have been connected to the “High” category and vice versa.

Strategy: at the end of the experiment, participants were asked to briefly describe orally the strategy adopted to perform the task during the experimental procedure.

To carry out the statistical analysis it was important to group the strategies adopted by participants in few categories.
To this end:

- Four proper strategy clusters were identified from literature: memory retrieval, mental manipulation, mind wandering, common to uncommon. See table nr. 3.
- A short questionnaire was created and sent out to 5 students.

Category	Category Description (Rif. Bridging the gap between Design and Neuro-physiological studies)
Mind-wandering	"Letting the mind run free and/ or coming up with funny or fanciful ideas"
Memory-retrieval	"Remembering if the object has already been used in uncommon ways before"
Common-to-Uncommon	"Thinking about the object common uses before generating the alternative uses "
Mental-Manipulation	"Creating a mental image of the object in order to manipulate or picture it in different situations-environments"

Table 3: Strategy clusters

The survey was organised to guarantee the same set of information to all respondents. Firstly, they were both described the general context and the aim of the questionnaire. Afterwards, the four macro categories were explained in relation to the list of participants strategies.

In the end, respondents were called to try and associate each participant strategy to a specific category among the four identified by putting an "X" in the cell corresponding to the chosen cluster.

As depicted in the figure below (fig. 10), for example, the strategy 1 of participant nr. 1 was associated to the common-to-uncommon category.

Subject	Strategy	Mind-wandering	Memory-retrieval	Common-to-Uncommon	Mental-Manipulation
1	Strategy 1 description			X	
2	Strategy 2 description		X		

Figure 10: Strategy questionnaire Excel sheet

It was created a fifth strategy category to include all strategies that did not get an absolute majority when assigned to a cluster by respondents. The category was named: combination of other strategies.
Below (tab. 4) are summarised the questionnaire results in terms of number of strategies associated to each cluster.

Category	Nr. of Strategies assigned
Mental manipulation	9
Memory-retrieval	10
Mind-wandering	5
Common-to-Uncommon	10
Combination of other strategies	4
Tot participants strategies	38

Table 4: Strategy questionnaire results

In order to check the reliability and the internal consistency of respondents' answers, the Cronbach's Alpha was, once again, adopted and computed through R.

Two analyses were carried with reference to strategy: one including all responses for which evaluations were available and a second adopting a dataset made up of the only responses that registered the highest evaluation scores in terms of originality. In the following section, only the latter will be reported because the former did not collect significant trends.

4.2 Results

4.2.1 Behavioural response: the influence of background & daytime

In this section it will be explored the relationship found between participants performances and two factors usually included by scholars in their analyses: daytime and subjects ‘educational background.

It was possible to observe that the background is not able to significantly affect any metric, neither alone nor in correlation with daytime.
The p-values registered were, indeed, all far from the 0.05 threshold and the lack of substantial distances between the scores obtained respectively by engineers and by designers is highlighted in fig. 11.
Originality was taken as an example, but the results were nearly the same for every metric.

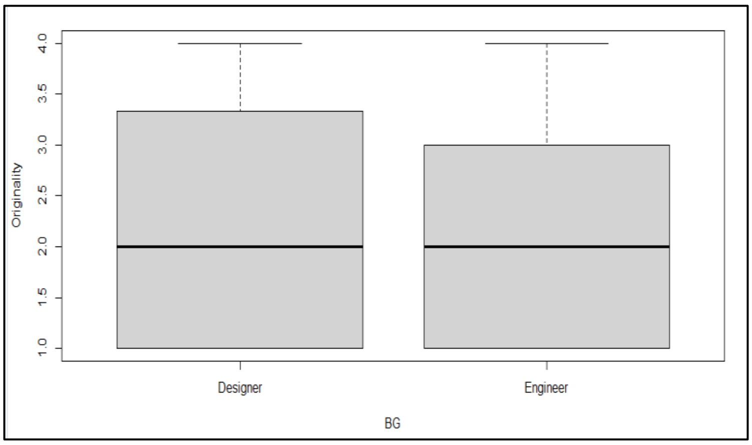

Figure 11: Background effect on originality

Daytime, on the other hand, produced some significant results relating to originality, paradigm relatedness and effectiveness, as depicted in the table below.

	Originality	Paradigm relatedness	Feasibility	Effectiveness
Daytime	0.0297*	0.0124*	NC	0.01*
Tukey Test	Lunch-Afternoon	Lunch-Afternoon Lunch-Morning	-	Lunch-Afternoon Lunch-Morning

Table 5: Daytime effect on perfomance metrics: ANOVAs (p-values) and Tukey Test results

It was found that the most original answers were given during Lunch as well as the ideas that collected the highest scores referring to paradigm relatedness while the most effective responses turned out to belong to the afternoon.
Moreover, a post-hoc analysis highlights that the most significant relationships were Lunch-Afternoon and Lunch-Morning.

Some explicative boxplots that describe the correlations identified will follow.

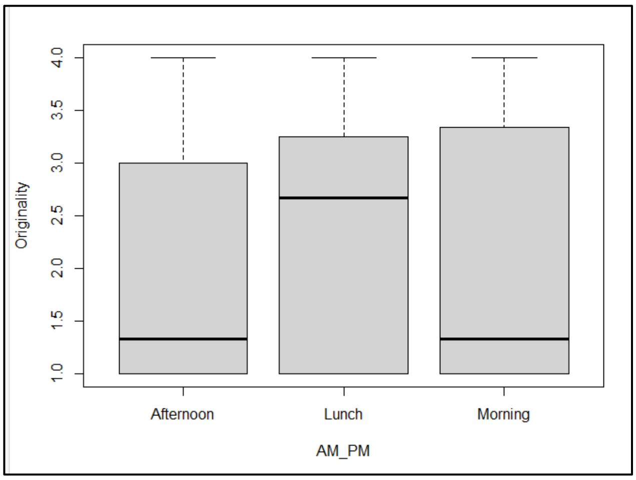

Figure 12: Daytime effect on originality

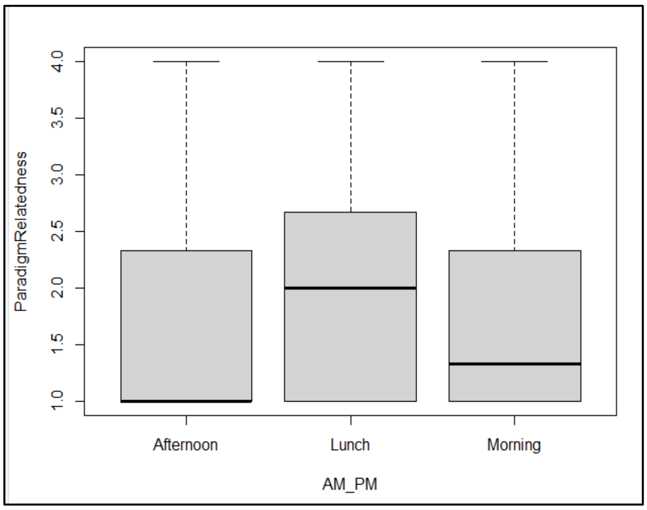

Figure 13: Daytime effect on paradigm relatedness

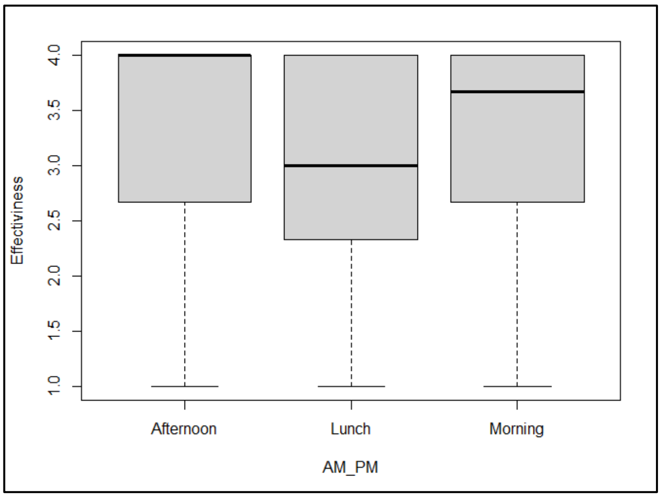

Figure 14: Daytime effect on effectiveness

4.2.2 Neurophysiological response vs behavioural response

The analysis carried out to spot possible trends between the neurophysiological and the behavioural response provided significant results, especially relating to gamma 1 and gamma 2 waves, some scattered results for alpha and beta and no meaningful correlations to any metric considering delta and theta brain frequencies. The resulting p-values are shown in the table below.

	ORIGINALITY						PARADIGM RELATEDNESS						FEASIBILITY						EFFECTIVENESS					
	FP	F	C	T	P	O	FP	F	C	T	P	O	FP	F	C	T	P	O	FP	F	C	T	P	O
ALPHA	NC	NC	0.000988 ***	0.0185 **	0.0102 *	NC	NC	NC	0.00467 **	0.0293 *	0.0114 *	NC	NC	NC	0.042 *	NC	NC	NC	NC	NC	0.0318 *	NC	NC	NC
BETA	0.00738 **	0.0289 *	NC	0.0225 *	0.0154 *	0.0032 **	NC	NC	NC	NC	NC	NC	0.0262 *	NC	NC	NC	0.05 .	0.0157 *	NC	NC	NC	NC	0.0505 .	0.00674 **
GAMMA 1	8.64e-05 ***	0.000432 ***	0.0017 **	0.00111 ***	8.73e-05 ***	5.6e-06 ***	0.00169 **	0.0141 *	0.0361 *	0.00155 **	0.00123 **	1.8e-05 ***	0.00639 **	0.024 *	NC	0.0195 *	0.0108 *	0.00135 **	0.00025 ***	0.00488 **	0.0362 *	0.0016 **	0.0011 **	0.00168 ***
GAMMA 2	8.61e-05 ***	0.00752 ***	0.0227 **	0.00189 ***	0.00118 ***	0.00168 ***	0.00886 **	0.0296 *	NC	0.00652 **	0.00316 **	0.000353 ***	0.00827 **	0.0152 *	0.0453 *	0.00959 **	0.006 **	0.00332 **	0.00183 **	0.0354 *	NC	0.00805 **	0.00457 **	0.00145 **
DELTA	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
THETA	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC

Table 6: Behavioural response vs neurophysiological response: ANOVAs (p-values)

Speaking of alpha wave, it is not difficult to observe that it registered a higher and positive correlation (alpha power synchronization), especially considering originality and paradigm relatedness metrics in the central, parietal and temporal lobes (fig. 15-16-17-18) while presenting a lower and reversed connection with feasibility and effectiveness in the central area of the brain (fig.19-20). It is, thus, possible to confirm a correlation between alpha wave and creativity, according to most of the Literature's findings.

It is evincible that alpha synchronisation is necessary, particularly during divergent thinking phases, to not being engaged in a bottom-up stimulation, being influenced by external stimuli, but to redirect the attention towards the "inner world" (Fink et al., 2010).

The strong activation of gamma 1 and gamma 2 underpins the importance held by these two waves in Design activities (Liu et al., 2016).

However, the nature of the influence exerted by gamma 1, gamma 2 and Beta waves on performance metrics is different comparing to alpha.
Actually, a completely opposite path can be read: a desynchronisation of those waves is registered for the most original ideas while an increase of TRP values is observed relating to feasibility and effectiveness (fig. 20-21-22-23-24-25-26-27-28-29-30).

Moreover, it is noticeable that, regardless the brain wave or the lobe considered, metrics associated to novelty showed an entirely different path from the ones associated to quality, highlighting the distance between the two macro criteria identified to describe creativity.

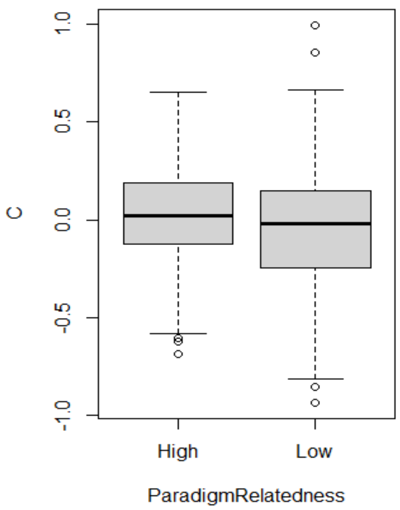

Figure 16: Paradigm Relatedness effect on central lobe-alpha

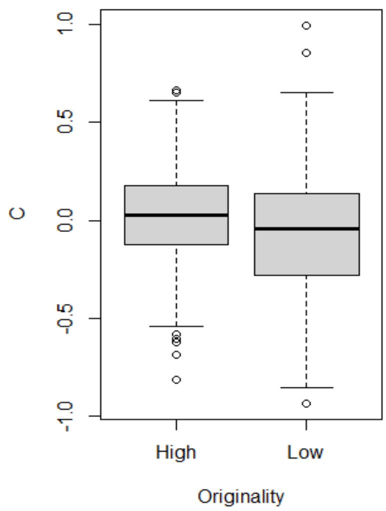

Figure 15: Originality effect on central lobe-alpha

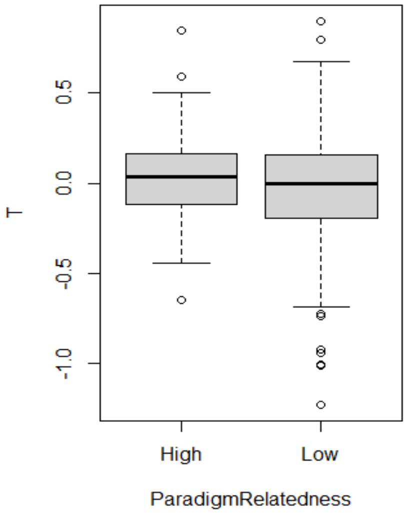

Figure 18: Paradigm Relatedness on temporal lobe-alpha

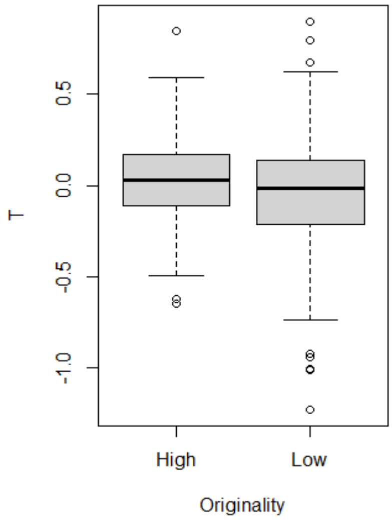

Figure 17: Originality effect on temporal lobe-alpha

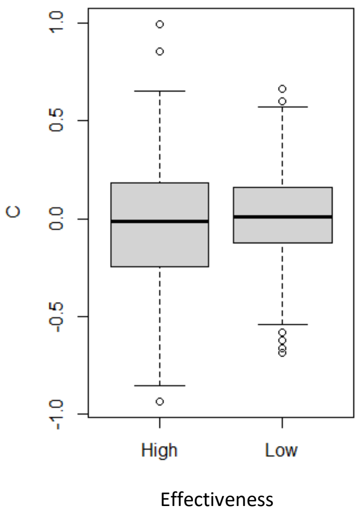

Figure 19: Effectiveness effect on central lobe-alpha

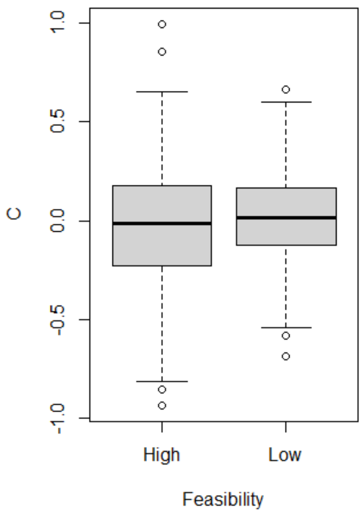

Figure 20: Feasibility effect on central lobe-alpha

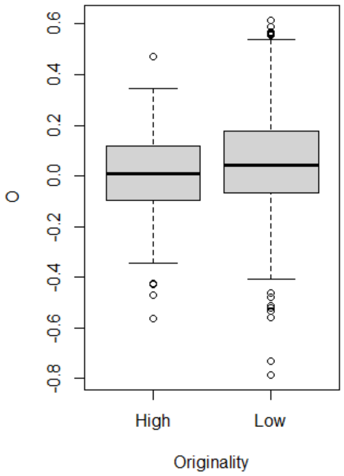

Figure 23: Originality effect on occipital lobe-beta

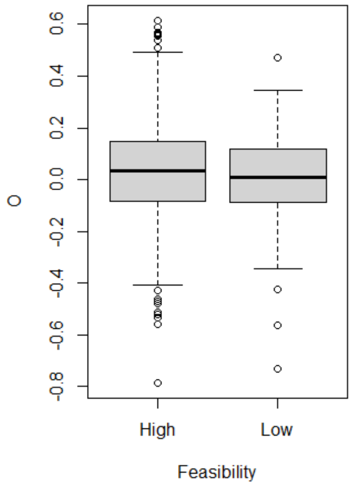

Figure 21: Feasibility effect on occipital lobe-beta

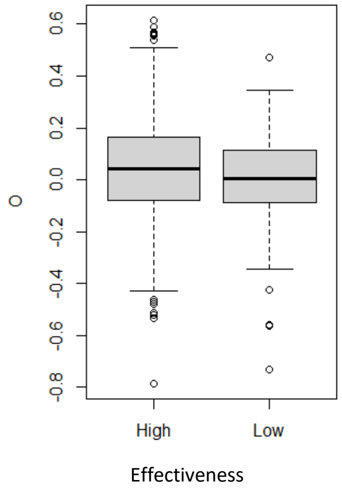

Figure 22: Effectiveness effect on occipital lobe-beta

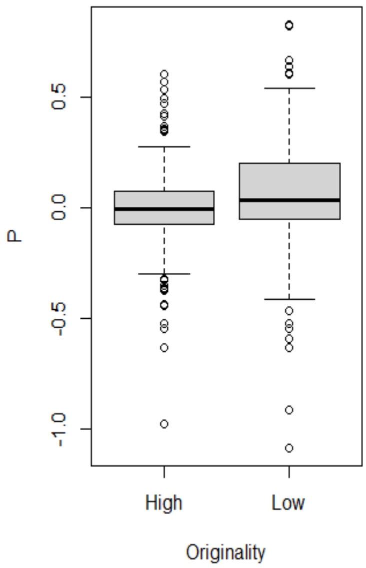

Figure 24: Originality effect on parietal lobe-gamma 1

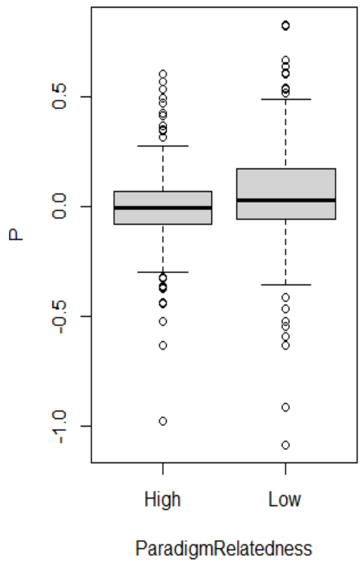

Figure 25: Paradigm Relatedness effect on parietal lobe-gamma 1

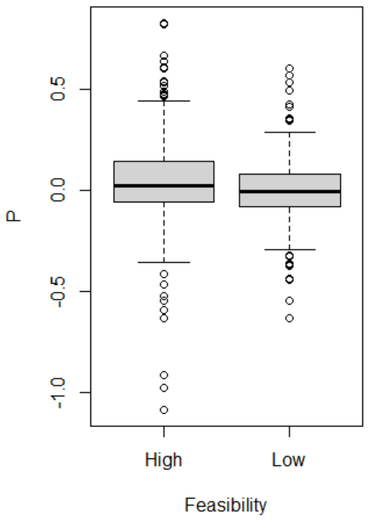

Figure 27: Feasibility effect on parietal lobe-gamma 1

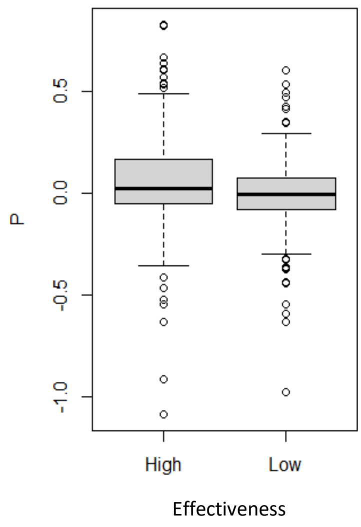

Figure 26: Effectiveness effect on parietal lobe-gamma 1

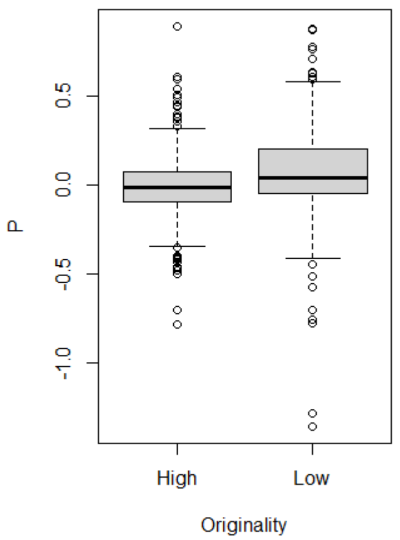

Figure 28: Originality effect on parietal lobe- gamma 2

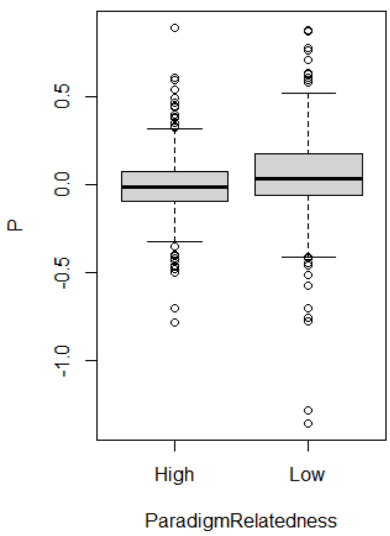

Figure 29: Paradigm Relatedness effect on parietal lobe- gamma 2

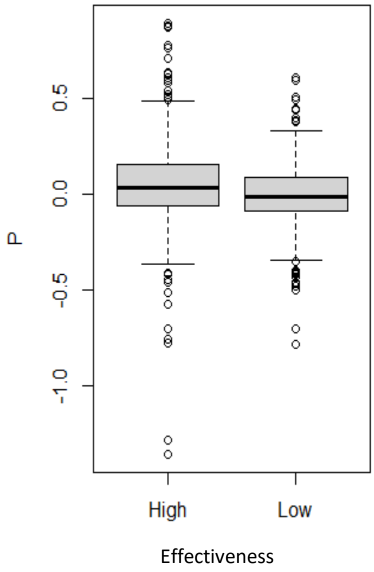

Figure 30: Effectiveness effect on parietal lobe-gamma 2

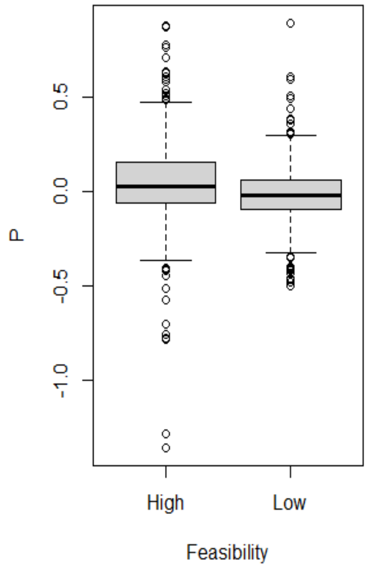

Figure 31: Feasibility effect on parietal lobe-gamma 2

4.2.3 The relationship between response time and daytime & background

As given in the table below, the correlation between educational background and participants response time was found significant. Daytime, on the contrary, appeared to be able to influence the dependent variable only if considered together with background.

Factor	Response Time
Background	0.0376 *
Daytime	NC
Background:daytime	0.0341 *

Table 7: Background and Daytime effect on response time: ANOVAs (p-values)

It was observed that generally designers are slightly slower at answering than engineers.
Moreover, introducing the time of the day as factor, it was possible to notice that engineers tend to be faster in the morning and slower at lunch.
Designers, on the other hand, register the highest response time during morning hours and appear to be quicker in the afternoon (fig. 32-33).

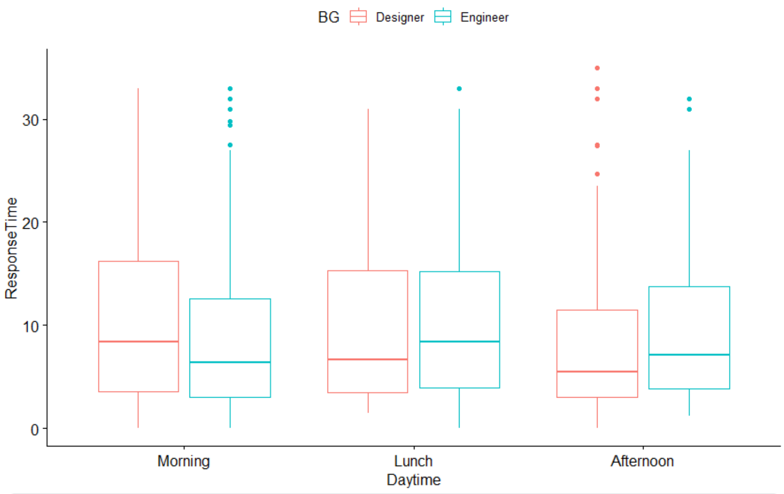

Figure 32: Daytime and background effect on response time

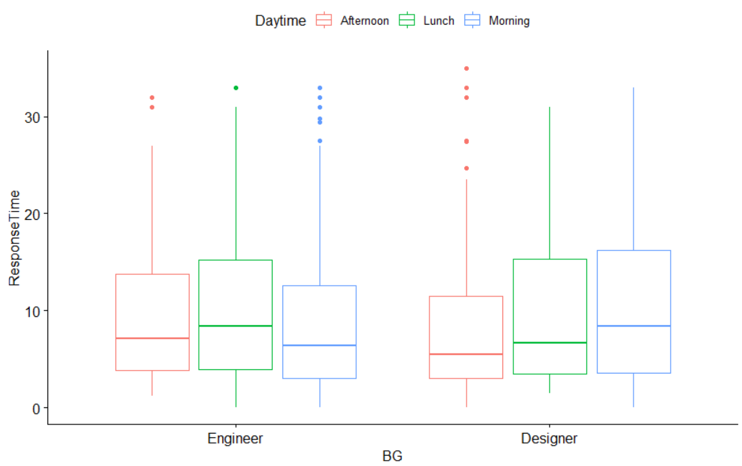

Figure 33: Daytime and background effect on response time

4.2.4 Behavioural response: the influence of stress and strategy

While stress did not turn out to be a significant factor, neither alone nor in correlation with daytime or background, strategy showed statistical meaningful relationships with participants behavioural response when interacting with other factors such as stress and daytime, as given in the table below.

	Originality	**Paradigm relatedness**	**Feasibility**	**Effectiveness**
Strategy	NC	NC	NC	NC
Strategy:Daytime	0.0240 *	NC	0.0056 **	NC
Strategy:BG	NC	NC	NC	NC
Strategy:Stress	5.1e-05 ***	NC	0.00777 **	NC

Table 8: Strategy influence on performance metrics: ANOVAs (p-values)

Both interactions showed significant results relating to two of the four performance metrics adopted to measure the creativity of the ideas generated by participants: originality and feasibility.

Taking daytime into consideration, originality and feasibility registered different trends during both morning and afternoon, highlighting once again the distance existing between quality and novelty dimensions.
Indeed, the strategies that were able to ensure the highest originality scores turned out to be, at the same time, the ones that generated the least feasible ideas (fig. 34-35).

For example, it is possible to notice that mind wandering strategy produced the most original ideas, but the least feasible ones in the morning while reporting the highest feasibility scores and the lowest originality results during the afternoon.
However, even if in different moments of the day, feasibility and originality reached the highest evaluations with reference to the same strategy.

Moreover, there are strategies, such as common to uncommon together with memory-retrieval in relation to originality and mental manipulation and combination of other strategies regarding feasibility, which did not appear much sensitive to the time of the day.
Memory retrieval strategy, for example, was always able to produce original ideas, being the most effective among the others during the afternoon.

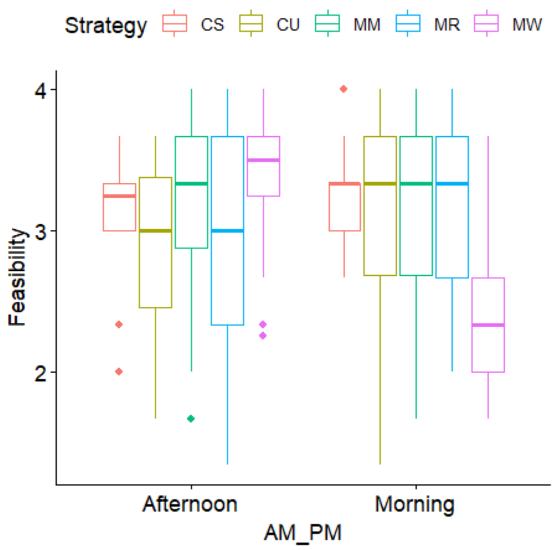

Figure 34: Strategy and daytime effect on feasibility

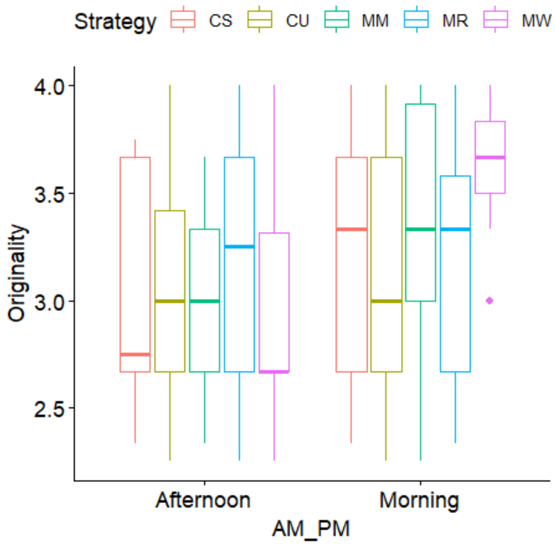

Figure 35: Strategy and daytime effect on originality

Feasibility and originality showed some differences (fig. 36-37), also considering the second and most meaningful interaction between strategy and stress.

Mind wandering once again was the go-to strategy to reach the highest scores according to both metrics, but not referring to the same level of stress felt by participants: with reference to Feasibility the highest values were registered when the stress level was low, on the contrary, regarding originality when the level was high.

It is worth focusing the attention on the stress effect over the two different metrics, observing that it can be considered stronger in relation to originality.

The stress level, indeed, was able to influence the results obtained by adopting each strategy, speaking of originality. When referring to feasibility, instead, there were strategies such as mental manipulation and combination of other strategies that did not seem to be much affected by the factor, being always associated with high scores.

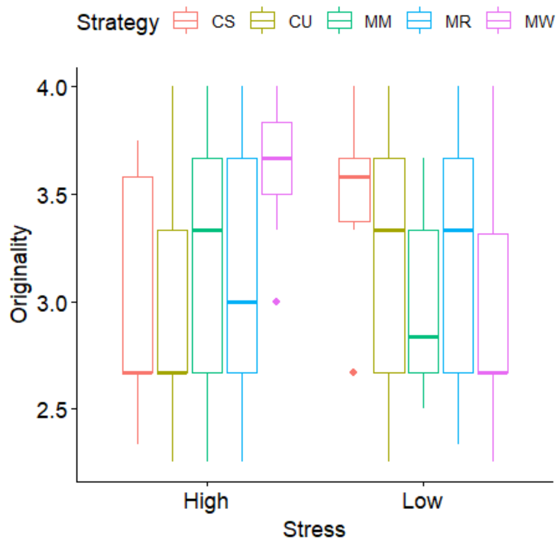

Figure 36: Strategy and stress effect on originality

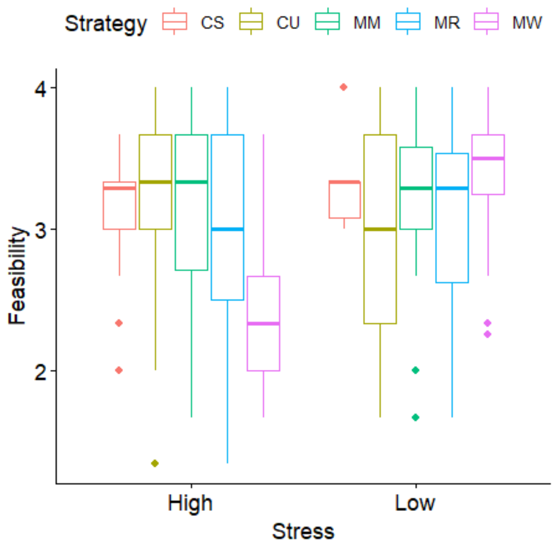

Figure 37: Strategy and stress effect on feasibility

4.2.5 Stress influence on brain activity

Stress is capable of influencing brain activity. Indeed, it turned out to represent a significant factor in all waves, but gamma 2 and in all the lobes with the only exception of pre-frontal and central lobes for Delta wave.

P-values are shown in the following table.

STRESS						
	FP	**F**	**C**	**T**	**P**	**O**
ALPHA	0.000333 ***	0.000838 ***	0.000617 ***	0.000221 ***	0.00326 **	0.010025 *
BETA	3.24e-05 ***	4.50e-05 ***	3.57e-06 ***	3.17e-07 ***	8.82e-06 ***	2.76e-05 ***
GAMMA 1	0.04005 *	0.03959 *	0.005196 **	0.00265 **	0.000441 ***	0.00474 **
GAMMA 2	NC	NC	NC	NC	NC	NC
DELTA	NC	0.005324 **	NC	0.0014 **	0.0246 *	0.0327 *
THETA	0.012958 *	0.00215 **	0.000184 ***	0.000117 ***	0.000148 ***	0.000396 ***

Table 9: Stress influence on brain activity: ANOVAs (p-values)

The trend is the same in every wave and in each lobe: higher TRP values are associated to the low stress level. The temporal lobe has been taken as an example in order to show the similarity of results across the different brain waves.

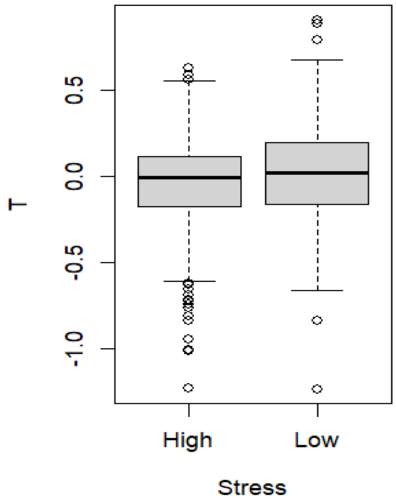

Figure 39: Stress effect on temporal lobe-alpha

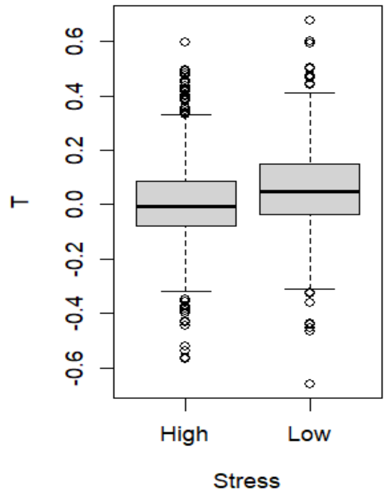

Figure 38: Stress effect on temporal lobe-beta

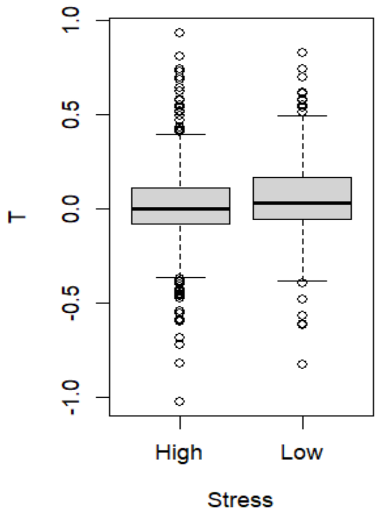

Figure 41: Stress effect on temporal lobe- gamma 1

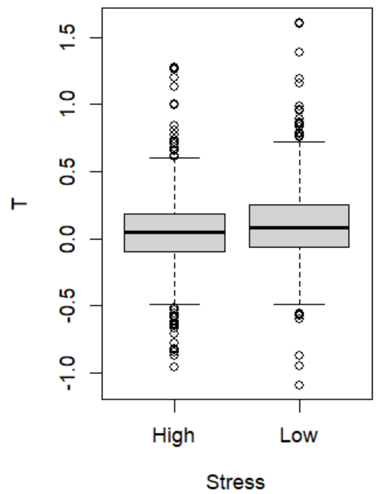

Figure 40: Stress effect on temporal lobe-delta

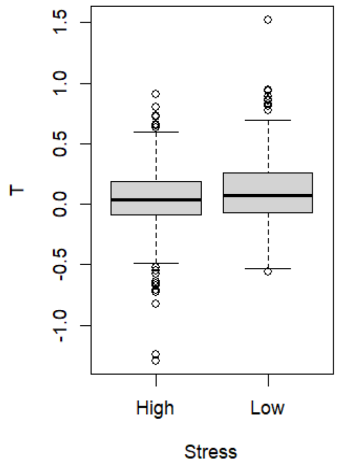

Figure 42: Stress effect on temporal lobe- theta

4.2.5.1 Stress daytime interaction*

The interaction between stress and daytime reported significant p-values at least in one lobe per each wave, exception made for beta and delta brain frequencies, as given in the table below (tab.10).

STRESS:DAYTIME						
	FP	**F**	**C**	**T**	**P**	**O**
ALPHA	NC	NC	NC	NC	0.00014 ***	0.000971 ***
BETA	NC	NC	NC	NC	NC	NC
GAMMA 1	NC	NC	0.021597 *	NC	NC	NC
GAMMA 2	NC	0.0431 *	0.00616 **	0.0375 *	0.0285 *	NC
DELTA	NC	NC	NC	NC	NC	NC
THETA	NC	NC	0.049067 *	0.037544 *	0.010053 *	0.005648 **

Table 10: Stress and daytime influence on brain activity: ANOVAs (p-values)

Alpha was the only wave to present a completely distinct trend between morning and afternoon referring to stress level. During morning hours higher TRP values are associated to the most stressed subjects, while in the afternoon the opposite pattern is followed (fig. 43-44).

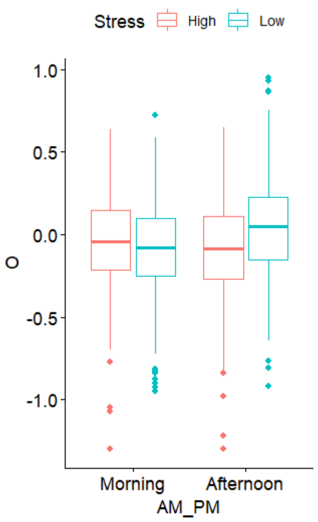

Figure 43: Stress and daytime effect on occipital lobe-alpha

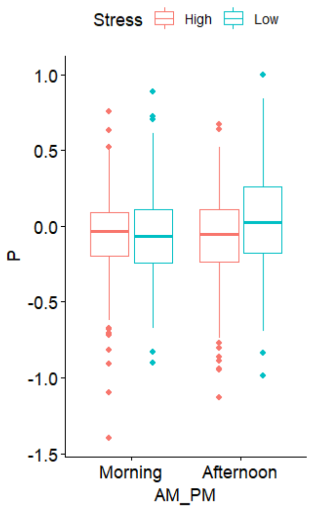

Figure 44: Stress and daytime effect on parietal lobe-alpha

All the lobes of the remaining waves showed a similar tendency. During the afternoon higher TRP values are always linked to the low stress level. However, in the morning the trend was usually not so clear and sometimes, considering for example the central lobe in theta wave, it presented a reverse tendency.

Some explicative graphs will follow in the next pages.

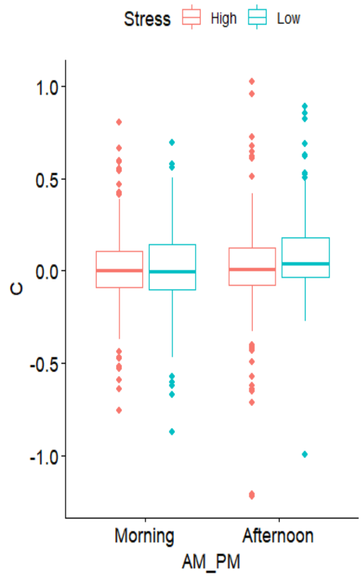

Figure 45: Stress and Daytime effect on central lobe-gamma 1

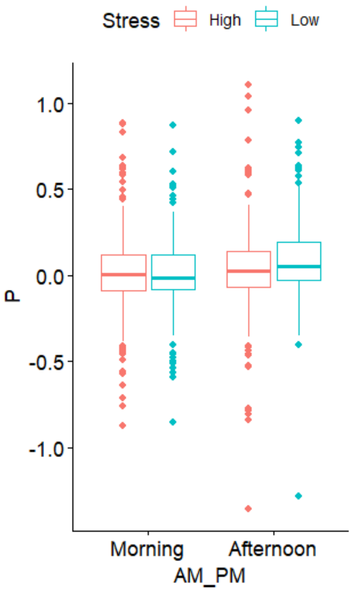

Figure 48: Stress and daytime effect on parietal lobe-gamma 2

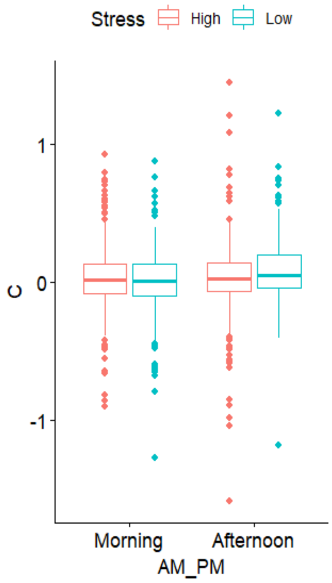

Figure 46: Stress and daytime effect on central lobe-gamma 2

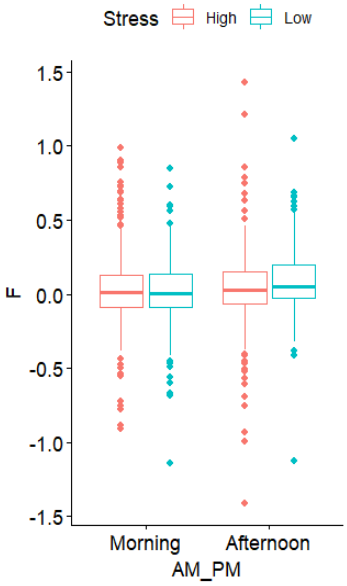

Figure 47: Stress and daytime effect on frontal lobe-gamma 2

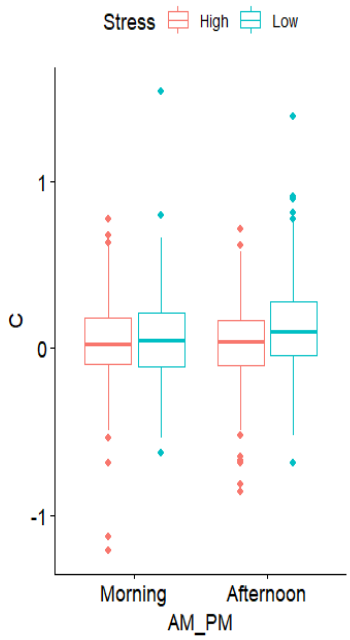

Figure 49: Stress and daytime effect on central lobe- theta

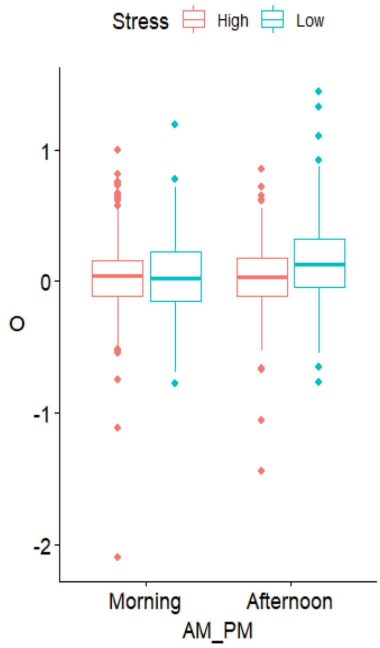

Figure 50: Stress and daytime effect on occipital lobe-theta

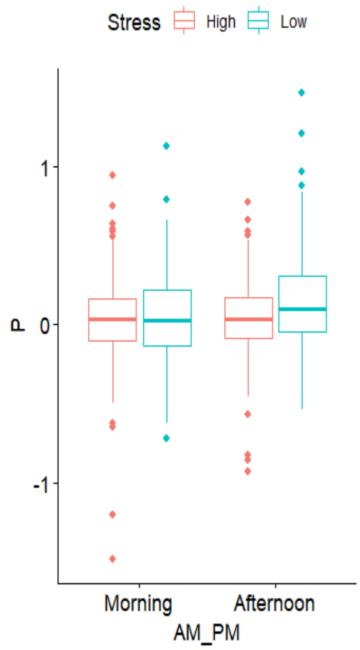

Figure 51: Stress and daytime effect on parietal lobe-theta

*4.2.5.2 Stress*background interaction*

It represents the most significant interaction, considering that the correlation turned out to be significant at least in one lobe per each wave. In particular, the lowest p-values can be found in relation to alpha, beta and especially theta wave, as it is shown in tab.11.

STRESS:BACKGROUND						
	FP	**F**	**C**	**T**	**P**	**O**
ALPHA	0.006460 **	0.000408 ***	0.007601 **	1.90e-05 ***	0.00343 **	4.74e-06 ***
BETA	NC	0.0385 *	0.0322 *	NC	NC	NC
GAMMA 1	0.00014 ***	0.00742 **	0.000544 ***	0.02005 *	0.000564 ***	0.00115 **
GAMMA 2	NC	NC	NC	NC	NC	0.0294 *
DELTA	0.04719 *	0.045325 *	0.04476 *	NC	NC	NC
THETA	0.000309 ***	1.56e-07 ***	2.28e-07 ***	1.35e-08 ***	2.12e-07 ***	1.05e-05 ***

Table 11: Stress and background effect on brain activity: ANOVAs (p-values)

It is possible to observe that designers appeared to be more affected by the stress factor, even if they shared with engineers the same trend, showing higher TRPs when feeling less stressed.

The pattern is evident in almost all waves. However, the stress level effect seems to become weaker in the occipital lobe of gamma 2 wave and in the frontal lobes for theta wave, but only referring to engineers (Fig. 56-57).

Below are shown the diagrams obtained for the frontal lobe per each wave, but all the lobes shared a similar path.

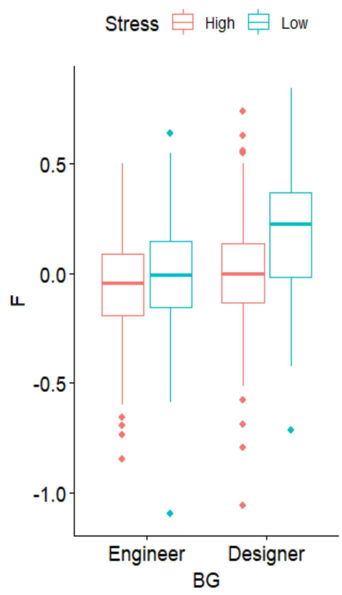

Figure 52: Stress and background effect on frontal lobe-alpha

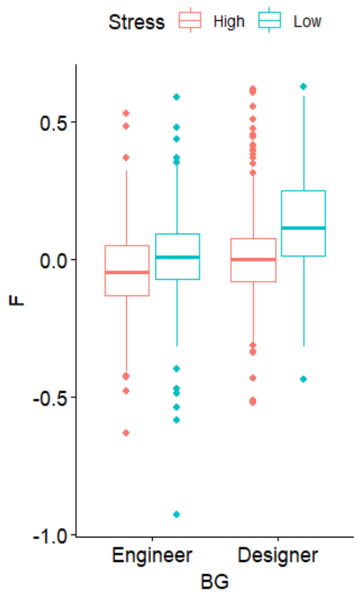

Figure 53: Stress and background effect on frontal lobe-beta

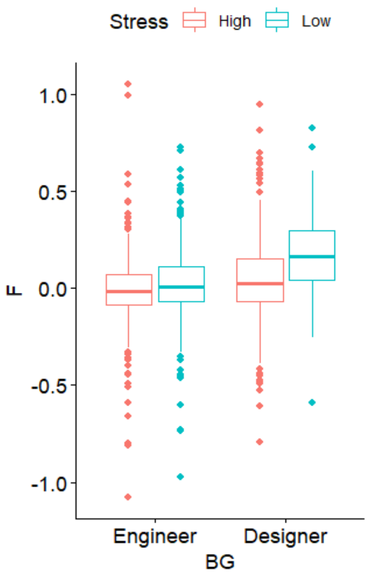

Figure 55: Stress and background effect on frontal lobe-gamma 1

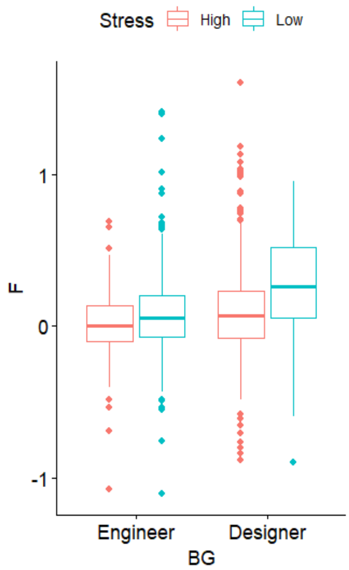

Figure 54: Stress and background effect on frontal lobe-delta

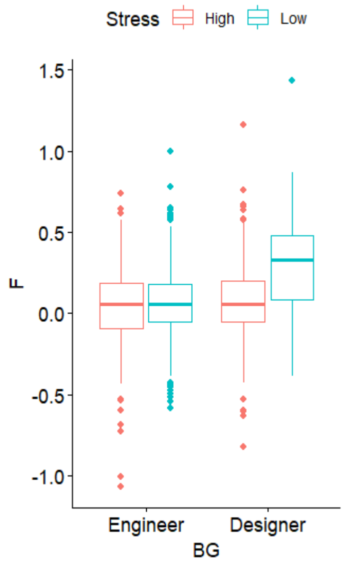

Figure 57: Stress and background effect on frontal lobe-theta

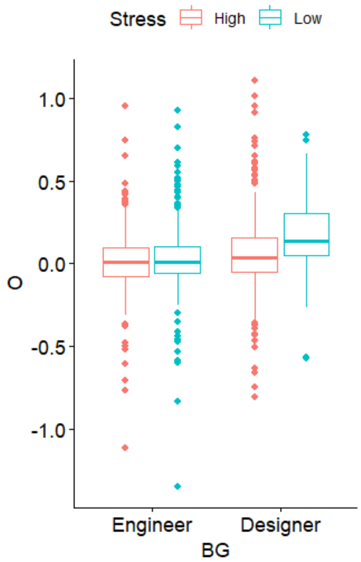

Figure 56: Stress and background effect on occipital lobe-gamma 2

*4.2.5.3 Stress*daytime*background interaction*

The 3- way ANOVA produced the least significant results; p-values under the threshold were registered only in gamma 2, delta and theta waves as it is exhibited in the table below.

STRESS: BACKGROUND: DAYTIME						
	FP	**F**	**C**	**T**	**P**	**O**
ALPHA	NC	NC	NC	NC	NC	NC
BETA	NC	NC	NC	NC	NC	NC
GAMMA 1	NC	NC	NC	NC	NC	NC
GAMMA 2	NC	NC	NC	NC	NC	0.0135 *
DELTA	NC	NC	0.03560*	NC	0.0200 *	NC
THETA	NC	0.01475 *	0.002759**	0.009736**	0.007872**	NC

Table 12: Stress, background and daytime effect on brain activity: ANOVAs (p-values)

Designers always show higher TRP values when less stressed, regardless the time of the day.

Engineers are less influenced by the stress level during both morning and afternoon comparing to designers and they present different trends across waves. For example, in theta wave they differ from designers because during morning hours they register a reverse trend: higher TRP values were linked to the high stress level.

Some boxplots will be shown in the next pages.

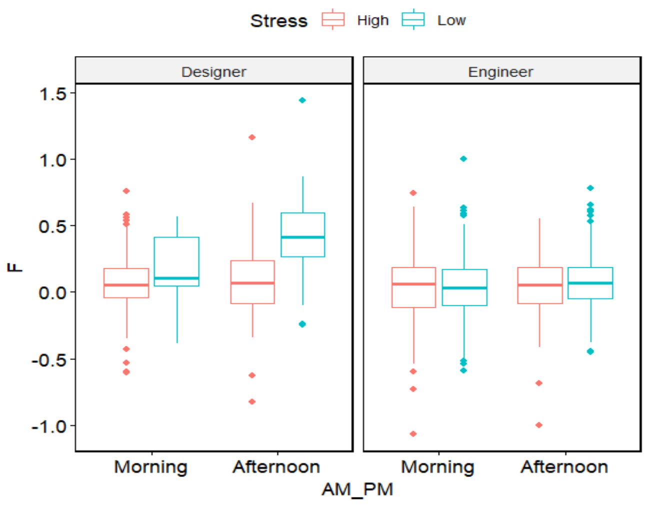

Figure 59: Stress, daytime and background effect on frontal lobe-theta

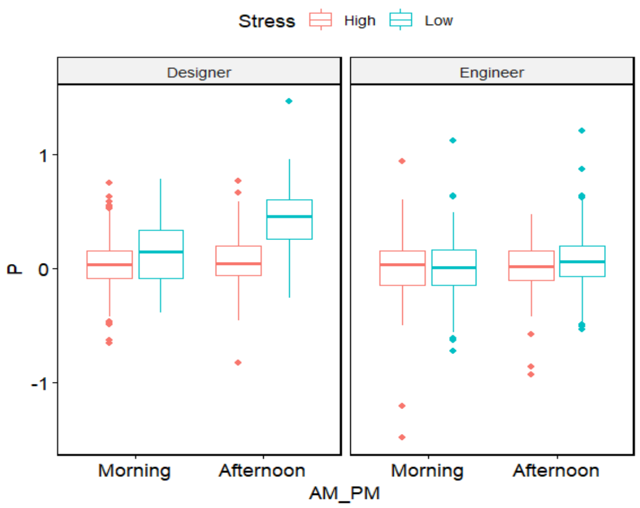

Figure 58: Stress, daytime and background effect on parietal lobe-theta

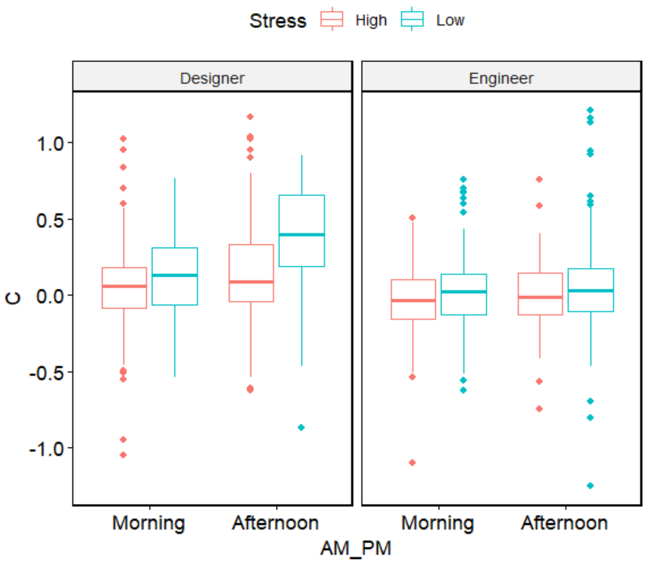

Figure 60: Stress, daytime and background effect on central lobe- delta

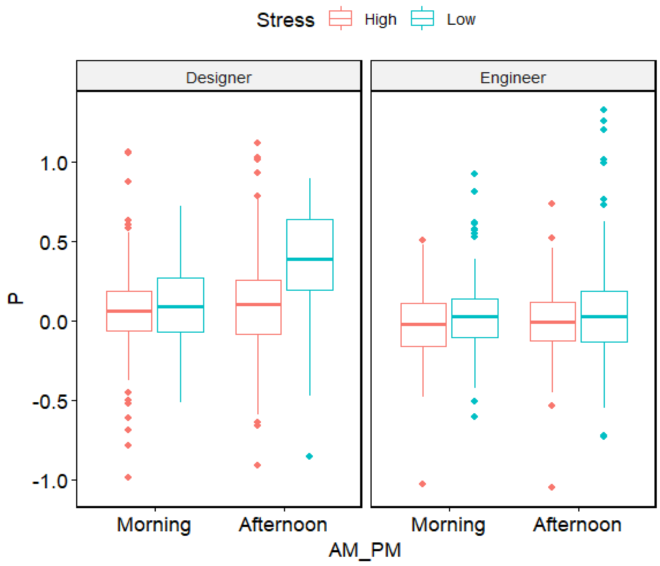

Figure 61: Stress, daytime and background effect on parietal lobe-delta

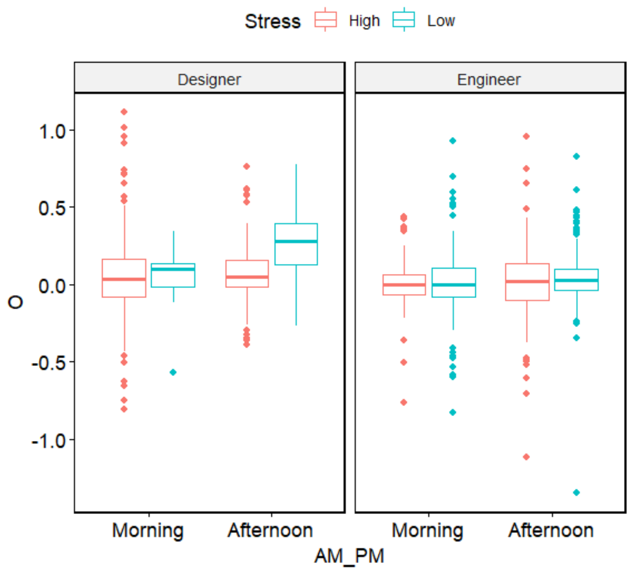

Figure 62: Stress, daytime and background effect on occipital lobe-gamma 2

4.2.6 Strategy influence on brain activity

Strategy alone narrowly influences brain activity, presenting significant results only with reference to delta wave and few lobes of alpha and gamma frequency bands, as shown in the table below.

STRATEGY						
	FP	**F**	**C**	**T**	**P**	**O**
ALPHA	NC	NC	0.00186 **	NC	NC	NC
BETA	NC	NC	NC	NC	NC	NC
GAMMA 1	0.0498 *	0.0407 *	NC	NC	NC	0.0407 *
GAMMA 2	0.024 *	0.015 *	NC	NC	NC	NC
DELTA	NC	0.0107 *	0.00695 **	0.00742 **	0.00794 **	0.0179 *
THETA	NC	NC	NC	NC	NC	NC

Table 13: Strategy effect on brain activity- ANOVA (p-values)

Giving a first look at the boxplots that will follow in the next pages, it can be observed that alpha wave presents a completely different output comparing to the other frequency bands.

Mind wandering strategy, for example, registered a synchronization in relation to alpha wave while it was associated with the lowest TRPs in all the remaining brain waves. A similar path was shared by memory-retrieval strategy.

On the other hand, gamma 1, gamma 2 and delta waves observed higher TRP values when the chosen method was a combination of more than one strategy which was not linked to a particularly important synchronization in alpha wave, but it found itself among the strategies that collected the lowest TRPs, instead.

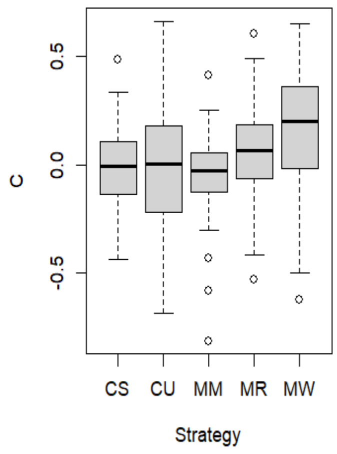

Figure 63: Strategy effect on central lobe-alpha

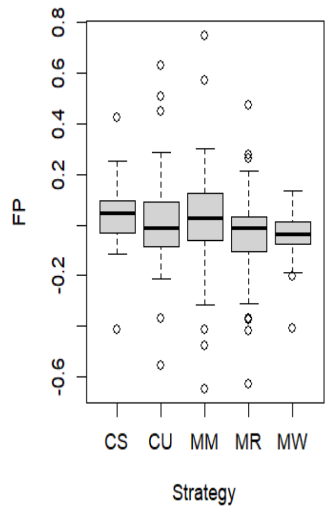

Figure 64: Strategy effect on prefrontal lobe-gamma 1

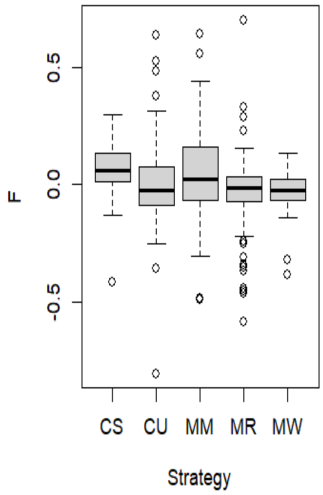

Figure 66:Strategy effect on frontal lobe-gamma 1

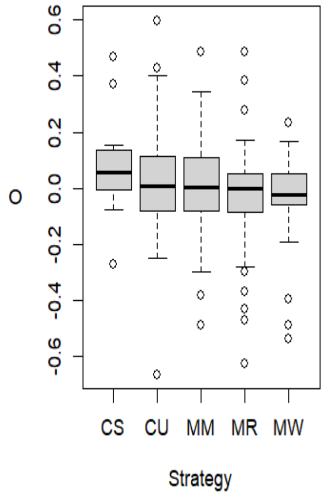

Figure 65:Strategy effect on occipital lobe-gamma 1

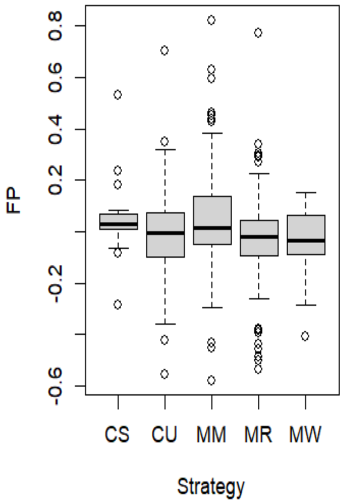

Figure 67: Strategy effect on the prefrontal lobe-gamma 2

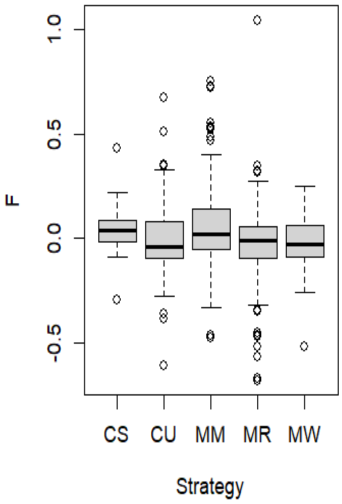

Figure 68:Strategy effect on the frontal lobe-gamma 2

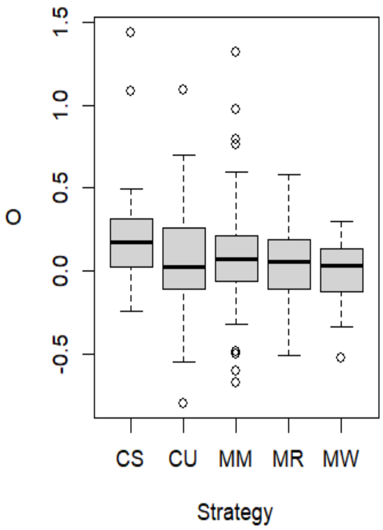

Figure 69: Strategy effect on occipital lobe-delta

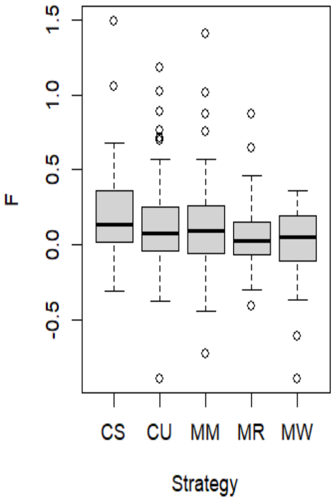

Figure 70: Strategy effect on frontal lobe-delta

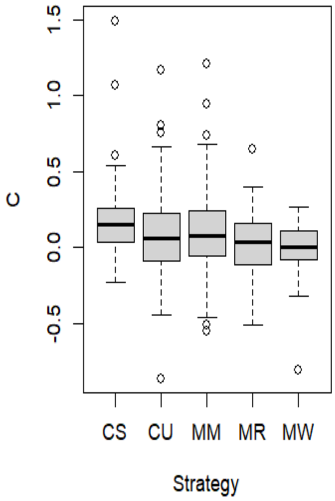

Figure 72: Strategy effect on central lobe-delta

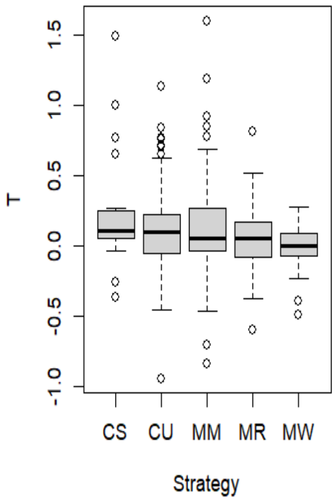

Figure 71: Strategy effect on temporal lobe-delta

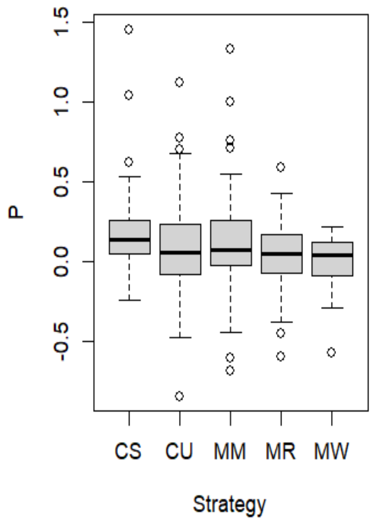

Figure 73:Strategy effect on parietal lobe-delta

Among the interactions between strategy and the other factors considered, daytime did not prove to be able to exert a significant statistical influence on any wave. Stress and background, instead, presented some meaningful relationships that will be deepened in the next two sections.

*4.2.6.1 Strategy*stress interaction*

The interaction between strategy and stress reported significant p-values only for each lobe of delta wave, as depicted in the table below.

STRATEGY:STRESS						
	FP	**F**	**C**	**T**	**P**	**O**
ALPHA	NC	NC	NC	NC	NC	NC
BETA	NC	NC	NC	NC	NC	NC
GAMMA 1	NC	NC	NC	NC	NC	NC
GAMMA 2	NC	NC	NC	NC	NC	NC
DELTA	0.00541 **	0.01044 *	0.01179 *	0.00099 ***	0.00255 **	0.00135 **
THETA	NC	NC	NC	NC	NC	NC

Table 14: Strategy and stress effect on brain activity-ANOVA (p-values)

Every lobe followed a similar trend according to both high and low stress level.

It is noticeable that mental manipulation presented a solid synchronization when participants declared to feel less stressed. The same pattern can be recognised looking at combination of other strategies.

In general, it is possible to underpin that the TRPs reached by each strategy were higher if the stress felt by subjects was little.

The only strategy that did not follow this specific path was the mind wandering strategy which presented higher TRPs relating to the high stress level for all brain regions, temporal lobe excluded.

Some explicative boxplots are reported below.

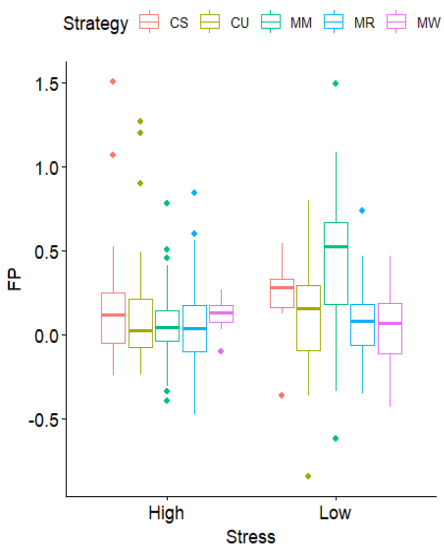

Figure 75: Strategy and stress effect on prefrontal lobe-delta

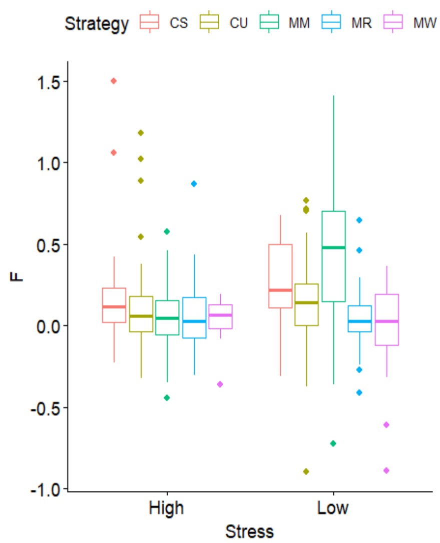

Figure 74: Strategy and stress effect on frontal lobe-delta

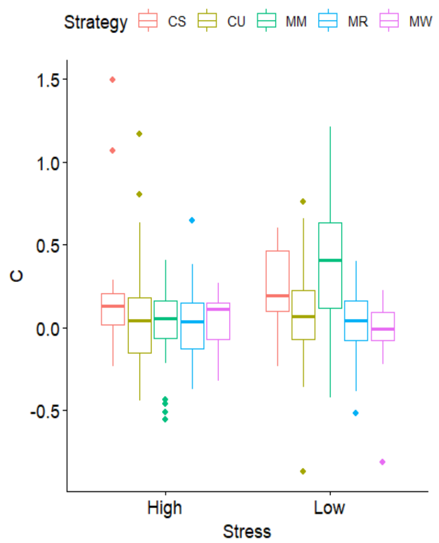

Figure 76: Strategy and stress effect on central lobe-delta

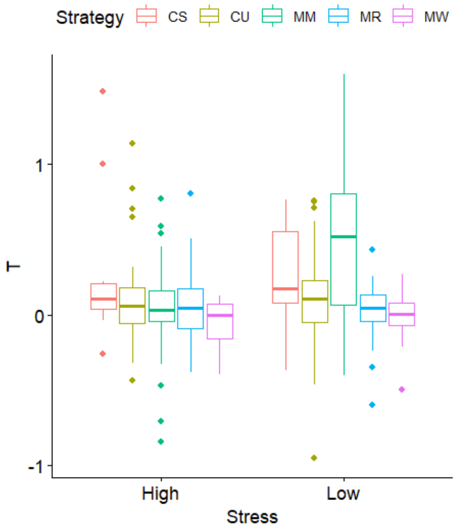

Figure 78: Strategy and stress effect on temporal lobe-delta

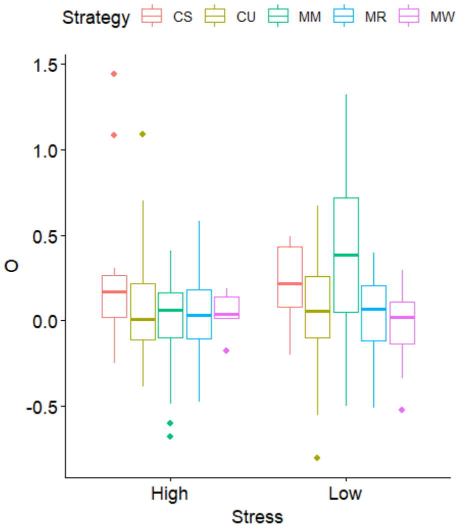

Figure 77: Strategy and stress effect on occipital lobe-delta

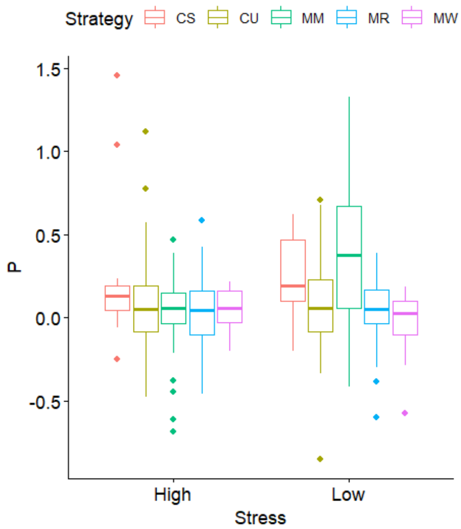

Figure 79:Strategy and stress effect on parietal lobe-delta

*4.2.6.2 Strategy*background interaction*

Strategy reported the most significant p-values in correlation with background, as shown in the table below.

The relationship between the two factors registered the highest level of significance considering the pre-frontal, frontal and temporal lobes of beta frequency band and each lobe of alpha, delta and theta waves. Lower p-values were observed for gamma 1 while no significant results were collected with reference to gamma 2 wave.

STRATEGY:BACKGROUND						
	FP	**F**	**C**	**T**	**P**	**O**
ALPHA	8.78e-08 ***	4.55e-07 ***	0.000309 ***	4.08e-05 ***	1.28e-05 ***	7.23e-05 ***
BETA	1.21e-05 ***	0.000407 ***	0.0108 *	0.00307 **	0.0164 *	NC
GAMMA 1	0.0309 *	0.0375 *	NC	NC	0.0154 *	0.0147 *
GAMMA 2	NC	NC	NC	NC	NC	NC
DELTA	0.000364 ***	7.65e-05 ***	0.000936 ***	5.72e-05 ***	0.000814 ***	0.000685 ***
THETA	0.000102 ***	1.67e-05 ***	4.62e-05 ***	4.44e-07 ***	5.55e-06 ***	0.00093 ***

Table 15:Strategy and background effect on brain activity-ANOVA (p-values)

The most important evidence relies on the fact that, once again, engineers and designers showed different neurophysiological paths.

For example, designers showed a synchronization relating to the common to uncommon strategy almost in all brain regions and waves. The opposite happened, a desynchronization, referring to engineers.

Moreover, engineers in alpha and beta waves registered il almost each the highest TRPs in relation to mind wandering strategy. In all the other waves, on the contrary, they showed the tendency to report stronger synchronization regarding mental manipulation and/or the combination of other strategies.

Finally, memory-retrieval, in almost every lobe of alpha and beta waves, displayed higher TRPs in relation to engineers, while starting from the occipital lobe of gamma 1 the strategy began to collect higher values according to designers.

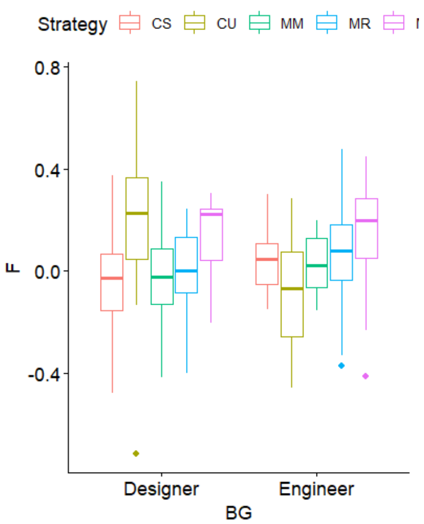

Figure 81: Strategy and background effect on frontal lobe-alpha

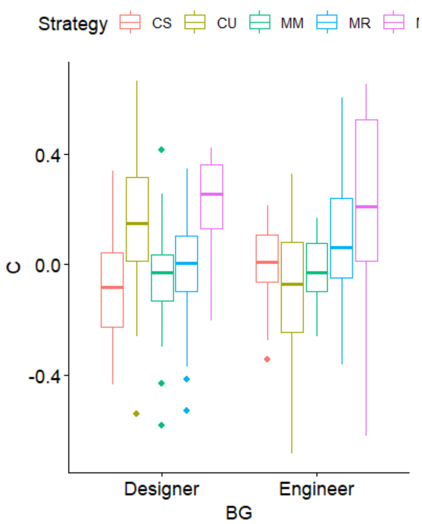

Figure 80:Strategy and background effect on central lobe-alpha

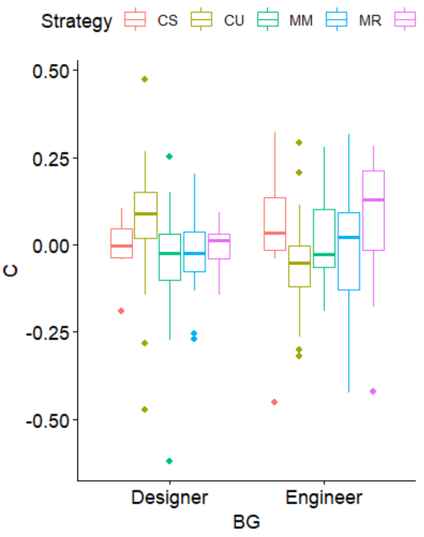

Figure 82:Strategy and background effect on central lobe-beta

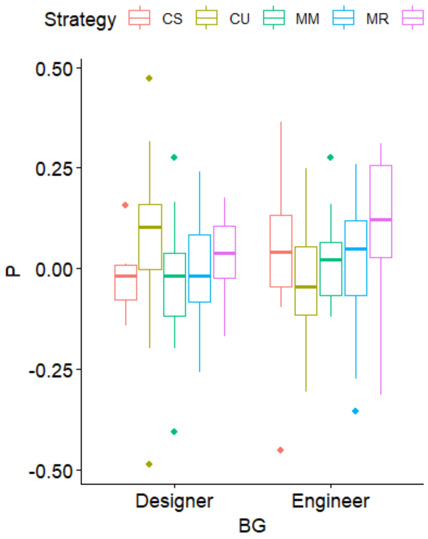

Figure 83:Strategy and background effect on parietal lobe-beta

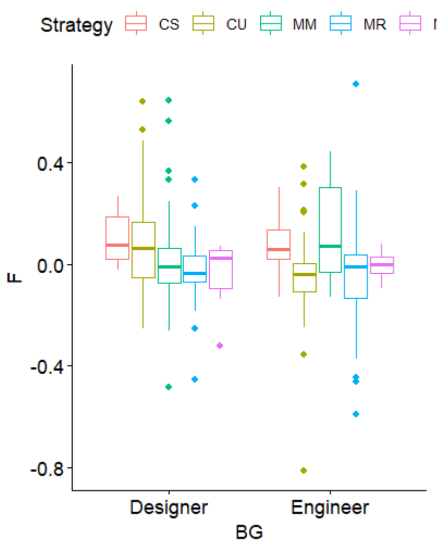

Figure 85:Strategy and background effect on frontal lobe-gamma 1

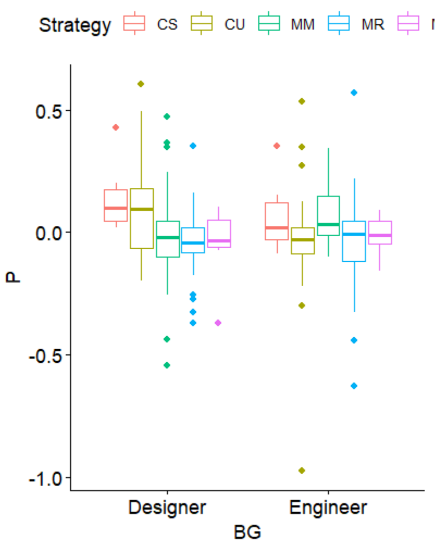

Figure 85:Strategy and background effect on parietal lobe-gamma 1

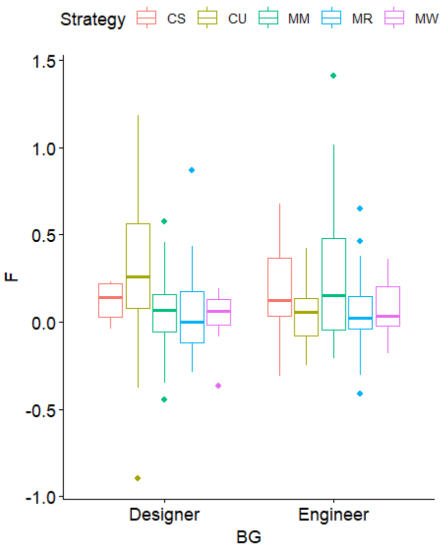

Figure 87:Strategy and background effect on frontal lobe-delta

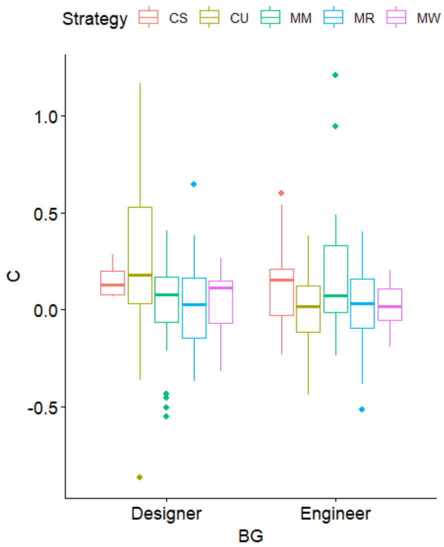

Figure 87:Strategy and background effect on central lobe-delta

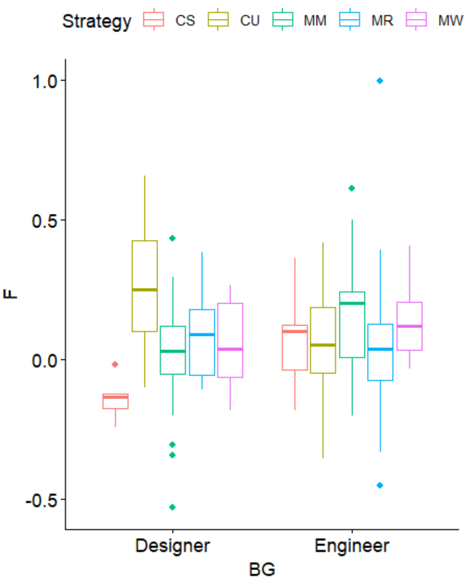

Figure 89:Strategy and background effect on frontal lobe-theta

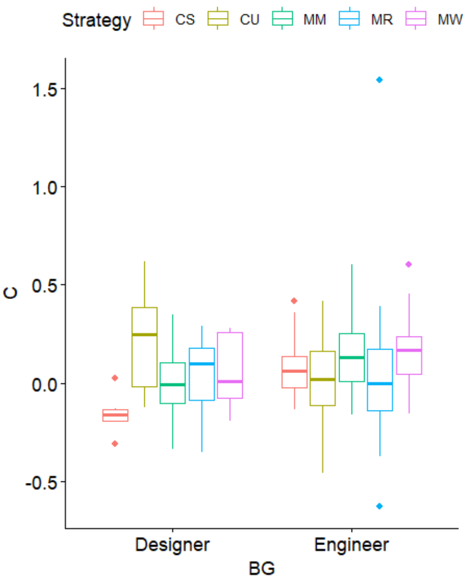

Figure 89:Strategy and background effect on central lobe-theta

Conclusions

The attention to Design has progressively grown in recent years and the research has focused on the study of its processes to improve their outcomes and help designers to perform their activities. In the beginning, studies relied on empirical methods, Protocol Analysis, allowing scholars to gain information about designers' cognitive behaviour looking at sketches, reports and verbal recordings carried out during the task.
However, this approach ignored designers' implicit cognitive activity. For this reason, a neurophysiological approach has lately been embraced, in parallel with Protocol Analysis. The new method is based on the adoption of biometric instruments that can also ensure a more impersonal data collection. Nevertheless, being literature still at the beginning and considering its explorative and descriptive nature, results obtained are quite contrasting and fragmented. Therefore, the present thesis aims to provide new insights regarding the existence of possible neurocognitive patterns during the idea generation process in relation to performances in terms of creativity or when considering the time of day, the educational background and behavioural aspects such as the stress felt by participants and the strategy employed to perform the task.

The first step to carry out the present thesis consisted of a brief literature review to understand the general context and the main objectives of research.
This work took as reference the contributions given by previous master theses, Candusso (2019) and Piga (2022). The former developed the methodology adopted to evaluate subjects' verbal responses in terms of creativity. The latter recognised the time of day as capable of influencing cognitive activations during the design task. The behavioural aspects, stress and strategy, were collected through a quick questionnaire, filled out by participants at the end of the experiment. The statistical analysis was carried out by employing R programming language and the Analysis of Variance (ANOVA) as statistical test.

It was confirmed that different performances in terms of creativity imply different neurophysiological patterns.

Precisely, alpha power synchronizations were associated to novel responses suggesting a possible correlation with divergent thinking while cognitive activations closer to convergent thinking were identified with reference to quality ideas. These findings confirmed the relationship existing between divergent thinking and originality and the importance of balancing convergent and divergent phases to reach creativity. The different results obtained can also be justified referring to other factors that could have influenced the production of ideas such as the strategy adopted by participants to perform the task and the daytime, both able to affect mental activity and creativity performance.

While the influence of daytime on brain activity was already confirmed before, the present work highlights the effect of the time of day also in relation to creative performances. More precisely, lunch and afternoon reported the highest scores respectively in terms of originality and effectiveness, much lower results for each metric were associated to morning, instead. The reason can be probably traced back to changes in cognitive performance during the day due to the existence of different chronotypes and/or the effect of biological rhythms. This perspective, indeed, suggests that during morning hours cognitive performance is low, while it increases at lunchtime and then again during the afternoon.

The analyses carried out in this thesis identified meaningful relationships between educational background and behavioural factors such as stress and strategy. These findings could be employed to better understand the reasons hiding behind different neurophysiological patterns followed by engineers and designers. Firstly, the distance between the two could be associated to the specific reaction to stimuli and factors such as daytime and stress; designers, for example, showed a higher sensitivity to stress.

Moreover, it was found that strategy is able to influence the neurophysiological response either alone and in correlation with background, underpinning the idea according to which designers and engineers' cognitive dissimilarities can be traced back to the tendency to adopt divergent strategies due to their studies and/or their experiences. For example, it can be highlighted that engineers tend to struggle more when adopting strategies that turned out to be more related to divergent thinking such as mental wandering and memory retrieval, in line with the greater effort spent by engineers during divergent phases already detected in Piga's Master Thesis (2022). Designers and engineers also differ regarding the time spent to generate their ideas, this could be linked to their individual reaction to stress which can influence mental effort and so the response speed. Designers showing more sensitivity in relation to stress and registering a higher response time, comparing to engineers, could be taken as a hint. However, it was found that performances in terms of creativity do not differ from engineers to designers.

Stress can't affect performances, unless in correlation with the type of strategy adopted to execute the task. In literature it is thought that too high or too low mental stress do not favour creativity (Nguyen & Zeng, 2012). The present thesis based the detection of the stress level on a quick questionnaire, administered at the end of the experiment, opting for an assessment methodology closer to self-reporting which didn't make it possible to consider an intermediate level of stress that maybe could have shown significant results. Moreover, mental effort and stress can also influence the auto evaluation process and, therefore, the output of the analysis (Nguyen & Zeng, 2017). On the contrary, stress can influence the neurophysiological response and the evidence of higher mental effort in relation to low stress level was in line with literature findings, although the different way of detecting stress.

Strategy showed quite peculiar trends in terms of creativity performance and brain activity only referring to the most original answers. This could be due to the fact participants followed a strategy only during the uncommon condition that produced the most unusual, therefore, original ideas. Moreover, mental strategies such as mind wandering and memory-retrieval registered higher alpha synchronizations as a sign of redirecting the attention towards the internal world, trying not to be influenced by external stimuli. Adopting a combination of other strategies or trying to picture the object in different environment showed synchronizations in the other waves.

To sum up, each factor turned out to be able to influence the neurophysiological response, but not always this was translatable into actual distances in the creative performances registered. Almost every time, analysis displayed the most significant results when factors were correlated. This could be read as a demonstration of the complexity and variety of the Design and creativity processes where rarely it is just one factor to determine the different cognitive aspects and the effectiveness of the output.

In conclusion, some hints relating to future studies will be briefly underlined, given the limits of the research, partially coming from the fact that it is not a stand-alone work that aims to completely and definitively disclosure all the aspects of the topic or to perform every possible analysis on the data available, but whose goal is to build new knowledge and enlarge the general view on the topic.

One limit of the research project lies in the dataset employed for the analysis regarding the performances in terms of creativity. It wasn't possible to include all the responses given by participants because the available evaluations performed by raters referred to 20 among the 40 stimuli presented to subjects during the experiment. It is, therefore, necessary for future researches to include all the assessments.

Due to the contradictory nature of some results obtained relating to stress if compared to literature's findings it could be useful in the future to develop an experiment during which the stress level will be collected by adopting neurophysiological tools, although always trying to balance the contributions within the approaches without leaving behind evidence emerged from Protocol studies. Beyond the stress level, it could be interesting to deepen the effect of strategy on cognitive processes, especially in correlation with educational background. A future experiment, for example, could use groups of engineer and designers and forcing them to adopt the same strategy.

Another hint for future works could be deepening the analysis on performances, trying to understand for example how they evolve during the duration of the task and to which variables this trend, if existing, can be ascribed.

Appendix

Anchor tables

The following tables, taken from Dean's study, have been employed by raters during the scooring phase of the idea evaluation process.

Originality

"The degree to which the idea is not only rare, but is also ingenious, imaginative or surprising".

Score	Level description
4	Not expressed before (rare, unusual) and ingenious, imaginative or surprising; may be humorous
3	Unusual, interesting; shows some imagination
2	Interesting
1	Common, mundane, boring

Paradigm relatedness

"The degree to which an idea is paradigm preserving (PP) or paradigm modifying (PM). PM ideas are sometimes radical or transformational."

Score	Level description
4	The object present both the addition of new components and the alteration of the relationships bewteen its already existing elements
3	The object present alteration of the relationships between its already existing elements (e.g. recombination of components)
2	The object architecture present some differences attributable to the addition or removal of components
1	The architecture is proposed without significant changes

Effectiveness

"The degree to which the idea will solve the problem without regard for feasibility."

Score	Level description
4	Reasonable and will solve the problem without regard for feasibility (If you could do it, it would solve the main problem)
3	Reasonable and will contribute to the solution of the problem (It helps, but it is only a partial solution)
2	Unreasonable or unlikely to solve the problem (It probably will not work)
1	Not useful for the problem resolution (It would not work, even if you could do it)

Feasibility

"An idea is feasible if it can be easily implemented and does not violate known constraints."

Score	Level description
4	Easy to implement common strategies, at low cost, that violate no norms or sensibilities
3	Some changes strategies, somewhat uncommon or unusual, that don't offend sensibilities
2	Significant change or expensive strategy, but not totally impossible to implement. Offends sensibilities somewhat but is not totally unacceptable
1	Totally infeasible to implement or extremely costly solutions, that radically violates laws or sensibilities or Totally unacceptable business practice.

R Script

The following script sums up the main functions employed to carry out the statistical analyses on RStudio.

```
------------------------------------------------------------------------------------------------
library(readxl)
library(ggplot2)
```

```
library(dplyr)
library(gridExtra)
library(MASS)
library("ggpubr")
```

ANOVA_RESPONSE TIME_BACKGROUND (BG)_DAYTIME

```
aov<-aov (ResponseTime~Daytime*BG, data=df)
summary(aov)

ggboxplot(df, x="BG",y="ResponseTime",col="Daytime")
```

ANOVA_METRICS_DAYTIME_BACKGROUND

```
aov<-aov(Originality~BG,data=df)
aov1<-aov(ParadigmRelatedness~BG,data=df)
aov2<-aov(Feasibility*BG,data=df)
aov3<-aov(FP~Effectiveness*BG,data=df)

aov<-aov(Originality~Daytime,data=df)
aov1<-aov(ParadigmRelatedness~Daytime,data=df)
aov2<-aov(Feasibility*Daytime,data=df)
aov3<-aov(FP~Effectiveness*Daytime,data=df)


aov<-aov(Originality~Daytime*BG,data=df)
aov1<-aov(ParadigmRelatedness~Daytime*BG,data=df)
aov2<-aov(Feasibility~Daytime*BG,data=df)
aov3<-aov(FP~Effectiveness~Daytime*BG,data=df)
```

```
summary(aov)
summary(aov1)
summary(aov2)
summary(aov3)

boxplot(Originality~Daytime, data=df)
boxplot(ParadigmRelatedness~Daytime, data=df)
boxplot(Feasibility~Daytime, data=df)
boxplot(Effectiveness~Daytime, data=df)
```

ANOVA_METRICS_BRAIN WAVES

```
aov<-aov(FP~Originality,data=df)
aov1<-aov(F~Originality,data=df)
aov2<-aov(C~Originality,data=df)
aov3<-aov(T~Originality,data=df)
aov4<-aov(P~Originality,data=df)
aov5<-aov(O~Originality,data=df)

aov<-aov(FP~ParadigmRelatedness,data=df)
aov1<-aov(F~ParadigmRelatedness,data=df)
aov2<-aov(C~ParadigmRelatedness,data=df)
aov3<-aov(T~ParadigmRelatedness,data=df)
aov4<-aov(P~ParadigmRelatedness,data=df)
aov5<-aov(O~ParadigmRelatedness,data=df)

aov<-aov(FP~Feasibility,data=df)
aov1<-aov(F~Feasibility,data=df)
aov2<-aov(C~Feasibility,data=df)
aov3<-aov(T~Feasibility,data=df)
aov4<-aov(P~Feasibility,data=df)
aov5<-aov(O~Feasibility,data=df)
```

```
aov<-aov(FP~Effectiveness,data=df)
aov1<-aov(F~Effectiveness,data=df)
aov2<-aov(C~Effectiveness,data=df)
aov3<-aov(T~Effectiveness,data=df)
aov4<-aov(P~Effectiveness,data=df)
aov5<-aov(O~Effectiveness,data=df)

boxplot(FP~Originality,data=df)
boxplot(F~Originality,data=df)
boxplot(C~Originality,data=df)
boxplot(T~Originality,data=df)
boxplot(P~Originality,data=df)
boxplot(O~Originality,data=df)

boxplot(FP~ParadigmRelatedness,data=df)
boxplot(F~ParadigmRelatedness,data=df)
boxplot(C~ParadigmRelatedness,data=df)
boxplot(T~ParadigmRelatedness,data=df)
boxplot(P~ParadigmRelatedness,data=df)
boxplot(O~ParadigmRelatedness,data=df)

boxplot(FP~Feasibility,data=df)
boxplot(F~Feasibility,data=df)
boxplot(C~Feasibility,data=df)
boxplot(T~Feasibility,data=df)
boxplot(P~Feasibility,data=df)
boxplot(O~Feasibility,data=df)

boxplot(FP~Effectiveness,data=df)
boxplot(F~Effectiveness,data=df)
boxplot(C~Effectiveness,data=df)
```

```
boxplot(T~Effectiveness,data=df)
boxplot(P~Effectiveness,data=df)
boxplot(O~Effectiveness,data=df)
```

ANOVA_DAYTIME

```
aov<-aov(FP~Dayitme,data=df)
aov1<-aov(F~Dayitme,data=df)
aov2<-aov(C~Dayitme,data=df)
aov3<-aov(T~Dayitme,data=df)
aov4<-aov(P~Dayitme,data=df)
aov5<-aov(O~Dayitme,data=df)

aov<-aov(FP~AM_PM,data=df)
aov1<-aov(F~AM_PM,data=df)
aov2<-aov(C~AM_PM,data=df)
aov3<-aov(T~AM_PM,data=df)
aov4<-aov(P~AM_PM,data=df)
aov5<-aov(O~AM_PM,data=df)

summary(aov)
summary(aov1)
summary(aov2)
summary(aov3)
summary(aov4)
summary(aov5)
```

ANOVA_STRESS_BRAIN WAVES

```
aov<-aov(FP~Stress*Daytime*BG,data=df)
aov1<-aov(F~Stress* Daytime *BG,data=df)
```

```
aov2<-aov(C~Stress* Daytime *BG,data=df)
aov3<-aov(T~Stress* Daytime *BG,data=df)
aov4<-aov(P~Stress* Daytime *BG,data=df)
aov5<-aov(O~Stress* Daytime *BG,data=df)

summary(aov)
summary(aov1)
summary(aov2)
summary(aov3)
summary(aov4)
summary(aov5)

boxplot(FP~Stress,data=df)
boxplot(F~Stress,data=df)
boxplot(C~Stress,data=df)
boxplot(T~Stress,data=df)
boxplot(P~Stress,data=df)
boxplot(O~Stress,data=df)

ggboxplot(df, x=" Daytime ",y="FP",col="Stress")
ggboxplot(df, x=" Daytime ",y="F",col="Stress")
ggboxplot(df, x=" Daytime ",y="C",col="Stress")
ggboxplot(df, x=" Daytime ",y="T",col="Stress")
ggboxplot(df, x=" Daytime ",y="P",col="Stress")
ggboxplot(df, x=" Daytime ",y="O",col="Stress")

ggboxplot(df, x="Stress",y="FP", col=" Daytime ")
ggboxplot(df, x="Stress",y="F",col=" Daytime ")
ggboxplot(df, x="Stress",y="C",col=" Daytime ")
ggboxplot(df, x="Stress",y="T",col=" Daytime ")
ggboxplot(df, x="Stress",y="P",col=" Daytime ")
ggboxplot(df, x="Stress",y="O",col=" Daytime ")
```

```
ggboxplot(df, x="BG",y="FP",col="Stress")
ggboxplot(df, x="BG",y="F",col="Stress")
ggboxplot(df, x="BG",y="C",col="Stress")
ggboxplot(df, x="BG",y="T",col="Stress")
ggboxplot(df, x="BG",y="P",col="Stress")
ggboxplot(df, x="BG",y="O",col="Stress")

ggboxplot(df, x="BG", y="P", facet.by = "Stress", col=" Daytime ")

ggboxplot(df, x=" Daytime ", y="FP", facet.by = "Stress", col="BG")
ggboxplot(df, x=" Daytime ", y="F", facet.by = "BG", col="Stress")
ggboxplot(df, x=" Daytime ", y="C", facet.by = "BG", col="Stress")
ggboxplot(df, x=" Daytime ", y="T", facet.by = "BG", col="Stress")
ggboxplot(df, x=" Daytime ", y="P", facet.by = "BG", col="Stress")
ggboxplot(df, x=" Daytime ", y="O", facet.by = "BG", col="Stress")


STRESS_METRICS

aov<-aov(Originality~Stress,data=df)
aov1<-aov(ParadigmRelatedness~Stress,data=df)
aov2<-aov(Feasibility~Stress,data=df)
aov3<-aov(Effectiveness~Stress,data=df)

boxplot(Originality~Stress,data=df)
boxplot(ParadigmRelatedness~Stress,data=df)
boxplot(Feasibility~Stress,data=df)
boxplot(Effectiveness~Stress,data=df)

summary(aov)
summary(aov1)
```

```
summary(aov2)
summary(aov3)

aov<-aov(Originality~Stress*Daytime,data=df)
aov1<-aov(ParadigmRelatedness~Stress*Daytime,data=df)
aov2<-aov(Feasibility~Stress*Daytime,data=df)
aov3<-aov(Effectiveness~Stress*Daytime,data=df)

ggboxplot(df, x="Daytime",Y="Originality",col="Stress")
ggboxplot(df, x="Daytime",Y="ParadigmRelatedness",col="Stress")
ggboxplot(df, x="Daytime",Y="Feasibility",col="Stress")
ggboxplot(df, x="Daytime",Y="Effectiveness",col="Stress")

aov<-aov(Originality~Stress*BG,data=df)
aov1<-aov(ParadigmRelatedness~Stress*BG,data=df)
aov2<-aov(Feasibility~Stress*BG,data=df)
aov3<-aov(Effectiveness~Stress*BG,data=df)

ggboxplot(df, x="BG",y="Originality",col="Stress")
ggboxplot(df, x="BG",y="ParadigmRelatedness",col="Stress")
ggboxplot(df, x="BG",y="Feasibility",col="Stress")
ggboxplot(df, x="BG",y="Effectiveness",col="Stress")

aov<-aov(Originality~BG* Daytime *Stress, data=df)
summary(aov)
aov1<-aov(ParadigmRelatedness~BG* Daytime *Stress, data=df)
summary(aov1)
aov2<-aov(Feasibility~BG* Daytime *Stress, data=df)
summary(aov2)
aov3<-aov(Effectiveness~BG* Daytime *Stress, data=df)
summary(aov3)
```

STRATEGY_METRICS

```
aov<-aov(Originality~Strategy,data=df)
aov1<-aov(ParadigmRelatedness~Strategy,data=df)
aov2<-aov(Feasibility~Strategy,data=df)
aov3<-aov(Effectiveness~Strategy,data=df)

aov<-aov(Originality~Strategy* Daytime,data=df)
aov1<-aov(ParadigmRelatedness~Strategy* Daytime,data=df)
aov2<-aov(Feasibility~Strategy* Daytime,data=df)
aov3<-aov(Effectiveness~Strategy* Daytime,data=df)

aov<-aov(Originality~Strategy*Stress,data=df)
aov1<-aov(ParadigmRelatedness~Strategy*Stress,data=df)
aov2<-aov(Feasibility~Strategy*Stress,data=df)
aov3<-aov(Effectiveness~Strategy*Stress,data=df)

aov<-aov(Originality~Strategy*BG,data=dfbg)
aov1<-aov(ParadigmRelatedness~Strategy*BG,data=dfbg)
aov2<-aov(Feasibility~Strategy*BG,data=dfbg)
aov3<-aov(Effectiveness~Strategy*BG,data=dfbg)

summary(aov)
summary(aov1)
summary(aov2)
summary(aov3)

ggboxplot(df,x="Strategy",y="Originality")
ggboxplot(df,x="Strategy", y="ParadigmRelatedness")
ggboxplot(df,x="Strategy", y="Feasibility")
ggboxplot(df,x="Strategy", y="Effectiveness")
```

```
ggboxplot(df, x="Stress",y="Originality",col="Strategy")
ggboxplot(df, x="Stress",y="ParadigmRelatedness",col="Strategy")
ggboxplot(df, x="Stress",y="Feasibility",col="Strategy")
ggboxplot(df, x="Stress",y="Effectiveness",col="Strategy")
```

STRATEGY-BRAIN WAVES

```
boxplot(FP~Strategy,data=df)
boxplot(F~Strategy,data=df)
boxplot(C~Strategy,data=df)
boxplot(T~Strategy,data=df)
boxplot(P~Strategy,data=df)
boxplot(O~Strategy,data=df)


ggboxplot(df, x="Stress",y="FP",col="Strategy")
ggboxplot(df, x="Stress",y="F",col="Strategy")
ggboxplot(df, x="Stress",y="C",col="Strategy")
ggboxplot(df, x="Stress",y="T",col="Strategy")
ggboxplot(df, x="Stress",y="P",col="Strategy")
ggboxplot(df, x="Stress",y="O",col="Strategy")


aov<-aov(FP~Strategy,data=df)
aov1<-aov(F~Strategy,data=df)
aov2<-aov(C~Strategy,data=df)
aov3<-aov(T~Strategy,data=df)
aov4<-aov(P~Strategy,data=df)
aov5<-aov(O~Strategy,data=df)
```

```
ggboxplot(df, x="Daytime",y="FP",col="Strategy")
ggboxplot(df, x=" Daytime ",y="F",col="Strategy")
ggboxplot(df, x=" Daytime ",y="C",col="Strategy")
ggboxplot(df, x=" Daytime ",y="T",col="Strategy")
ggboxplot(df, x=" Daytime ",y="P",col="Strategy")
ggboxplot(df, x=" Daytime ",y="O",col="Strategy")


aov<-aov(FP~Strategy*Stress,data=df)
aov1<-aov(F~Strategy*Stress,data=df)
aov2<-aov(C~Strategy*Stress,data=df)
aov3<-aov(T~Strategy*Stress,data=df)
aov4<-aov(P~Strategy*Stress,data=df)
aov5<-aov(O~Strategy*Stress,data=df)


aov<-aov(FP~Strategy*BG,data=df)
aov1<-aov(F~Strategy*BG,data=df)
aov2<-aov(C~Strategy*BG,data=df)
aov3<-aov(T~Strategy*BG,data=df)
aov4<-aov(P~Strategy*BG,data=df)
aov5<-aov(O~Strategy*BG,data=df)


ggboxplot(df, x="BG",y="FP",col="Strategy")
ggboxplot(df, x="BG",y="F",col="Strategy")
ggboxplot(df, x="BG",y="C",col="Strategy")
ggboxplot(df, x="BG",y="T",col="Strategy")
ggboxplot(df, x="BG",y="P",col="Strategy")
ggboxplot(df, x="BG",y="O",col="Strategy")
```

```
summary(aov)
summary(aov1)
summary(aov2)
summary(aov3)
summary(aov4)
summary(aov5)
```

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