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RESEARCH ARTICLE

The experience of virtual reality: are individual differences in mental imagery associated with sense of presence?

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Abstract
The concept of "presence" describes the quality of subjective experience in immersive virtual reality (IVR). Presence refers to a specific state of consciousness: we behave and feel as if we actually were in the virtual world even though we know there is nothing there. In their handbook of Virtual Reality, Burdea and Coiffet (Virtual reality technology, Wiley, New York, 2003) suggested that the experience of presence in IVR would emerge from the combination of three Is: *Immersion* or capacity to isolate from the external world, *Interaction* or capacity to naturally exploring the virtual environment, and *Imagination* or individual aptitudes with mental imagery. So far, several studies have investigated the technological and psychological factors affecting the degree of immersion and interaction. However, no study has explored the relationship between perceived presence and mental imagery. Here we aim at filling this gap through a correlational study comparing self-reports about sense of presence and mental imagery abilities. After experiencing two IVR scenarios (an art gallery and a living room), 142 male and female users were administered with questionnaires assessing the degree of presence (Igroup Presence Questionnaire), the degree of vividness (Vividness of Visual Imagery Questionnaire) and control (Test of Visual Imagery Control) of subjective mental images. Results showed a clear positive correlation between presence and vividness: the higher the vividness of mental images the stronger the reported sense of presence felt in IVR scenarios. Instead, the capacity to control mental imagery showed a weaker association with presence. We may conclude that individual differences in the degree of perceived presence and mental imagery ability are associated.

Keywords Immersive virtual reality · Presence · Mental imagery ability · Vividness of mental imagery · Control of mental imagery · Individual differences

Introduction

Nowadays the technology of immersive virtual reality (IVR) is spreading more and more in many areas of daily life. After wearing the head-mounted display (HMD) connected to the computer that generates the virtual world, people have the impression of being in the simulated environment and interacting with the virtual agents within it (e.g. Bailenson et al. 2003; Iachini et al. 2016; Mihelj et al. 2014; Ruggiero et al. 2017; Slater 2009). The concept of "presence" has been proposed to describe the quality of this subjective experience in IVR. Presence refers to the "feeling of being" in the virtual world as if it were the real world (Slater and Wilbur 1997; Slater 2009; Steuer 1992). Therefore, the sense of presence is rooted on a paradoxical state of consciousness: we behave and feel as if we actually were in the virtual world even though we know there is nothing there (Slater 2009; Sanchez-Vives and Slater 2005). The real world that we naturally experience is always mediated by the sensory-motor system. The result of our perception of the physical world is the phenomenal world, i.e. a construction of the senses of which we are aware. IVR affords a phenomenal world by means of input and output devices that allow "naturalistic" perception and action (Loomis 1992). Therefore, even though participants know that they are not "there" and

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that the simulated events are not occurring, they are fooled by the sensorimotor contingencies afforded by the virtual reality system and by the credibility of the scenario (Slater 2009; Sanchez-Vives and Slater 2005).

Several factors may induce a high sense of presence, such as the quality of the 3D graphics, the efficacy of technological devices, the availability of multisensory simulations, the possibility of interaction with the virtual environment, the involvement of virtual agents (Slater and Usoh 1993; Steuer 1992; Witmer and Singer 1998). Understanding how technological and psychological factors may influence sense of presence is important for both theoretical (e.g. the nature of consciousness) and applied purposes. The high quality of virtual immersion and interaction makes the virtual experience fully realistic in various applied fields, from flight simulators to biomedical and rehabilitation settings, and so forth (Iachini et al. 2016; Riva et al. 2005; Sanchez-Vives and Slater 2005; for a review see Mihelj et al. 2014).

In their handbook of Virtual Reality, Burdea and Coiffet (2003) suggested that from a psychological point of view the experience of presence in IVR would emerge from the combination of three interwoven features, the *three Is*: *Immersion* or capacity to isolate from the external world, *Interaction* or capacity to naturally exploring the virtual environment, and *Imagination* or individual aptitudes with mental imagery. So far, several studies have investigated the technological and psychological factors affecting the degree of immersion and interaction. However, no study has explored the relationship between perceived presence and mental imagery ability.

Mental imagery can be defined as the capacity to voluntarily generate multisensory mental images on the basis of information stored in long-term memory, without the corresponding external stimuli (Barsalou 1999; Holt 1964; Iachini 2011; Kosslyn 1994). In the literature, two characteristics of mental imagery, vividness and capacity of control, have been typically associated with individual differences in imaginative ability. Vividness refers to the capacity of evoking clear, colourful, and well-defined mental images such that the more mental images are vivid, the more they are similar to actual percepts (Ahsen 1990; Kihlstrom et al. 1991; Marks 1989; see also Antonietti and Crespi 1995). This is the reason why vividness is considered a key factor for unrevealing individual differences in mental imagery ability. On the other hand, the capacity of control is also important because assesses the ability of transforming mental images. For instance, the way in which we are able to control our images reflects the capacity to retain, actively manipulate, and intentionally transform mental images (Gordon 1949; Kihlstrom et al. 1991; see also Antonietti and Crespi 1995). Through the individual differences approach, a general positive association between the two aspects has been found (for a meta-analysis see LeBoutillier and Marks 2003). Moreover, introspective vividness assessments have shown a positive correlation with various visual perception tasks (e.g. Wallace 1990; see also Blajenkova et al. 2006).

Even though it has been suggested that mental imagery may affect the quality of experience in IVR and specifically the degree of perceived presence (Burdea and Coiffet 2003), so far no research has explored the relationship between individual differences in mental imagery and sense of presence. In the present study, we aim at filling this gap through a correlational study comparing self-reports about sense of presence and mental imagery. More specifically, we seek to understand if the sense of presence experienced in IVR is associated with vividness and capacity of control of mental images.

Finally, we also wanted to assess whether gender differences affected subjective sense of presence and mental imagery ability. Few studies have shown that women report higher sense of presence in virtual worlds than men (for a review Felnhofer et al. 2014). Gender differences have been also documented in mental imagery. Typically, men perform better than women on spatial tasks and women report higher vividness ratings than men (see Ashton and White 1980; Blajenkova et al. 2006; Harshman and Paivio 1987; Isaac and Marks 1994; Linn and Petersen 1985; McKelvie 1995; Richardson 1995; Ruggiero et al. 2008; Voyer et al. 1995). However, it is still unclear if individual differences in mental imagery are associated with sense of presence in virtual experiences.

After experiencing immersive virtual scenarios, a large sample of male and female participants was administered questionnaires assessing the degree of presence with the whole virtual reality experience, the vividness and capacity of control of mental images. We hypothesized that the ability to generate vivid and controlled visual images should be positively associated with the capacity to feel present in a virtual world. Moreover, a gender difference favouring women should emerge in sense of presence and vividness imagery ratings.

Method

Participants

One hundred and forty-two right-handed participants (65 women and 77 men), whose age ranged from 15 to 69 years ($M = 30.4$ years, SD = 15.1), with 8–24 years of formal education ($M = 15.1$, SD = 3.6) were recruited. The recruitment took place during a scientific public event in Naples (Italy), a Science Festival called “Futuro Remoto”, that aimed at disseminating the new technologies and the latest scientific advances among the general public. People who visited the virtual technology pavilion and wanted to experience IVR scenarios were asked if they were willing to fill in short questionnaires at the end of the experience. If they agreed, they were asked to sign the informed written consent before taking part in the study. Thus, participants were members of the general public who volunteered to participate in the study. Participants were asked if they had any vision problems. All participants had normal or correct to normal vision as self-reported. Nobody claimed discomfort or vertigo during the IVR experience and reported being aware of the purpose of the experiment during the post-experimental interview. Recruitment and testing were in conformity with the local Ethics Committee requirements and the Declaration of Helsinki (World Medical Association, 2013).

Setting and apparatus

The study took place in a quiet and limited area of the virtual technology pavilion during the Science Festival in Naples. The equipment included a computer workstation, the Vizard Virtual Reality Software Toolkit 4.10 (WorldViz, LLC, USA) with the Oculus Rift DK2 head-mounted display (HMD), having two OLED displays for stereoscopic depth (resolution 960 × 1080 per eye; nominal field of view 100°; refresh rate 60–75 Hz). The IVR system allowed continuous tracking and recording of participant's position by means of a marker placed on the HMD; visual information was updated in real time. Participants explored the virtual environment through a joystick in their hand.

Graphic modelling of the presented scenarios was carried out starting from a 3D modelling software, Autodesk 3Ds Max. In this software, all the 3D elements of the environments were modelled and/or inserted with respective materials and shades. Then, in order to have a more realistic visual effect, a baking texture procedure was carried out with by means of Mental Ray engine (Berlin, Germany). Finally, the entire models were implemented into the WorldViz Vizard 4.10. This platform allows to connect exploration devices and to add the audio stimuli. Audio stimuli were recorded on site by means of a portable recorder Head Acoustics SQuadriga II, equipped with a BHS II Binaural Headset. In the case of the art gallery, the recordings were carried out in a real gallery located in Naples. They substantially consist of background sound with voices of visitors who were inside. For the living room, recordings were carried out within an indoor living space in a quite silent residence zone. The selected audio tracks were implemented in the software that provided the spatialization of the sound, in order to have a more realistic effect of the overall environment.

Virtual scenarios

Participants explored two different immersive virtual environments: an art gallery and a classical living room. We chose a museum and a living room as virtual scenarios in order to allow participants to experience common everyday places such as a flat and a public context. In this way, they could have a more general experience of IVR. The first scenario presented a selection of masterpieces from classic (e.g. Leonardo's Monna Lisa) to contemporary (e.g. Keith Haring patterns) ages within a modern building with a glass ceiling. The participants could move along the various rooms and stop in front of the paintings. The second scenario simulated a common living room of a flat, complete with all furnishing items. Both scenarios had very detailed modelling, with similar visual and geometric features. Participants were presented with both scenarios according to a counterbalanced order. For both experiences, the participants could just move and explore the scenarios with full 360° movement of the head. No other interactions were programmed.

Questionnaires

Three self-report questionnaires were administered to all participants to measure vividness of subjective mental images, ability to control mental images, and sense of presence. All the scales were submitted in the Italian form.

Vividness of subjective mental images The Vividness of Visual Imagery Questionnaire (*VVIQ*; Marks 1973; see Antonietti and Crespi 1995) is a scale that measures individual differences in vividness of subjective visual imagery. The subject is asked to generate a mental image and then to assess its vividness. Each participant had to evoke four kinds of mental images: (1) think of some dear relative or friend ("Dear person") whom you frequently see (but who is not with you at present); (2) visualize a rising sun ("Rising Sun"); (3) think of the front of a shop where you often go to ("Front of a shop"); (4) think of a country scene which includes trees, mountains, and lake ("Country scene"). For each image, participants had to respond to four items evaluating the vividness of the subjective mental images, for a total of 16 items. Responses were collected on a five-point Likert scale ranging from 1 "no image at all" to 5 "perfectly clear and vivid as if you were really seeing". To get a single vividness score for each dimension, four principal component analyses were carried out on the four items related to each image and the relative latent score was computed. Each dimension showed an adequate reliability ($\alpha = .76$, $\alpha = .68$, $\alpha = .69$, and $\alpha = .78$, for Dear person, Rising Sun, Front of a shop, and Country scene, respectively). Finally, to get a unique and general vividness score, a principal component analysis was carried out on the four latent scores ($\alpha = .69$), and a single general latent score was computed. For each latent score, a greater value indicated a greater vividness of subjective mental images.

Ability to control mental images The Test of Visual Imagery Control (TVIC; Gordon 1949; see Antonietti and Crespi 1995) is a scale developed to assess individual differences in the ability to create "controlled" and "autonomous" mental images, that is, the ability to modify them intentionally. Participants were asked to mentally visualize a car and then to transform it according to ten descriptions (e.g. "Can you now see it in a different colour?"). Responses were collected on a five-point Likert scale ranging from 1 "no image at all, you only know that you are thinking of the object" to 5 "perfectly clear and vivid as real seeing". To get a single measure of the ability to control mental images, a principal component analysis was carried out on the items and the latent score was computed. The scale showed an adequate reliability ($\alpha = .86$).

Sense of presence The Igroup Presence Questionnaire (IPQ; Regenbrecht and Schubert 2002; Schubert 2003; Schubert et al. 1999, 2001) was administered to evaluate how deep the feeling of being in the virtual environment or the sense of presence was. The IPQ is composed of 13 items (see Table 1) investigating various aspects linked to the concept of presence and grouped by Schubert et al. (1999) in three areas: *Spatial Presence* that describes the sense of being physically present and acting in a virtual space; *Involvement* that measures the degree of awareness of the virtual scenario while isolating the external world; and *Realism* that regards the degree of realism attributed to the virtual scenario. Furthermore, a single item assessing the *Sense of Being There,* i.e. the sense of being actually located within the virtual environment, was also included in the scale (Slater and Usoh 1993; see also Slater 2009). The final scale consisted of 14 items. Participants were presented with statements describing the virtual experience and were asked to indicate their agreement on a seven-point Likert scale ranging from "complete disagreement" (− 3) to "complete agreement" (+ 3). Spatial Presence was measured by items 2, 4, 5, and 6: "2) Somehow I felt that the virtual world surrounded me"; "4) I did not feel present in the virtual environment"; "5) I had the sense of acting in the virtual space, rather than operating something from outside"; "6) I felt present in the virtual space" (Schubert et al. 1999). Involvement was measured by the items 7, 8, 9, and 10 (Schubert et al. 1999): "7) How aware were you of the real world surrounding while navigating in the virtual world (i.e. sounds room temperature, other people etc)?" (Witmer and Singer 1994); "8) I was not aware of my real environment"; "9) I still paid attention to the real environment"; "10) I was completely captivated by the virtual world". Realism was measured by items 3 (Schubert et al. 1999), 11 (Hendrix 1994), 12 (Witmer and Singer 1994), 13 (Carlin, et al. 1997), and 14 (Schubert et al. 1999): "3) I felt like I was just perceiving pictures"; "11) How real did the virtual world seem to you?"; "12) How much did your experience in the virtual environment seem consistent with your real world experience?"; "13) How real did the virtual environment seem to you?"; "14) The virtual world seemed more realistic than the real world". Finally, the questionnaire is completed by the Slater and Usoh's (1993 single item (Presence item 1): "In the computer-generated world I had a sense of «being there»". To get a single index of presence for each IPQ dimension, three principal component analyses were carried out on the dimension-related items and the relative latent score was computed. Each dimension showed an adequate reliability ($\alpha = .62$, $\alpha = .60$, and $\alpha = .60$ for Spatial Presence, Involvement, and Realism, respectively).

Table 1 Igroup Presence Questionnaire items and Presence item as a function of the dimension and the source

#	Stem	Dimension	References
1	In the computer-generated world I had a sense of «being there»	Presence	Slater and Usoh (1993)
2	Somehow, I felt that the virtual world surrounded me	Presence	Schubert et al. (1999)
4	I did not feel present in the virtual environment (R)	Presence	Schubert et al. (1999)
5	I had the sense of acting in the virtual space, rather than operating something from outside	Presence	Schubert et al. (1999)
6	I felt present in the virtual space	Presence	Schubert et al. (1999)
7	How aware were you of the real world surrounding while navigating in the virtual world (i.e. sounds room temperature, other people etc)? (R)	Involvement	Witmer and Singer (1994)
8	I was not aware of my real environment	Involvement	Schubert et al. (1999)
9	I still paid attention to the real environment (R)	Involvement	Schubert et al. (1999)
10	I was completely captivated by the virtual world	Involvement	Schubert et al. (1999)
3	I felt like I was just perceiving pictures (R)	Realism	Schubert et al. (1999)
11	How real did the virtual world seem to you?	Realism	Hendrix (1994)
12	How much did your experience in the virtual environment seem consistent with your real world experience?	Realism	Witmer and Singer (1994)
13	How real did the virtual environment seem to you?	Realism	Carlin et al. (1997)
14	The virtual world seemed more realistic than the real world	Realism	Schubert et al. (1999)

(R) reverse item

Procedure

In order to become familiar with the entire procedure and devices, participants were introduced to the IVR devices and then asked to wear the HMD Oculus Rift DK2 and to handle a joystick. Once immersed in the virtual scenarios, participants were invited to freely explore the space using the joystick. The maximum exploration time for each scenario was 5 min, but the participants could stop at any time. Then, they had to remove the HMD and afterwards to fill out the questionnaires. The questionnaires were presented in a counterbalanced order across participants. The participants were asked to evaluate their whole experience with the virtual scenarios. The entire session lasted about 20 min.

Data analysis

Preliminary descriptive analyses were executed to investigate the missing values and variable distributions. Univariate distributions of observed variables were examined for normality (Tabachnick and Fidell 1996). In order to investigate the association between the sense of presence and the mental imagery ability, correlation analyses between the Presence item 1 (Slater and Usoh 1993), the three sub-scales of IPQ, and the VVIQ and TVIC mean scores were performed. As regards the Presence item 1, the Spearman's rank correlation coefficient was computed. In all other cases, the Pearson's correlation coefficient was used. As regards the VVIQ, the correlations with the four sub-scales ("Dear person", "Rising Sun", "Front of a shop", "Country scene") were also considered. Moreover, to control the familywise type I error, we used as correction the false discovery rate (FDR; Benjamini and Hochberg 1995). Finally, to investigate gender differences in sense of presence and mental imagery ability, two MANCOVAs that treated the Gender as between-subject factor and Age as a covariate were performed separately on Presence item 1 and IPQ sub-scales, and on VVIQ and TVIC mean scores. Moreover, to test if the Gender were observed independently of Age, the same analysis was repeated by excluding the Age as a covariate. The magnitude of significant effects was indicated by partial eta squared (η_p^2). The alpha value was set at .05 for all analyses.

Results

The overall pattern of correlations is shown in Table 2. Correlation analyses showed that Item 1 was significantly correlated with the "Dear person" sub-scale, $r(142) = .188$, $p = .025$, FDR-corrected p value = .050, "Front of a shop" sub-scale, $r(142) = .287$, $p = .0005$, FDR-corrected p value = .007, and with the VVIQ general score, $r(142) = .195$, $p = .020$, FDR-corrected p value = .025. The higher was the vividness of global VVIQ, and in particular "Dear person" and "Front of a shop" mental images, the more individuals reported a sense of "being there" in the computer-generated world. No significant association was observed between the Item 1 and the other VVIQ sub-scales ("Rising Sun" and "Country scene"). Moreover, no significant association was observed between the Item 1 and the TVIC dimension.

As regards the IPQ sub-scales, results showed that the Spatial presence sub-scale was significantly and positively correlated with "Dear person", "Front of a shop" and "Country scene" sub-scales, $r(140) = .211$, $p = .013$, FDR-corrected p value = .034, $r(137) = .263$, $p = .002$, FDR-corrected p value = .014, and $r(137) = .226$, $p = .007$, FDR-corrected p value = .029, respectively, and with the VVIQ general score, $r(140) = .254$, $p = .003$, FDR-corrected p value = .010. No significant association was observed between the Spatial presence and "Rising sun" VVIQ sub-scale, or with the TVIC total score.

The Involvement sub-scale was significantly and positively correlated with "Front of a shop" sub-scale, $r(140) = .189$, $p = .026$, FDR-corrected p value = .049, and with the VVIQ general score, $r(140) = .220$, $p = .009$,

Table 2 Correlation between Presence dimensions (Item 1 and Igroup Presence Questionnaire sub-scales), Vividness of Visual Imagery Questionnaire, and Test of Visual Imagery Control sub-scales ($N = 142$)

Presence dimensions	VVIQ					TVIC
	Dear person	Rising Sun	Front of a shop	Country scene	Total	
Item 1	.188[a, *]	−.045[a]	.287[a, *]	.114[a]	.195[a, *]	.022[a]
IPQ						
Spatial presence	.211*	.023	.263*	.226*	.254*	.153
Involvement	.175	.125	.189*	.145	.220*	.136
Realism	.183*	.032	.094	.153	.159	.002

Item 1 = Presence item (Slater and Usoh 1993)

IPQ Igroup Presence Questionnaire; *VVIQ* Vividness of Visual Imagery Questionnaire; *TVIC* Test of Visual Imagery Control

*FDR-corrected p value < .05

[a]Spearman's rank correlation coefficient

FDR-corrected p value = .018. A correlation with "Dear person" sub-scale emerged, $r(140) = .174$, $p = .039$, that did not survive the FDR correction procedure. No significant association was observed between Involvement sub-scale and "Rising Sun" or "Country scene" VVIQ sub-scales, or with the TVIC total score.

Finally, the Realism sub-scale showed a significant but weak correlation with "Dear person" sub-scale, $r(140) = .183$, $p = .031$, FDR-corrected p value = .049. No other significant associations were observed with VVIQ sub-scale, or with the TVIC total score.

As regards gender effects on Presence dimensions, the MANCOVA showed no significant effect, Wilks' lambda = 0.972, $F(4, 136) < 1$, multivariate $\eta_p^2 = .027$. Moreover, there was no significant effect of Age, Wilks' lambda = 0.944, $F(4, 134) = 2.011$, $p = .096$, multivariate $\eta_p^2 = .056$. Univariate analyses confirmed the absence of significant results. The same results were observed when excluding Age as a covariate. As regards gender effects on mental imagery, the MANCOVA showed no significant effect, Wilks' lambda = 0.972, $F(2, 138) = 1.965$, $p = .144$, multivariate $\eta_p^2 = .028$. There was no significant effect of Age, Wilks' lambda = 0.988, $F(2, 138) < 1$, multivariate $\eta_p^2 = .011$. Univariate analyses showed a main effect of Gender close to significance as regards VVIQ, $F(1, 139) = 3.846$, $p = .0518$. No more significant results emerged. The same results were observed when excluding Age as a covariate.

Discussion

The present study aimed at exploring the relationship between sense of presence and mental imagery by assessing whether the degree of presence experienced in IVR is associated with the vividness and capacity of control of mental images. The results overall confirmed the hypothesis that the ability to generate vivid visual images is positively associated with the capacity to feel present in a virtual world. Indeed, a positive correlation between presence and vividness emerged: the higher the vividness of mental images the stronger the reported sense of presence felt in IVR scenarios. In particular, the capacity to generate vivid images of a common everyday context such as a shop was associated with a high sense of "being there" in the computer-generated world. Similarly, the more individuals reported vivid mental images of personal and common memories, such as a dear person, a familiar shop or a country scene, the more they felt spatially present in the virtual world. Vividness of mental images was also associated with the degree of involvement with the virtual scenarios and specifically with the feeling of being unaware of the real world by withdrawing attention from the external world and getting involved in the virtual world. Finally, vivid mental images of a dear person were associated with the realism of the IVR experience. Indeed, individuals reporting more vivid images also perceived the virtual world as realistic and not just a collection of images, such that the virtual experience was felt as consistent with the real experience.

These results, then, suggest that the capacity of feeling present and involved in a virtual world is associated with the capacity to generate vivid images of common everyday situations. Instead, the capacity to control, or transform, mental images showed a weak or null association with sense of presence. The TVIC scale assesses the ability to transform mental images while maintaining them in a temporary buffer. This capacity involves visuospatial imaginative processes and executive attentional resources (Rudkin et al. 2007). We may argue that this capacity is more important when mental images are self-generated than when we just perceive computer-generated virtual worlds. The VVIQ and the TVIC scales assess aspects of mental imagery that are close, respectively, to the object imagery scale and the spatial imagery scale of the Object-Spatial Imagery Questionnaire (OSIQ) proposed by Blajenkova and colleagues (2006). The former assesses preferences for representing and processing colourful, pictorial, and high-resolution images and showed a correlation with object imagery behavioural tasks. The latter assesses preferences for representing and processing schematic images, spatial relations among objects, and spatial transformations and showed a correlation with spatial imagery tasks. Future studies could use this questionnaire to see whether the two scales show differential association patterns with imagery tasks and whether spatial imagery is more important when extensive navigation in virtual scenarios is required.

As regards gender effects, we did not find higher sense of presence in virtual environments by women than men, as instead previously reported (e.g. Felnhofer et al. 2014). Further studies should assess the robustness of gender effects with IVR subjective experiences and check whether they might reflect sociocultural factors.

Similarly, gender did not affect the capacity to transform and control mental images. In contrast, females reported higher global vividness ratings than men. This effect was weak although close to significance, in line with the literature showing a slight tendency for women to report more vivid images than men (Richardson 1995). However, it is possible that the non-perfectly balanced number of females (65) and males (77) masked a weak effect. More studies with an equal number of females and males should assess this possibility. The overall findings, then, confirm that the capacity of feeling present and involved in a virtual world is associated with individual differences in mental imagery, and specifically with the capacity of creating vivid and clear mental images (Burdea and Coiffet 2003). We should consider that people may spontaneously adopt different mental imagery strategies to process memorized sensorimotor information. Therefore, stored sensorimotor information can be modified in various ways, thereby generating mental images that can be schematic, poor of details and abstract, or concrete, detailed and closer to actual experiences (e.g. Iachini and Ruggiero 2010; Kosslyn et al. 2001; Munzert et al. 2009; Palmiero et al. 2009). We suggest that the feeling of presence should be linked to the capacity to represent vivid mental images according to our natural egocentric perspective and close to our original sensorimotor experiences (Iachini and Ruggiero 2006, 2010). In some way, sense of presence and mental imagery share a common feature: they constitute a conscious phenomenal state that raises the impression of perceiving an object without the corresponding actual stimulus. The input for this conscious state is the simulated virtual environment in the first case and past memorized experiences in the last case. We could say that virtual experiences are akin to "actualized" mental images.

However, we recognize that the present study has some limitations and more studies are needed in order to further explore how individual differences and the features of the virtual scenarios may affect sense of presence. In particular, familiarity and attitude with new technologies should be controlled. The imagery capacity should be assessed by cognitive tasks instead of self-reports, such mental rotation tasks. Moreover, different types of scenarios should be compared to see if they differentially affect sense of presence. Finally, our sample had a strength and a weakness. The strength was that it represented different ages, professions, and social conditions and therefore constituted a good starting point for the generalization of results. However, this heterogeneity may also represent a weakness that limits the robustness of the results. Nevertheless, this first study showed an association between sense of presence and imaginative skills that can pave the way for further research.

To conclude, understanding how individual differences in mental imagery may affect virtual reality subjective experiences could be important for applied purposes and specifically for designing user-centred virtual projects. Let us consider, for example, the case of rehabilitation (e.g. Morganti et al. 2003). The assessment of individual differences in mental imagery ability can help create more effective virtual environments and define administration protocols that enhance user's characteristics.

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Compliance with ethical standards

Conflict interest We know of no conflicts of interest associated with this publication, and there has been no significant financial support for this work that could have influenced its outcome. As Corresponding Author, I confirm that the manuscript has been read and approved for submission by all the named authors.

Ethical approval All procedures performed in the present study involving healthy participants were in accordance with the ethical standards of the Institutional Review Board of the Department of Psychology (University of Campania Luigi Vanvitelli) and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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