



Article

# Association of Individual Factors with Simulator Sickness and Sense of Presence in Virtual Reality Mediated by Head-Mounted Displays (HMDs)

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**Abstract:** Many studies have attempted to understand which individual differences may be related to the symptoms of discomfort during the virtual experience (simulator sickness) and the generally considered positive sense of being inside the simulated scene (sense of presence). Nevertheless, a very limited number of studies have employed modern consumer-oriented head-mounted displays (HMDs). These systems aim to produce a high the sense of the presence of the user, remove stimuli from the external environment, and provide high definition, photo-realistic, three-dimensional images. Our results showed that motion sickness susceptibility and simulator sickness are related, and neuroticism may be associated and predict simulator sickness. Furthermore, the results showed that people who are more used to playing videogames are less susceptible to simulator sickness; female participants reported more simulator sickness compared to males (but only for nausea-related symptoms). Female participants also experienced a higher sense of presence compared to males. We suggest that published findings on simulator sickness and the sense of presence in virtual reality environments need to be replicated with the use of modern HMDs.

**Keywords:** simulator sickness; presence; virtual reality; virtual environments; personality; head-mounted displays



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## 1. Introduction

The term “virtual reality” (VR) is generally used to describe a synthetic environment generated by a computer [1]; however, many terminological definitions have been proposed [2–4]. These definitions share a reference to three features common in VR systems: immersion, perception, and presence [2]. Immersion is generally described as the objective features of the simulated environment (senses stimulated, capacity of interaction, and realism of the stimulation). Perception refers to the subjectivity elicited by the stimuli, while presence is the subjective psychological sense of “being there”, involving the sensation of physical presence in the simulated environment. VR can induce a higher sense of presence [5] in the user compared to traditional visualization technologies (screens, projectors, etc.) due to the increased level of realism of the visual stimuli.

In the present manuscript, VR is used to indicate general virtual environments, independent of the type of equipment used for the exposure. Head-mounted display (HMD) VR will be used to specifically indicate HMD-mediated VR experiences. Furthermore, the term “presence” will be used to describe the subjective feeling of being in a simulated scenario (instead of, e.g., immersion), following the terminological descriptions as discussed in the important work of [6].

During the past five years, VR has attracted the interest of users and, consequently, investors; for example, the tech giant Facebook purchased the VR development firm Oculus in 2014 for the shocking sum of US \$2 billion [7]. While a wide variety of hardware on the market has been proposed to mediate the VR experience, this term has recently been

associated with HMDs, such as Oculus Rift and HMD VIVE. HMD devices are quickly becoming more portable, and new models—among the most popular are Oculus GO and Oculus Quest—feature stand-alone solutions, where the HMDs do not need to be connected to a computer. Currently, several companies have started developing and making investment in the business [2,8].

Nevertheless, modern HMD VR is only the latest iteration of a technological idea that to date has more than 50 years of development behind it [9–11]. Technological advancements have now made the technology more available for widespread use and have contributed to decreased product costs. Videogames employing VR are becoming more common in the market, and VR is increasingly finding space as a tool for scientists. VR technology allows experimental studies that are not possible to perform in standard laboratory settings, for example, experiments that require a large space to study aspects of spatial navigation and a sense of space. VR-based software is currently widely used for entertainment as well as to adequately train industrial personnel to perform dangerous work tasks [12].

Several studies have investigated human experience in VR, especially regarding the sense of presence and user discomfort during its use. However, most of the experimental results reported in the literature have not used modern HMDs devices but are often limited to military simulators. Many of the published articles have used technology that is generally quite different from the nowadays widely available consumer-oriented HMDs, and their findings need to be re-assessed in the framework of modern visualization technologies that allow for a more realistic and user-friendly modality of simulation.

### 1.1. The Present Study

In the framework of a quickly developing and a growing audience for VR technology, the present study aims to update and extend the current literature on the individual factors associated with simulator sickness (SS) and the sense of presence. Especially relevant is the role that the present study plays in update the current literature on VR to modern consumer-oriented HMDs. Most of the published studies have investigated these associated factors using technologies that are rarely accessible to the public because very expensive or very specialized (e.g., simulators employed for pilot training). By contrast, the present study employed modern consumer-oriented HMD technology.

Several factors that the literature reported to be associated with sense of presence and SS were selected for analysis in the present study. The factors were selected among cognitive and psychological factors that were found among the most prominent in the literature on virtual environments, but for whose little empirical data was reported in relationship with modern consumer-grade HMD VR. However, it is worth mentioning that the subjective evaluation by the study authors had played a role in selecting these variables on interest that were investigated in the present study. The goal of the present investigation is to provide an answer to the following questions: (1) Which individual factors are related to SS and sense of presence in the context of modern virtual reality mediated by head-mounted displays? (2) What are the best predictors of SS and sense of presence among the analyzed individual factors?

### 1.2. Simulator Sickness

SS is sometimes called also cyber-sickness; however, the two terms are sometimes distinguished and at times considered as a sub-category of a similar phenomenon called motion sickness (MS; [13]). Both conditions share a similar set of symptoms, including fatigue, dizziness, sweating, and nausea. There is no comprehensive scientific explanation for SS and MS. Nevertheless, a few theories have been proposed: Among the two most cited are the postural instability and the sensory mismatch theories. According to the postural instability theory, SS symptoms arise due to a prolonged state of instability in posture control: The individual does not possess a sufficiently effective strategy to control and maintain postural stability within the virtual environment [13]. In the more recent literature, the theory of sensory mismatch has become the most supported theoretical approach to SS.

According to this theory, SS symptoms arise from conflicting or desynchronized sensory inputs; in the context of VR, they refer to the lack of coherence on the perceived visual stimuli and expected physical motion in the virtual environment. This type of stimulation incongruency has been often described as the cause of regular MS [14]

Several factors have been linked to the etiology of SS. Technical characteristics (e.g., low refresh rate, visual flicker, and latency delay) of the display delivering the immersive images are contributing factors for SS symptoms [15,16]. A comprehensive body of research in simulation/cyber sickness is particularly relevant to the military because military training, especially in avionics, depends heavily on environmental simulation. The Institute of Research for Sciences and Social Behaviour, in the United States, has investigated flight simulators and found that around half of the training pilots reported SS symptoms [16]. SS susceptibility has been widely studied, and many factors have been individuated as possible predictors. Kennedy et al. [17] listed 13 factors implicated in SS and divided them into three sub-categories: individual, simulator, and task factors. A later review [18] individuated as many as 40 different factors associated with SS symptoms.

Users' age has also often been reported as a predicting factor of SS, following the same pattern of findings reported for motion sickness [18–22]. Children under 2 years of age are usually not susceptible, while the susceptibility reaches its maximum between the age of 2 and 12 years. A steep decline is reported between 12 and 21 years of age. The tendency to experience SS continues to decline during adulthood until the age of 50 years. However, as [23] pointed out, these findings are from an outdated review [24] based on self-reported data that often did not directly assess SS but rather the similar phenomenon of MS. To date, there are few studies that have attempted to study the relationship more directly between age and SS, and some did not find a clear association [25]. To further complicate the issue, it is reportedly common knowledge in avionics that older individuals who participate in simulator-based training are more susceptible to SS compared to young ones [23].

In many studies, females have been found to be more susceptible to SS compared to males (e.g., [18,19]). The reasons for the sex imbalance of SS symptoms are unknown. Some researchers have theorized that it relates to hormonal levels during the female menstrual cycle (women are more susceptible to SS during a specific portion of their menstrual cycle); however, this hypothesis is not accepted by all the scholars [19]. Other researchers have noted how females generally have a larger visual field of view (FOV), and a larger FOV is associated with a greater level of SS [19]. Given that data on SS intensity is based on self-reports, it has been also suggested that males may be more likely to underreport the degree of subjective discomfort (e.g., [19,26]). However, some investigations have failed to replicate earlier published findings, and did not report any difference related to users' sex (see [27] for a review).

Older studies have suggested that neuroticism, anxiety, arousal, introversion, and perceptual style are associated with MS [24]; therefore, individual personality traits were believed to have a role also in SS. However, newer investigations have shown that none of the "big five" personality types—openness, conscientiousness, extraversion, agreeableness, neuroticism—are associated with MS [28]. To our knowledge, associations between the big five personality types and SS has not been directly assessed by the published literature. However, it has been reported that SS may be associated to other factors related to personality, as reported level of anxiety (see [29]).

Golding [28] proposed that psychological momentary "state" variables underlie emotional discomfort; for example, an extreme feeling of fear or anxiety may be associated to MS (and by extension to SS). By contrast, previous studies have shown that the "fight-or-flight" arousal observed in warfare and other situations suppresses MS [24].

Individual mental rotation abilities have also been reported as one of the predicting factors for SS. Parker and Harm [30] theorized that mental rotation abilities serve a role in efficiently perform goal-directed locomotion, and such an ability is commonly employed in VR. Mental rotation ability is inversely correlated with MS [31] and connected to a sex

difference in spatial rotation ability (with women performing more poorly and experiencing more motion sickness).

A number of other individual factors have been reported in the literature as associated with SS [26], including the concentration level during the VR task [32], ethnicity [33,34], experience with the simulated task (with users who are used to the real task experiencing more SS in a simulated scenario (see [18]), and adaptation to the simulation (users who have experience with the simulation report a lower level of SS; see [35]). It has been advised that only physically fit subject should experience simulator exposure [17] and simulators should be avoided in case of several conditions, including fatigue, sleep loss, hangover, and flu, among others. Moreover, people with visual deficits may have a tendency for elevated susceptibility to SS (as hypothesized in [36]). Further, a history of susceptibility to MS is correlated with the degree of SS discomfort [37]. Contrasting results have been reported about the association between previous gaming experience and SS: [38] reported a negative association, while [39] showed no association.

### 1.3. Sense of Presence

Presence is commonly described as the psychological feeling of being transported from the real to a simulated environment. In the literature, it is often simply described as the feeling of “being there” [40]. An elegant description of the sense of presence was proposed by Lee ([41], p. 32): “a psychological state in which the virtuality of experience is unnoticed”.

Inducing a high sense of presence has often been regarded as of the sign of a successful experience in a simulated environment [42] and has frequently been viewed as the goal to achieve with the use of such technologies [43]. Several different definitions and dimensions of presence have been proposed over the years (see [19,44,45]), and this fact is clearly reflected by the number of different questionnaire instruments that aim to measure this psychological construct (for a review see [46]). Presence is crucial for the evaluation and design of products that employ modern visualization technologies in the field of entertainment, telecommunications, and education [41].

Many individual factors are related to the experienced sense of presence in VR. Researchers have theorized that presence relates to the degree of possible interactions in the simulated environment [47], as well as the degree of realism of the virtual scenes [48]. Individual factors seem to be important in predicting the experienced degree of presence of a user [48].

Several studies have explored the possible association between age and the sense of presence, but these experiments have provided contrasting results. Bangay and Preston [49] reported, in a large study with 355 participants (swimming with dolphin interactive simulator), that younger participants (10–20 years old) reported a higher sense of presence compared to older (35–45 years old) ones. More recently Schuemie et al. [50] exposed 41 participants to a virtual environment with the aim to expose the participants to acrophobic settings (fear of heights). They found a positive association between age and the score of presence. The very different environment used in these simulations, together with the heterogeneous results, suggest that the content of the simulation may affect the sense of presence depending on the age of the participants.

The effect of sex on presence rating has been widely discussed [51,52]. Previous research has shown conflicting evidence on the topic. Gamito et al. [39] presented evidence for a higher level of presence in men compared to women, and older studies have shown that men report a higher sense of presence compared to women [51,53]. Some studies, such as Khashe et al. [54], De Leo et al. [55] and Schuemie et al. [50], found no differences on the sense of presence experienced by male and female participants.

Previous research has reported no relationship or a minimal association between the degree of reported presence and previous experience with gaming [50,56]. However, Gamito et al. [39], found an association between gaming experience and immersion (Immersive Tendency Questionnaire (ITQ); [48]).

Studies that investigated the association between presence and personality traits have reported heterogeneous results. Kober and Neuper [57] found that the big five personality traits do not correlate with the experienced sense of presence when it is measured using the Slater-Usoh-Steed (SUS) questionnaire, the Presence Questionnaire (PQ), and a five-point scale for assessing presence. However, they found that that possible associations between presence and personality traits may be sensitive to the questionnaire used to evaluate presence. They reported an association between openness and presence when presence was measured using the Short Feedback Questionnaire (SFQ). Other studies have revealed that users with high degrees of openness, neuroticism, and extraversion experience a higher sense of presence [58,59]). However, Laarni et al. [60] did not find any association between neuroticism and presence. Other studies that investigated personality traits other than the big five, found that imagination, immersive tendencies, and empathy [61,62] are positively correlated with the sense of presence experienced in VR.

Sense of presence and SS have often been reported as inversely correlated (for a review, see [63]). Researchers have hypothesized that the relationship between presence and SS may be mediated by other factors, including vection (illusion of self-motion produced uniquely by visual stimulation), navigation control, and display characteristics [63].

## 2. Methods

### 2.1. Participants

Fifty-five volunteers, recruited among the student population of the Norwegian University of Science and Technology (Trondheim campus), participated in the experiment. A minimum number of 50 participants was established prior to the experiment, considering the number of participants reported in previous studies that investigated similar research questions (e.g., [57,64]).

The data set for one of the participants was incomplete for several questionnaire responses, and therefore the participant was excluded from all analyses. The remaining 54 participants (33 females) were between 18 and 40 years old ( $M = 23.91$ ,  $SD = 3.13$  years). All volunteers declared not to be affected by psychological disorders and generally healthy. All the participants received a short study description and were asked to read and sign the informed consent before the experimental session. The study was conducted with permission from the Norwegian Data Protection Agency (NSD) and in accordance with the ethical guidelines of the Declaration of Helsinki.

### 2.2. VR Scenario

The virtual environment showed a first-person roller-coaster ride. The ride is part of a VR customer-oriented video game called “Epic Roller Coaster” (B4T Games). This VR setting was chosen among others for its ability to induce, even after a short use, a good level of sense of presence due to its emotionally arousing content. After a pilot test of the experiment, we noticed a high degree of variation in the reported MS for different subjects; Hence, we thought this environment would be ideal to explore the role of individual differences in evoking sense of presence and MS. Furthermore, the use of a roller-coaster (highly arousing) scenario to induce a good level of presence has been used in several previous study (e.g., [65]).

The virtual ride was set in a forest and rocky environment, and the environment generally showed a good level of photographic realism; examples from the scenario are presented in Figure 1. None of the participants declared to be familiar with the game prior to the experiment. The virtual environment was delivered using the Oculus GO HMD, which features a 5.5-inch LCD display with a  $2560 \times 1440$  ( $1280 \times 1440$  pixels per eye) resolution, a refresh rate of 72 or 60 Hz (depending on the application running), and a FOV of 101 degrees (see the producer website at <http://www.oculus.com/go/> (accessed on 19 February 2021) for more technical information). The developer and copyright holder of the software gave written consent for the use of the game as well as for disclosing images of the game in activities aimed at scientific communications.



**Figure 1.** Example images from “Epic Roller Coaster” by B4T Games.

### 2.3. Questionnaire Instruments

All questionnaires were presented in the Norwegian language because all the participants were native Norwegian speakers. All utilized questionnaires were translated from a pre-existing English version by the authors of the present article. We used the already published and validated Norwegian translation of the Neuroticism-Extraversion-Openness Five-Factor Inventory (NEO-FFI; Martinsen, [66]). The questionnaire was used with permission by the copyright holder (Hogrefe Verlag GmbH & Co., Göttingen, Germany). The Norwegian translation of the Positive and Negative Affects Schedule (PANAS) questionnaire was based on the combination of the English and Swedish published versions. The PANAS questionnaire is very widely used in many fields of psychology. Nevertheless, it is currently not available in Norwegian.

For the “joystick years” questionnaire, we used a translation of the questionnaire presented by Kühn and Gallinat [67]; it was developed to quantify the use of video games. It contains three questions that assess “how many hours per day”, “how many days a week”, and “for how many years”, a person has been playing videogames. The questionnaire was used to assess the participants’ video-gaming experience and, in a modified version, to specifically assess the time and familiarity of using VR. The final score of the questionnaire is calculated (following the scoring instructions described in [67]) as follows: hours  $\times$  days per week  $\times$  52 (weeks per year)  $\times$  years. For this reason, the joystick years final scores are, somehow counterintuitively, in the range of thousands.

We used the PANAS scale [68] to assess positive and negative affects as transient states as well as for a long-term feeling. In the present experiment, the PANAS was used for evaluating the feeling of the participants both “right now” (i.e., right before the experiment) and after the VR experience (with the aim to assess the participants emotion during the simulation). The version of the PANAS used in the present study presents 20 items/words that describe different positive and negative affects (e.g., active, proud, irritable, afraid). Each item needs to be rated on a 5-point scale of 1 (not at all) to 5 (very much).

The Motion Sickness Susceptibility Questionnaire (MSSQ; [69]) assesses the level of MS experienced during various transportation or activities. It contains 9 items/words; each one describes a category of possible experiences that elicit MS (e.g., cars, buses, swing, funfairs, etc.). Each item is rated on a 5-point scale of 1 (never) to 5 (always).

The Mental Rotation Test (MRT, [70]) measures the mental rotation ability. The test shows, on paper, a geometrical object and four variations of a it (the same object rotated in space). Two of these variations are wrong (not an actual rotation/another object). The participant is asked, after a short explanatory training session, to find, among the

four objects, the ones that do not represent the rotation of the sample item. In the original version of the test, the participant has 3 min to perform the task on 20 different sample items, then, after a short pause, to repeat the test for 3 more minutes (and 20 different items). However, due to the time limitation in our experimental setting, only half of the original experiment was used (20 items, 3 min).

The NEO-FFI [71] is a personality inventory that comprises 60 items; it is a shorter version of the Neuroticism, Extraversion, Openness Personality Inventory-Revised (NEO-PI-R) personality inventory [72]. This inventory examines the big five personality traits. Each of the questions can be answered on a 5-point scale.

The SUS questionnaire [52] measures the level of presence experienced by a user in an immersive environment (for a review on the differences between presence questionnaires see [73]). It contains six items (phrases) that can be answered on a 7-point scale. This questionnaire was chosen among the many available because it is highly correlated with other type of presence questionnaires (Short Feedback Questionnaire—SFQ, PQ, and 5-point rating scale) from a previous study that examined individual difference association with the sense of presence [57].

The Simulator Sickness Questionnaire (SSQ, [74,75]) is a widely used tool for the assessment of the severity of perceived SS symptoms. It contains 16 items (e.g., nausea, headache, blurred vision, etc.) divided into three subscales based on the type of symptoms (nausea, oculomotor, and disorientation subscales). For each item, the participant rates the severity of the experienced discomfort using a 4-point scale (1 for none, 4 for severe).

#### 2.4. Experimental Procedure

The participants arrived at the laboratory facilities upon their appointment and were asked to sit and read and sign the informed consent form. Subsequently, in order of time, the participants were asked to complete a questionnaire assessing their general information (age and sex), as well as their familiarity with both gaming and virtual reality environments (joystick years, two forms of a modified version of the questionnaire). Next, the participants were asked to complete the 20-item PANAS asking to assess their emotions “right now” (hereinafter referred to as PRE-PANAS). Furthermore, they completed, in the following order, the MSSQ, the MRT, and the NEO-FFI. The participants were then instructed to wear the Oculus GO HMD and experience a roller-coaster simulation experience for 3 min. After VR exposure, the participants were asked to complete the SUS questionnaire and the SSQ. Finally, they were asked to again complete the PANAS by recalling and reporting their emotions “during the VR experience” (hereinafter referred to as POST-PANAS; please note that this formulation of the PANAS is not standard and was adapted by the investigators of the present study). Raw questionnaire data (after appropriate scorings were computed) was used in all the analyses. The experiment lasted a total of around 45 min. A break of around 1 min was given after each of the questionnaire batteries, in which the experimenter introduced to the participant to the questionnaire instruction.

#### 2.5. Data Analysis and Statistics

We used IBM SPSS Statistics for Windows, version 25 (IBM Corp., Armonk, NY, USA) to perform statistical analysis. To understand the relationship between dependent and independent variables, we used non-parametric Spearman’s correlation analyses. This test handles ordinal data and is robust to outliers (often found in questionnaire data). Non-parametric correlation statistics have also been preferred in similar published studies (e.g., [57,64]).

To understand the possible difference between males and females in our study, we computed independent sample *t*-tests. For these tests, when Levene’s test for equality of variance was statistically significant, we reported corrected *p* and *t* values. Finally, to individuate independent variables that predict sense of presence and the SS subscales and total score (dependent variables), we used a stepwise regression. This method is consistent

with the analysis performed in a previous similar study [57]. Due to the exploratory nature of some of the analyses, we utilized two-tailed tests for all the statistical analyses.

### 3. Results

#### 3.1. Descriptive Statistics

Descriptive data for the scores obtained in the present study are shown in Table 1. The data related to the joystick years questionnaire evaluating the use of VR was eliminated from this and further analysis because all the participants were revealed to be new to the use of HMD-mediated VR. Instead, we analyzed the joystick years questionnaire that evaluated general gaming experience. Hereinafter, when referring to the joystick years questionnaire, we are specifically referring to the latter one. In [67], where the joystick years questionnaire was used to assess frequency of gaming, the authors reported for their sample an average of 3844 joystick years (SD 5057), which is substantially higher than our sample.

**Table 1.** The results for all the questionnaires used in the present study.

	Variable	M	SD
PRE-PANAS	Joystick years (gaming)	1876.81	3585.22
	Positive affects	30.42	5.24
	Negative affects	15.28	4.13
	Motion sickness susceptibility	17.59	5.13
Neo FFI	Neuroticism	2.02	0.81
	Extroversion	2.55	0.69
	Openness	2.64	0.55
	Agreeableness	2.50	0.56
	Conscientiousness	2.60	0.74
SSQ	Mental rotation ability	5.44	2.62
	Presence (SUS)	4.44	1.35
	Nausea subscale	60.77	36.09
	Oculomotor subscale	41.83	32.15
	Disorientation subscale	105.43	68.49
	Total simulator sickness	72.79	44.44
POST-PANAS	Positive affects	32.28	7.15
	Negative affects	17.72	5.99

Note. FFI: Five Factor Inventory; SUS: Slater-Usoh-Steed questionnaire; SS: simulator sickness; PANAS: Positive and Negative Affects Schedule; Neo-FFI: Neuroticism-Extroversion-Openness Five-Factor Inventory.

The PRE-PANAS scores were in line with the average reported in the questionnaire validation article (see [68], which reported a mean of 29.7 (SD 7.9) for positive affection and 14.8 (SD 5.4) for negative affection when asking for to rate the feelings “right now”). However, the POST-PANAS questionnaire (asked to evaluate the affections during the simulator) showed significantly higher scores for both positive and negative affection compared to the means reported by the previously cited study.

The SSQ results in our study were higher than the average scores reported for older simulators (see [75]) as well as for newer virtual environments [76]. The MSSQ mean score was consistent with the one reported by the adult population in [69], namely 16.7 (SD 17.5). The mean values for NEO-FFI inventory were in line with the average reported in the literature (see [57]). The mental rotation ability mean scores were consistent with the results reported in Peters et al. (2006) [70], when considering that the participant of the present study only performed half of the test.

For the SUS presence questionnaire, the mean presence ratings were comparable to previous studies that have employed the same questionnaire. According to [77], the SUS presence questionnaire showed an average score between 2.6 and 4.6, depending on the type of simulator type and simulated environment employed. The more recent study of [57] reported a SUS score of 4.26.

### 3.2. Individual Factors and VR Experience

We conducted correlation analyses to assess the association between the dependent variables of interest (presence and SS) with individual variables such as age, gaming experience, positive and negative affects prior to the experiment, MS susceptibility, big-five personality traits, and mental rotation ability (see Table 2). MS susceptibility was associated with the reported degree of SS (excluding the oculomotor subscale). The neuroticism personality trait was associated with the nausea subscale of the SS inventory. Our follow-up analyses showed that presence and the SSQ (in all its subscales) were not associated ( $p > 0.435$ ).

**Table 2.** Spearman's correlations between the analyzed individual factors and reported sense of presence and experienced degree of simulator sickness.

		Presence SUS	Nausea Subscale	Simulator Sickness Questionnaire		
				Oculomotor Subscale	Disorientation Subscale	Total Simulator Sickness
PRE-PANAS	Age	0.075	-0.080	-0.165	0.000	-0.080
	Joystick years (gaming)	-0.059	-0.232	-0.244	-0.267	-0.263
	Positive affects	0.179	-0.079	-0.029	-0.158	-0.101
	Negative affects	0.20	0.265	0.268	0.196	0.267
	Motion sickness susceptibility	0.046	0.404 **	0.208	0.331 *	0.339 *
Neo FFI	Neuroticism	0.077	0.300 *	0.138	0.121	0.191
	Extroversion	0.200	-0.077	-0.084	-0.101	-0.100
	Openness	0.093	-0.113	0.055	0.109	0.033
	Agreeableness	0.006	-0.040	0.0060	0.121	0.026
	Conscientiousness	-0.140	-0.039	0.052	0.083	0.026
	Mental rotation ability	-0.190	0.83	0.121	0.209	0.170

Note. Spearman's Rho values are reported; \*  $p < 0.05$ ; \*\*  $p < 0.01$ ; SUS: Slater-Usuh-Steed questionnaire; PANAS: Positive and Negative Affect Schedule; Neo-FFI: Neuroticism-Extroversion-Openness Five-Factor Inventory.

### 3.3. Affections during the VR Experience

We conducted correlation analyses to understand the relationship between the dependent variables of interest (presence and SS) and the emotions experienced by the participants during the VR experience, using the POST-PANAS scores. An overview of the analyses is presented in Table 3. The degree of presence was significantly correlated with positive and negative affects experienced in the simulation. Positive emotions negatively correlated with the nausea and disorientation subscales of the SSQ, but not with the oculomotor subscale (nor in the total score). Predictably, negative emotions showed a strong correlation with all the SSQ subscales, including the total score.

**Table 3.** Spearman's correlations between the analyzed individual factors and reported sense of presence and experienced degree of simulator sickness.

		Presence SUS	Nausea Subscale	Simulator Sickness Questionnaire		
				Oculomotor Subscale	Disorientation Subscale	Total Simulator Sickness
POST-PANAS	Positive affects	0.319 *	-0.337 *	-0.141	-0.299 *	-0.266
	Negative affects	0.294 *	0.594 ***	0.320 *	0.436 **	0.489 ***

Note. Spearman's Rho values are reported; \*  $p < 0.05$ ; \*\*  $p < 0.01$ ; \*\*\*  $p < 0.001$ ; SUS: Slater-Usuh-Steed questionnaire; PANAS: Positive and Negative Affects Schedule.

### 3.4. Sex Differences

For the dependent variables, we identified a sex difference for the sense of presence, with females experiencing a higher sense of presence compared to males ( $t(52) = 2.46$ ,  $p = 0.017$ ). Females were also more inclined to experience nausea (nausea subscale, SSQ) symptoms during the simulation ( $t(52) = 2.033$ ,  $p = 0.47$ ). However, there was no sex difference for the other SSQ subscales on the total SSQ score ( $p > 0.201$ ).

To further explore sex differences, we performed independent sample  $t$ -tests for all the independent variables (including the POST-PANAS scores) with sex as the grouping variable. For the independent variables, male participants showed a higher score in video-game use (joystick years;  $t(52) = -3.24$ ,  $p = 0.004$ ) as well as higher mental rotation abilities ( $t(52) = -3.20$ ,  $p = 0.002$ ). We then separately analyzed the independent variables that

showed statistically significant differences between the sexes for each sex in correlation analyses. Video-game use was not associated with presence in males or females.

Score on video-game uses was negatively associated with SS symptomatology in the male sample, but it was statistically significant only for the disorientation subscale ( $Rho = -0.392$ ,  $p = 0.024$ ). However, the same trend was evident also in all SSQ subscales (nausea subscale,  $Rho = -0.197$ ,  $p = 0.271$ ; oculomotor subscale,  $Rho = -0.244$ ,  $p = 0.170$ ; total score,  $Rho = -0.329$ ,  $p = 0.061$ ). There were no statistically significant associations or trends for female participants ( $ps > 0.731$ ). As we previously mentioned, the authors of the joystick years questionnaire [67] reported an average of 3844 joystick years (SD 5057) for their sample, which is well above the one reported for the present study. However, when we only considered the males in our sample, the average joystick years score was of 4034.95 (SD 4924.89), a value that is more in line with the data reported in [67]. A low overall score in the female participants ( $M = 503.45$ ,  $SD = 1062.26$ ), with 23 out of the 33 female participants having a total score of 0 (completely unfamiliar with video-gaming). The mental rotation ability was not associated with the sense of presence in either sex.

### 3.5. Predictors of Presence and SS

To understand how the studied independent variables can predict sense of presence (SUS score) and SS (in its three different subscales and the total score), we employed an exploratory stepwise regression analysis. We included all the possible predictor variables: age, sex, video-gaming experience, positive, and negative affection (PRE-PANAS), MS susceptibility, neuroticism score, extroversion score, openness score, agreeableness score, conscientiousness score, and mental rotation ability. The POST-PANAS scores were not included: Given that they were reported during the experience (i.e., together with the experience of presence and eventually SS), we believe that they cannot be considered real predictors. The results of the four separated regression analyses are shown in Table 4. The regression model for the sense of presence (SUS score) was significant ( $F(1,52) = 6.05$ ,  $p < 0.017$ ). The model only included sex as a predicting variable. The regression model for SS (nausea sub-score) was significant ( $F(1,52) = 16.58$ ,  $p < 0.001$ ). The regression model for SS (oculomotor sub-score) was also significant ( $F(1,52) = 9.53$ ,  $p = 0.003$ ). The regression model for SS (disorientation sub-score) was significant ( $F(1,52) = 13.38$ ,  $p = 0.001$ ). The regression model for SS (total) was significant ( $F(1,52) = 15.95$ ,  $p < 0.001$ ). All the regression models that predicted SS scores included only MS susceptibility as a predicting variable. The results are presented in Table 4.

**Table 4.** Results of the regression analyses for the dependent variables: Presence and simulator sickness subscale (Nausea, Oculomotor, and Disorientation sub-scores) and total Scores.

	R	R <sup>2</sup>	Predictor	b	SE b	Standardized b
Presence (SUS)	0.323	0.104	Constant	4.788	0.224	
			Sex	-0.883	0.359	0.323
Nausea (SSQ)	0.492	0.242	Constant	-0.33	15.546	
			MS	3.456	0.849	0.492
Oculomotor (SSQ)	0.394	0.155	Constant	-1.544	14.619	
			MS	2.466	0.798	0.394
Disorientation (SSQ)	0.452	0.205	Constant	-0.731	30.216	
			MS	6.034	1.650	0.452
Total (SSQ)	0.484	0.235	Constant	-0.971	19.228	
			MS	4.193	1.050	0.484

Note. SUS: Slater-Usuh-Steed questionnaire; SSQ: Sickness Susceptibility Questionnaire; MS: motion sickness.

Given that MS and SS are similar phenomena, it is not surprising that the MS score was a predictor for all the SSQ subscale scores and the total score. To study the influence of other variables with a much smaller effect on the model, we removed the MS score from the analysis and again ran a block regression. Please note that these following analyses were decided post-hoc and only have an explorative value. These analyses

revealed that neuroticism (NEO-FFI) is a predicting factor for the nausea subscale of the SSQ ( $F(1,52) = 5.10, p = 0.028$ ). The detailed results are presented in Table 5. Analyses for the other sub-categories of the SSQ are not reported as the analyses yielded non statistically significant results.

**Table 5.** Results of the regression analyses for the dependent variables.

Dependent Variable	R	R <sup>2</sup>	Predictor	b	SE b	Standardized b
Nausea (SSQ)	0.299	0.089	Constant	34.02	12.758	0.299
			Neuroticism (NEO-FFI)	1.11	0.490	

Note. Simulator Sickness Questionnaire (SSQ) partial (nausea, oculomotor, and disorientation sub-scores) and total scores after motion sickness were removed from the pool of predicting variables; NEO-FFI: Neuroticism-Extraversion-Openness Five-Factor Inventory.

#### 4. Discussion

In the framework of the present investigation, we aimed to study the relationship between individual characteristics and the human experience in VR environments. Specifically, this study focused on the sense of presence and the degree of experienced SS during exposure to a VR environment. Previous investigations have shown that several individual factors are associated with sense of presence and SS. We selected those factors that have shown to be relevant in the published literature. The research questions that we aimed to answer were: (1) Which individual factors are related to SS and sense of presence in the context of modern virtual reality mediated by HMDs? (2) What are the best predictors of SS and sense of presence among the analyzed individual factors?

##### 4.1. Users' Sex

In the present study, women were more susceptible to SS compared to men; however, this difference was only statistically significant for the SSQ nausea subscale. This result is consistent with a wide body of literature (e.g., [19,20,26,55]), but in contrast with other results from modern study using HMDs (e.g., [78–80]). In this regard, a previous work [50] used a different method for administrating the SSQ questionnaire compared to the one used in the present study; they obtained a final SSQ score by subtracting a pre-VR experience SSQ score from the post-VR experience SSQ. Their aim was to establish a baseline value for each one of the subjects. However, it is unclear from their article what was the basis for the evaluation of SS in the pre-VR experience SSQ. A non-standard method for administrating the SSQ, and possibly the ambiguity of the instructions in administrating the pre-experiment questionnaire, may have affected the obtained SSQ scores and weakened their results. Furthermore, none of the above-mentioned studies used HMD-mediated VR.

The effect of sex on presence rating has been extensively discussed in the published literature (e.g., [52,81]). The study of Bracken [52] found that women report more perceived realism compared to men. Their results are in line with our present study. However, [39] as well as other studies (e.g., [50,55]), found that male participants experience a higher sense of presence or showed no differences between males and females. These discrepancies are difficult to understand based on the current knowledge on the phenomenon; however, it is possible that sex differences in the level of presence may be sensitive to the content presented in the virtual environment. In favor of this argument is the data reported in [39] for the ITQ-F [82] "emotion" sub-component, where female participants scored significantly higher than men. This finding seems to confirm a different sensitivity to the content of the simulated environment depending on users' sex. The environment used in our experiment (emotionally arousing) may have modulated the emotional component of the sense of presence more than previous studies. Consequently, the overall sense of presence for women may have been greater than for men.

#### 4.2. Gaming Experience

Some published articles have reported no relationship between the degree of reported presence and previous gaming experience (see [50,56]), while others have found associations, specifically when considering the presence-related construct of “immersion” (see e.g., [39]). We did not find an association between sense of presence and gaming experience. However, we found an inverse association between gaming experience and SS for male but not female participants. Further, we did not identify this association when the scores were analyzed together for males and females. Notably, in the present study, joystick years scores for female participants lacked adequate variance, and only a few female subjects had a non-zero score. This factor may have affected the correlation tests. These results are partially in line with those reported in [38], that found that participants who are more used to gaming are less susceptible to SS. Due to the heterogeneous results, the association between media use (including gaming) and SS deserve further investigations.

#### 4.3. Emotional States

The positive and negative affections measured using PANAS prior to the experiment (PRE-PANAS) were not associated with the studied dependent variables. The relationship between emotions and experience in VR reported in the literature have often been complex and contradictory (e.g., [83]). We did not have any a priori hypothesis on the association of emotions measured with PANAS with either simulator sickness or presence, and the published literature did not have addressed the issue directly.

The post questionnaire (POST-PANAS) was positively correlated with presence for both the positive and the negative scores. This result suggests that the VR environment promoted the emotional involvement of the participants, both positively (e.g., possibly as enjoyment of the simulated roller-coaster ride) and negatively (e.g., discomfort, and sickness due to SS symptoms; in fact, negative affects score strongly correlated with all the simulator-sickness sub-scores). The positive effects were also inversely correlated with the SSQ scores (but statistically significant only for the disorientation subscale). This result suggests, not surprisingly, that the subjects who experienced less SS had more positive emotions during the experiment. These results also confirm the high capacity of immersive visual technologies (which can greatly modulate the sense of presence) in affecting human emotions [84].

#### 4.4. MS Susceptibility

Our correlation analyses showed that MS susceptibility correlated with the nausea and disorientation subscales of the SSQ as well as with the total SSQ score, but not with the oculomotor subscale. These results suggest an overall association of MS with SS. This finding was expected because the two phenomena are often treated as connected, and previous studies have shown a personal history of MS is predictive of SS [85].

#### 4.5. Personality Traits

Correlation analyses revealed that neuroticism was associated with the nausea subscale of the SSQ. Previous studies have shown a relationship between neuroticism and human health (e.g., [86,87]). Further, neuroticism may play a role in modulating psychological and physiological response to stress. Neuroticism is also believed to be particularly important in increasing reactivity to stressors, and people with high level of neuroticism tend to experience greater stress vulnerability [88] and use coping strategies when they feel they are in a stressful situation [89]. Our experiment may have been perceived as emotionally stressful (either for its contents or the situation of being tested as a subject) and may have triggered stronger physiological reactions in those participants with a high level of neuroticism.

The influence of personality traits related to anxiety (including neuroticism, see [90,91]) on visuo-vestibular system involved in the control of balance is a well-known phenomenon that has been often reported in the literature (see [92,93]). However, only recent scientific

research has explored the complex interactions between the visuo-vestibular systems and anxiety (e.g., [92–94]). In controlled animal laboratory experiments, rats that show high anxiety levels also display balance deficits [95–97]. Behavioral studies in healthy humans have also suggested that anxiety traits crucially modulate balance control [97]. Clinical research has confirmed that visual, vestibular, and anxiety systems may interact in the control of balance [92,98]. In tasks that require balance control, patients with vestibular and anxiety disorders rely more on visual information compared to healthy participants [99]. People without vestibular deficits are less likely to develop anxiety disorders compared to patients with vestibular disorders [100,101]. Similarly, patients with anxiety disorders frequently report an increased sensitivity to visuo-vestibular stimuli [102].

A previous study [93] examined the brain activity (using functional magnetic resonance imaging (fMRI)) during a VR experience of a roller coaster ride (it is worth mentioning that, from the images they presented in their publication, the simulation they have used had a lower level of visual realism compared to the ones used in the present study). They reported that individual differences in neuroticism (measured using the NEO-PI-R questionnaire) modulate brain activity and brain functional connectivity between brain areas related to visuo-vestibular and anxiety during the VR exposure.

Taken together, these findings support the idea that a tendency toward neuroticism and anxiety may have a role in shaping the human experience in VR, especially regarding the visuo-vestibular system, which is tightly linked with experience of SS (e.g., [103,104]). However, the physiological and neural mechanisms responsible for the interaction between these systems are poorly understood [93]. Finally, people with a more neurotic personality may be predisposed to report more of their negative symptomatology, as suggested by previous investigations (see [105]).

It is worth noting that only the nausea subscale of the SSQ correlated with neuroticism, and this fact surely weakens the interpretation of our results. This finding may also suggest that the nausea-related symptoms are related to different psychophysiological phenomena compared to the other symptoms investigated by the SSQ. However, this interpretation is post-hoc and should only be considered as speculative.

The other big five personality traits analyzed (extraversion, openness, agreeableness, and conscientiousness) did not show any relationship with SS. These data are consistent with other investigations [93]. They are in contrast with some older study about MS that found (negative) associations with extraversion [24] but not with neuroticism. Our findings are in line with previous published studies that have found the big five personality traits are unrelated to the sense of presence [57]. Interestingly, in [57] it was also found that the big five personality traits are unrelated with the sense of presence when the latter were measured with different types of questionnaires (PQ, SFQ, and five-point rating). Nevertheless, some studies have found that personality traits (measured using the Big Five or other types of personalities constructs) may related to the sense of presence. In previous studies, presence was found to be associated with empathy and locus of control [62,106], extraversion, impulsivity, and self-transcendence [60], absorption [57], and domain-specific interest and agreeableness [107]. The study of the association between personality traits and individual characteristics with both SS and sense of presence remains a line of research that deserves future investigations.

#### 4.6. Spatial Abilities (MRT)

The present study found that mental rotation abilities differed between male and female participants. However, the mental rotation ability did not correlate with SS or sense of presence when male and female participant scores were analyzed together or separately. Previous studies have sometimes reported that individual mental rotation abilities are one of the predicting factors for SS (e.g., [30]); however, based on our knowledge, the recently published literature has not attempted to replicate these results. Spatial ability correlates with the sense of presence (e.g., [108,109]) in studies using desktop systems. Research using HMDs has failed to replicate the association between presence (specifically in the compo-

ment of spatial presence) and individual spatial ability (see [56,110]). Consistently, [110] failed to confirm an association between spatial intelligence and spatial presence. The study of Coxon and colleagues [64] found no correlation between mental rotation abilities and sense of presence; however, they reported that other cognitive abilities (i.e., self-reported mental imagery capabilities) are positively related with the sense of presence. Our results are consistent with those obtained in HMD-mediated experiments [56,64,110].

#### 4.7. Association Between the Dependent Variables

In the present study, sense of presence and SS were not correlated, a finding that partially contrasts a recent literature review by Weech et al. [63] that reported SS and presence are generally negatively related (but see [111]). Nevertheless, almost all the studies reported by [63]—with the important exception of [112]—used older HMD technologies from the early 2000s (difficult to compare with modern HMDs) or delivered the VR using projectors or screens. The study reported in [112] used one of the earliest models of modern HMDs, although it was only a prototype and is currently quite outdated (the Oculus Rift DK2). The researchers did not report any association between sense of presence and SS. Our results suggest that sense of presence and SS may be related to the method in which VR is mediated (in this case HMD) and may be sensitive to the presented VR environment. In our case, the environment was a simulation of a roller-coaster ride, which represents an experience that (in real life) commonly induces some degree of motion sickness for most of the people. An increase in sense of “being” there (presence) may have increased the degree of experienced SS (as related with motion sickness experienced in a real roller coaster). Such a phenomenon may have counter-balanced a possible effect of reduced SS on the sense of presence. However, [112] did not report any association between sense of presence and SS and did not use a MS-inducing VR scenario (the VR displayed a scenario where the participant was sitting in a café). Hence, the latter argument loses its strength if their results are also considered.

Regression analyses showed that users’ sex had the best predicting power for the sense of presence, while MS tendency showed was highly predictive of SS in all its subcategories and in the total score. However, neuroticism was a good predictor of the nausea sub-score when MS tendency was removed from the regression model.

#### 4.8. Limitations

The present study presents several limitations, and the findings we have reported should be treated cautiously. Some of the average scores for the questionnaires used in the present study were substantially different from the ones reported in previous investigations. The abnormal data distribution for the scores of joystick years in female participants, and the low overall number of female participants with non-zero scores ( $N = 10$ ), influenced the population average score for this questionnaire. However, when we considered only male participants, the average joystick years were in line with the data reported in previous literature [67]. The SSQ results were higher than the average scores reported in previous studies (e.g., [75]). This finding is not surprising because we employed a VR environment to simulate a situation (roller-coaster ride) that commonly induces some degree of motion sickness even when experienced in the real world. Nevertheless, none of the participants dropped out of the experiment before its conclusion, even though they were clearly informed before the experiment that they could drop out at any time, in case they would experience excessive discomfort. This phenomenon may be due by the short duration of the VR experience.

Even though our sample size ( $N = 54$ ) is in line or even larger than several published studies on similar topics (for example, [50,57,64]), it may have been insufficient to identify small relationships between the investigated variables. However, several the relationships we found are consistent with published research. Furthermore, we used a non-standard administration for the MRT [70] in the present study (utilizing only half of the items), and therefore our results for such test may not be fully comparable to the outcomes ob-

tained using the normal administration of the test. Finally, we administered questionnaires in Norwegian (and in some case in a non-validated translation, for example, the PANAS), while most of the previously published studies have used them in English. Additionally, due to the multiple correlation analyses and many parameters used in the present study, several of the reported findings should be considered explorative. Moreover, it is wise to remember that correlation does not imply causation; therefore, different experimental designs should be implemented to deduce a cause-and-effect relationship among the variables.

The utilized VR scenario (a roller coaster ride) may not have been optimal to promote some associations between the variables, due to its possible influence on SS in the general population (e.g., may have reduced the association between presence and SS while modulating a higher level of association for neuroticism and SS). In many recent studies, the considered virtual environment is a first-person roller-coaster ride. However, in the virtual roller-coaster ride, differently from many VR simulator applications, no interaction is performed by the participants. However, past studies have shown that SS may be different in VR environment promoting user interaction compared to passive ones [113]. This represents a limitation about generalization of our findings. Further studies utilizing different type of VR environments should assess these problems.

It is worth mentioning that most previous VR studies did not HMD equipment. Thus, the present study represents an attempt to update, replicate, and discuss similarities and divergences with those previous investigations. However, it is problematic to understand whether some of the difference between the results of the present study and previously published literature are specifically related to the use of HMD-mediated VR. Indeed, for each of the studied factors, there are several investigations that used non-HMD equipment that present consistent and contrasting results regarding the present study. An exception for this phenomenon seems to be the relationship between spatial abilities and sense of presence that has been commonly reported for studies that did not use HMD, but not in studies using HMD [64]. It is also possible that the association between presence and SS may depend on the utilized visualization media.

A limitation is related to the study of the effect of age. Age has been associated with SS in previous studies [19–22]. However, our study did not show an association between age and SS. There was also no association between sense of presence and age, in line with some findings (see e.g., [50]) but in opposition with others [49]. However, the study reported in [49] showed much greater age variability in their participants compared to our study (they divided their participants into two groups, namely, 10–20 and 35–45 years of age). In our study, only 1 participant was older than 35 years. The correlation analyses for age may have been weakened due by the small variance of age in our sample (50 of the 54 subjects analyzed were between 20 and 28 years old). Future studies that aim to identify an association between age, SS, and presence may want to use data from a population with a higher degree of variability in age.

A further limitation is related to the questionnaire that was used to examine simulator sickness (SSQ). The was chosen as one of the most popular and commonly used questionnaire to assess simulator sickness, also in the context of modern HMD technology (see [114]). However other questionnaires have been recently developed more specifically for virtual reality in non-simulator environments, which could have some advantages (see e.g., the Virtual reality sickness questionnaire—VRSQ—[69]). We cannot exclude that the use of a different questionnaire to assess SS would have affected the main findings of the present study.

Finally, our study employed a specific HMD technology (Oculus GO), but the results reported here may be non-generalizable with other modern HMDs that feature technical differences (e.g., different FOV, framerate, and resolution). Future investigations should use different types of HMDs to validate the results presented in the present study.

#### 4.9. Practical Implications of the Present Study

The present results have implications in the way modern technology may be adopted in practical settings. The results from simple questionnaires (e.g., MSSQ) had a high predicting ability for the negative effects of SS; therefore, this questionnaire could be used to assess the likelihood that someone would experience discomfort during the VR experience. Furthermore, the results from the Big Five personality traits are generally collected in organizational settings, as the test is often administered to perspective employees. Some of the results from the NEO-PI test (neuroticism scale), may be used to assess the likelihood of adoption of HMD technology by a category of employees in organizational settings. Furthermore, this information can be used to determine which sample of employees may be less susceptible to the use of these new visualization technologies. HMD-mediated VR environments are now often proposed to employees as training methods for safety procedures (for example, [115,116]) and has been proposed as a method to train specific tasks [117,118]. Thus, this kind of assessment will likely become increasingly important. Furthermore, this finding may imply that employees that display a high level on neuroticism might be less likely to adopt or feel comfortable with VR training. The association we have reported between negative feelings during the VR experience (POST-PANAS) and the degree of experience SS also underscore how the discomfort of SS experience in VR may be substantially associated with negative emotions. Negative emotions may reduce the likelihood of adoption of the technology, as well as the long-term well-being of the user. Furthermore, when these technologies need to be used as part of work activities, negative emotions that arise from the negative experience of SS may impact employees' productivity and work satisfaction, even well after the VR experience is terminated. Our results call for future investigations to understand this phenomenon and evaluate possible negative outcomes on the use of modern HMD-mediated VR technologies. In order to improve the quality of users' VR experience, and the rate of speed of adoption of these new technologies, future research should investigate methods in which SS can be effectively reduced.

#### 5. Conclusions

Taken together, our results support the idea that some individual characteristics are related to the degree of SS symptomatology experience during VR, as well as the experienced sense of presence. MS susceptibility is highly correlated with SS symptoms (except for oculomotor symptoms) and is a good predictor for all the symptoms of SS. Neuroticism also seems to relate to the symptomatology of SS and is an apparent predictor specifically for the symptomatology related to nausea. This finding is in line with psychophysiological research that found anxiety-related personality to be linked to the function of visuo-vestibular system (connected to SS symptoms). Prior exposure to videogames seems to have a positive effect, and it is related to a reduction of some of the symptoms of SS (but only those related to disorientation and only on male subjects).

Positive and negative affects during the VR experience (even though evaluated after retrospectively after the simulation) were positively correlated with the reported level of presence. Such relationships suggest an important connection between emotions and sense of presence. Furthermore, the sense of presence was experienced more in female compared to male participants, and sex was found to be a good predictor for the level of presence.

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