A study of the effects of a natural virtual environment on creativity during a product design activity

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Abstract

Numerous studies have shown a beneficial effect of exposing people to natural landscapes and plants on their well-being and attentional functioning. The aim of the present study was to evaluate the effects of a natural virtual environment on creativity in a task consisting of sketching ideas of creative solutions to a problem. The participants in this experiment were asked to sketch ideas of innovative workstation for a person in a wheelchair. To do this, they used a virtual reality sketching tool. They performed this task once in a neutral environment (all in the dark), one in a natural virtual envirnment (forest) and once in a non-natural environment (office). The results revealed that people tend to be more creative in this task when they are immersed in a natural environment than when they are in a neutral environment without any vegetation.

1. Introduction

1.1. Ideation and co-creation methods

In the context of product design, ideation is the generation of ideas for possible solutions to the defined problem or needs (Thoring & Muller, 2011). Brainstorming is a method of collective ideation based on the creativity of the participants and generally used with a group of 8 to 10 people. The aim of brainstorming is to collectively come up with a limited number of creative ideas on a given topic. In a brainstorming session, participants are invited to express ideas on a given subject, initially focusing on quantity rather than quality. Brainstorming is traditionally practised in groups, because the ideas of other participants are supposed to inspire each other to generate other ideas by association. However, this way of practising brainstorming suffers from several shortcomings that have been well identified by research. Participants tend to give less original and fewer ideas when they are in a group than when they perform the divergence stage alone (Furnham & Yazdanpanahi, 1995). When they are in a group, they can inhibit ideas when they think they will not be understood by everyone (Stroebe, Nijstad & Rietzschel, 2010). The idea selection stage is also subject to social influence biases related to the collective nature of brainstorming (Fleury *et al.*, 2020b).

In order to neutralise these different defects of brainstorming, several variants have been designed. For example, brainwriting is a creativity method close to brainstorming, but which has the particularity of being practiced entirely in writing. There is a variant of this exercise called "C-Sketch" for "Collaborative Sketching" (Shah, Vargas-Hernandez, Summers & Kulkarni, 2001). The “brainsketching” method consists of asking participants to make three individual sketches of ideas, each one responding to the problem posed. After a few minutes, the papers are handed over by each participant to the person on their right. They then have time to add changes or new ideas. The process is repeated until each paper has passed through all the hands. Brainsketching leads to an average improvement in the quality and quantity of the ideas compared to brainstorming (Choo *et al.*, 2014). However, brainsketching does not particularly improve ideas in terms of variety or originality, in some circumstances it can even decrease these aspects compared to brainstorming carried out individually (Choo *et al.*, 2014). Bodystorming is another kind of brainstorming designed for physically experiencing a situation and deriving ideas to be developed (Schleicher, Jones & Kachur, 2010). The aim of bodystorming is to physically test a situation. Bodystorming can generate unexpected ideas, facilitate empathy and identify pain points or help consideration of alternatives to existing solutions. Bodystorming can also be carried out using digital tools (Boletsis, Karahasanovic & Fjuk, 2017).

Many other variations have been evaluated to improve the performance of ideation workshops. For example, Bornet and Brangier (2016) evaluated the effects of using personas on the outputs of co-design workshops. The authors showed that a team with personas generated more relevant ideas than a similar team without personas. Each variant of brainstorming has a specific name to designate it, brainwriting, brainsketching, bodystorming, because each one refers to different advantages and constraints. The term "immersive-storming" describes the practice of carrying out a collective ideation activity in virtual reality. The use of virtual reality facilitates standing upright and encourages movement, which are beneficial to creativity (Oppezzo & Schwartz, 2014). Moreover, immersive-storming makes it possible to sketch and increase the participants' creative performance by, for example, mobilising the effects linked to avatars (Guegan *et al*., 2016), but also by working on the environment since it is known that it can influence creativity (*e.g.* Bonnardel, 2000; Fleury *et al.*, 2020a).

1.2. Sketching for ideation

For a designer, sketching ideas refers to what Dorta (2004) calls reflection-in-action. This means that the designer externalises mental images, represents and represents again, producing new discoveries with each iteration that will lead to new ideas. The designer needs external representations that are rather imprecise, but focused on important concepts, in order to interact with his own mental representations. The process therefore consists of an alternation of actions and assessments. The designer's actions may produce unexpected results, with *back-talks* likely to suggest concepts. The tools conducive to spontaneity, *i.e.* natural gesture and letting go, are the most likely to generate back-talks and will then tend to stimulate reflection, reflective conversation, and thus improve the ideation (Schön, 1983). An external representation constructed in a design process is considered as a cognitive design artefact (Visser, 2006) in the sense that this artefact contains knowledge, or at least information that aims to be re-mobilised by the designer or his partners. When the designer does not have the experience to mentally visualise and solve design problems, or when the problem is too complex, these cognitive artefacts are essential to the ideation process.

Goel (1995) describes the design process as an evolution of different types of representations. For each stage, a particular type of representation is used for specific tasks. During the ideation stage, a first type of representation consisting of freehand sketches or physical models is mobilized to externalize and visualize the design intentions or to communicate them to others. These first representations are what Goldschmidt (1992) calls idea-sketches. Later in the process, presentation sketches appear, in the form of digital 3D models, drawings or images, to better communicate asynchronously with colleagues and clients about proposals. At the end of the process the representations composed of detailed technical drawings appear as well as the prototyping models to communicate the exact and definitive information to build the product. During these three successive stages, the representations are likely to be mobilised during synchronous and asynchronous collaborations with other designers or customers. For example, team ideation requires cognitive artefacts adapted to different visualisation capacities, and these artefacts must also be intuitively manipulable.

Sketching allows the designer to transform ideas into concepts (Ullman, Wood & Craig, 1990), to make these concepts communicable, and then to specify technical details (Bertoline, 1999). Sketching also enables designers to change their level of abstraction, to extend their short-term memory to facilitate problem solving (Ullman, 2003) and to improve their exploratory processes which are essential to understanding (Cross, 1999).

To be effective, the tools used to produce sketches must be quick to use, enabling easy correction and being appropriate to making large numbers of sketches (Buxton, 2007). To be conducive to creativity, the sketch should keep some ambiguity by having a rather low level of visual fidelity (Tseng & Ball, 2011). This low visual fidelity makes it possible to avoid superfluous or purely aesthetic details that can be distracting. Indeed, technical details are not useful at the beginning of the process and will even tend to hinder the ideation activity (Rodger, Green & McGown, 2000).

1.3. Differents tools for sketching

Robertson and Radcliffe (2009) have identified risks associated with using Computer Aided Design (CAD) software too early in the design process. This tends to circumscribe thinking and to create early fixation. It is generally accepted and widely demonstrated that sketching by hand, with or without digital media, is more conducive to the discovery of new concepts than working with a keyboard and mouse (see for example Jackson and Keefe, 2016). Mille, Christmann, Fleury and Richir (2020) have conducted a study on both the creativity and communicability of ideas (their capacity to be understood by partners) associated with different sketching tools. In their study, the participants were asked to imagine improvements to be made to an umbrella so that it would also be useful when it is not raining. They were asked to imagine and sketch as many ideas as they could within 15 minutes. They did this using each of the following four tools: paper/pencil, Time2Sketch[1], Google Blocks and SolidWork. The results indicate that participants generate on average more ideas when they use paper/pencil or Time2Sketch than when they use Google Blocks or SolidWork. In other words, they generate more ideas when the tool allows them to make freehand sketches in a way that allows natural gestures. Moreover, Time2Sketch surpasses the other 3 conditions in terms of user experience, probably because it combines the stimulating side of virtual reality with freehand use.

When you draw a 3D object on paper, tablet or with a mouse, you are in fact making important mental transformations because the correspondence between the gesture and the shape of the object is not direct. In virtual reality, one can draw directly with the gesture corresponding to the shape of the object. It is generally considered that in order to be creative, the materials used must be simple and uncluttered to avoid distracting the user (Kosmadoudi *et al.,* 2013).

Lee, Yang and Sun (2019) explored the differences in designers' cognitions and creativity related to the use of a 2D or immersive virtual reality design tool. The experience was focused on the sketching activity, *i.e.* the ideation phase. Ten fashion designers participated. Half of them used Photoshop CS6 with a digital pen, while the other half used an immersive 3D drawing tool (Google Tilt Brush). The objective of the participants was to draw a woman's dress in 20 seconds and then in 30 seconds. For this task, the performance was superior with Tilt Brush in terms of creativity. In particular, the authors explain that changing points of view in virtual reality leads participants to evaluate their initial idea and change their mind. Conversely, the 2D drawing tool leads designers to iterate to develop their initial idea, rather than changing their mind in a divergent thinking way.

As mentioned above, the sketches made in the ideation phase are usually made on paper, or in the worst case on CAD software with a keyboard and mouse. Both of these uses have been experimentally compared with a virtual reality equivalent for tasks consisting of imagining new products. In the study by Yang *et al.* (2018), participants were asked to represent a wearable technological object with the properties of a smartphone and which is not a connected watch. In one condition, they had to perform this ideation task in an immersive 3D sketching environment, while in the other condition, they had to make their sketches on paper. The results indicate that the participants were more creative with virtual reality than with paper. According to the authors, the virtual reality tool tends to induce a state of flow for the participants, which is beneficial to creativity. In the study by Feeman *et al.* (2018), participants were asked to design a chair, either in virtual reality or with computer CAD software with a keyboard and mouse. By observing the participants' productions, the authors note that on the computer, the modelled chairs were simplistic. Many of them look like the most minimalist possible representation of a chair, i.e. 4 legs, a straight backrest. This suggests that the participants, faced with unsatisfactory use of the tool, considered the task completed as soon as their production resembled a chair. The models made by the group of participants using virtual reality were more original in form, and also more complex. It seems that with the immersive tool, the participants were more involved in the task, and even when their production resembled a chair, continued working to add extra elements. Virtual reality sketches are clearly a superior alternative to paper/pencil and CAD software. Adopting an immersive sketching solution is therefore a simple way to increase the speed and quality of the innovation process.

Thus, virtual reality tools are identified for creative sketches as superior to paper (Yang *et al.*, 2018), touchscreen tablets (Obeid, 2019), graphics tablets (Lee *et al*., 2019) and CAD software that can be used with a keyboard and mouse (Feeman *et al.,* 2018). Even within virtual reality tools, freehand sketching software appears superior for creativity compared to a volume creation tool (Mille *et al.,* 2020).

Overall, the tools that allow freehand sketching are the most conducive to creativity (Mille *et al.,* 2020), and are therefore suitable in the very early stages of design. This concerns paper/pencil and some tablet and virtual reality

[1] Virtual reality sketching tool

software. Digital tools (tablets, virtual reality) have the added advantage of allowing simple archiving and easy sharing within geographically distributed teams. Finally, immersive sketching requires less mental transformation than drawing on a 2D surface such as a touch pad or graphic tablet (Lee *et al*., 2019), and also allows for spatial explorations which facilitate creation (Yang *et al.*, 2018).

1.4. Environmental influences on creativity

Concerning the effects of the environment on creativity, a distinction should be made between stimuli which could be relevant for the task, such as photos that could be the base of a focus group, and irrelevant stimuli, not related to the task, such as a car driving by or people talking loudly in the corridor, which can also have an impact on creativity. It has long been known, for example, that music with lyrics or even just people talking tend to interfere with the understanding of a cognitive task if it has a verbal component (Martin, Wogalter & Forlano, 1988). Cognitive ergonomists know that in order to capture someone's attention, it is sufficient to make noise (Escera *et al*., 2003) or to create movement in the peripheral visual field (Johnston *et al*., 1990).

However, these external elements are not necessarily detrimental, they can even be beneficial. In some cases, external stimuli can help to trigger new thinking mechanisms for proposing new ideas (Jett & George, 2003). A rich environment can also increase the quality of the ideas generated (Goldschmidt & Smolkov, 2006). Conversely, some studies show detrimental effects of external stimuli on creativity (*e.g.* Mochi & Madjar, 2018), leading some authors to recommend a streamlined and easy-to-understand environment to increase creative performance (Kosmadoudi *et al.*, 2013) because external stimuli would be likely to interfere with the performance of creative tasks (Kasof, 1997).

The concept of attention restoration based on the presence of natural elements was developed by Kaplan (1995). It suggests that mental fatigue could be reduced by looking at natural elements for a few tens of seconds. According to the attention restoration theory, exposure to natural environments mobilises cognitive functions that are inexpensive in terms of mental effort, thus allowing the recovery of attentional capacities.

According to Kaplan, in order to have attention restoration properties, the natural environment must have the following four characteristics:

- The individual must feel immersed in the environment, so it is not a simple image, but an environment that surrounds him or her.
- This should not be his or her usual environment. It allows him to let go of his daily worries.
- "soft fascinating", which corresponds to an environment that is both eye-catching without being tiring to look at.
- Exposure to this environment must be voluntary and correspond to the person's current preferences and goals.

The soft fascinating quality appears to be the key element, while the other three characteristics only reduce or increase the relaxing effect.

In a study by Lee *et al* (2015), 150 participants were asked to perform a simple task of pressing keys according to numbers appearing on the screen. After 5 minutes, participants took a 40-second break before repeating the same exercise. During these 40 seconds, an image of a building roof appears on the screen. For 75 participants, it was a grey building roof, without vegetation, while for the other 75 participants, the roof was covered with a green meadow with flowers. The authors noted a greater fall in concentration with the grey roof than with the green roof. Thus, according to Lee *et al* (2015), this suggests that in work situations, it is possible to engage in "green micro-breaks" by looking at the vegetation through the window, taking a walk outside, or even to a lesser extent through a screensaver. In contrast, Hicks, Smith, Ralph and Smilek (2020) fail to significantly improve performance on an attentional task using natural landscape image viewing. It should be noted that the conditions implemented in this study do not meet Kaplan's (1995) first criterion that exposure to nature should be immersive.

Many studies have shown that being in a natural environment, or even just looking at natural elements, improves cognitive functioning, including attention and memory (*e.g.* Berto, Baroni, Zainaghi & Bettalla, 2010; Raanaas *et al*., 2011), in addition to reducing perceived or physiological stress (*e.g*. Tyrväinen *et al.*, 2014; Valtchanov & Ellard, 2010). For example, offices with a view of natural elements are known to improve job satisfaction and well-being, reduce stress and bad moods, and also reduce the number of sick days compared to offices without natural elements (*e.g.* Bringslimark, Hartig & Patil, 2007; Kweon *et al.,* 2008). Even hospitals with a view of natural landscapes induce better recovery, less stress and lower pain perception (*e.g*. Beukeboom *et al*., 2012; Lechtzin *et al.*, 2010).

Regarding performance on creative tasks of different kinds, the results clearly point in the same direction. On creative problem-solving tasks, hikers perform better after 4 days in the wilderness (Atchley, Strayer & Atchley, 2012). Performance on convergent creative tasks (remote association test) also tends to be higher for participants who have taken a 6-day canoe trip (Ferraro III, 2015). When students walk around a campus, they perform better on a task of divergent creativity (finding as many alternative uses for a given object as possible) than when they are inside a building (Oppezzo & Schwarz, 2014), but no significant difference appears for convergent creativity. In the study by Shibata and Suzuki (2004), female students were better on a creativity task when sitting in a room with an indoor plant than when sitting in the same room with magazines. Moreover, even managers in industry, if they have to judge from photos of offices, believe that those with plants and windows are more conducive to creativity (Ceylon, Dul & Aytac, 2008).

Plambech and Van Den Bosch (2015) interviewed 70 creative professionals of different ages, genders and professions about their relationship to nature and how they feel it stimulates their creativity. The results of this study indicate that, overall, they believe that nature increases their creativity. It tends to make them more curious and flexible in their thinking. Nature also helps to regain the attentional skills needed to analyse and develop ideas. It plays a role in the first two phases of the creative process: preparation and incubation. This effect also works with sounds such as wind or bird songs (Alawad, 2012).

Mattila *et al* (2020) compared the attention restoration obtained during a break in a forest with a similar break in a simulated forest in virtual reality. The results indicate that immersion in the virtual forest provides similar results to immersion in the real forest in terms of attention restoration.

1.5. Objectives and hypotheses

Freehand sketching is more conducive to creativity than tools that make the result of the gesture more indirect (Jackson & Keefe, 2016). Virtual reality has been identified as being more effective than other media in fostering creativity because it provides contextualisation of the problem, facilitates spatial inspection and promotes engagement in the task (Mille *et al*., 2020; Feeman *et al*., 2018; Yang *et al.*, 2018; Obeid, 2019; Lee *et al*., 2019).

Moreover, many studies have shown the attention restoration effect linked to the phenomenon of soft fascinating which tends to increase performance in intellectual tasks in the presence of natural landscapes or plants in the environment. Natural environments seem to increase the creativity of individuals (Shibata & Suzuki, 2004), and a virtual forest environment is capable of producing an attention-restoration effect comparable to a real forest (Mattila *et al.*, 2020). Based on these elements, we hypothesise that a virtual forest environment can lead to better performance in a creative task involving sketching, compared to the same task in virtual reality in a neutral environment. To verify this hypothesis, two types of control conditions are possible: a black environment without elements present or an environment that allows to project oneself in the solution of the problem, with 3D elements, but without natural elements. The applied objective of the study is therefore to identify whether it is possible to make the participants more creative in the early stages of an innovation project by using specific virtual reality environments.

2. Method

2.1. Participants

The participants in this study were 14 engineering school students specialized in the design of wooden furniture. They were all male, the youngest was 20 years old and the oldest 24 years old with an average age of 21.5 (SD=1.016). None of them were used to using virtual reality tools to make sketches.

2.2. Procedure

After signing a consent form, participants started by taking the virtual reality sketching tool in hand through a half-hour exercise during which they had to draw a logo representing themselves. During this hands-on exercise, they were accompanied by the experimenter who gave indications and made sure that every functionalities was well mastered by the participants. When they felt comfortable with this tool, participants were presented with a problem to which they would have to respond by sketching ideas. The problem was to imagine and sketch an adapted workspace for a future colleague in a wheelchair in an open space. Each participant spent three times 45 minutes on this exercise, in three different virtual environments (see figure 1): neutral environment (all in the dark), suitable environment (realistic open space with some desk) and natural environment (with trees and a warterfall).

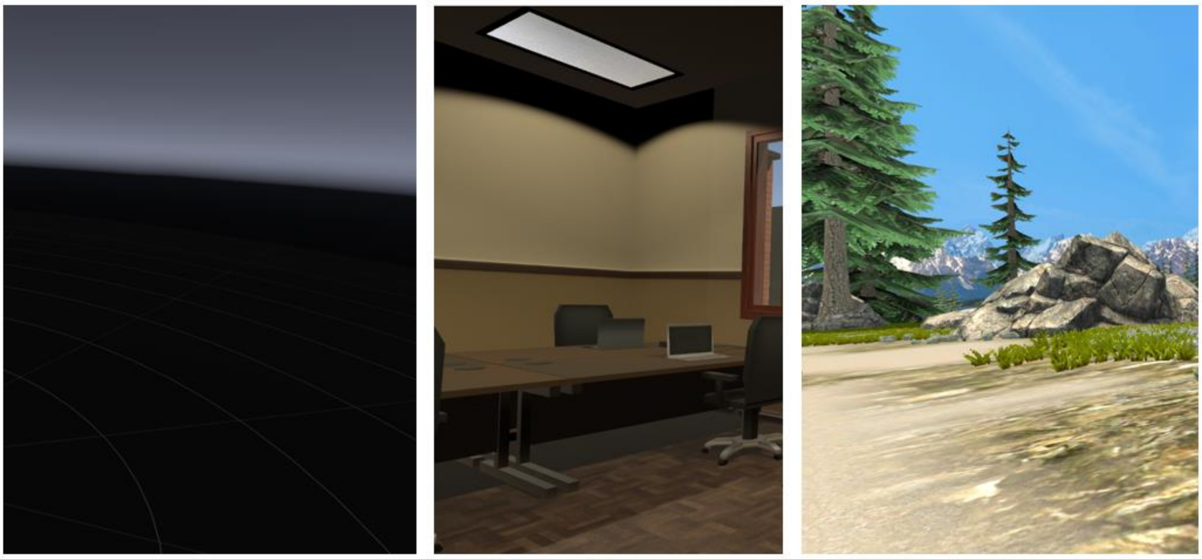

Figure 1. The 3 environments used for the experiment: neutral environment (left), suitable environment (center) and natural environment (right).

The order of these three conditions was balanced for participants. During the experiment, the participants could move freely in the space, stand on the floor or on the ground, or they could take a chair if they wanted to "put themselves in a situation" to test their virtual workspace while sitting (see figure 2).

Figure 2. Examples of participants situations during the experiment

2.3. Material

The immersive sketching software used in the experiment was Time2Sketch, an application that allows the users to draw freehand lines with a pad, change colour, brush size, erase lines, cancel the last action, resize the sketch, teleport into the scene and position an axis of symmetry.

The virtual reality headsets used were Oculus Quest, HTC Vive pro and HTC vive Cosmos. To ensure that differences in hardware did not bias the experiment, the materials were balanced against the experimental conditions.

2.4. Analysis of creativity

All the ideas generated by the participants were analyzed through Cropley and Cropley (2008) criteria. The four criteria were relevance (the product does what it is supposed to, fits within task constraints and reflects conventional facts, principles of techniques), novelty (the product helps to see how it could be transferred to a new setting, and to see new way of using it), elegance (the product in convincing, beautiful and internally consistent) and genesis (ideas go beyond the immediate situation, generalizability).

3. Results

A total of 68 ideas were generated by participants, an average of 1.619 ideas per session per participant, with no significant difference between conditions (p=.971). This represents an average of 27 minutes per idea. Overall, the participants seemed to take their time to work on their sketches. On the whole, participants in all three conditions and without significant difference tended to use all of the software's features. For example, they made an average of 14.745 color changes, 6.712 brush size changes or 7.88 teleports into the scene.

Most of the ideas were furniture with a wheelchair-friendly shape (rounded), some of them with a modular aspect to adjust the height of the tabletop or to rotate it. A few ideas were not about the desk, but about another element of the workstation, such as a « catch-all » bin so that you do not have to walk to it, or a shelf that can be lowered easily. We did not notice a clear difference in the content of ideas depending on the virtual environment. Some examples of concepts are shown in Figure 3.

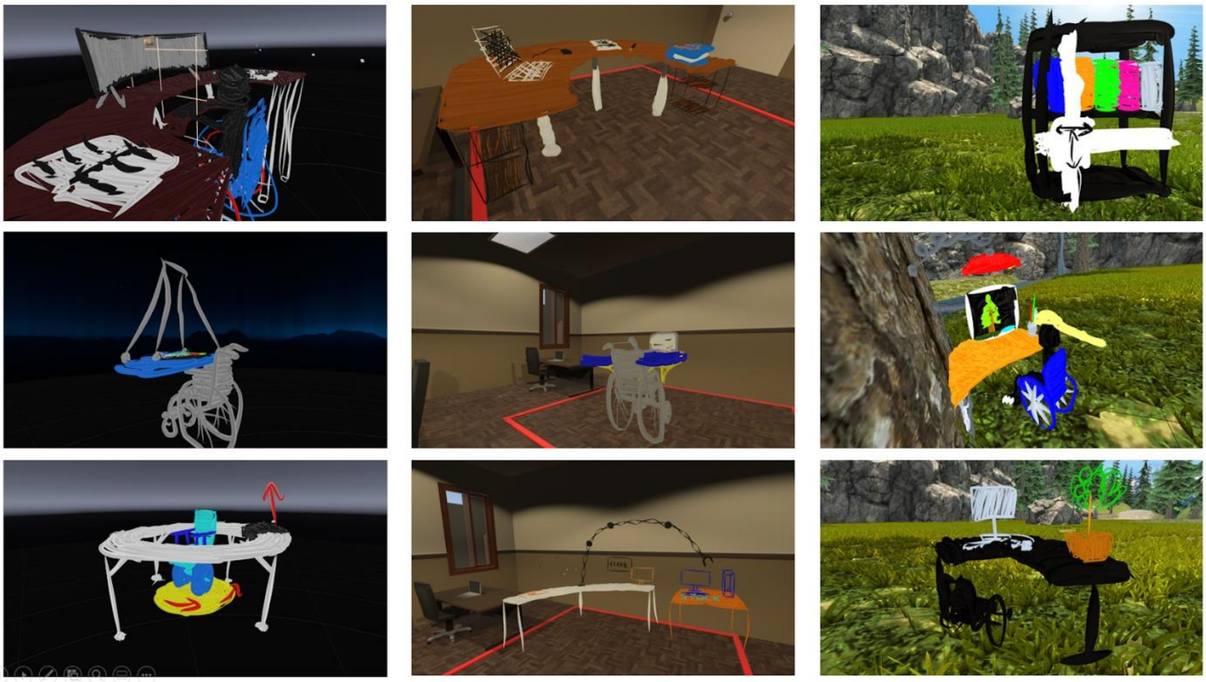

Figure 3. Example of ideas generated by participants in the neutral environment (left), suitable environment (center), and natural environment (right) conditions.

Creativity scores were awarded by two judges using the method of Cropley and Cropley (2008). A Pearson's correlation was calculated to verify that the two evaluations co-vary significantly (r=.348, t(270)=6.100, p<.001). Regarding the distribution of the overall creativity scores obtained by adding the scores on the Cropley and Cropley (2008) criteria, a Levene test was used to verify homoscedasticity (F(3)=1.224, p=.308). An analysis of variances reveals a statistically significant difference between neutral environment (M=6.963, SD=3.736), suitable environment (M=7.773, SD=3.677) and natural environment (M=10.000 SD=3.383, F(2)=3.757, MS=43.460, p=.032). This overall higher score in creativity under the "natural environment" condition is in line with our hypotheses. However, in order to understand the phenomena in more detail, an analysis of the sub-criteria was performed.

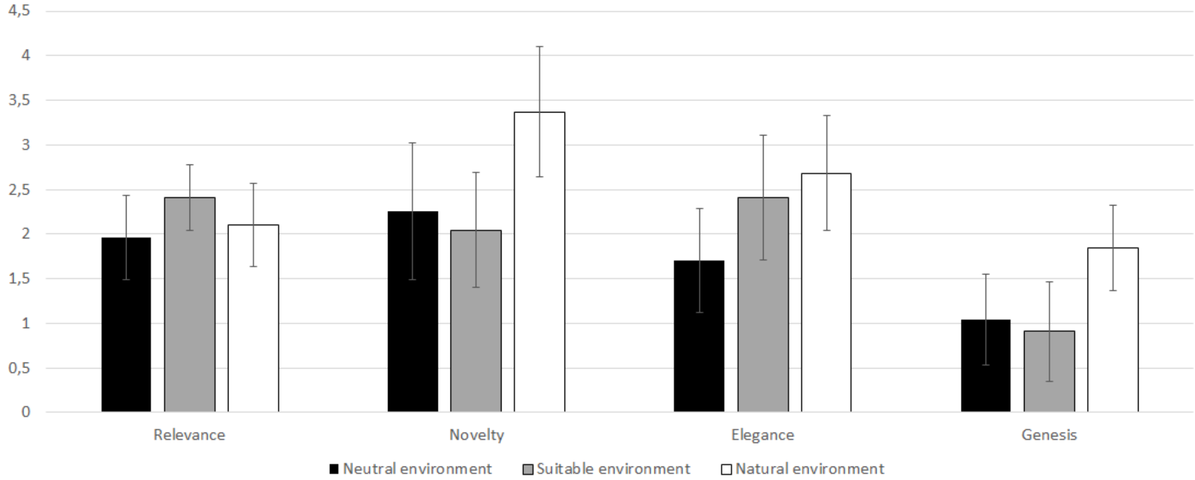

Figure 4. Means and standard deviations of creativity scores on the Cropley and Cropley scale (2008)

The homogeneity of the variances of the creativity scores was verified using Levene tests. These indicate acceptable homoscedasticity for relevance ($F(3)=1.411$, $p=.248$), novelty ($F(3)=.478$, $p=.699$), elegance ($F(3)=.661$, $p=.579$) and genesis ($F(3)=1.622$, $p=.193$). Analyses of variances show no statistically significant difference between the conditions for relevance ($F(2)=1.785$, $MS=1.391$, $p=.181$) and genesis ($F(2)=2.404$, $MS=2.169$, $p=.103$). On the other hand, there is a trend for elegance ($F(2)=2.702$, $MS=2.924$, $p=.079$) and a statistically significant difference for novelty ($F(2)=3.911$, $MS=8.437$, $p=.028$).

4. Discussion and conclusion

The objective of this study was to identify whether for a virtual reality sketching task, immersing participants in a virtual environment representing a natural landscape increases their creativity. The hypothesis was that compared to groups in a neutral and unnatural environment, participants would produce more creative concepts in terms of scores on the Cropley and Cropley (2008) scale. The results are consistent with this hypothesis since the average creativity score is significantly higher in the natural environment condition than in the other two conditions. When the sub-criteria are analyzed one by one, this difference appears significant for novelty. These results are in line with those obtained by Lee *et al.* (2015) and Mattila *et al.* (2020) on the effects of the natural environment on cognitive performance, but also in line with Kaplan's (1995) attention restoration theory. The experimental situation of the present research is consistent with the abovementioned Kaplan's (1995) criteria of being immersed in the natural environment, the unusual nature of the experiment, the soft fascinating environment and the suitability for the participant's objectives. Thus, it can be thought that participants benefited from more effective attention restoration with the natural environment than under other conditions, which gave them more attentional resources for the realization of their sketches.

The main limitations of this study relate to the characteristics of the sample. The participants were relatively few in number and were engineering school students. It is unclear whether the findings would be applicable to populations of professional designers who would likely have a less technical and more needs-based approach. Furthermore, from an application point of view, this study refers to work situations in the upstream phases of the design process, using virtual reality sketching tools, since these tools are identified as the most effective (Yang *et al.*, 2018; Feeman *et al.*, 2018; Obeid, 2019; Lee *et al.*, 2019; Mille *et al.*, 2020). In this case, in the early stages that require the generation of new ideas, it leads to recommend to favour natural virtual environments. Future studies are needed to clarify how these environments can be used. In particular, it is questionable whether allowing users to navigate between several environments, some of which are natural, would not allow them to benefit both from the effect of attention restoration and possibly from the benefits of other environments that may be inspiring. In addition, it will also be necessary to conduct tests with professional designers who are used to sketch to verify that the results are similar with these different profiles.

In addition, another limitation is that we did not measure psychological variables during the experment. For example, it would be useful to measure user experience and mental workload during the experiment to better understand the psychological process underlying the effects of natural environment on creativity.

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