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# NEUROPHYSIOLOGICAL EVIDENCE IN IDEA GENERATION: DIFFERENCES BETWEEN DESIGNERS AND ENGINEERS

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**Abstract**

The paper describes the rigorous implementation of a validated methodological experimental protocol to divergent and convergent thinking tasks occurring in Design by neurophysiological means (EEG and eye-tracking). EEG evidence confirms the findings coherently to the literature. Interesting is the confirmation of such results through eye-tracking ones, and further evidence emerged. In particular, neurophysiological results in idea generation differ between designers and engineers. This study was supported by a multidisciplinary team, both for the neuropsychological and data analysis aspects.

*Keywords: idea generation, electroencephalography, eye-tracking, design creativity, design process*

## 1. Introduction

The socio-economic relevance of Design is increasingly being recognised in the last decades, and contemporaneously the interest of researchers in this area is growing. Design can be studied as a phenomenon with a scientific approach that is part of Design research that is classified as Science of Design (Cross 2001). There are different perspectives generally based on experimental or empirical studies, and, usually, they refer to Protocol Studies. These studies, however, mostly neglect the designer's internal cognitive activity and do not consider investigating the ongoing implicit neurophysiological patterns. In order to avoid the gap between behavioural outcomes and the respective cognitive processes, scholars are recently moving to neurophysiological means of investigation (Alexiou, 2010; Gero, 2011).

Nonetheless, in this fascinating interdisciplinary context a trade-off is needed. Protocol Studies show that behavioural outcomes of a typical design ideation task are evident and measurable: it is in fact possible for the observer to identify and classify the different ideational phases along the task. Anyway, during this whole process a multitude of underlying cognitive activities (e.g. memory retrieval, mental imagery, attention shifts, etc.) may take place, possibly overlapping and repeatedly recurring over time across the different design phases: thus, they cannot be precisely discretized and separated. Given this issue, the neuropsychological methodology requires isolating the smallest atoms of cognition and studying them as separate modules. On the one hand, this approach is not lossless, as it does not take into account all the co-occurring factors which coordinate a whole design activity; on the other hand, it allows aiming to shed light on each of these factors individually.

The starting point is noting that one of the core features characterizing a design task is creativity. The term ‘creativity’ has heterogeneous definitions and meanings, from Arts to Industrial and Engineering Design; generally, it refers to idea generation and solution definition. The phases where designers should be creative are the most complex to study, from a neuro-cognitive point of view. This is due to the fact that when you ask someone to generate a creative solution, you usually ask to feel free to think, and not to think with a particular path. Instead, from a psychometric point of view, creativity is more complex to be studied, for two reasons: a) it has not a clear unique definition in literature; b) it calls into play different cognitive subprocesses (i.e. it is a compound construct; Dietrich, 2017). Thus, in Psychology, creativity has been heterogeneously defined and assessed (Arden et al., 2010) and standardized experimental procedures are missing (Dietrich and Kanso, 2010), leading to very inconsistent evidence (Dietrich and Kanso, 2010; Sawyer, 2011). These issues make it hard to develop a construct that could represent the perfect creative reasoning - if it exists - thus generating the need of designers and neuroscientists’ collaboration.

On the one hand, designers have already started to be interested in the use of neuropsychological tools for the investigation of a designer’s cognition; on the other hand, psychologists have been approaching the study of creativity by a neuroscientific point of view only in the last two decades (Benedek, 2018).

As we will discuss, electroencephalography (EEG) and eye-tracking represent ideal tools to collect implicit measures in a standard impersonal manner (Teplan, 2002) with regard to creative idea generation. To understand how to apply them rigorously in Design environment, in order to have results validated from a technical point of view, we started from the neuropsychological side.

Recently, some elements of consistency have emerged from literature. Indeed, creativity has been strongly linked to the production of ideas (Guilford, 1956; Fink and Benedek, 2012) and, in turn, idea generation relies on to two specific cognitive processes: convergent thinking (CT) and divergent thinking (Guilford, 1956), which represent two complementary ways of generating an idea (Cropley, 2006). Moreover, DT - defined as the generation of multiple alternative solutions to an initial ill-posed problem - gained popularity as an accurate proxy of creativity (Cropley, 2006; Dietrich and Kanso, 2010; Arden et al., 2010; Sawyer, 2011; Fink and Benedek, 2012; Jauk et al., 2012; Runco and Yoruk, 2014; Benedek, 2018), as it “leads to originality, and originality is the central feature of creativity” (Runco and Acar, 2012). The study of creativity through DT tasks has in fact shown a good validity in detecting creative thinking and a high reliability across studies (Runco and Acar, 2012; Runco and Yoruk, 2014). This means, DT is not synonymous of creativity; rather, it is a good indicator of creativity, but as such it is subject to uncertainty. Thus, in the study of design process, the focus on DT could be a good choice for replicating initial micro phases of generating solutions.

The present study does not aim to target creativity as a whole, but rather aims to investigate potential differences between two sub-components of creativity, namely CT and DT, that occur in idea generation. These are investigated in order to highlight the neurocognitive sub-processes from which they are, in turn, composed, and which characterize them as necessary - but maybe not sufficient - boosters of idea generation activities. With regard to the design activity, DT and CT can be respectively accounted as exploration of new ideas and evaluation of the old ones, in order to generate new solutions (Dym et al., 2005).

One of the most employed DT tasks in literature is the Alternative Uses Task (AUT) proposed by Guilford in 1967. The AUT requires participants to find original/uncommon uses for everyday objects. Revised versions of the AUT add a second condition, where subjects are asked to find common/usual uses for everyday objects too. Finding common uses for objects is a task which elicit a convergent way of thinking (Jauk et al., 2012), as it refers to situations where “there is usually one conclusion or answer that is regarded as unique, and thinking is channelled or controlled in the direction of that answer” (Guilford, 1956), instead of fluctuating in multiple equally valid directions as in DT. This improvement allows to better separate, identify and contrast the two main kinds of thinking occurring during creative idea generation.

How the brain works during DT tasks has not still been fully understood. Neuroimaging studies, mostly employing functional magnetic resonance (fMRI) or electroencephalography (EEG), generally indicate that creative ideation can be related to a generally decreased cortical activity. In literature, most studies investigating DT from a neuropsychological point of view employ EEG; furthermore, they are the ones which yielded more robust evidence in the DT literature. In detail, these studies mostly report the deactivation of certain brain regions, namely the prefrontal cortex (PFC), the temporoparietal junction (TPJ) or broader parieto-occipital areas - frequently in the right hemisphere (Fink and Benedek, 2012). With regard to EEG studies, literature shows that when employing the revised version of AUT a strengthened alpha (8-12 Hz) power - i.e. cortical inhibition - is observed over the aforementioned brain areas (Jauk et al., 2012; Benedek et al., 2014) during the divergent condition with respect to the convergent condition.

The interpretations of such evidence lie on the fact that, in general, this pattern occurs during tasks requiring people an active top-down inhibition over the elaboration of task-irrelevant external stimuli which may interfere with the ongoing mental operations (Benedek et al., 2014). This process allows for a shift of attention towards the internal world (Jauk et al., 2012; Benedek, 2018), thus facilitating mechanisms such as mental imagery, mental representations of scenarios and mental manipulation of objects (Rataj et al., 2018).

Ocular activity is being recently studied with regard to DT and idea generation. Literature in this field is still poor; nonetheless, some consistent and interesting studies seem to converge to the conclusion that eye activity plays a crucial role for some of the aforementioned cognitive processes necessary to thinking divergently. Eyes can facilitate internal cognition in two ways: first, mechanically, when they close there are no interfering visual inputs getting the brain; second, cognitively, by a specific behaviour - i.e. gaze aversion - that has been found to be coupled to deep mental information processing and memory retrieval. In fact, every time we are engaged in remembering a scene, our eyes follow a certain moving pattern: interestingly, this pattern reflects the visual attributes of the scene or object we are retrieving or imaging (Walcher et al., 2017). Moving eyes shield us from the external world and connect us to the internal world (Doherty-Sneddon and Phelps, 2005). In fact, gaze shifts are correlated with the cognitive effort being performed (Walcher et al., 2017). Moreover, literature also suggests a main role of leftward eye movements: when people look towards their left during problem-solving tasks, they show clearer mental imagery (Salvi and Bowden, 2016) and, when they are forced to look leftward, they get better scores in DT tasks (Hines and Martindale, 1974).

Having a look to EEG and eye-tracking evidence, it seems that specific brain electrical activity and oculomotor patterns coherently point towards a common direction by highlighting the central role of certain cognitive subprocesses necessary to creative idea generation through the study of DT and CT - namely, external stimuli inhibition, internally directed attention, memory retrieval and mental imagery. Nonetheless, there is a lack of studies investigating the possible differences between designers and engineers with regard to these neuropsychological measures. To our knowledge, this is one of the first studies employing both EEG and eye-tracking for the analysis of idea generation. Thus, the present work addresses two questions: (i) is it feasible to use both EEG and eye-tracker to detect neurophysiological activities? If yes, are these activities consistent with literature and with each other? (ii) Are there specific neurophysiological differences between design students and engineering students?

These questions require some hypotheses to be tested, respectively: (a) EEG and eye-tracking signals consistently differ between DT and CT; (b) EEG and eye-tracker activities differ between design students and engineering students.

A revised-AUT experiment is proposed in this paper. It follows the experimental protocol defined in Colombo et al. (n.d.), that is an adapted version of the experimental paradigm proposed by Jauk et al. (2012) and Laspia et al. (2019). This paradigm has shown to be an effective and promising representation of how to use electroencephalogram and eye-tracker to detect brain electrical activity and subconscious physiological activations. In particular, it allowed identifying some underpinnings the cognitive processes involved in idea generation related to Design. Therefore, this paper does not aim to present such a paradigm as this is already validated, but it intends to present the results of the experiment that emerge from it. In particular, not only EEG data confirmed the previous findings in the literature, but eye-tracking results also significantly contribute to a coherent interpretation of the present findings. In addition to the global results about idea generation, the specific investigation of the factor "background" (e.g. to be whether a designer or an engineer) highlighted some relevant differences in both the EEG and eye-tracking analyses.

The paper is structured in the following three sections: the Experimental Protocol (section 2) describes how the experiment was structured, the task and the procedure adopted, the equipment and methods used to collect data; the Results (section 3) explain the main findings found from different sources, namely, EEG and eye-tracking; finally, the document presents interpretation of results and some conclusive remarks in the Conclusion (section 4), with some suggestions for further studies.

## 2. The experimental protocol

The design of the experiment (DOE) adopted in the present study was structured according to a deep investigation of literature in the domain of neuropsychological study of DT (Sawyer, 2011; Runco and Acar, 2012; Runco and Yoruk, 2014). The task was a revised version of the AUT adaptation proposed by Jauk et al. (2012), as described in section 2.2. Both behavioural and neurophysiological data were collected during the task, with the experimental setting presented in Figure 1. Behavioural measures consisted of different idea-generation parameters, response times and the qualitative self-reports; neurophysiological measures consisted of EEG and eye-tracking.

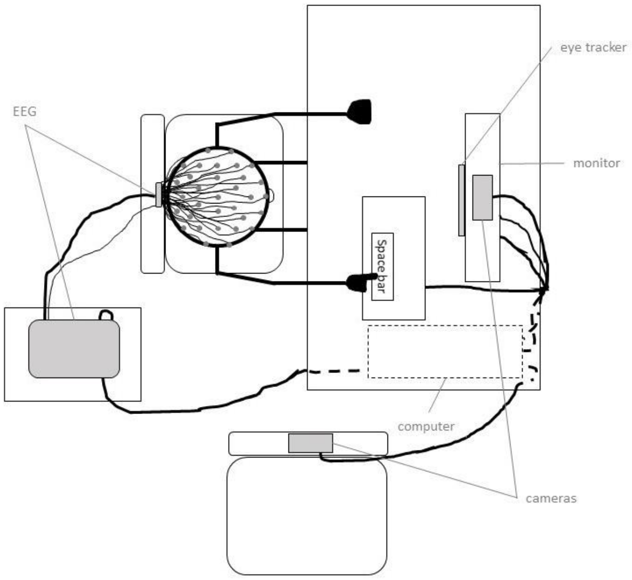


**Figure 1. Experimental setting**

### 2.1. Participants

Forty volunteers took part in the experiment. In the sample, all the participants were students at Luleå Tekniska Universitet (LTU). They were 11 females and 29 males, with a heterogeneous educational background mainly in Engineering, belonging to different years of their career; Figure 2 describes such distribution. The average age was 23.67 years (SD = 2.55, range = 19 - 32 years). With respect to the educational background, participants were firstly selected in order to reach a satisfactory sample size for the second research question. Once a sufficient number was obtained, the educational backgrounds of all other participants were neglected, as they could enlarge the sample for the first research question.

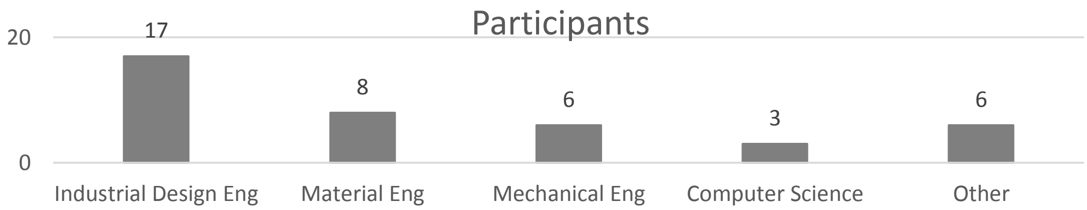


**Figure 2. Participants' educational background**

To determine participants' handedness, the Edinburgh Handedness Inventory was used, and thirty-seven of them were right-handed. In previous research, there is no evidence about the role of handedness, but left-handed participants were anyway excluded from the analyses, to avoid the possibility that part of variance could be explained by this variable. The experimental items were translated into the mother tongue of the participants, with the support of mother tongue people, to avoid the cognitive process of translation in the analysis.

## 2.2. Task and procedure

The AUT requires the subjects to find uses for everyday objects. In the present study, the task was performed under two well-state conditions: common versus uncommon, representing convergent and divergent thinking, respectively. In the uncommon condition, the subjects had to find a highly uncommon/original use for the presented everyday object. In the common condition, the subjects had to find a highly common use for the presented everyday object. For example, if the object is "glasses", a common way of using it could be "to read better", and an uncommon way of using it could be "to start a fire". A total of 40 different items were randomly assigned to the condition common or uncommon (20 items per condition). Each condition consisted of a block of 20 consecutive trials, and each item could never be repeated nor within or between the conditions. Each subject underwent both conditions. The order of appearance of the two blocks/conditions was counterbalanced across subjects. The procedure was structured as in Figure 3: first, a blank screen was displayed for 5 seconds representing the inter-trial interval; a fixation cross was then presented in the centre of the screen for another 5 seconds, representing the reference period; subsequently, the stimulus/word appeared in the centre of the screen for 500 milliseconds; then, a fixation cross – identical to the reference period one - again appeared in the centre of the screen for a maximum of 30 seconds, representing the idea generation period. The subject was instructed to press the spacebar as soon as he/she wanted to vocalise his/her idea and, subsequently, a speech balloon appeared on the screen, indicating that the idea could be vocalised; then the subject pressed the spacebar again, and the next trial started. At the end of the first block, a two-minutes pause preceded the start of the second block. Finally, at the end of the experiment, a brief questionnaire was administered to the subjects in order to collect additional qualitative data, that are excluded from this document. For both sensors, only the reference and idea generation periods of each trial were analysed, in order to avoid the movement artefacts due to, for example, the vocalisation.

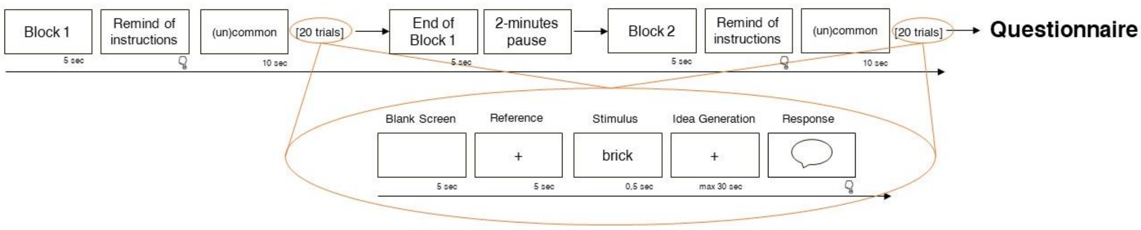


**Figure 3. Task presentation and procedure**

## 2.3. EEG

The EEG device used in this study was the BrainVision ActiCHamp (developed by BrainProducts© GmbH, Germany) with a 32 electrodes splitter box connected to the ActiCap and a sampling rate of 500 Hz. 31 electrodes were applied on the scalp according to the International 10-20 system. Reference electrode was placed on the tip of the nose. The ground electrode was placed on the forehead, in Fpz position. No EOG electrodes were used. The impedance of each electrode was kept below 5 kΩ. EEG recordings were pre-processed with FFT frequency filter and ICA spatial filter, in order to remove physiological and non-physiological artefacts. Alpha (7.5 - 12.5 Hz) power (mV^2) was extracted via the Welch method.

The analysis regarded alpha power during task performance. A 4-way mixed factorial design was used in this case. The four factors are Condition (Common vs Uncommon), Hemisphere (Right vs Left), Area (Frontal vs Central vs Posterior) as within-subject factors and Background (Designers vs

Engineers) as a between-subjects factor. In particular, the last one was added to assess potential differences between design students and engineering students. The result was a mixed 2x2x3x2 factorial design. For the factor Hemisphere, electrodes were aggregated according to the even/odd number classification, where right-hemisphere electrodes are labelled with even numbers, and left-hemisphere electrodes are labelled with odd numbers; central electrodes were excluded from the analyses; for the factor Area, electrodes were aggregated as follows: Frontal (F; with Fp1, F3 and F7 for the left hemisphere, and Fp2, F4, F8 for the right hemisphere), Central (C; with FC1, FC5, FT9, C3, C7, CP1, CP5, CP9 for the left hemisphere and FC2, FC6, FT10, C4, C8, CP2, CP6, CP10 for the right hemisphere), Posterior (P; with P3, P7, O1 for the left hemisphere, and P4, P8, O2 for the right hemisphere). The subdivision of the subjects in the two groups of the factor Background was based on their educational background.
The dependent variable was calculated as the Task Related Power (TRP): for each electrode, for each trial, for each subject, TRP was calculated as the difference between the mean log-transformed alpha power of the idea generation period and the corresponding reference period with the equation (1), according to Pfurtscheller and Da Silva (1999):

$$TRP = log(Power_{Activation}) - log(Power_{Reference}) \tag{1}$$

## 2.4. Eye tracker

For ocular data acquisition, a Tobii© X2-30 Eye Tracker Compact Edition with 30 Hz sampling frequency was used. The device was installed just below the screen, on its lower border, and required the subject to be at a 60 cm optimal distance from the screen. Data collection and analysis was focused on ocular movements. The screen was divided into three vertical Areas Of Interest (AOIs), as shown in Figure 4: a central one - the tightest, centred on the fixation cross, with a 3.44° angle width - and two equally larger lateral ones, which covered the rest of the screen, on the right and left side, respectively. As the interest of the present study is focused only on the differences of decentralised eye movements between the common and uncommon conditions, data from the central AOI were excluded from the analysis. Four eye-movement measures have been extracted: Time Spent, Fixation Count, Average Fixation Duration and Relative Time Spent.

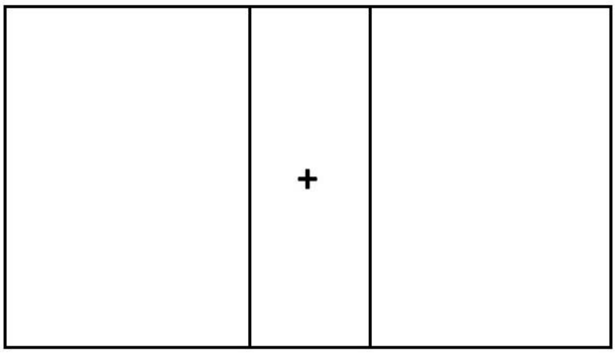


**Figure 4. Eye-tracker, areas of interest (AOI)**

For each measure, a mixed 2x2x2 design was drawn, comprising Side (Left vs Right) and Condition (Common vs Uncommon) as within-subject factors, and Background (Engineers vs Designers) as between-subjects factor.

# 3. Results

## 3.1. EEG

For the EEG analysis, data of 6 out of 40 participants were excluded due to poor quality of the data, left-handedness or poor compliance to the task. A 4-way ANOVA for repeated measures was run for 34 valid subjects and significant results are reported in Table 1.

**Table 1. EEG TRP - ANOVA: significant effects and interactions**

**Tests of Within-Subjects Effects**

**Measure: TRP**

| Source (Greenhouse-Geisser) | Type III Sum of Square | df | Mean Square | F | Sig. | Partial Eta Squared |
|---|---|---|---|---|---|---|
| HEMISPHERE* Background | .890 | 1.000 | .890 | 14.951 | .000 | .033 |
| Error (HEMISPHERE) | 26.026 | 437.00 | .060 | - | - | - |
| AREA | 65.719 | 1.305 | 50.376 | 187.374 | .000 | .300 |
| AREA*Background | 4.856 | 1.305 | 3.722 | 13.845 | .000 | .031 |
| Error (AREA) | 153.271 | 570.093 | .269 | - | - | - |
| CONDITION* HEMISPHERE | .359 | 1.000 | .359 | 6.512 | .011 | .015 |
| CONDITION* HEMISPHERE* Background | .262 | 1.000 | .262 | 4.748 | .030 | .011 |
| Error (CONDITION* HEMISPHERE) | 24.125 | 437.000 | .055 | - | - | - |
| CONDITION*AREA | 4.055 | 1.292 | 3.139 | 26.469 | .000 | .057 |
| Error(CONDITION* AREA) | 66.946 | 564.485 | .119 | - | - | - |
| HEMISPHERE*AREA | .233 | 1.603 | .145 | 5.508 | .008 | .012 |
| Error (HEMISPHERE*AREA) | 18.492 | 700.406 | .026 | - | - | - |

Results indicate a main effect of the factor AREA ($p<.000$). Bonferroni-corrected post-hoc analyses specified that Frontal electrodes recorded larger TRP values than Central and Posterior electrodes. In general, a monotonic decrease of Alpha TRPs from frontal to posterior regions was observed. The effect was significant for Frontal vs Central areas ($p<.001$) and Frontal vs Posterior areas ($p<.001$). The ANOVA also revealed a double interaction AREA*CONDITION ($p<.000$). Frontal sites show larger TRPs in the common condition than in the uncommon condition; instead, Central and Posterior areas show the opposite pattern, with the Posterior sites displaying the largest difference.
Concerning the between factor BACKGROUND, ANOVA revealed a significant triple interaction BACKGROUND*CONDITION*HEMISPHERE ($p=.030$) (Figure 5). Specifically, design students showed greater inter-hemispheric differences in alpha power. While there is no difference in alpha power between the hemispheres when designers are called to generate common ideas, they show a significantly stronger alpha activity in the right hemisphere during the generation of uncommon ideas. The same is not true for engineer students.

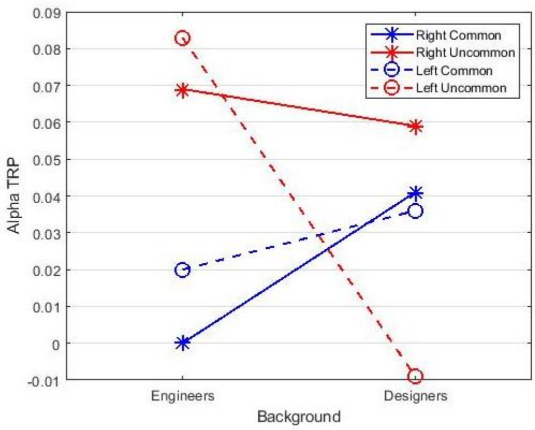


**Figure 5. EEG - ANOVA: CONDITION*HEMISPHERE*BACKGROUND**

## 3.2. Eye tracker

For eye-tracker results, only right-handed participants were taken into account, to control for any possible hemisphere dominance effect. Furthermore, only participants with at least 80% of the eye-tracking quality of data were included in the analyses. A total of N=33 subjects was taken into account for analyses. Four separate ANOVAs, reported in Table 2, were run for (a) Relative Time Spent, (b) Time Spent, (c) Fixation Count and (d) Average Fixation Duration. ANOVAs for Relative Time Spent and Time Spent revealed significant interactions SIDE*CONDITION (both with $p<.001$) indicating that subjects tended to preferentially look leftward during uncommon condition than during common condition. A higher gaze decentralisation is observed when subjects are engaged in divergent thinking processes.

**Table 2. Eye Tracker - ANOVA: Significant effects and interactions for: a) Relative time spent; b) Time Spent (ms); c) Fixation count; d) Average fixation duration**

| Source | Type III Sum of Square | df | Mean Square | F | Sig. | Partial Eta Squared |
|---|---|---|---|---|---|---|
| **a. Measure: Relative Time Spent** | | | | | | |
| SIDE | 569.275 | 1 | 569.275 | 53.723 | .000 | .086 |
| SIDE*Background | 410.799 | 1 | 410.799 | 38.767 | .000 | .063 |
| Error (SIDE) | 6061.194 | 572 | 10.596 | - | - | - |
| CONDITION | 224.017 | 1 | 224.017 | 26.957 | .000 | .045 |
| CONDITION*Background | 151.604 | 1 | 151.604 | 18.243 | .000 | .031 |
| Error (CONDITION) | 4753.396 | 572 | 8.310 | - | - | - |
| SIDE*CONDITION | 179.405 | 1 | 179.405 | 22.271 | .000 | .037 |
| SIDE*CONDITION* Background | 143.735 | 1 | 143.735 | 17.843 | .000 | .030 |
| Error (SIDE*CODNITION) | 4607.880 | 572 | 8.056 | - | - | - |
| **b. Measure: Time Spent (ms)** | | | | | | |
| SIDE | 59434.821 | 1 | 59434.821 | 54.472 | .000 | .087 |
| SIDE*Background | 41960.076 | 1 | 51960.076 | 38.456 | .000 | .063 |
| Error (SIDE) | 623027.134 | 571 | 1091.116 | - | - | - |
| CONDITION | 24390.061 | 1 | 24390.061 | 28.770 | .000 | .048 |
| CONDITION*Background | 15953.911 | 1 | 15953.911 | 18.819 | .000 | .032 |
| Error (CONDITION) | 484074.602 | 571 | 847.766 | - | - | - |
| SIDE*CONDITION | 19651.471 | 1 | 19651.471 | 23.812 | .000 | .040 |
| SIDE*CONDITION* Background | 14695.384 | 1 | 14695.384 | 17.807 | .000 | .030 |
| Error (SIDE*CONDITION) | 471233.411 | 571 | 825.277 | - | - | - |
| **c. Measure: Fixation Count** | | | | | | |
| SIDE | 10283.018 | 1 | 10283.018 | 53.783 | .000 | .086 |
| Error (SIDE) | 109362.504 | 572 | 191.193 | - | - | - |
| CONDITION | 971.433 | 1 | 971.433 | 5.839 | .016 | .010 |
| Error (CONDITION) | 95170.913 | 572 | 95170.913 | - | - | - |
| **d. Measure: Average Fixation Duration** | | | | | | |
| SIDE | 7465.714 | 1 | 7465.714 | 37.719 | .000 | .062 |
| SIDE*Background | 3566.324 | 1 | 3566.324 | 18.018 | .000 | .031 |
| Error (SIDE) | 113215.523 | 572 | 197.929 | - | - | - |

Concerning the between factor BACKGROUND, ANOVAs on the first two measures revealed a significant triple interactions SIDE*CONDITION*BACKGROUND (p<.001 and p<.001), with designers preferentially looking leftward in the uncommon condition (see Figure 6). The ANOVA for Average Fixation Duration also revealed an interaction SIDE*BACKGROUND (p<.001), suggesting that designers stare longer when they look leftward. These results indicate that design students are those that preferentially look leftward during the generation of uncommon ideas.

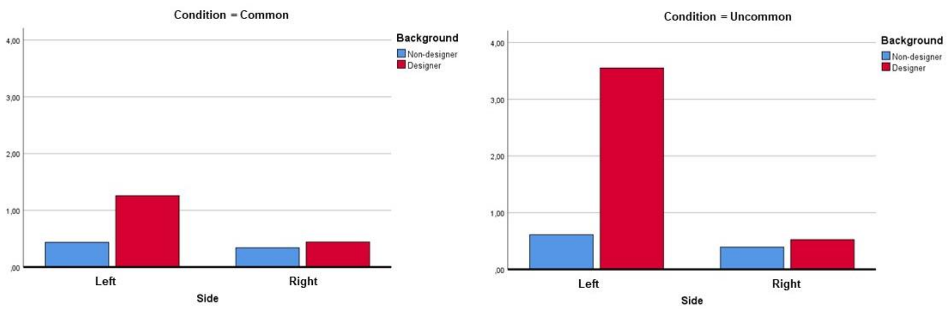


**Figure 6. Eye Tracker - Time Spent: SIDE*CONDITION*BACKGROUND**

## 4. Conclusion

The main goal of the present work was to collect data about the neurocognitive correlates of creative idea generation, with a specific focus on the differences between design students and engineering students. Creativity represents a major topic of interest for designers, as their work requires them to be constantly engaged in the revision of known concepts and the production of new ideas. The evidence presented here is mostly in line with previous literature according to general results on design processes; instead, the elements of novelty are two: first, the investigation of the differences between the designers' and engineers' educational background; second, the feasibility of complementing and validating EEG data through the use of the eye tracking technique.

When called to generate creative ideas, people need to convey as many cognitive resources as possible towards their internal world. This process is accompanied by specific neural cognitive processes, both at an oculomotor level - higher gaze decentration, possibly towards left - and at a cortical level - strengthened right centro-parieto-occipital alpha activity. In fact, these neurophysiological measures cooperate in promoting inhibition of external distracting events, internally directed attention, memory retrieval, mental manipulation of objects and semantic associational processes (Sawyer, 2011; Benedek et al., 2014; Jauk et al., 2012; Benedek, 2018).

The generation of ideas is one of the most characterizing phases of a design process. The cognitive activities during this phase are usually associated with thinking divergently (Eris, 2003) to detach the mind from the concreteness of the scenario and the environment and create new alternatives.

Our results confirm these observations; importantly, they also significantly suggest that such neuro-electrical and oculomotor patterns underpinning the aforementioned cognitive processes tend to be more robust in design students than in engineering students. It is known that design students are trained to use imaginative visual tools, such as sketching. These tools call into play visuospatial abilities necessary to internal representations of objects and scenarios. In design, such tools are explicitly developed and used to facilitate associations of different ideas. As reported above, creative idea generation relies on these semantic associations of ideas which, in turn, are the result of a set of specific cognitive processes working in parallel. Following these interpretations, it can be speculated that design students' educational background could significantly affect their brain in such a way that it is more trained and specialized in working through a characteristic activation which underlies their enhanced ability in generating novel ideas.

Finally, it has been shown that such a paradigm is feasible and strongly informative. First, it allowed the acquisition of different implicit measures through the employment of different devices (EEG and eye-tracker), which are compatible and do not affect each other's data. Second, it made possible to study the conjoint activity of central and peripheral nervous systems (via brain and eye activities, respectively) which yielded complementary pieces of information and consistent results. The compatibility and complementarity of investigation tools have represented a strong point for a reliable neuropsychological methodology. Providing as many data as possible is fundamental both in individuating the subconscious activities involved in overt explicit behaviour and in delineating their crucial interplay underpinning it. This applies to all the fields of investigation which are interested in going deeper in the study of human mind.

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