Imagine That! Imaginative Suggestibility Affects Presence in Virtual Reality

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ABSTRACT

Personality characteristics can affect how much presence an individual experiences in virtual reality, and researchers have explored how it may be possible to prime users to increase their sense of presence. A personality characteristic that has yet to be explored in the VR literature is imaginative suggestibility, the ability of an individual to successfully experience an imaginary scenario as if it were real. In this paper, we explore how suggestibility and priming affect presence when consulting an ancient oracle in VR as part of an educational experience – a common VR application. We show for the first time how imaginative suggestibility is a major factor which affects presence and emotions experienced in VR, while priming cues have no effect on participants' (n=128) user experience, contrasting results from prior work. We consider the impacts of these findings for VR design and provide guidelines based on our results.

CCS CONCEPTS

• **Human-centered computing → Empirical studies in HCI**; **Human computer interaction (HCI)**; **HCI theory, concepts and models**.

KEYWORDS

virtual reality, presence, imaginative suggestibility, priming

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1 INTRODUCTION

The recent development of commercial head-mounted displays (HMD) has increased the popularity of virtual reality (VR) [71]. The distinguishing feature of VR is the immersion it provides which can lead to higher feelings of presence in users [7]. Presence is a complex construct, made up of three sub-types [40]: spatial presence which refers to the sense of being spatially located in a virtual space [11], social presence which is the sense of being with another social agent [21], and self presence which represents the coherence between the actual self and the self presented in the virtual environment [66]. Presence has been shown to improve engagement [7], motivation [62], and enjoyment [69] and is therefore an important factor that substantially contributes to the overall experience of VR environments.

Despite the added immersion and sense of presence provided by VR experiences, it is still a niche technology that does not seem to appeal to everyone. While some technical factors, such as display quality, have improved markedly, other technical factors like headset weight are still problematic [53, 84]. Similar design issues have even led some researchers to declare that VR is sexist in its design, as device characteristics appear to cause more VR sickness in women than in men [18, 46, 67]. Clearly, these aspects need to be addressed. However, while several of these issues may improve as the technology continues to mature, there are other aspects that seem to make VR experiences more enjoyable and engaging for some but not others.

It is clear that individual differences that affect presence need to be better understood given that VR does not seem to appeal to all equally, and that presence is a key factor in what makes VR an amazing experience for some people. To date, a number of personality characteristics including spatial intelligence, introversion, and anxiety have been shown to support the formation of presence [29]. However, for other human factors, such as gender, there is contradictory research [16, 65]. It is not clear whether other personality characteristics contribute to, or are ultimately responsible for, observed differences in the formation of presence across the groups.

An underexplored characteristic that may contribute to the formation of presence is imaginative suggestibility [10, 73]. Imaginative suggestibility is the degree to which an individual succeeds in requests, or suggestions, to experience an imaginary state of affairs as if they were true [32], for example "*imagine you've been out in the hot sun for hours and you're very, very thirsty and your lips are dry*" [4]. Importantly, this type of suggestibility focuses on the individual's ability to imagine a different state of affairs, in contrast to suggestions that try to deceive individuals about the true state of the world (e.g., placebo) [32]. Given that presence is a measure of the user's subjective feeling of being in a virtual environment (VE) [81], it stands to reason that an individual's imaginative suggestibility may affect the level of presence they experience in VR. Despite this, no work to date has explored the role of imaginative suggestibility on presence in VR.

While imaginative suggestibility is a personal characteristic of an individual that may affect presence, an active area of VR research is the pursuit of methods that can directly improve presence and, in turn, enhance the VR experience. Priming is one such method which exposes a user to stimuli prior to an experience, with the aim of subsequently impacting the processing of elements related to said stimuli that exist in the experience [22]. In non-VR contexts imaginative suggestibility has been shown to increase participant receptiveness to priming [10], and recent work has suggested that priming may positively influence presence in VR [9]. However, the processes which underpin this relationship are not fully understood and it is unclear how priming affects the different sub-types of presence.

Developing a better understanding of how human factors influence the formation of presence is key to improving people's experience in VR. This is especially important for designers who wish to engage the wider population of potential VR users. Additionally, exploring approaches that might allow VR designers to not only understand who will experience presence, but understand how to influence and increase levels of presence across all users will help accelerate the growth and adoption of VR. In order to address these research gaps, we pose the following research questions:

RQ1: What is the role of suggestibility in the formation of spatial, social and self presence?

RQ2: Do individuals who are more suggestible benefit from priming in the context of VR?

To address these questions, we conducted a study with 128 participants exploring the formation of presence in a professionally-produced VR environment of an Ancient Greek Oracle which was designed for learning purposes. To address RQ1, we demonstrate how imaginative suggestibility, measured using the validated [4] Creative Imagination Scale (CIS) [80], significantly affects the formation of presence across all sub-types. Furthermore, we show how imaginative suggestibility, not gender, is responsible for the formation of social- and spatial-presence, while both gender and suggestibility are involve in the formation of self-presence. To address RQ2, we developed three auditory recordings to prime participants with which targeted the three presence sub-types. Our results contrast prior work on priming in VR, suggesting that priming does not affect an individual's experienced presence. In answering these questions, we make the following contributions:

(1) Evidence that suggestibility is an important factor that contributes to the formation of spatial, social and self presence.
(2) Insights that suggestibility, not gender, is important for the formation of social and spatial presence.
(3) Both gender and suggestibility are important factors in the formation of self presence.

2 RELATED WORK

Arguably the most distinguishing and attractive characteristic of VR for users is its increased ability to elicit higher feelings of presence compared to conventional 2D displays [12]. Presence is particularly important as a driver of adoption by the public given that VR is still a niche technology yet to be adopted by the masses [24, 53]. Due to its undeniable importance for the appeal of VR [78], a significant amount of research has investigated the factors that contribute to presence. However, these efforts have mostly considered presence as a unitary variable, when in fact it may be a multifaceted construct [58]. Early VR technology was only capable of representing simplistic VEs that lacked in social elements such as other avatars or hand tracking. This led to presence being synonymous in meaning with spatial presence, or the feeling of 'being there', or being surrounded by inanimate elements of the VE [83]. However, with the rapid advancements in VR technology there is an increased need to account for the separate elements that impact presence. More precisely, Lee [40] proposed that presence could be further divided into multiple sub-types: spatial, social and self-presence. Despite these concepts allowing for a more granular assessment of user experience in VR, a relatively small body of research has investigated presence with reference to its individual sub-types.

In the quest to enhance presence, considerable progress has been made in the graphical fidelity of VR environments, but also the hardware; for example display resolution [2, 77] and field of view [45]. Improvements in technical characteristics, however, require increased computational resources and state-of-the-art hardware, which are still financially and computationally prohibitive. Aside from the technical factors, presence is also strongly driven by user factors. As highlighted recently by Weber et al. [77], presence is determined by the total amount of attentional resources the user directs towards the VE, to the detriment of elements from the outside world. However, VR HMDs isolate the user from the real world by default. Therefore, what is of most importance is whether the VE is perceived as highly realistic, coherent, or believable [77]. Given that no (current) VE can reach the realism of the real world, it becomes apparent that the user needs to overcome technical limitations in order to feel present. This is supported by Blake et al. [6] and Jones and Dawkins [28] who argue that perfect realism is not necessary for presence to be formed, if the VE feels sufficiently real for the user to suspend disbelief and overlook the role of technology in mediating the experience [59].

Given the important role of the user in the presence-formation process, it seems that not just the content within a VE contributes to presence but also the way said content is interpreted and processed internally by the user [77]. Personality traits play an important role in how we interpret incoming sensory information from the real world. Applied to VEs, it has been suggested before that personality traits play a decisive role in how users engage with factors determining presence [5, 16, 27, 29, 35, 44, 55–57]. In particular, extraversion [37], agreeableness [56], willingness to try [57], openness to experience [79], and empathy [30, 48, 57, 76] seem to be factors which impact presence within a VE. However, as observed by Kober et al. [34], findings showing the impact of personality traits on presence have been difficult to replicate, partly due to different stimuli and measures of presence being used across literature [34].

One characteristic in particular that holds relevance in VR presence is gender. There is a significant body of literature suggesting that women are more prone to experiencing negative side-effects of VR, for example motion sickness [18, 46, 67], which can lead to women being reluctant to spending extended periods of time in VR or repeating VR experiences [52]. Presence has been described as instrumental enabler for the adoption and retention of VR by the public since it has the potential to outweigh the negative effects that still exist [24]. However, the effect of gender on presence is unclear, with contradictory findings in the literature which may be dependent on the level of immersion (i.e., 2D screen versus VR HMD). Research has shown how women experience reduced [16, 38], more [42], or the same amount of [48, 63] presence compared to men. In an attempt to explain these potential differences, it has been argued that women might show different presence levels to men due to processing emotions differently [16, 41, 42]. In particular, Felnhofer et al. [16] looked at gender differences in the formation of presence within a VR public speaking task. Males reported significantly higher presence, with a potential contributing factor being the levels of anxiety felt during the task, which were potentially higher amongst women (but did not reach significance due to sample size limitations). Understanding, predicting and leveraging the ways in which different users interact with VR content may present an opportunity for VR developers to better engage with the wider population of potential users.

One promising personality trait that is particularly underexplored in the context of presence is imaginative suggestibility – the degree to which an individual succeeds in requests to experience an imaginary state of affairs as if they were true [33]. Presence relies on the suspension of disbelief and perceiving imperfect VEs as "real" [77]. Therefore, the extent to which someone is imaginatively suggestible could be a central characteristic of users that needs to be investigated. In addition, similar to presence, suggestibility itself has been shown to vary with other individual characteristics, namely gender, with women showing higher scores compared to men [36, 51, 54]. These findings, however, are not unanimous as other studies found no such effect [30, 49]. Preliminary work has scratched the surface of how visual imagination and presence may be linked [35, 57, 76], however they have only focused on non-immersive "desktop VR" environments [57, 76] or focused only on spatial presence with the VE being shown on a projection screen [35]. In contrast, we explore imaginative suggestibility in a VE using an HMD VR where levels of presence are generally significantly higher than that for screens [12].

While imaginative suggestibility can provide deeper understanding of an individual's feelings of presence, other techniques are required to enhance it. One such technique that has shown promise in enhancing presence, and which could be linked to suggestibility, is priming. Priming involves being exposed to stimuli prior to an experience in the hope that the exposure subsequently impacts the processing of elements related to said stimuli that exist in the experience [22]. Recently, research has shown how priming can potentially enhance social [13] and spatial presence [9]. Not all research into priming has shown effects on presence [8]; however this could be due to the priming being aimed at social elements despite spatial presence being measured. Prior research outside the context of VR has shown how highly suggestible participants may be more receptive to priming [10, 73]. For example, Condon et al. [10], found that priming participants with task-related motivational suggestions increased their reaction times to semantically related word pairs compared to non-related word pairs. Furthermore, this relationship was stronger for individuals who were highly suggestible, as measured by the CIS. Whether this same relationship between suggestibility and priming is applicable in VR is an open question that we address.

In summary, there is a need to better understand the role played by suggestibility in the formation of presence, and its interaction with gender and priming. Furthermore, studies on personality traits and gender have focused only on the spatial element of presence (e.g., [16, 37, 56]) or did not distinguish between sub-types and measured presence as a unitary variable (e.g., [38, 48]). We provide a clear understanding of the role of suggestibility in the formation of presence sub-types, and further explore the extent to which suggestibility can explain disparate gender and priming effects in presence.

3 METHODOLOGY

To understand the role imaginative suggestibility has on feelings of presence in VR and to gain a greater understanding of how different types of priming can affect sub-types of presence, we conducted a study with a between-groups design. We designed three different types of priming material targeted at each of the three sub-types of presence, as well as looking at the case where participants received no priming. This resulted in four conditions for our independent variable: $\textit{Spatial Priming}_{VE}$, $\textit{Social Priming}_{VE}$, $\textit{Self Priming}_{VE}$ and $\textit{Baseline}_{VE}$ in which users received no priming. Participants were randomly allocated to one of the four conditions, and in each condition their subjective measures of *Spatial Presence*, *Social Presence*, *Self Presence*, and *Imaginative Suggestibility* were measured. Hereafter we refer to *Imaginative Suggestibility* as just *Suggestibility* for brevity.

3.1 Stimuli

3.1.1 Virtual Reality Environment. It is common for VR applications to immerse users in VEs that are not intended to be representations of real-life current settings, but instead enable users to experience scenarios beyond those encountered in everyday life. It has been shown before that perceived realism, or the plausibility of an environment is formed based on the extent to which said environment meets a user's expectations, rather than the way it looks [64]. We used a fictional, yet historically-accurate VE to minimise the likelihood that presence would be affected by discrepancies noticed by users and avoid memory-based matching of expectations. A custom VR environment was professionally developed, which depicted a historically-accurate impression of the Ancient Oracle of Dodona [47]. The VR Oracle (VRO) environment is a seven minute first-person VR experience of an oracular divination at the ancient Greek oracle of Zeus at Dodona c. 465 BCE. The user embodies the character of a slave who ran away and reached the sanctuary at Dodona. The environment is separated into different scenes, with each scene telling the story of ancient Greek men and women as they consult the oracle.

In the first scene (Figure 1a), the user is welcomed and given an introduction to the sanctuary by a guide. They introduce other scenes such as the market and campsite. The guide also assures that the sanctuary is a safe haven for all that have been enslaved. The guide describes how he has written a question about freedom on a tablet which he intends to bring forward to the oracle. The next scene takes place en route to the marketplace, showing an interaction between two Spartan brothers (Figure 1b) who talk about why they are visiting the oracle. This is followed by another scene where two more characters discuss their use of multiple oracles (Figure 1c). The last scene presents a representation of the Dodona Oracle, as an Oak tree where an entire ancient ritual takes place (Figure 1d). At the end of the ritual, the user is approached by a priestess who informs them that the answer to the question about freedom was "to stay at the sanctuary".

Greek actors were hired to voice the characters in the VE so as to create a more authentic experience, which was recorded in the English language. The avatars were animated using motion-tracking data from the same actors, who performed all the scenes. A team of Ancient historians were involved designing the narrative, physical environment, characters, and speech content so as for it to be historically accurate. Details such as period-accurate clothing and colour shades were all implemented to make VRO a usable educational tool. The VE was designed to run on low-end hardware and offers 3 degrees of freedom, allowing participants to look around. No elements of agency or interaction were implemented, however prior research has shown that agency does not affect presence in VEs that are designed to induce happiness [26]. The entire experience was designed to last for approximately seven minutes. This duration has been shown to be ideal for inducing presence in VR, without allowing for the onset of boredom [85].

3.1.2 Priming Material. The priming material was designed to provide additional information to that present in the VE. Texts of similar length were compiled by a team of Ancient historians so that the information would be historically accurate and congruent with the VRO environment. Each text was also curated so that it would only contain information intended to prime users on one of the three sub-types of presence. The full text used for priming can be found in Appendix A.

The *Spatial Priming*$_{VE}$ text contained a vivid description of the spatial elements of the VRO environment. The description focused on different modalities such as scent ("there is a lingering scent of rain"), vision ("a perilous road stretches"), audio ("birdsong rises and falls around") and touch ("the ground is damp underfoot"). Furthermore, elements of mysticism were described ("the age of the sanctuary manifests in the shape and slow movement of the tree"). The script did not use pronouns to avoid the description feeling personal to a specific gender.

For the *Social Priming*$_{VE}$ condition, users were given a description and background information on the characters they would meet along the way in the VRO narrative. The descriptions included additional information that was not contained in the actual VRO environment, such as the characters' motivations, personalities and back stories. Providing these additional details was intended to facilitate better understanding of the intentions of each character and feeling more connected to them; thus priming participants on the social elements of the environment.

The *Self Priming*$_{VE}$ script introduced a rich back history and background to the user's character as a slave that had ran away and reached the sanctuary at Dodona. This text used second person (i.e. 'you are a slave') to address the user to aid identification with the character. The script did not use any gender related pronouns, removing the issue of gender biases.

The priming texts were narrated and recorded to be administered as audio. The auditory modality was chosen for two main reasons. First, it was intended to administer the priming via the same modality used as the Creative Imagination Scale. For narrating the priming material we recruited a male actor and Ancient historian, so that pronunciations of Greek names would be accurate. The audio of each priming script lasted roughly 1 min and 10 seconds +/- 10 seconds.

3.2 Outcome Measures

3.2.1 Presence questionnaire. Spatial Presence, *Social Presence* and *Self Presence* were measured using the Multimodal Presence Scale (MPS), a 15-item questionnaire with sub-sections dedicated to each of the three sub-types of presence, which have been validated through factor analysis [43]. As observed by Toet et al. [72] in a recent study, the MPS is the only validated measure of presence that assesses all three sub-types of presence, with others only addressing spatial or social presence, for example. The MPS has been used widely to measure presence in VR experiences (e.g., [20, 25, 74, 75]). Moreover, it was shown that scores on the spatial and self presence components of the MPS were significantly correlated with those in the Ingroup Presence Questionnaire (IPQ) [58]. While the IPQ is a more traditional and widely-used [19] measure of presence, it only focuses on spatial presence [74]. In another study Volkmann et al. [75] showed that the social presence component of the MPS highly correlates with the Presence Questionnaire (PQ) [82], another widely used VR presence scale. Each question was assessed using a 5-point scale ranging from strongly disagree to strongly

Figure 1: Scenes from the first-person VR experience of an oracular divination at the ancient Greek oracle of Zeus at Dodona used in the study. The experience involved participants being introduced to the environment by a guide (a), listening to social conversations between different characters (b–c), before finally meeting the Dodona Oracle and experiencing an ancient ritual.

agree. The spatial element contains questions such as "the virtual environment seemed real to me", the social element includes questions such as "the person in the environment appeared to be sentient (conscious and alive) to me", and finally the self element includes questions such as "during the simulation, I felt like my virtual embodiment and my real body became one and the same".

3.2.2 Suggestibility Questionnaire. The Creative Imagination Scale (CIS) was used to measure *Suggestibility* [80]. The CIS has been well validated [4, 80] and has been used before in conjunction with priming [10]. The CIS includes 10 test items, each a suggestion, that ask participants to think and imagine a certain state of affairs. These include suggestions that their arm is levitating, that they are drinking water, that they are listening to music, that they feel that time is slowing down, or that their mind and body are relaxed. The procedure lasted around 20 minutes in total and was followed by a questionnaire where participants reported the extent to which each of the suggestions felt comparable to a real-life experience. This was reported on a 5-point Likert scale ranging from 0% (not at all the same) to 90% (almost exactly the same).

3.3 Apparatus

The study was conducted in a University research laboratory. All of the outcome measures were deployed on Qualtrics and completed on a desktop computer. The VRO environment was deployed on an Oculus Quest 2 which was upgraded with an Elite Strap for extra comfort. The audio of the VE, the priming material, and the suggestibility measure were played via a pair of high quality noise cancelling headphones (Sony WH-1000XM5).

3.4 Procedure

Following informed consent, participants were randomly allocated to the $\mathit{Spatial\ Priming}_{VE}$, $\mathit{Social\ Priming}_{VE}$, $\mathit{Self\ Priming}_{VE}$ or $\mathit{Baseline}_{VE}$ conditions. They then filled in a demographics questionnaire in Qualtrics. Participants were then fitted with the VR HMD and noise cancelling headphones and entered an HMD calibration phase in which they viewed a blank Unity scene which only contained text in decreasing size. Users were asked if the smallest text was clear and the HMD was adjusted if necessary. This first scene also served the purpose of adjusting the users with the distance compression that is commonly experienced in VR [17]. The priming audio recording corresponding to the assigned condition was then played, directly followed by the VRO experience. At the end of the VR experience, participants were instructed to remove the HMD and asked to fill in the presence questionnaire on a computer screen, also in Qualtrics.

In order to exclude the impact of any external noise participants were then led to a sound proof room where they completed the suggestibility procedure using an identical pair of noise cancelling headphones before filling in the accompanying questionnaire. For this part of the study participants were left alone in the sound proof room so that the experimenter's presence would not distract them from the task. Lastly, participants were debriefed and signed the payment form. The entire experimental procedure lasted approximately 50 minutes.

3.5 Hypotheses

Based on the findings of previous related work on presence, suggestibility and priming, we posed the following *a priori* hypotheses:

- **H1** *Suggestibility* will significantly impact *Spatial Presence* (**H1A**), *Social Presence* (**H1B**) and *Self Presence* (**H1C**).
- **H2** *Suggestibility* will moderate the relationship between priming and *Spatial Presence* (**H2A**), *Social Presence* (**H2B**) and *Self Presence* (**H2C**).
- **H3** *Suggestibility* will moderate the relationship between *Gender* and *Spatial Presence* (**H3A**), *Social Presence* (**H3B**) and *Self Presence* (**H3C**).

3.6 Participants

A total of 128 participants were recruited, who were equally distributed across the four conditions, resulting in 32 participants within each group. They had an overall average age of 29.65 ($Mean = 29.65, SD = 10.33, Min = 18, Max = 71$). The sample was composed of 68 females ($Mean = 29.35, SD = 10.52, Min = 18, Max = 69$) and 60 males ($Mean = 29.98, SD = 10.20, Min = 18, Max = 71$). The gender distribution across conditions was also approximately uniform: 15 Females and 17 Males for $Baseline_{VE}$, 19 Females and 13 Males for $Spatial\ Priming_{VE}$, 17 Females and 15 Males for $Social\ Priming_{VE}$ and 17 Females and 15 Males for $Self\ Priming_{VE}$. For safety, participants were screened for pregnancy, history of epilepsy, and vertigo/fainting spells. They all had normal or corrected vision and hearing.

The sample size for each group was calculated with an a priori power analysis for an ANCOVA for fixed effects, main effects and interactions by using G*Power 3.1 [15]. For the estimation we used a partial eta-squared η_p^2 of 0.06 (for a medium effect size), a level of power of 0.80, 4 groups, 1 numerator df (degree of freedom; for main factor $2 - 1 = 1$, for interaction $(2 - 1) \times (2 - 1) = 1$), 1 covariate and an α-level of 0.05. Participants were recruited via word of mouth or via flyers. They received a £10 monetary incentive for their participation. This analysis returned a necessary sample size of 125, or 31 participants per group. The study received ethical approval from the Department of Psychology Ethics Committee at the University of Bath (Ethics code: 21-233).

4 RESULTS

First we confirmed that our data satisfied the assumption of equality of variances through Levene's tests ($p > .05$) and Q-Q plots to verify that distributions were close enough to normal. Both measures confirmed that an analysis of covariance (ANCOVA) could be conducted. We used Pearson's tests to investigate the relationship between *Suggestibility* and all sub-types of presence. We used ANCOVAs to compare the effects of priming and then gender on *Spatial Presence*, *Social Presence* and *Self Presence*, with *Suggestibility* as a covariate. All tests for significance were made at the $\alpha = 0.05$ level. In this section we mark a p-value below .05 with '*' and one less than or equal to .01 with '**'. The error bars in the graphs show the 95% confidence intervals of the means.

4.1 Suggestibility, Priming and Presence

To investigate the relationship between *Suggestibility* and presence sub-types, we used Bonferroni-corrected Pearson's correlations, so as to account for multiple comparisons. Results showed that *Suggestibility* was positively highly correlated with *Spatial Presence* ($r = .387, p < .001^{**}$), *Social Presence* ($r = .393, p < .001^{**}$), and *Self Presence* ($r = .314, p < .001^{**}$).

With this knowledge, we used one-way ANCOVAs to investigate the effect of priming on *Spatial Presence*, *Social Presence* and *Self Presence* while controlling for the effect of *Suggestibility*. We found *Suggestibility* was significantly associated with all sub-types of presence, but the different types of priming had no effect. For *Spatial Presence*, no main effect of priming was found ($F(3, 123) = .747, p = .526, eta_p^2 = .018$), although greater *Spatial Presence* was associated with higher *Suggestibility* ($F(1, 123) = 22.380, p < .001^{**}, eta_p^2 = .154$), which validates **H1A**. Similarly, for *Social Presence*, no main effect of priming was found ($F(3, 123) = .541, p = .511, eta_p^2 = .019$), although greater *Social Presence* was associated with higher *Suggestibility* ($F(1, 123) = 22.936, p < .001^{**}, eta_p^2 = .157$), which validates **H1B**. Finally, for *Self Presence*, no main effect of priming was found ($F(3, 123) = 1.056, p = .303, eta_p^2 = .029$), although greater *Self Presence* was associated with higher *Suggestibility* ($F(1, 123) = 13.828, p < .001^{**}, eta_p^2 = .101$), which validates **H1C**.

The lack of any significant effect of priming in either condition suggests that priming alone does not impact either sub-type of presence. However, the significance effect of *Suggestibility* in all ANCOVAs suggests that it is a significant predictor of all three sub-types of presence, or it could potentiate the effect of priming on presence through an interaction. To investigate this possibility we employed regression analysis.

A multiple linear regression with enter method was used to predict *Spatial Presence* from $Spatial\ Priming_{VE}$, *Suggestibility* and their interaction. The model explained a statistically significant amount of variance in *Spatial Presence*, ($F(3, 124) = 8.531, p < .001^{**}, R^2 = .171$, Adjusted $R^2 = .151$). *Suggestibility* was the only significant predictor ($\beta = .44, t(124) = 4.698, p < .001^{**}$). An increase in one point for *Suggestibility* corresponded, on average to an increase of .442 points in *Spatial Presence*, ($B = 438, 95\%CI[.254, .623]$). This rejects (**H2A**) and converges with results of the ANCOVA validating **H1A**.

A second multiple linear regression with enter method was used to predict *Social Presence* from $Social\ Priming_{VE}$, *Suggestibility* and their interaction. The model explained a statistically significant amount of variance in *Social Presence*, ($F(3, 124) = 7.912, p < .001^{**}, R^2 = .161$, Adjusted $R^2 = .140$). *Suggestibility* was the only significant predictor ($\beta = .43, t(124) = 4.719, p < .001^{**}$). An increase in one point for *Suggestibility* corresponded, on average to an increase of .442 points in *Social Presence*, ($B = 499, 95\%CI[.290, .708]$), thus further validating **H1B** and rejecting **H2B**.

A third multiple linear regression with enter method was used to predict *Self Presence* from $Self\ Priming_{VE}$, *Suggestibility* and their interaction. The model explained a statistically significant amount of variance in *Self Presence*, ($F(3, 124) = 5.977, p < .001^{**}, R^2 = .126$, Adjusted $R^2 = .105$). *Suggestibility* was the only significant predictor ($\beta = .26, t(124) = 2.500, p = .014^{*}$). An increase in one point for *Suggestibility* corresponded, on average to an increase of .329 points in *Self Presence*, ($B = .329, 95\% CI[.069, .590]$), thus further validating **H1C** and rejecting **H2C**.

4.2 Individual Differences and Presence

To explore gender differences in presence, we first ran independent samples t-tests with *Gender* as a grouping variable. To investigate the magnitude of the observed differences we report Cohen's d [39]. Females reported significantly higher presence scores for each of the sub-types, in addition to scoring significantly higher on imaginative suggestibility. Results showed that female participants felt more *Spatial Presence* (($t(126) = 2.310, p = .023^{*}, d = 409$)), *Social Presence*($t(126) = 2.053, p = .042^{*}, d = .364$), and *Self Presence* ($t(126) = 2.36, p = .002^{**}, d = .574$) compared to males. In addition, females scored significantly higher on *Suggestibility* scores than males ($t(126) = 2.050, p = .042^{*}, d = .363$). Mean and standard deviations for the different sub-types of presence and *Suggestibility* can be found in Table 1.

Given that females scored higher on all types of presence and also on *Suggestibility*, we conducted ANCOVAs to investigate the effect of *Gender* on *Spatial Presence*, *Social Presence* and *Self Presence* while controlling for *Suggestibility* as a covariate. *Gender* did not affect *Spatial Presence* or *Social Presence* when *Suggestibility* was accounted for. However, *Self Presence* was affected by both *Suggestibility* and *Gender*. ANCOVA results showed no main effect of *Gender* on *Spatial Presence* ($F(1, 125) = 2.706, p = .102, eta_p^2 = .021$), but greater *Spatial Presence* was associated with higher *Suggestibility* ($F(1, 125) = 19.079, p < .001^{**}, eta_p^2 = .132$), which validates **H3A**. Similarly for *Social Presence*, no main effect of *Gender* was found ($F(1, 125) = 1.277, p = .176, eta_p^2 = .015$), but greater *Social Presence* was associated with higher *Suggestibility* ($F(1, 125) = 13.951, p < .001^{**}, eta_p^2 = .139$), which validates **H3B**. In contrast, for *Self Presence*, a main effect of *Gender* was found ($F(1, 125) = 7.410, p = .007^{*}, eta_p^2 = .056$), and also greater *Social Presence* was associated with higher *Suggestibility* ($F(1, 125) = 10.575, p < .001^{**}, eta_p^2 = .078$), which validates **H3B**. A post-hoc, Holm-corrected test showed that females scored significantly higher *Self Presence* compared to males ($p = .007^{*}$).

5 DISCUSSION

Our results show that imaginative suggestibility, a personality trait underexplored so far in the context of immersive VR, has a significant role in the formation of spatial, social and self presence. The extent of the relationship is remarkable, especially given the past inconclusive findings on other personality characteristics [34]. Other personality traits such as extraversion [37], agreeableness [56] or empathy [30, 48, 57, 76] could have more pronounced effects on certain sub-types of presence because they more specifically change the way social information is interpreted. In contrast, imaginative suggestibility appears to have a uniform effect across all sub-types of presence and is robust to the user's internal processing of different content elements in the VE.

The uniform effect of imaginative suggestibility on all sub-types of presence could mean that it has a broad effect across the visual, auditory and motor characteristics of VR. For example, spatial presence can be enhanced by increasing the visual realism of a VE [23]. Social presence is facilitated by the existence [31] and accuracy of social information in the environment, such as anatomically-accurate body and limb vection of other avatars [3]. Self presence is heavily impacted by the representation of the self and level of tracking afforded in the VE [66]. The distinction between the elements that lead to the creation of the three types of presence is also supported by a recent study showing they can be manipulated individually through design decisions [74]. It is not immediately clear then, how imaginative suggestibility can have such a broad effect on all three sub-types of presence, which depend on a multitude of diverse factors. There has been no evidence yet that personality traits directly alter sensory experience, but rather how people interpret incoming sensory information [56].

One explanation for this effect could be that more suggestible individuals simply elevate the effects of those immersive features that are found in a VE, by leveraging their imaginative skills. Perhaps the conceptual information in a VE helps more suggestible individuals to 'fill in the gaps' made by the hardware or software limitations in the believability of the experience. For example, perceiving a low resolution virtual tree may in turn elicit a more vivid mental representation of a tree for a highly suggestible user, which in turn increases the perceived realism of the VE and in turn presence. The same process may apply to other elements such as the visual or motor realism of other avatars or that of the user, thus enhancing social and self presence.

Another possibility, is that rather than 'filling in the gaps' imaginative suggestibility helps users to 'ignore the gaps'. It has been shown that some users choose to ignore inconsistencies or other elements that break presence, a trait which has been operationalised and measured as one's willingness to become immersed in a VE [57]. Highly suggestible individuals who also score high on this trait may find it easier to ignore some sensory information that is less immersive. Overall, our results on *Suggestibility* reinforce the idea that realism is a more abstract term than previously thought. What the user perceives as realistic is not strictly a result of technical factors that make a VE look or sound closer to the real world, but is heavily impacted by how the user internalises the VE [77].

The finding that females achieved higher levels of presence for all sub-types is in contrast with some previous work that found no effects of gender on presence [48], and others that found an inverse effect [16, 48]. In the case of Felnhofer et al. [16], they found that males scored higher on presence, but attributed this effect to higher anxiety levels felt by females in the VE, which was designed to elicit this emotion.

We contrast these findings with our results, which show that some gender differences previously found in VR literature may in fact be partially due to user variability in the level of imaginative suggestibility. In particular, we found that despite female users scoring significantly higher on *Spatial Presence* and *Social Presence* compared to males, this effect disappeared when accounting for *Suggestibility*. This means that females may interact with the VR content differently to males due to their increased level of imaginative suggestibility. In contrast it was found that both *Suggestibility* and *Gender* played a significant role in the formation of *Self Presence*. A previous study by de Almeida Scheibler and Rodrigues [14] found that female users were able to more readily embody a virtual avatar in VR, which led to higher levels of reported presence. We

Table 1: The Mean and SD for scores of Spatial, Social, Self Presence and Suggestibility, divided by Gender.

	Spatial Presence		Social Presence		Self Presence		Suggestibility	
	Female	Male	Female	Male	Female	Male	Female	Male
Mean	3.574	3.263	3.368	3.043	2.900	2.360	2.784	2.505
Std. Deviation	0.669	0.848	0.866	0.920	1.013	0.852	0.688	0.849

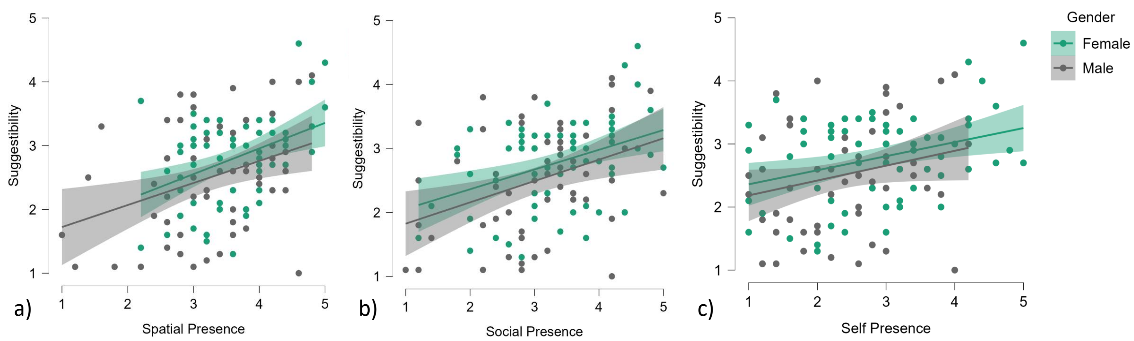

Figure 2: Correlation scatter plots between *Suggestibility* **and a)** *Spatial Presence***, b)** *Social Presence* **and c)** *Self Presence***, split across** *Gender*

add to this finding, showing that imaginative suggestibility is another factor that contributes to self presence. The remaining gender effect could, in some part, be explained by the fact that females usually score higher on empathy, which can lead to higher levels of identification with their virtual character [48]. This possibility should be explored further.

Ultimately, imaginative suggestibility is a characteristic that helps explain the mechanisms of the different types of presence. Understanding the applicability of our findings to other VEs and VR hardware configurations is an important next step. For example, an interesting question is whether the cartoon style of the VRO visuals and lack of other immersive features such as agency led to a higher effect of *Suggestibility* on presence. It could be that in higher-end VEs or HMDs users rely less on visual imagination to overcome the limitations in realism presented by the system. Still, it is possible that even in high-end, visually impressive VEs, higher *Suggestibility* could help alleviate the well-known "uncanny valley" effect [61]. On the other hand, providing an increased level of detail to a VE may also stimulate visual imagination further and potentially could bring added benefits to presence for users scoring higher on *Suggestibility.* If this is the case, imaginative suggestibility is particularly useful, especially given that rendering high fidelity VEs comes at a considerable computational cost, or to the detriment of other qualities [1]. Thus, the observed effects of user imaginative suggestibility and gender on presence provide further evidence that understanding individual differences and the way they interact in the presence-formation process may be the key to enabling a wider appeal and adoption of VR by the masses.

In contrast to some research that found priming to enhance presence in VR [9, 13], we found no such effect. In particular, we show that targeted auditory conceptual priming is not able to elicit higher scores on any of the three presence sub-types. The lack of any priming effect is interesting and could be due to particular characteristics of our priming material and administration method. Skarbez [64] suggests that in fact the perceived realism, or plausibility of a VE is not necessarily a function of how accurately it can replicate real life, but rather the extent to which the VE meets user's expectations. Arguably, however, these expectations can vary in how concrete or rich in detail they are. Our priming material may not have been detailed enough to elicit vivid mental representations of the VE prior to experiencing it. This is because we aimed to implement priming as a time-efficient method of enhancing presence and thus created paragraph-long materials. In contrast, Cerda et al. [9] provided contextual priming via a whole page of information that participants had to read prior to experiencing a VE. Another contributing factor could be that our priming was administered via the auditory modality, which is much poorer in terms of conveyed information compared to the visual [68]. In contrast, Daher et al. [13] administered visual priming which showed to be successful in enhancing presence. This raises interesting questions about the effectiveness of different types of priming techniques for enhancing presence.

5.1 Limitations

The present work only recruited participants who self identified as male or female. Although beyond the scope of this study, future work should explore these effects on non-binary or other classifications of gender to further broaden and expand our understanding of the relationship between gender, presence, and imaginative suggestibility. Further studies should aim to recruit samples of gender-diverse people in order to further widen the applicability of these findings and the use of VR for the most inclusive population possible.

In addition, we administered our presence questionnaires outside of the VR environment on a computer screen. While no differences have been found in scores of reported presence between within-VR and screen-based presence measurements [60], it has been shown that administering presence questionnaires within VR may increase score consistency [60]. Future studies should aim to adopt this practice to decrease variability in responses.

5.2 Future Work

While our work focused on one VE, in future it is important to explore the effects of imaginative suggestibility within a variety of VEs characterised by different technical qualities. In particular, agency has been shown to have a strong effect on presence, especially within VEs that are designed to elicit fear [26]. The lack of effect with our priming material shows there are rich avenues to explore, in particular in what concerns visual and multisensory priming, as they might provide a richer impression of what to expect in the main VR experience.

The MPS has been highly correlated with both the IPQ [74] and PQ [75], therefore we expect that suggestibility would show the same effects on presence as measured via these widely-used questionnaires. Still, further studies should employ other measures of presence and verify if there are more nuanced relationships with suggestibility. Future work could also consider electroencephalograms (EEG) brain-related measures for measuring presence [19] which has been explored with 2D screen content [70]. Additionally, a recent study has shown promising results for measuring presence in VR with EEG, finding that some signals were correlated to spatial and self presence as measured by the MPS questionnaire [20]. Despite this, EEG measures are currently difficult to administer in VR because of electromagnetic interference, movement artefacts, increased discomfort to the user as well as a long setup time. There are also open questions around which signals can be predictors of presence, considering not all have even been measured yet with users experiencing VR [20]. Thus, despite showing great potential, more research needs to be conducted to form the necessary theoretical and practical basis before one can readily use EEG in VR to measure presence.

While we only focused on imaginative suggestibility, there are several other methods of measuring suggestibility and further studies should aim to extend our findings to them. Additionally, other personality traits should be explored with regards to their impact on presence, while accounting for the effect of imaginative suggestibility. Similarly to our observed effects in conjunction with gender, there may be other distinct individual differences that interact with imaginative suggestibility in the presence-formation process. Finally, given the observed effects of imaginative suggestibility for presence in VR, new measures should be developed and validated. The CIS was administered in a sound proof room and took approximately 20 minutes to complete. Ideally, shorter measures to be administered in VR could be developed that tap into the same cognitive processes as suggestible visual imagination does [50].

5.3 Impact

The strong and uniform effect of imaginative suggestibility across all types of presence is remarkable and presents a step forward in better understanding the role of user individual differences in the context of VR. Based on our findings, measuring imaginative suggestibility is important for studies that explore presence in VR because it provides richer information about what levels of presence the user may achieve prior to entering the VR environment. If not controlling for imaginative suggestibility, findings of increased presence (or lack thereof) may not accurately represent the experimental conditions being manipulated. This is particularly relevant given that other technical improvements come with prohibitive costs and expertise that are still not always feasible for consumer-grade HMDs and virtual experiences. Our findings on imaginative suggestibility and gender provide a better understanding of the role gender plays on presence in VR, and confirms the need to understand these differences at a more fundamental level. Overall, our results are a testament to the importance of understanding the diverse populations that could use VR.

6 CONCLUSIONS

In conclusion, the present study showed that a previously unexplored characteristic, imaginative suggestibility, can impact three sub-types of presence in VR. We also show that suggestibility may be the mediating factor between gender and some types of presence. Furthermore, we show that targeted auditory priming in VR does not enhance any sub-types of presence.

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A PRIMING MATERIALS

The following paragraphs present the priming material that was recorded and presented to participants in the relevant conditions.

A.1 Spatial Priming

A perilous road stretches from the western coast to the Sanctuary of Zeus of Dodona. The sacred place is surrounded by a heavily wooded valley. There is a lingering scent of rain, and the ground is damp underfoot. The air is warm and humid. There is smoke rising from a recent sacrifice. Cattle and sheep are grazing in nearby meadows. Birdsong rises and falls all around. At the behest of the priest, lies the sacred way towards the oracle. Traces of those who have walked this path in the past emerge from the sunlit haze in the form of dedications to the god. Statues, vases, weapons and jewellery adorn the plinths that line the path as the uppermost branches of the tree come into view. The age of the sanctuary manifests in the shape and slow movement of the sacred tree.

A.2 Self Priming

You are enslaved—and you have managed to run away from those who currently enslave you/owners, to seek refuge at the sanctuary of Dodona. You lived in a small village on the Illyrian coast, but when you were a child you were captured by pirates. Your family could not pay the ransom that the pirates demanded and so you were sold to a slave trafficker. The trafficker sold you to a rich family, who had made their money trading in amber. They used you mainly for domestic chores. They said you didn't work hard enough—and finally decided to sell you. They have taken you up the coast to a big slave market in a nearby city, but you have managed to escape and made your way to the sanctuary of Zeus at Dodona.

A.3 Social Priming

Xanthias, your guide, is a priest of the sanctuary. He was born in Thrace and sold into slavery. He escaped from slavery and sought safety at the sanctuary. He has tattoos on his body like many people in Thrace. Then you meet two brothers, who are soldiers wearing the red cloaks of the Spartan army. One brother thinks that someone has tried to poison his wife and child. They meet Dorios, who sells spells of protection. Before seeing the oracle, you meet two traders, Archephon and Timodamos, who are talking about how they use the oracle. Archephon is not as wealthy as Timodamos, and he is looking for ways to increase his business. Timodamos is at the top of his game and very confident. He often consults the oracle and believes that his success come from his devotion to the gods.