# I am a Genius! Influence of Virtually Embodying Leonardo da Vinci on Creative Performance

Geoffrey Gorisse, Simon Wellenreiter, Sylvain Fleury, Anatole Lécuyer, Simon Richir, and Olivier Christmann

Fig. 1: Leonardo da Vinci's virtual workshop designed for the experiment.

**Abstract**—Virtual reality (VR) provides users with the ability to substitute their physical appearance by embodying virtual characters (avatars) using head-mounted displays and motion-capture technologies. Previous research demonstrated that the sense of embodiment toward an avatar can impact user behavior and cognition. In this paper, we present an experiment designed to investigate whether embodying a well-known creative genius could enhance participants' creative performance. Following a preliminary online survey ($N$ = 157) to select a famous character suited to the purpose of this study, we developed a VR application allowing participants to embody Leonardo da Vinci or a self-avatar. Self-avatars were approximately matched with participants in terms of skin tone and morphology. 40 participants took part in three tasks seamlessly integrated in a virtual workshop. The first task was based on a Guilford's Alternate Uses test (GAU) to assess participants' divergent abilities in terms of fluency and originality. The second task was based on a Remote Associates Test (RAT) to evaluate convergent abilities. Lastly, the third task consisted in designing potential alternative uses of an object displayed in the virtual environment using a 3D sketching tool. Participants embodying Leonardo da Vinci demonstrated significantly higher divergent thinking abilities, with a substantial difference in fluency between the groups. Conversely, participants embodying a self-avatar performed significantly better in the convergent thinking task. Taken together, these results promote the use of our virtual embodiment approach, especially in applications where divergent creativity plays an important role, such as design and innovation.

**Index Terms**—Virtual Reality, Creativity, Avatar, Embodiment, Body Ownership, Proteus Effect

## 1 Introduction

Over the past decade, extensive research on immersive virtual reality has demonstrated that this medium allows users to embody virtual characters (avatars) through multisensory integration [30]. Head-mounted displays and body-tracking technologies enable real-time visuomotor synchronization between users and their virtual representations [34, 57] to induce a phenomenon known as the Body Ownership Illusion [41].

Using such technologies, previous work demonstrated that embodying virtual characters altering one's self-representation and perception in immersive environments could affect both behavior [48, 61] and cognition [3, 33]. These experiments demonstrated that participants embodied as Albert Einstein [3], or collaborating with this scientific figure [33], led to increased cognitive performance. We were inspired by such research to investigate whether this effect would apply to creativity in an embodied paradigm. Creativity is often assessed with regard to both divergent and convergent thinking. According to Cropley [12], divergent thinking involves producing multiple or alternative answers from available information, while convergent thinking is oriented toward deriving the single best answer to a clearly defined question. In this context, we designed a virtual reality experiment aiming at investigating the potential effect of embodying a famous and universally recognized creative genius on participants' creative performance. To this end, we first designed a gamified online survey ($N$ = 157) to select a well-known character who best fitted the role. Leonardo da Vinci emerged as the most creative figure in popular culture among the 15 characters considered. We then developed a virtual reality experiment based on a between subject design ($N$ = 40) allowing to embody Leonardo da Vinci or a self-avatar (matched skin tone and morphology)

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using a first-person perspective and real-time synchronous body tracking [19,20]. We hypothesized that embodying Leonardo da Vinci would have allowed for better creative performance due to psychological and behavioral priming induced by popular stereotypes associated with this creative genius. The experimental protocol included three tasks to be performed in the virtual environment to assess both divergent and convergent thinking from a quantitative and qualitative standpoint.

The following related work section introduces previous research on the sense of embodiment in virtual environments with a special focus on behavioral and cognitive correlates. Research on creativity and its intersection with virtual reality studies will also be explored. Section 3 presents the design of the study and its experimental protocol. Section 4 reports the results which are discussed in section 5. Limits and potential future work are outlined in section 6. Section 7 concludes and summarizes the contributions of this study.

## 2 Related Work

### 2.1 Embodiment and Behavior in Virtual Reality

#### 2.1.1 The Sense of Embodiment

Numerous user studies demonstrated that it was possible to embody virtual characters in immersive environments leading users to the illusion of being located inside, of controlling and owning a different body. The sense of embodiment was defined by Kilteni *et al.* [30] as the sense that emerges when the properties of a virtual body are processed as if they were the properties of one's own biological body, a definition on which virtual reality researchers tend to agree. While recent work contributes to refining the definitions and metrics of the sub-dimensions of the sense of embodiment [26, 46, 49], three factors are commonly considered in experimental research: self-location, agency and ownership.

Self-location refers to the volume of space where the user feels located. As such, having the impression of being located in the virtual body of the avatar favors the emergence of a sense of embodiment. Previous research demonstrated that both a congruent first-person perspective [14, 19, 20] and visuotactile stimulation [16, 37], inducing a proprioceptive drift toward fake or virtual limbs [8, 53], contribute to self-location. While self-location can be manipulated in static conditions, the sense of agency, however, refers to motor control over performed actions [7]. Several factors may impact agency where a correlation between the initial intention, the performed action and both the expected and actual outcomes. Previous work demonstrated that it heavily relies on visuomotor synchronization [11, 26], but it should be noted that synchronous input triggering coherent pre-recorded animations also lead to high illusory agency in virtual reality [34]. In a similar fashion, body ownership, defined as one's self-attribution of a body, can be induced by both visuotactile and visuomotor stimulation [41, 51]. These previous research demonstrated that bottom-up stimulation heavily contributes to the sense of embodiment in immersive virtual environments. Besides multisensory integration, it should be noted that top-down processes, such as self-identification induced by similarity between users and their avatar [21, 36, 59], may also affect body ownership. This consideration was taken into account in the frame of the reported experiment, where the control condition was expected to be closer to participants' physical appearance.

In the scope of this paper, self-location and agency were not assessed as we relied on consistent and theoretically ideal conditions as demonstrated by aforementioned previous work. In each experimental condition, participants were immersed using a first-person perspective and visuomotor synchronization (body-tracking). Although we did not expect significant difference thanks to the predominant effect of multisensory integration, the sense of body ownership was evaluated using psychometric questionnaires to ensure we were comparing homogeneous groups. Body ownership being identified as a driver of behavioral induction [40], having balanced groups with similar ownership levels was a prerequisite to identifying any relevant effect of our experimental conditions (embodied avatar appearance) on creative performance.

#### 2.1.2 Behavioral and Cognitive Correlates

While several investigations focused on identifying the factors that allow for the emergence of a sense of embodiment toward virtual characters [19], others investigated the associated behavioral inductions and cognitive correlates. To date, it is still debated whether these effects originate from psychological concepts, as claimed by the Proteus Effect theory [61], or whether they originate primarily from lower level neurological processes induced by congruent sensorimotor contingencies in immersive virtual reality [54]. While the answer may lie at the crossroads of these underlying concepts, measurable outcomes are observed in virtual environments.

Yee and Bailenson introduced the Proteus Effect theory [61–63] stating that users may conform to expectations and stereotypes associated with the appearance of their avatars (both in 3D and immersive virtual environments). Ratan *et al.* [48] conducted a meta-analysis and concluded that, among the 46 studies considered, the Proteus Effect was a reliable phenomenon with a small to medium effect size. This theory relies on three psychological concepts: self-perception theory [5], deindividuation [27] and behavioral confirmation [56]. The deindividuation process (reduction or loss of self-awareness) is often associated with being part of a group, and behavioral confirmation requires a social context for users to behave in a way that is believed to match others' expectations. As such, these concepts may not apply to the present study. However, the self-perception theory is of particular importance to this experiment and may be a way to explain a potential impact of embodying a well-known creative genius on creative performance. The self-perception theory states that, by observing themselves, people tend to infer their behavior in a way that is consistent with their appearance.

Virtual reality researchers demonstrated the effect of the appearance of embodied characters on user behavior. For instance, embodying a black-skinned avatar led to a reduction in implicit racial bias [2, 47], or an increase in movement patterns during drumming sessions [29]. Morphological changes perceived when embodying a childish body, compared to an adult body reduced in size, resulted in greater overestimation of objects' size and led to faster responses in implicit association tasks when it came to child-like attributes [1]. 3D scanned self-representation induced safer behavior to preserve the integrity of the embodied characters as subjectively reported by participants in a virtual reality gaming context [21]. Increased physical performance was also repeatedly observed when embodying athletic avatars [31, 32, 38], yet it may be conditioned by the level of body ownership experienced toward the virtual body [40]. Another related line of work demonstrated higher-level cognitive effects of embodiment in immersive environments. Osimo *et al.* [45] and Slater *et al.* [52] observed that embodying Sigmund Freud, in the frame of the self-counseling paradigm, resulted in greater improvement in participants' mood by altering their habitual way of thinking. Previous studies also reported improvements in cognitive performance. Banakou *et al.* [3] demonstrated that virtually embodying Albert Einstein increased participants' cognitive processing compared to participants embodying a younger control character of similar age when performing a subsequent (post-exposure) Tower of London (TOL) task [50]. Authors argue that that seeing oneself as a super-intelligent genius may have led to what is described as a higher level of their cognitive abilities. More recently, Kocur *et al.* [33] investigated whether this effect would also occur in a collaborative context. Previous results were not replicated, and embodying Albert Einstein did not result in significant improvements in cognitive performance. However, collaborating with another participant embodying Albert Einstein improved performance and decreased perceived workload during the TOL task in virtual reality.

While an inconsistency was observed in the aforementioned studies, numerous experiments revealed promising results regarding the effect of avatar appearance on behavior [48] and cognition [3]. Building on previous research, we were interested in investigating whether these effects would apply to creative performance when embodying a well-known creative genius.

### 2.2 Creativity

#### 2.2.1 Divergent and Convergent Thinking

According to Guilford's theory [23], two main abilities based on different cognitive processes are believed to contribute to creative thinking, namely divergent production and transformation. Nowadays, these processes are also defined as divergent and convergent thinking [12]:

- **Divergent thinking** relates to the ability of people to solve problems by generating a variety of ideas. It was originally characterized by three sub-abilities, namely fluency (number of generated ideas), flexibility (variety) and elaboration (level of detail) [23]. Divergent thinking involves producing multiple or alternative answers from available information. It requires making unexpected combinations, recognizing links among remote associates, transforming information into unexpected forms [12].

- **Convergent thinking** refers to the ability of deriving a single concept based on previous experiences and knowledge. According to Cropley [12], convergent thinking emphasizes speed, accuracy, logic and focuses on recognizing the familiar, reapplying set techniques, and accumulating information. It is argued that the proposed solution must be recalled from stored information or derived from existing knowledge through conventional and logical search, recognition, and decision-making strategies.

In the frame of this study, it is most important to differentiate divergent and convergent thinking, as what may improve the former may not necessarily be effective for the latter. For instance, previous work demonstrated that posture and physical activity could affect creativity [44]. In this experiment, participants were either seated or walking on a treadmill. They were instructed to perform a divergent thinking task known as the Guilford's Alternate Uses test (GAU) [23], which consisted in generating as many alternative uses for a specific object. To subsequently assess convergent thinking, they completed compound remote associate problems [9] derived from the Remote Associates Test (RAT) [42] and consisting in finding a single word that combines with three different ones. Results revealed that walking on the treadmill improved divergent thinking performance, while a decrease in convergent thinking was observed. Therefore, physical activity stimulated idea generation, but interfered with the Remote Associates Test. By manipulating mental workload, the experiment by De Dreu *et al.* [15] showed that convergent thinking is distraction-sensitive. Recent work also demonstrated that inter-individual differences (education level) could impact creative performance in a rather surprising way [60]. Trained designers performed better on alternate uses tests compared to an untrained control group. While one could expect such an improvement in divergent thinking, results also revealed that the untrained group performed significantly better when it came to convergent thinking on remote associates tests. Authors suggest that focusing on divergent thinking training may inhibit convergent thinking abilities, since they rely on different cognitive processes.

#### 2.2.2 Creativity and Virtual Environments

Virtual reality, as a medium, provides researchers with a versatile and ecologically valid technology. It also allows to test potential levers triggering creative performance improvements that would be difficult, if not impossible, to test in real-world scenarios. Among these levers, both participants' surroundings and physical appearance can be manipulated. In this context, previous research demonstrated that users immersed in a natural environment generated more ideas and concepts in a 3D sketching task compared to participants immersed in a virtual office [18]. In line with recent work on the Attention Restoration Theory [4], authors suggest that the "softly fascinating" natural landscape would have left mental space for reflection, improving their creative performance in return. Building on previously introduced research revealing the potential benefits of walking on creativity [44], another virtual reality experiment demonstrated that divergent thinking could also be improved for seated participants thanks to visual movements perceived in their peripheral vision [17]. Consistently, no significant differences were observed in terms of convergent thinking. As such, these results further demonstrate the difference between divergent and convergent thinking abilities.

Moving on from environment to user representation, we must first step back and introduce existing perspective-taking techniques. In the field of innovation, the "roleplaying" or "hall of fame" techniques consist in imagining how a well-known relevant character would solve a problem [43]. Although the mental process may differ, a parallel can be drawn between the behavioral and cognitive correlates associated with the Proteus Effect theory [61] and these perspective-taking techniques aiming at solving a problem from a different angle. Guegan *et al.* [22] and Busine *et al.* [10] conducted two experiments using a virtual environment displayed on desktop computers. Participants controlled either an inventor or a so-called neutral avatar in brainstorming group sessions. Results revealed higher divergent thinking performance (fluency and originality) for the groups controlling inventors. Following the Proteus Effect theory, authors argue that the observed outcomes would be the consequences of a priming effect induced by controlling a virtual character perceived as more creative. It should be noted that convergent thinking was not considered in these experiments. In light of the aforementioned research, and to the best of our knowledge, there was still much work to be done to assess whether embodying a well-known creative character could impact creative performance. Promising results were observed when embodying Albert Einstein in virtual reality on cognitive performance [3] and a couple of research investigated the effect of controlling a virtual inventor using a desktop computer on divergent thinking in the frame of the Proteus Effect theory [10, 22]. Building on these previous studies, we were interested in investigating whether these effects would occur on both divergent and convergent thinking assessed through three tasks in the frame of an embodied paradigm with a well-known character considered a creative genius.

## 3 Materials and Methods

### 3.1 Creative Genius Selection

First, we developed a gamified online survey to select an easily recognizable famous character to be used for this experiment. We selected 15 characters, both male and female, among a pool of famous inventors, designers, artists, singers, filmmakers, etc. Some were real historical or contemporary figures, while others were fictional characters. Participants were challenged to recognize these famous characters. In addition, they had to answer a couple of questions we used to determine which character best fitted the content of the virtual reality experiment to be developed. Participants were asked to answer whether they recognized these characters in a binary way (yes/no). If they did, they had to type in their names. Misspelled names were taken into account in the final recognition percentage. Then, they had to write a couple of words describing the characters and to rate on 7-point Likert scales how creative they considered them to be. Finally, they selected one or more categories related to the creativity domains these characters could have been associated with (see supplementary materials for additional information).

157 participants (58 females, 100 males and 5 persons who chose not to reveal their gender) aged from 19 to 76 ($M$ = 32.42, $SD$ = 11.23) took part in this online survey. Among the 15 characters, we first shortlisted the 8 ones having a recognition rate above 90%. We then removed 2 ambivalent characters who were either recognized as actors or fictional characters depending on the participants. Based on qualitative data, we selected 3 characters out of 5 associated with creativity domains mainly related to the experiment (design and innovation): Steve Jobs, Elon Musk and Leonardo da Vinci. Finally, we compared the creativity scores where Leonardo da Vinci ($M$ = 6.56) scored more than one point and a half over Steve Jobs ($M$ = 4.98) and Elon Musk ($M$ = 4.75). Given the significant gap in perceived creativity and the fact that Leonardo da Vinci was not considered as a divisive character, we decided to select this famous creative genius. Looking at open-ended questions, Leonardo da Vinci was associated with relevant keywords such as "engineering, science, art, painting, visionary, inventor" making him a wise choice for the purpose of this study.

(a) Lucan Portrait (b) Virtual model

Fig. 2: Lucan Portrait (a) and virtual model (b) of Leonardo da Vinci.

(a) (b) (c)

Fig. 3: Avatars of the control condition to be chosen by participants with three potential skin tones (light (a), medium (b) and dark (c)) and morphologies (small (a), medium (b) and large (c)).

### 3.2 Experimental Conditions

We used two conditions for this experiment following a between subject design. Half of the participants embodied Leonardo da Vinci (Figure 2), whereas the control group embodied a self-avatar (Figure 3):

- **Leonardo da Vinci:** We designed the virtual model of Leonardo da Vinci (Figures 1, 2b) based on the Lucan Portrait (Figure 2a), a painting of Leonardo da Vinci from the late 15th or early 16th century exhibited at the *Museo delle Antiche Genti di Lucania*. This portrait was named after the Italian region previously known as *Lucania*, now called *Basilicata*, where it was found in 2008 as part of a private collection[1]. The virtual character was designed using Character Creator 3.

- **Self-avatar:** Participants in the control group were told to select a virtual character that best matched their body in terms of skin tone and morphology. 9 characters were designed for the self-avatar condition (3 skin tones $*$ 3 morphologies) using Character Creator 3 (Figure 3). We wanted to ensure that participants inferred that this was a virtual body that matched their own being to avoid inducing any stereotyped behavior associated with the appearance of the embodied virtual character.

[1]https://en.wikipedia.org/wiki/Lucan_portrait_of_Leonardo_da_Vinci Accessed February 14, 2023

### 3.3 Virtual Environment

The application was developed using the 2019.4 LTS version of the Unity engine. The virtual environment designed for the experiment (Figure 1) was inspired by a modern reconstitution of Leonardo da Vinci's workshop. We paid particular attention to model an environment that would fit with every virtual character. If the avatar of Leonardo da Vinci appeared coherent with the virtual workshop, the casually dressed self-avatars were also plausible in such an environment. The selected furniture may also be found in contemporary workshops avoiding potential anachronisms. The virtual space consists of a simple desk to support the terrestrial globe required for the divergent thinking task (Figure 4a), a black board to display the instructions and the triplets of the convergent thinking task (Figure 4b), an umbrella used during the sketching task (Figure 4c), and a mirror allowing the participants to observe their virtual body during the embodiment phase and throughout the experiment. It should be noted that the virtual workspace fitted the experiment room allowing the participants to move around the virtual environment using natural navigation.

### 3.4 Apparatus

A HTC Vive Pro Eye and its wireless adapter was used to immerse the participants in the virtual environment at a refresh rate of 90 Hz with a resolution of 1440 x 1600 per eye (2880 x 1600 pixels combined) and a horizontal field of view of 110°. We combined the headset and the controllers with three Vive Trackers to capture participants' body movements ensuring a visuomotor synchronization with the avatars using inverse kinematics algorithms. The computer running the application was composed of an Intel i9 10900 @ 2.8 GHz / 5.2 GHz processor, 64 GB of RAM and a Nvidia GeForce RTX 3090 graphics card with 24 GB of VRAM.

### 3.5 Participants

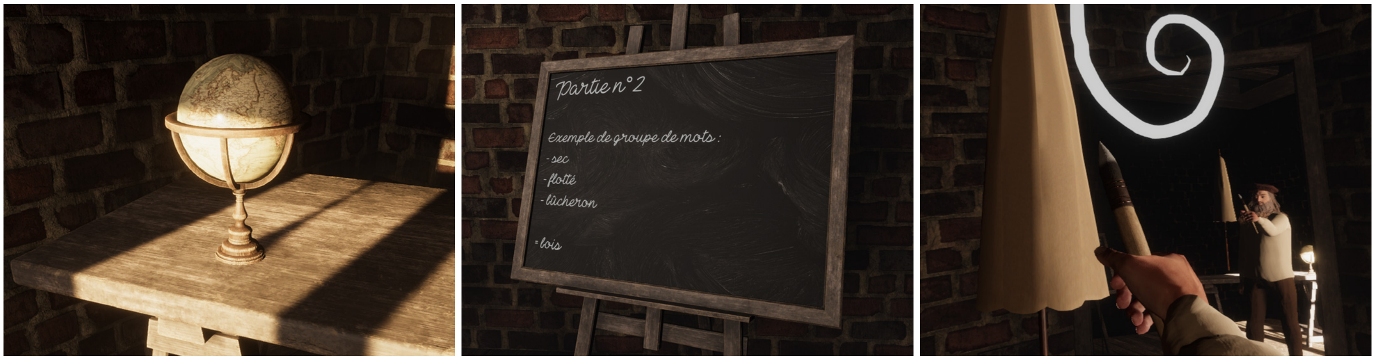
We hired 40 male participants aged from 20 to 33 ($M$ = 22.30, $SD$ = 2.94) to ensure a gender matching with Leonardo da Vinci. Previous studies demonstrated that it was possible to embody non-gender-matched, non-anthropomorphic or unrealistic avatars under synchronous visuomotor/visuotactile stimulation (see Section 2.1). However, to avoid any potential interference, we decided to keep this variable under control for this first experiment where a creative genius was to be embodied and to keep this potential investigation as a future work (see Section 6). Every participant had a normal or corrected-to-normal vision. They all had prior experience with immersive virtual reality to avoid any novelty effect causing potential distractions while performing the tasks. Participants self-reported a high familiarity with information technology ($M$ = 5.15, $SD$ = 1.05) and fairly high programming ($M$ = 4.50, $SD$ = 1.54) and gaming experience ($M$ = 4.45, $SD$ = 2.24) on 7-point Likert scales. No significant demographic differences were observed between the groups.

### 3.6 Procedure and Measures

#### 3.6.1 Pre-experiment Procedure

Participants were invited to sign an information sheet and a consent form to take part in the experiment. They completed a demographic questionnaire and they self-reported their estimated knowledge about information technology, as well as their gaming, virtual reality and programming experience. To complete the pre-experiment procedure, they filled out the Kaufman Domains of Creativity Scale (K-DOCS) [28] to assess creativity categorized in five domains labeled as follows:

1. Self/Everyday (11 items)
2. Scholarly (11 items)
3. Performance (10 items)
4. Mechanical/Scientific (9 items)
5. Artistic (9 items)




(a) Terrestrial globe (b) Black board (c) Paintbrush

Fig. 4: Terrestrial globe (a) used as a reference during the Divergent Thinking Task (DTT), black board (b) displaying the triplets during the Convergent Thinking Task (CTT) and paintbrush (c) used to draw the concepts during the 3D Sketching Task (ST).

In the frame of our study, we were particularly interested in the Mechanical/scientific domain (*e.g.* "Taking apart machines and figuring out how they work", "Constructing something out of metal, stone, or similar material") and the Artistic domain (*e.g.* "Sketching a person or object", "Making a sculpture or piece of pottery"), those being closely related to the tasks of the proposed experiment. Following the pre-experiment questionnaire completion, the experimenter gave general information regarding the sequence and the three tasks to be carried out in the same order for all participants. They were then geared up with the virtual reality devices, including the headset, the controllers and the trackers. The headset was adjusted by the experimenter and they received the required instruction to adjust the interpupillary distance.

#### 3.6.2 Experiment Procedure and Tasks

Depending on their group, participants were told that they were about to embody Leonardo da Vinci or a virtual character. They entered the virtual environment and the calibration phase was initiated. Participants in the self-avatar group were told that they had to choose a character that fitted the best their morphological properties between three body shapes and three skin tones (Figure 3). They had to stand still for a second and the calibration algorithm adjusted the scale of the virtual body and the body tracking was activated. The embodiment phase lasted 90 seconds. Participants had to perform a couple of movements in front of the virtual mirror before beginning the three tasks of the experiment (Figure 4):

- **Divergent Thinking Task (DTT):** The DTT was based on a Guilford's Alternate Uses test [23], consisting in coming up with as many ideas as possible in a limited time. Participants were first given the necessary instructions introducing the objective of the task. Then, they had two minutes to imagine and verbally express alternative and unusual uses of the terrestrial globe located on the desk in the virtual environment (Figure 4a). While doing so, participants were able to interact and manipulate the 3D model of the globe. All their answers were recorded by the experimenter. Following the method introduced by Benedek *et al.* [6], participants were asked to select three ideas they considered the most creative among their concepts as part of the post-experiment procedure (after VR exposure).

- **Convergent Thinking Task (CTT):** The CTT was based on a Remote Associates Test (RAT) [42]. Participants had to find a word that could be associated with three other words (a triplet) written on the black board. An example of triplet association was presented on the blackboard (Figure 4b) along with audio instructions. They then performed the task by verbally expressing their answers for each of the 15 triplets (see supplementary materials). It should be noted that the triplets were classified according to three levels of difficulty (five triplets per level) and were presented in the same order to all participants.

- **Sketching Task (ST):** Similar to the DTT, the ST consisted in using a paintbrush to draw 3D sketches around an umbrella to design potential alternative uses (Figure 4c). Participants went through a training phase to master the interactions: umbrella manipulation (position and open/closed state), draw, undo and creation of a new sketch. Then, they were given 15 minutes to sketch out as many ideas as possible while ensuring the clarity of the proposed concepts. After the task, they were asked to review their sketches while immersed in the virtual environment (during VR exposure) and to select their three most creative ideas.

#### 3.6.3 Post-experiment Procedure

After the immersion session in the virtual environment, participants had to complete a post-experiment questionnaire to assess their sense of body ownership using the Ownership dimension of the Virtual Embodiment Questionnaire (VEQ) [49] (Table 1). They then had to select three ideas produced during the divergent thinking task they considered the most creative. Finally, they were thanked for their participation and the experimenter was in charge of saving their virtual sketches produced during the final task in anticipation of the analysis. A few days after the experiment, a dedicated jury evaluated the originality of the ideas proposed during the DTT using a top-scoring method [6] based on Hass *et al.*'s scale [24]. This jury was also subsequently in charge of evaluating the concepts proposed during the sketching task based on Cropley & Cropley's criterion of creativity [13]. A custom 3D viewer was developed for this purpose. Each of the three previously selected sketches was assessed with respect to four criterion:

1. Relevance and effectiveness (1 subdimension, 3 items)
2. Generation of novelty (3 subdimensions, 11 items)
3. Elegance (2 subdimensions, 5 items)
4. Genesis (1 subdimension, 4 items).

Table 1: Body ownership questionnaire adapted from the Virtual Embodiment Questionnaire (VEQ) [49]. Items range from 1 to 7.

| **Body ownership** (Scoring: ([O1] + [O2] + [O3]) / 3) |
|---|
| [O1] - It felt like the virtual body was my body. |
| [O2] - It felt like the virtual body parts were my body parts. |
| [O3] - It felt like the virtual body belonged to me. |

A Consensual Assessment Technique (CAT) [13, 25] was used to conduct the evaluation. Three members of the lab who did not take part in the experiment were selected. Instructions were given to the three solicited judges to ensure they understood the items the same way using training sketches. All the sketches selected by the participants during the experiment were then rated in a random order by each member of the jury blind to the experimental conditions. Items were rated in a binary way and a Fleiss's kappa was calculated to select the items to be considered in the subsequent group comparisons.

### 3.7 Hypotheses

Based on our literature review and considering the proposed experimental protocol, we expected participants to perform better on divergent thinking tasks (including 3D sketching) when embodying a creative genius. Leonardo da Vinci was a famous painter, but also a renowned engineer. One might argue that embodying this character would also potentially increase convergent abilities as a result of the Proteus Effect. However, previous research revealed that convergent thinking is sensitive to distraction and embodying Leonardo da Vinci could also interfere with participants' ability to focus on the convergent task. To sum up, we expected potential differences in convergent thinking, without being able to predict whether embodying such a creative genius would have led to an increase or a decrease in convergent abilities. We formulated three hypotheses accordingly:

- H1: Embodying Leonardo da Vinci in an immersive virtual environment increases fluency in both divergent thinking (H1.1) and 3D sketching tasks (H1.2).
- H2: Embodying Leonardo da Vinci in an immersive virtual environment increases the originality of the proposed ideas in both divergent thinking (H2.1) and 3D sketching tasks (H2.2).
- H3: Embodying Leonardo da Vinci in an immersive virtual environment influences performance in convergent thinking tasks.

## 4 Results

### 4.1 Pre-experiment Creativity Assessment

We first ensured that both groups of participants shared similar initial creativity levels and that the results were not likely to be affected by unbalanced groups. We considered the five dimensions of the Kaufman Domains of Creativity Scale (K-DOCS) [28] (see section 3.6), with a special focus on the *Mechanical/Scientific Creativity* ($\alpha$ .70) and the *Artistic Creativity* ($\alpha$ .88) domains. Data were tested for normality and equality of variances. The Shapiro–Wilk's test revealed that all variables were normally distributed ($p > .05$) and the Levene's test for equality of variances revealed no significant difference across the groups. Therefore, independent-samples t-tests were used to compare creativity levels between the Leonardo da Vinci and the self-avatar groups. Results indicated no significant differences between the groups for each of the five creativity domains considered. Descriptive statistics indicated that average scores were above 2.50 out of 5 for every subdomain of creativity (Table 3). We concluded that both groups could be considered homogeneous and that it was safe to assume that the results on both divergent and convergent abilities were likely to be solely impacted by the embodied avatar (Leonardo versus Self-avatar) during the three tasks carried out in the virtual environment.

### 4.2 Body Ownership

Following the pre-experiment creativity assessment, we had to ensure that the average body ownership level was balanced to observe a potential impact of the embodied avatar on creative performance. In other words, we considered that a fairly high average level of body ownership toward the avatar at the group level was necessary for a potential effect on creativity to arise. Cronbach's alphas for the ownership questionnaire was .84. Ownership data were tested for normality and equality of variances. The Shapiro–Wilk test revealed that the scores were normally distributed for the Leonardo group ($p$ = .164), but not for the self-avatar group ($p < .025$). However, the Levene's test for equality of variances revealed no significant difference across the groups. Considering that independent-samples t-tests are quite robust to deviation from normality, they were used to compare ownership levels between the Leonardo and the self-avatar groups. Results revealed no significant differences between the groups. Descriptive statistics indicated that average body ownership scores were above 4.40 out of 7 for both groups (Figure 5). This result further confirms that both groups seemed homogeneous and that prerequisites were met to measure a potential effect of the embodied avatar on participants' creativity in both the divergent and the convergent thinking tasks, as well as in the 3D Sketching Task.

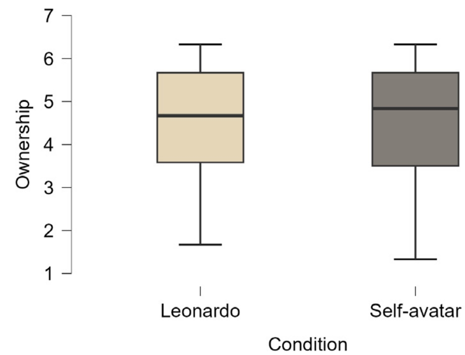


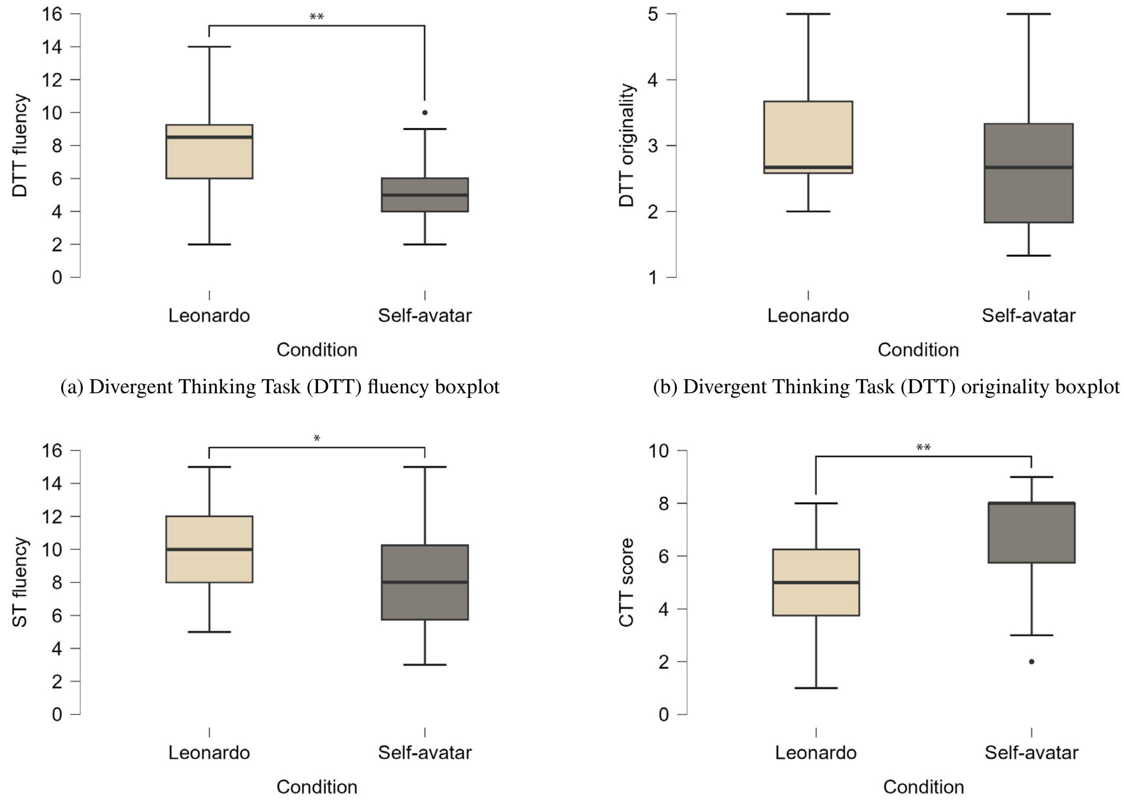

Fig. 5: Ownership boxplot

### 4.3 Task 1: Divergent Thinking

The Shapiro–Wilk test indicated that fluency scores were normally distributed for each group ($p > .05$), whereas the normality assumption for the originality scores was not met for the Leonardo group. However, the Levene's test for equality of variances revealed no significant difference across the groups for both fluency and originality. Since most of the data were normally distributed and assumptions of equal variances (homoscedasticity) were met, we used independent-samples t-tests to compare divergent thinking scores (fluency and originality) between the Leonardo and the self-avatar groups (Table 2, Figures 6a, 6b). The independent-samples t-test used to compare fluency scores between the Leonardo and the self-avatar groups revealed a significant difference. The Leonardo group generated significantly more ideas ($M$ = 7.80, $SD$ = 2.93) than the self-avatar group ($M$ = 5.30, $SD$ = 2.13; $t$ (38) = 3.09, $p$ = .004, two tailed). The effect size was large (Cohen's d = .976, 95% $CI$: .313 to 1.627, mean difference = 2.50). The second independent-samples t-test used to compare originality scores (Figure 6b) revealed no significant difference between the Leonardo group ($M$ = 3.12, $SD$ = 0.85) and the self-avatar group ($M$ = 2.53, $SD$ = 1.03; $t$ (38) = 1.96, $p$ = .058, two tailed). Although the originality of the ideas was not significantly different, participants embodying Leonardo da Vinci demonstrated greater divergent abilities, since they generated significantly more ideas (fluency) than the self-avatar group.

Table 2: Divergent Thinking Task (DTT) and Sketching Task (ST) fluency descriptive statistics.

| Task | DTT Fluency | | ST Fluency | |
|---|---|---|---|---|
| Condition | Leonardo | Self-avatar | Leonardo | Self-avatar |
| Mean | 7.80 | 5.30 | 10.65 | 8.25 |
| Std. Dev. | 2.93 | 2.13 | 3.91 | 3.29 |
| Minimum | 2 | 2 | 5 | 3 |
| Maximum | 14 | 10 | 21 | 15 |




(a) Divergent Thinking Task (DTT) fluency boxplot

(b) Divergent Thinking Task (DTT) originality boxplot

(c) Sketching Task (ST) fluency boxplot

(d) Convergent Thinking Task (CTT) scores boxplot

Fig. 6: Creativity boxplots

### 4.4 Task 2: Convergent Thinking

The Shapiro–Wilk test indicated that the convergence scores were normally distributed for both groups ($p > .05$) and the Levene's test for equality of variances revealed no significant difference across the groups. We used an independent-samples t-test to compare convergence scores between the Leonardo and the self-avatar groups (Figure 6d). There was a significant difference in the scores for Leonardo ($M$ = 4.90, $SD$ = 1.94) and self-avatar ($M$ = 6.75, $SD$ = 2.10; $t$ (38) = 3.09, $p$ = .006, two tailed). The effect size was large (Cohen's d = -.914, 95% *CI*: -1.562 to -.256, mean difference = 1.85). Participants embodying a self-avatar demonstrated greater convergent abilities. In other words, embodying Leonardo da Vinci led to a decrease in participants' ability to focus and find a relevant association between the triplets proposed in the convergent thinking task.

### 4.5 Task 3: 3D Sketching

The Shapiro–Wilk test indicated that the fluency scores were normally distributed for both groups ($p > .05$) and the Levene's test for equality of variances revealed no significant difference across the groups. Therefore, we used an independent-samples t-test to compare fluency scores between the Leonardo and the self-avatar groups (Figure 6c, Table 2). There was a significant difference in the scores for Leonardo ($M$ = 10.65, $SD$ = 3.91) and self-avatar ($M$ = 8.25, $SD$ = 3.29; $t$ (38) = 2.10, $p$ = .042, two tailed). The effect size was medium (Cohen's d = .664, 95% *CI*: .023 to 1.297, mean difference = 2.40). The results of the subsequent assessment by the jury on the three concepts selected by the participants did not reveal significant differences with respect to Cropley & Cropley's criterion of creativity. In line with the results of the divergent thinking task, participants demonstrated greater fluency when embodying Leonardo da Vinci considering that they sketched more concepts. However, a similar level of relevance, novelty, elegance and genesis was observed compared to the self-avatar group.

### 4.6 Correlations

The relationship between Mechanical/Scientific and Artistic creativity domains (as assessed prior to the experiment by the K-DOCS), previous VR experience, fluency and originality and convergence scores was explored using Pearson's product-moment correlations (Table 4). A strong correlation was observed between fluency and originality in the divergent thinking task, $r$ = .57, $n$ = 40, $p < .001$, suggesting that the most productive participants were likely to generate more original ideas. A moderate correlation was observed between fluency in the divergent thinking task and fluency in the sketching task, $r$ = .34, $n$ = 40, $p$ = .035. Participants having a greater number of ideas during the divergent thinking task were more likely to come up with more concepts in the final 3D sketching task. Additionally, there was a moderate correlation between previous virtual reality experience and fluency in the sketching task, $r$ = .39, $n$ = 40, $p$ = .013, with greater virtual reality experience associated with greater fluency when sketching in 3D space.

## 5 Discussion

This experiment was designed to investigate whether embodying a well-known creative genius in an immersive virtual environment would influence creative performance. Using a body tracking system and a head-mounted display, 40 participants were either embodied as Leonardo da Vinci, a famous character selected thanks to a prior online survey ($n$ = 157), or as a self-avatar similar to their physical appearance in terms of skin tone and morphology. Statistical analyzes revealed significant differences with large effect sizes for both divergent and convergent thinking. What is most interesting about this experiment is that we observed results in favor of Leonardo da Vinci on divergent abilities and results in favor of the self-avatar control condition on convergent abilities. These results are discussed in this section in light of prior experimental studies, with an emphasis on results that contribute to extending previous findings and knowledge.

Table 3: Creativity domains descriptive statistics (K-DOCS [28]) for the Leonardo da Vinci and self-avatar (Self-A) experimental conditions.

| K-DOCS | Self/Everyday | | Scholarly | | Performance | | Mechanical/Scientific | | Artistic | |
|---|---|---|---|---|---|---|---|---|---|---|
| Condition | Leonardo | Self-A | Leonardo | Self-A | Leonardo | Self-A | Leonardo | Self-A | Leonardo | Self-A |
| Mean | 3.49 | 3.28 | 3.44 | 3.09 | 2.60 | 2.51 | 3.43 | 3.41 | 3.34 | 3.07 |
| Std. Dev. | 0.46 | 0.41 | 0.45 | 0.63 | 0.89 | 0.78 | 0.55 | 0.73 | 0.87 | 0.86 |
| Minimum | 2.73 | 2.73 | 2.55 | 1.64 | 1.10 | 1.40 | 2.56 | 1.78 | 1.44 | 1.56 |
| Maximum | 4.18 | 4.27 | 4.09 | 4.36 | 4.20 | 4.10 | 4.44 | 4.89 | 4.67 | 4.56 |

Table 4: Pearson product-moment correlations between the Mechanical/Scientific (Mech/Sci) and Artistic creativity domains (K-DOCS [28]), previous Virtual Reality experience (VR), fluency and originality in the Divergent Thinking Task (DTT), scores in the Convergent Thinking Task (CTT) and fluency in the Sketching Task (ST).

| Variable | Mech/Sci | Artistic | VR | DTT Fluency | DTT originality | CTT Score | ST Fluency |
|---|---|---|---|---|---|---|---|
| 1. Mech/Sci | - | | | | | | |
| 2. Artistic | −0.082 | - | | | | | |
| 3. VR | −0.011 | 0.181 | - | | | | |
| 4. DTT fluency | 0.102 | 0.122 | 0.027 | - | | | |
| 5. DTT originality | −0.036 | 0.191 | −0.098 | 0.571*** | - | | |
| 6. CTT score | 0.110 | −0.149 | 0.048 | −0.190 | −0.196 | - | |
| 7. ST fluency | 0.127 | 0.088 | 0.390* | 0.335* | 0.005 | −0.107 | - |

* $p < .05$, ** $p < .01$, *** $p < .001$

First of all, it should be noted that both groups appeared to be rather homogeneous regarding participants' creativity as assessed before the experiment by the Kaufman Domains of Creativity Scale (K-DOCS) [28]. We observed similar average scores without significant differences (Table 3) when comparing self-reported creative abilities in the five domains of the scale, and especially in the Mechanical/Scientific and the artistic ones that were considered the most relevant in the frame of this experiment. Additionally, a fairly high and balanced level of body ownership between both groups was expected for a potential effect induced by the embodied avatar to arise. Results indicated that average body ownership scores were above 4.40 out of 7 for each condition with no significant differences between the groups (Figure 5). Bottom-up stimulation induced by multisensory integration, and especially visuomotor synchrony [34, 51], must have led to a similar sense of body ownership between participants embodying Leonardo da Vinci and those embodying a self-avatar. Given the homogeneous creativity assessments and body ownership levels, prerequisites were met to measure a potential effect of the embodied avatars on participants' divergent and convergent abilities.

### 5.1 Divergent Thinking

Divergent thinking, or the ability to generate a variety of original ideas [12], was assessed through a divergent thinking task and a 3D sketching Task (ST). The DTT was based on a Guilford's Alternate Uses test [23] consisting in suggesting unusual uses of a terrestrial globe (Figure 4a). The ST consisted in sketching alternative uses of an umbrella using a virtual paintbrush (Figure 4c). Fluency (number of generated ideas) and originality were assessed in both tasks. In line with our first hypothesis (H1), results revealed significant differences in favor of Leonardo da Vinci in terms of fluency (Figures 6a, 6c, Table 2). The difference between the experimental conditions was substantial in the divergent thinking task, while a medium effect size was observed in the 3D Sketching Task. Fluency in the DTT was positively correlated with fluency in the ST (Table 4). Interestingly, analyses revealed a larger effect size in the DTT, a purely intellectual task, compared to the ST. One might have assumed that embodying a creative genius known for his painting skills would have led to a similar improvement in sketching performance. Nevertheless, it should be considered that fluency in the 3D Sketching Task was correlated with previous VR experience, suggesting a gap between the emergence of an idea and the ability to sketch the concept using the provided tools. In addition, there was insufficient evidence to support our second hypothesis (H2), as results revealed no significant differences in terms of originality.

Our findings in terms of fluency are consistent with the work of Guegan *et al.* [22] where controlling a virtual inventor in a 3D environment increased the number of ideas generated by participants taking part in brainstorming sessions. However, we did not observed significant differences in terms of originality. While the Proteus Effect theory applies to both 3D applications and immersive virtual reality [63], our study differs in several aspects from this prior investigation. Setting aside the underlying mechanisms allowing to embody Leonardo da Vinci in VR [30] and the identification process with an avatar controlled through traditional inputs in a third-person perspective 3D application, fundamental differences in the protocols must be highlighted. On the one hand, Guegan *et al.* [22] used a binary assessment of uniqueness (number of unique ideas [58]) as a measure of originality, while we used a 5-point rating scale [24] on a subset of three ideas selected by participants as suggested by Benedek *et al.* [6]. On the other hand, Guegan *et al.* [22] invited participants to take part in brainstorming sessions with three persons collaborating simultaneously. Participants may have been able to further refine their concepts. Moreover, as stated by the behavioral confirmation paradigm [56], performing a creative task as an inventor with two "peers" may have prompted participants to come up with original ideas, as others might have expected from such a character. An additional major difference with this previous investigation [22] is that convergent abilities were not considered.

### 5.2 Convergent Thinking

Convergent thinking, or the ability to derive a single concept based on previous experiences and knowledge [12], was evaluated through a task based on a Remote Associates Test (RAT) [42]. Participants had to find a word associating three other words written on a blackboard in the virtual environment (Figure 4b). 15 triplets were used for this experiment. Significantly higher convergence scores were observed for participants embodying a self-avatar (Figures 6d). According to the large effect size, the difference between the groups was substantial. This result is in line with our third hypothesis (H3) stating that we expected a difference, but without being able to predict which condition would have improved convergence scores. As mentioned in the experimental protocol, Leonardo da Vinci could have been perceived by the participants as a famous painter, but also as a renowned engineer. Therefore, it would have made sense to observe results in favor of the group embodying such a figure in terms of convergent abilities. However, considering that converging toward a single answer requires speed, accuracy, logic, focus and so on [12], any distractions could also reduce performance. For instance, previous work demonstrated that physical activity [9] or mental workload [15] interfere with convergent thinking. In this context, it could have been expected that embodying an avatar that is very different from the real self would have decreased convergent abilities.

It turned out that in the frame of this experiment, participants embodying a self-avatar approximately matched in terms of skin tone and morphology significantly outperformed participants embodying Leonardo da Vinci in the convergent thinking task. To the best of our knowledge, this is the first experiment investigating the way avatars could impact convergent thinking. However, it is not possible to disentangle whether embodying Leonardo da Vinci decreased convergent abilities, or whether embodying a self-avatar in a virtual reality context led to improved performance. On the one hand, one might argue that actively trying to think like Leonardo da Vinci could have increased mental workload, decreasing in return the ability to focus on the association test. On the other hand, embodying an avatar closer to the real-self in an immersive environment reducing distractions occurring in the real world could have improved convergent abilities. In other words, in the self-avatar condition, virtual reality would have provided a context that enhanced participants' nominal convergent abilities by limiting interference. Additionally, greater identification [39] with the self-avatar could have improved participants' motivation [35]. In any case, embodying a well-known creative genius should be avoided when it comes to convergent thinking. Further investigations should be considered to shed light on this newly identified potential of VR technologies to improve creative performance.

## 6 Limitations and Future Work

While we observed several significant results in terms of both divergent and convergent thinking, potential future work can be extrapolated from the present study considering some of its limitations to explore new avenues for enhancing creativity using immersive technologies. First of all, future investigations should focus on inter-individual differences to account for user diversity. In the frame of this experiment aiming at investigating the effect of embodiment on creative performance, we focused on male participants in order to ensure a gender matching with Leonardo da Vinci. This well-known creative genius was pre-selected among men and women through an online survey. While mutlisensory integration [55] may have allowed female participants to embody Leonardo da Vinci, in line with previous studies [3, 33], we decided to keep a matching to conduct this experiment. Future research should focus on comparing different virtual characters, including famous creative women, to consider potential gender effects.

This study also lacks a comparison between the proposed embodied paradigm and traditional perspective-taking techniques [43]. It might be possible that for some participants, roleplaying as Leonardo da Vinci could lead to improved creative abilities without being embodied in an immersive virtual environment thanks to multisensory integration. In this experiment, participants were not told to think like Leonardo da Vinci, they were simply embodied in the virtual character. Such a study would allow for the comparison of these methods to investigate whether results converge despite being based on different mechanisms.

Another potential line of research could focus on replicating this experiment in a collaborative context. Such an investigation would provide additional results on the impact of embodying versus collaborating with Leonardo da Vinci on creative performance. As demonstrated by previous studies, embodying Albert Einstein led to inconsistent outcomes in terms of cognitive performance. Banakou *et al.* [3] observed post-exposure cognitive improvements when performing the Tower of London task (ToL). Kocur *et al.* [33] were not able to replicate this result when performing the ToL task in virtual reality when embodying the same character. However, they observed significant improvements in terms of cognitive performance and perceived task load when observing another user embodying Einstein. If our results demonstrate that embodiment can influence creative performance, in light of this previous experiment, one might also hypothesize that similar effects could occur when collaborating with Leonardo da Vinci. Considering that we observed greater divergent abilities when embodying Leonardo da Vinci and greater convergent abilities when embodying a self-avatar, it would be most interesting to test different avatar combinations in a collaborative context.

## 7 Conclusion

The reported experiment aimed at investigating the effect of embodying a well-known creative genius on creative performance. Immersed in a virtual workshop, participants embodied either Leonardo da Vinci or a self-avatar that matched their skin tone and morphology. Through three tasks, we assessed participants' divergent and convergent abilities. Results demonstrated that participants performed better in the divergent thinking task when embodying Leonardo da Vinci. Significantly greater fluency was measured thanks to the Guilford's Alternate Uses test. The large effect size also suggests that embodying Leonardo da Vinci induced a substantial quantitative difference in terms of idea generation with the group embodying a self-avatar. In line with the results of the divergent thinking task, participants demonstrated significantly greater fluency in the 3D sketching task. A correlation in fluency was also observed between both tasks. While divergent thinking was improved for participants embodying Leonardo da Vinci, the opposite effect was observed in terms of convergent thinking. The analysis revealed significant performance improvements in the Remote Associates Test in favor of the group embodying a self-avatar. Participants demonstrated greater convergent abilities when their avatar was closer to their physical appearance. This similarity may have prevented additional distractions that would have interfered with their concentration on a cognitively demanding task. Here again, the large effect size indicated a substantial difference in terms of convergent abilities between the experimental conditions. Taken together, these results on divergent and convergent thinking contribute to identifying factors that enhance creative performance using the potential of virtual reality technologies. From a broader perspective, this experiment further demonstrates the way avatars can shape user behavior and cognition in immersive virtual environments.

## Contributions

G.G., S.F., A.L. and O.C. came up with the concept of the study. S.R. obtained funding. G.G., S.W., S.F., A.L. and O.C. designed the details of the experiment. G.G. and S.W. developed the VR application. G.G., S.F. and O.C. analyzed the data. G.G., S.F. wrote the paper and all authors contributed to the proofreading and the final version.

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