Ann Kristin Luzi

Individual Differences in Simulator Sickness and Presence in Virtual Reality

Master's thesis in Work and Organizational Psychology
Supervisor: Karin Laumann
May 2020

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Ann Kristin Luzi

Sammendrag

I løpet av de siste årene har en ny generasjon rimelige og teknologisk avanserte *head-mounted displays* (HMD) blitt lansert, noe som har gjort virtuell virkelighet (VR) teknologi stadig mer populær og tilgjengelig. I arbeidssammenheng brukes VR til ulike former for profesjonell trening, men utfallene kan imidlertid påvirkes av i hvilken grad brukere opplever simulatorsyke og *presence*. Simulatorsyke er en ubehagelig bivirkning assosiert med kvalme-, okulomotoriske- og desorienteringssymptomer, mens presence refererer til en følelse av «å være der» i VR omgivelsene. Hensikten med denne studien var å undersøke påvirkningen av individuelle faktorer på simulatorsyke og opplevelse av presence, samt den potensielle assosiasjonen mellom de to fenomenene. Femtifem deltakere ble rekruttert og fikk presentert en VR berg-og-dalbane via en Oculus Go HMD. Funnene indikerte at nevrotisisme korrelerte med og var en signifikant prediktor for kvalmesymptomer. Videre rapporterte kvinner, i gjennomsnitt, å oppleve signifikant mer kvalmesymptomer enn menn. I tillegg ble det funnet at kvinner opplevde høyere grad av presence, sammenlignet med menn. Det ble ikke funnet noen sammenheng mellom simulatorsyke og presence. Organisasjoner bør ta individuelle forskjeller i betraktning, slik at VR-trening kan optimaliseres. Funnene av denne studien kan bidra til å identifisere personer som er mer og mindre mottagelige for simulatorsyke og presence, slik at tilpasninger kan gjøres for å forbedre brukeropplevelsen og treningsutfallene for disse individene.

Abstract

In the last couple of years, a new generation of affordable and technologically advanced head-mounted displays (HMD) have been launched, making virtual reality (VR) technology increasingly popular and accessible. In the context of work, VR is used for different types of professional training, however the outcomes could be influenced by the extent to which users experience simulator sickness and presence. Simulator sickness is an uncomfortable side effect associated with nausea, oculomotor, and disorientation symptoms, whereas presence refers to a feeling of “being there” in a VR environment. The aim of the present study was to investigate the influence of individual factors on simulator sickness and sense of presence, as well as the potential association between the two phenomena. Fifty-five participants were recruited and presented with a VR roller coaster ride via an Oculus Go HMD. The findings indicated that neuroticism correlated with and was a significant predictor of nausea symptoms. Furthermore, females, on average, reported experiencing significantly more nausea symptoms than men. In addition, females were found to experience a higher sense of presence, compared to men. No association was found between simulator sickness and presence. Organizations should take individual differences into account, in order to optimize VR training. The findings of the present study could help identify individuals who are more and less susceptible to simulator sickness and presence, so that adjustments may be made in order to improve user experience and training outcomes for these individuals.

Contents

Individual Differences in Simulator Sickness and Presence in Virtual Reality

One of the key strengths of virtual reality (VR) is that, in theory, there is no limit to what can be simulated. VR environments and the possible actions within them can be programmed to resemble the real world or move beyond what is physically possible. What makes VR different from more traditional media is the level of interactivity it provides (Fox et al., 2009). Users can choose their point of view by positioning their bodies and influence events in the VR environment (Sherman & Craig, 2003). As a result of the countless possibilities VR offers, a range of VR applications have been developed over the years (see e.g. Brooks, 1999, for a review). VR technology has been employed in contexts such as entertainment, education, science, professional training, sports, exercise, and travel (Slater & Sanchez-Vives, 2016).

VR has been defined as “a computer-generated perceptual simulation of a three-dimensional image or environment with which the viewer can interact, often requiring a headset or goggles providing visual stimuli and gloves or other bodily attachments fitted with sensors” (Colman, 2015, p. 806). The foundation for what we think of as VR today, was laid down by Ivan Sutherlands’ envisions of an “ultimate display” (Sutherland, 1965) more than 50 years ago. Sutherland ended his essay by stating that “with appropriate programming such a display could literally be the Wonderland into which Alice walked” (Sutherland, 1965, p. 2). In the last couple of years, a new generation of affordable and technologically advanced head-mounted displays (HMD), also referred to as VR headsets, have been developed (Khan et al., 2016; Slater, 2014). The launch of these HMD-systems has contributed to VR becoming widely accessible to and increasingly popular among consumers, researchers, and businesses (Pan & Hamilton, 2018). Technological advances, including wider viewing angles, higher resolution, and better motion tracking, has improved user experience and made it possible to interact with fully immersive VR environments.

In the context of work, VR has typically been used for different types of professional training. Some examples include military (Alexander et al., 2017; Bhagat et al., 2016), surgical (Bric et al., 2016; Thomsen et al., 2017), firefighting (Williams-Bell et al., 2015), astronautical (Liu et al., 2016), and industrial training (Lawson et al., 2016). The use of VR technology in organizations will likely increase as accessibility increases. One advantage of using VR in such settings, is that scenarios that would be physically or economically impossible to create in real life, can be simulated. Another advantage is that training in safety critical environments can occur without the associated risks. However, the usefulness of such VR applications might be limited by user experience issues.

Although there have been major improvements in the technology for the past decades, two remaining issues may be a hindrance to the application of VR. Firstly, an inherent problem with VR is the uncomfortable side effect of simulator sickness, which is associated with symptoms such as eye strain, disorientation, and nausea (Kennedy et al., 1993; LaViola, 2000). The occurrence of simulator sickness can interfere with the use of VR, and thereby, training and learning outcomes. People experiencing simulator sickness might stop using VR (LaViola, 2000), drop out and/or alter their behavior in order to reduce the symptoms (Cobb et al., 1999). Furthermore, experiencing such symptoms while in a VR environment can be distracting. Secondly, consistently generating an experience of presence in VR users has proven difficult (Weech et al., 2019). In this context, presence is commonly defined as the experience of "being there" in a VR environment (Cummings & Bailenson, 2016; Slater & Sanchez-Vives, 2016; Slater & Wilbur, 1997). Eliciting a sense of presence is central to providing simulations experienced as natural and real, which is considered to be the ultimate goal of VR (Weech et al., 2019). Presence is assumed to play an essential role in realistic responses to VR, and to facilitate the transfer of behavioral knowledge from VR environments to equivalent real-world situations (Slater, 2009; Slater et al., 1996; Slater & Wilbur, 1997). Thus, a low sense of presence might also reduce training and learning outcomes. Conducting empirical studies investigating VR user experience is therefore critical to the development and application of VR technology.

However, simulator sickness and presence are complex phenomena, and the extent to which they are experienced varies across individuals. As such, in addition to technological factors, individual factors are assumed to play a role (e.g. LaViola, 2000; Steuer, 1992). An individual's susceptibility might be influenced by their sex, age, personality traits, mental rotation ability, and previous experience (Kolasinski, 1995; Sacau et al., 2008). Knowledge about which individual factors might influence simulator sickness and presence, and how, is of relevance to the field of work and organizational psychology for several reasons. In general, awareness of how VR use in the workplace affects individuals and how it can be optimized is desirable. VR could be a useful tool for professional training in many instances, but it could also have a detrimental effect on employee health and wellbeing. Furthermore, the recognition that there are individual differences in experienced simulator sickness and presence also implies that training and learning outcomes varies across individuals. If organizations are able to identify who are more or less susceptible to simulator sickness and presence, it could be possible to make adjustments in order to improve user experience and training outcomes for these groups. This is also how this thesis is connected to work and organizational psychology.

Ultimately, identification of related individual factors could help inform how simulator sickness can be minimized and presence maximized. In addition, there might be an association between simulator sickness and presence (Weech et al., 2019). Therefore, the overall aim of the present study is to investigate: 1. Which individual factors might be related to the occurrence of simulator sickness and presence? 2. Is there a relationship between simulator sickness and presence?

In the following sections, I will first provide a brief history of the development of VR, as well as a description of how the technology works. Then, I will describe the concepts of simulator sickness and presence in more detail and depth, as well as summarize previous research and theories. Finally, I will briefly present previous findings on the relationship between the two phenomena, before introducing the present study.

Brief History of VR

The precursors to modern VR can be traced back prior to Ivan Sutherland's initial work (Sutherland, 1965). The first HMD was patented by Albert B. Pratt in 1916, Edward Link invented a flight simulator for training pilots in 1929, and in 1956, Morton Heilig developed the Sensorama system (Sherman & Craig, 2003). The Sensorama provides simulated experiences, such as a motorcycle ride through Manhattan, with visual, auditory, olfactory, and tactile stimuli. Sutherland, however, imagined a display in which users could interact with virtual objects (Sutherland, 1965), which was the first description of the concepts that constitute a VR system (Slater & Sanchez-Vives, 2016). In the following years, Sutherland and his research team developed a VR HMD-system that was able to update the presented image with respect to the orientation and position of the user's head (Sutherland, 1968). Although work contributing to the development of VR was ongoing in several fields, including flight simulation, robotics, and military and space-related research from the early 1970s, the technology did not gain widespread interest until the late 1980s (Schroeder, 1993).

During the 1980s, computer technology became increasingly advanced, enabling developers to produce complete VR systems, in comparison to previous prototypes. The first commercial VR systems also appeared around this time (Cipresso et al., 2018). The first fully immersive system, consisting of a HDM, body suit, and glove, was developed by Jaron Lanier and his colleagues. Lanier went on to be the founder of VPL, the first company to sell VR systems commercially, and he is also credited with coining the term "virtual reality" (Schroeder, 1993). Another example of a full VR system developed during the 1980s is the

Virtual Interface Environment Workstation (VIEW) system, which was created at NASA's Ames Research Center (Fisher et al., 1987). Towards the end of the 1980s, excitement and expectation surrounding VR technology had grown (Slater & Sanchez-Vives, 2016). When talking about VR during a panel session at the SIGGRAPH computer graphics conference in 1989, Lanier stated that "it's a very hard thing to describe to people, if you haven't experienced it, but there's an experience when you're dreaming of all possibilities being there - that anything can happen, and it's just an open world where your mind is the only limitation" (Conn et al., 1989, p. 8). The hope during the late 1980s and early 1990s was that low-cost VR systems would soon become available on a mass scale (Slater & Sanchez-Vives, 2016). This vision however, did not come to fruition at the time, due to the inability to develop low cost HMDs with high quality displays and adequate ergonomics. The development and application of VR continued thereafter, but only recently is it becoming a mass consumer product (Slater & Sanchez-Vives, 2016). This shift has been attributed to the release of the Oculus Rift development kit 1 in 2013 (Davis et al., 2015; Oculus VR, 2012; Somrak et al., 2019), which was followed by the release of a consumer version in 2016 (Oculus VR, 2015). Other companies, such as Google, Sony, and Samsung, have followed and released their own VR devices.

VR Technology

Modern VR systems commonly consists of a HMD and one or two handheld devices, enabling users to affect changes in the VR environment. HMDs display computer-generated images on two screens, one dedicated to each eye (Slater & Sanchez-Vives, 2016). The projected images are two-dimensional (2D) and accommodated to the perspective of the corresponding eye. These two images are fused together by the brain, making it possible for humans to extract depth information and perceive a stereoscopic view of the content (Urey et al., 2011). Furthermore, HMDs are equipped with a head tracking device, which captures the position and orientation of the user's head in real time (Slater & Sanchez-Vives, 2016). Thus, given that the eyes are looking straight ahead, the displayed image corresponds to the direction of the user's gaze in the VR environment (Davis et al., 2015). Through this feature, HMDs generate a sense of immersion, as users are able to move within the simulated three-dimensional (3D) environment.

Immersion refers to the technological qualities of a VR system (Cummings & Bailenson, 2016; Slater & Wilbur, 1997). More specifically, VR systems can be more or less immersive depending on which senses are stimulated, to what extent, and how precisely (Somrak et al., 2019). Thus, one technological goal of VR systems is to stimulate the senses so that realistic perceptions are substituted by computer-generated ones (Slater & Sanchez-Vives, 2016). Ideally, all the senses should be accounted for, which can be achieved through incorporating elements including head tracking and visual, auditory, tactile, force-feedback, thermal, and olfactory displays (Slater, 2009). VR systems are generally focused around vision (Slater & Sanchez-Vives, 2016), which is typically the perceptually dominant sense for humans in a range of situations (Lukas et al., 2010; Posner et al., 1976). For instance, an individual experiencing a VR roller coaster while seated in a chair in their living room, might act as if they were really on a roller coaster. VR systems also commonly include audio, which, similarly to vision, is updated with respect to head position and orientation. Several additional factors influencing the effectiveness of sensory substitution have also been identified. These include image quality, field of view, and tracking latency (Slater, 2009), to mention a few. Taken together, immersive VR devices enable users to perceive through using their bodies in a natural way, within the limits of the given system (Slater & Sanchez-Vives, 2016).

Thus far I have focused on HMD driven VR systems, as they have been developed since the early days of VR and are the most widespread today (Dużmańska et al., 2018). However, it is worth noting that different types of VR systems have been conceptualized and developed over the years. One example of another immersive VR system is the audio-visual experience automatic virtual environment (CAVE), in which images are projected to the walls, ceiling, and floor of a room (Cruz-Neira et al., 1992). Users wear shutter glasses with head tracking, which synchronize with the projected images (Cruz-Neira et al., 1993). This generates 3D stereovision of the environment, and the correct perspective of the image is computed with respect to the user's position. CAVE-like systems typically had to be custom made for a given space and never became widespread, but have nonetheless been employed in VR research and applications from the late 1990s until recently (Slater & Sanchez-Vives, 2016). Somrak et al. (2019) classified four types of VR devices currently available: portable devices, wired devices, CAVE-like systems, and large monitors.

Simulator Sickness

Descriptions of motion sickness-like symptoms can be traced back at least to the writings of Hippocrates, more than 2000 years ago (Golding, 2016; Reason & Brand, 1975). Motion sickness is associated with symptoms such as sweating, pallor, and, most commonly, nausea and vomiting. These symptoms can arise from a variety of situations, including car, sea, and air travel. Thus, traditional motion sickness symptoms are typically triggered by the physical movement of vehicles (Golding, 2016; Reason & Brand, 1975). In contrast, simulator sickness can arise as a result of visually perceived self-motion, in the absence of physical motion (Hettinger & Riccio, 1992). This illusionary sense of self-motion is referred to as vection (Gallagher & Ferrè, 2018). As such, simulator sickness has been classified as a type of visually induced motion sickness (Gallagher & Ferrè, 2018).

The term simulator sickness was originally used to describe the aversive symptoms arising during training in flight simulators (Kennedy et al., 1993). More recently, it is also used to describe the side effects of using HMD-driven VR systems (e.g. Dużmańska, 2018; Moss & Muth, 2011). However, it is important to note that different terms have been used for describing this phenomenon, including VR sickness (Somrak et al., 2019) and cybersickness (LaViola, 2000). Some researchers treat these as separate phenomena (e.g. Davis et al., 2015), but the terms are often used interchangeably (Keshavarz et al., 2015; Rebenitsch & Owen, 2016). Therefore, I will refer to the side effects of using HMD VR as simulator sickness.

The symptoms of simulator sickness also differ somewhat from those associated with traditional motion sickness. For instance, disorientation symptoms are more prominent in simulator sickness, while emetic responses are rare (Stanney & Kennedy, 1997). Common symptoms include; eyestrain, general discomfort, difficulty concentrating, and fatigue (Jinjakam & Hamamoto, 2012). The number of symptoms associated with simulator sickness, as well as the differences in symptom manifestation across individuals, add to the complexity of understanding the phenomenon (Rebenitsch & Owen, 2016).

Simulator sickness has been a known side effect since the early days of VR. The issue was discussed at the 1989 SIGGRAPH computer graphics conference, but at the time the general assumption was that technological advances would soon make simulator sickness a rare experience (Conn et al., 1989). However, simulator sickness is still a significant problem, and estimates indicate that 20-80% of users experience the condition (Cobb et al., 1999; Munafo et al., 2017). Moreover, the review article of Rebenitsch and Owen (2016) pointed out that reports of simulator sickness have even been increasing with technological advancements, and suggested that this trend will likely continue as VR availability increases.

Theories

Over the years, a variety of theories attempting to explain why individuals experience motion sickness have been developed. These theories have been applied in research on simulator sickness as well, given the relation between the two phenomena (Brooks et al., 2010; Gallagher & Ferrè, 2018). The three most common theories regarding the cause of simulator sickness are poison theory, postural instability theory, and sensory conflict theory (LaViola, 2000).

Treisman (1977) proposed an evolutionary explanation as to why motion sickness symptoms occur, commonly referred to as the poison theory. In this context, ejecting stomach contents is viewed as a protective mechanism against ingested toxins. According to the poison theory, conflicting information from the spatial reference systems is misinterpreted by the body and it responds as if a toxic substance has been ingested. Thus, experiencing nausea when using VR might be caused by the body misidentifying toxins due to conflicting visual and vestibular information (LaViola, 2000).

The postural instability theory (Riccio & Stoffregen, 1991) is based on the premise that maintaining control of posture is a primary behavioral goal for humans and animals. In situations where people lack the experience needed to maintain postural stability, or if abrupt or significant changes occur in the environment, control might be lost. The postural instability theory proposes that motion sickness occurs in situations in which people are unable to maintain a stable posture for a prolonged period of time. As such, postural instability is believed to precede and be a prerequisite for motion sickness. The severity of the symptoms are, in turn, assumed to depend on the duration of the instability. In VR, users may rely on the cues of the visually presented VR environment when attempting to maintain postural stability (Rebenitsch & Owen, 2016). However, the visual changes are unrelated to the normal constraints on control of the body, and therefore the strategies for maintaining postural control do not work (LaViola, 2000). In other words, the person's posture becomes unstable because they adjust it with regard to what they see, but gravity is straight down (Rebenitsch & Owen, 2016).

According to Reason and Brand's (1975) sensory conflict theory, motion sickness arises as a result of conflicting position and motion information. The theory postulates that when incongruent information from the spatial senses arrive simultaneously in the spatial integration centers of the brain, discord or confusion occurs, resulting in the adverse symptoms. Simply put, the motion a person sees and the motion they experience do not match. This principle can be transferred to VR scenarios such as driving simulations. Users visually perceive that they are moving within the VE but since they remain stationary, the vestibular sense provides no such information (LaViola, 2000).

Although these theories might contribute to a broader understanding of simulator sickness, there are several issues with them. The poison theory postulates why simulator sickness exists, but does not account for other symptoms than nausea, or explain why simulator sickness is not always associated with an emetic response (LaViola, 2000). The postural instability theory and sensory conflict theory attempt to explain the mechanisms behind simulator sickness but cannot fully explain why it occurs (Gallagher & Ferrè, 2018). These theories also have some shared issues. First, the theories lack predictive power in determining how severe the simulator sickness symptoms will be, given a certain situation (Davis et al., 2015; LaViola, 2000). Second, they do not explain why some VR users experience simulator sickness and others do not in identical situations. In other words, these theories suggest all individuals should experience some degree of simulator sickness in a VR environment. However, this is often not corroborated by both scientific and anecdotal evidences, as a number of users do not experience any type of simulator sickness during a VR experience.

Individual Factors

Numerous software, hardware, and individual factors have been investigated in previous research on simulator sickness. Sex is one of the most commonly investigated individual factors. For instance, Munafo et al. (2017) found that, although symptom severity did not differ, females were more susceptible to simulator sickness. Similarly, further studies have found that females are more susceptible to simulator sickness than males (Chen et al., 2015; De Leo et al., 2014; Stanney et al., 2020; Weech et al., 2018). In line with this, motion sickness appears to be more widespread among females (Golding, 2016). It has been suggested that sex differences in susceptibility could be related to females tending to have a larger field of view (LaViola, 2000), sex differences in postural stability (Munafo et al., 2017), and the female hormonal cycle (Golding, 2016). However, several studies have also found that simulator sickness did not differ between males and females (Clifton & Palmisano, 2019; Gamito et al., 2008; Knight & Arns, 2006; Ling et al., 2013; Melo et al., 2018; Sagnier et al., 2020; Weech et al., 2020).

When it comes to age, children between the ages of two to twelve are most prone to motion sickness (Reason & Brand, 1975). From the age of 12 to 21 motion sickness susceptibility significantly decreases, and it continues to decrease thereafter. It has been suggested that simulator sickness susceptibility follows the same trends (Kolasinski, 1995; LaViola, 2000). However, the findings of previous studies have not provided clear support of this notion. On the contrary, Knight and Arns (2006) found that the incidence and severity of simulator sickness was higher among older, compared to younger, participants. Furthermore, Arcioni et al. (2019) found no significant difference in age when comparing participants who became sick from VR to those who remained well. Similarly, Weech et al. (2018) found no correlation between age and simulator sickness.

Mental rotation has been proposed as an individual factor that might influence simulator sickness susceptibility. Mental rotation refers to the ability to mentally visualize what an object or picture looks like when rotated in 3D space (Casey, 2013). Parker and Harm (1992) suggested that individuals who succeed at mental rotations might find it easier to manipulate and move within a VR environment, and experience less simulator sickness symptoms when transitioning between real and VR environments. To my knowledge, the potential association between mental rotation and simulator sickness has not been empirically investigated previously.

The findings of previous studies investigating the effect of prior experience with video games and VR have also been mixed. For instance, Knight and Arns (2006) found that simulator sickness decreased with increased gaming and VR experience. Similarly, De Leo et al. (2014) found that video gaming experience and knowledge about how VR technology works were negatively correlated with simulator sickness symptoms. Weech et al. (2020) found that gamers, defined as those who played video games more than five hours a week, experienced less nausea and oculomotor discomfort, compared to non-gamers. Sagnier et al. (2020) however, found no significant difference in simulator sickness between participants with and without prior experience with VR. In addition, Stanney et al. (2020) found that gaming experience was not a significant predictor of simulator sickness.

Reason and Brand (1975) suggested that neuroticism and low extroversion could be related to motion sickness. Relatedly, anxiety is considered to influence individual susceptibility to motion sickness and simulator sickness (Mittelstädt et al., 2019). Characteristics of neuroticism and low extroversion include experiencing emotional distress and being reserved and somber (McCrae et al., 2012), respectively, and they both correlate with anxiety-related disorders (Costa & McCrae, 1992). To my knowledge, the potential influence of neuroticism and extroversion on simulator sickness has not been investigated previously. However, in one study Farmer et al. (2015) used a motion video to elicit motion sickness and compared participants who developed nausea to those who did not. They found that, while trait anxiety differed, neuroticism and extroversion did not differ significantly between the two groups. At the same time, there are findings indicating that these traits could influence stimuli processing and symptom perception.

These anxiety-related traits have been studied in relation to processing of vestibular and visual stimuli. In one functional magnetic resonance imaging (fMRI) study, Indovina et al. (2014) used tone bursts to evoke vestibular responses, and correlated measures of brain activity and connectivity with personality traits of the five factor model (FFM): neuroticism, extroversion, openness, agreeableness, and conscientiousness (McCrae et al., 2012). They found that neuroticism and low extroversion influenced the activity and connectivity of vestibular, visual, and anxiety systems. Riccelli et al. (2017) had participants undergo fMRI while being immersed in a VR roller coaster, simulating vertical and horizontal self-motion. Their results indicated that, in response to simulated vertical self-motion, neuroticism was associated with greater connectivity and activity in visual-vestibular and anxiety-related brain regions.

Neuroticism and extroversion might also affect how simulator sickness symptoms are perceived. Mittelstädt et al. (2019) investigated whether pain catastrophizing, which is defined as a negative attitude toward pain and related sensations, influenced simulator sickness in VR. They found that pain catastrophizing was positively correlated with both motion sickness history and simulator sickness. Pain catastrophizing has, in turn, been found to be related to neuroticism (Goubert et al., 2004). In addition to this, pain catastrophizing appears to be negatively correlated with extroversion (Goubert et al., 2004). These findings indicate that individuals with high levels of neuroticism and/or low levels of extroversion could process VR stimuli and following bodily sensations in a manner that increases their risk of developing simulator sickness.

In summary, a variety of individual factors that might help shed light on individual differences in simulator sickness have been proposed and examined. However, whether and how specific factors relate to simulator sickness largely remains unclear. The heterogeneity of previous findings is likely at least partially due to the use of different VR devices and VR environments. In reviewing studies comparing different displays, Rebenitsch and Owen (2016) found that the incidence of simulator sickness is higher for HMD-driven VR, compared to devices like CAVE-like systems, large screens, and desktops. Regarding the effects of different VR environments, reports of simulator sickness have, for instance, been found to differ between two VR roller coaster rides (Davis et al., 2015; Nesbitt et al., 2017).

Presence

The term presence, originally referred to as telepresence, was coined by Minsky (1980) in reference to operating remote robots. He stated that "the biggest challenge to developing telepresence is achieving that sense of 'being there'" (p. 48). Early conceptualizations of presence were technologically driven, but presence has since been understood from a psychological point of view (Sacau et al., 2008). Most previous research has focused on and conceptualized presence, as the illusory sense of being located within a VR environment (Cummings & Bailenson, 2016; Skarbez et al., 2017; Weech et al., 2018).

This feeling of "being there" has also been referred to as physical presence (Lee, 2004) and spatial presence (Schubert et al., 2001). However, presence remains a difficult phenomenon to measure and a universally accepted definition does not exist (Alsina-Jurnet & Gutiérrez-Maldonado, 2010; Grassini & Laumann, 2020). A variety of definitions and measurements of presence have been proposed (see Grassini & Laumann, 2020, for a recent review), as well as related concepts such as social presence, embodiment, and fidelity (Skarbez et al., 2017). In addition to this, the terms presence and immersion are sometimes used synonymously (e.g. Rebenitsch & Owen, 2016). I will use the distinction put forward by Slater and Wilbur (1997), where immersion refers to the technological capabilities of a system and presence is the sense of being in a VR environment.

Whereas immersion refers to the objective degree of stimulation, presence is considered to be its subjective correlate (Slater & Sanchez-Vives, 2016). As such, the immersive quality of a VR system is assumed to facilitate the level of presence experienced by users (Slater & Wilbur, 1997). A meta-analysis by Cummings and Bailenson (2016) indicated that immersion has a medium-sized effect on VR users' sense of presence. At the same time, presence is considered to be influenced by both technological and individual factors (Steuer, 1992). Slater and Usoh (1993) distinguished between external factors, which are determined by the technology, and internal factors. Internal factors relate to how information from VR environments is processed internally and varies across individuals. Thus, different individuals might experience different degrees of presence and respond to the environment in various ways, even within the same VR environment (Steuer, 1992; Usoh & Slater, 1995).

Individual Factors

The conceptualization of presence as a subjective feeling has led to an increased recognition of the role of individual factors (Sacau et al., 2008), although research into individual differences remains scarce (Kober & Neuper, 2013; Ling et al., 2013). It is commonly assumed that spatial skills play a role in the formation and maintenance of presence (Coxon et al., 2016). Spatial skills encompass various abilities related to the processing of spatial elements within the environment and often include creating mental visualizations (Casey, 2013). Wirth et al. (2007) proposed that presence is generated through a two-step process, which is assumed to be influenced by technological and individual factors, such as spatial visual imagery. According to this model, the first step involves constructing a mental model of the situation based on spatial information ("Is this stimulus a space?", and "If yes, what kind of space is it?"). During the second step, a sense of presence is formed if the individual perceives being located within that space. There is some evidence that self-reported spatial visual imagery is related to constructing a mental model of the mediated environment (Hofer et al., 2012) and that imagery and presence are correlated (Hartmann et al., 2016). However, this evidence comes from studies using desktop computers. Studies investigating whether spatial abilities are related to presence in HMDs have been inconclusive. For instance, Ling et al. (2013) found no significant association between mental rotation and presence. Similarly, Coxon et al. (2016) found that presence was not related to mental rotation, but they did find it was positively correlated with self-reported imagery. Alsina-Jurnet and Gutiérrez-Maldonado (2010) found a significant positive correlation between mental rotation and presence, but only in the group who scored high on test anxiety.

Regarding sex differences in sense of presence, previous research have shown mixed findings. Some articles have reported that males experience a higher sense of presence (Gamito et al., 2008; Felnhofer et al., 2012; Felnhofer et al., 2014), while others have found no difference (De Leo et al., 2014; Ling et al., 2013; Schwind et al., 2019; Weech et al., 2020). Melo et al. (2018) found that females scored higher on one subscale (experienced realism) of the presence measure used but found no sex difference for spatial presence, suggesting that sex may influence different aspects of the sense of presence.

Previous findings on age differences in presence are limited, as research has generally been centered around younger age groups, and the generalizability of studies including older age groups might be limited due to small sample sizes (Felnhofer et al., 2014). In a recent study, Weech et al. (2020) compared presence levels in a group of participants under the age of 18 and a group over the age of 18. They found that the younger group reported higher presence on a single-item measure, however no difference was found between the two groups on a more comprehensive measure of presence. Similarly, Felnhofer et al. (2014) found that presence did not differ between older and younger adults, and Ling et al. (2013) reported null correlations between age and presence.

The potential influence of previous experience with gaming and VR on presence has also been investigated. Sagnier et al. (2020) found that participants with prior VR experience reported higher levels of presence, compared to those without prior VR experience. In contrast, several studies have found no relation between previous gaming experience and presence (Alsina-Jurnet & Gutiérrez-Maldonado, 2010; De Leo et al., 2014; Ling et al., 2013; Weech et al., 2020).

A variety of personality variables have been investigated in relation to presence, with heterogenous results. For instance, Weibel et al. (2010) investigated whether the FFM personality traits were related to immersive tendency. Immersive tendency refers to an individual's tendency to become immersed or involved in mediated environments, and thereby to experience presence (Witmer & Singer, 1998). The results indicated that openness, neuroticism, and extroversion were positively related to immersive tendency. Openness is associated with being aesthetically sensitive and openminded, and needing variety (McCrae et al., 2012). In line with the findings of Weibel et al. (2010), Parsons et al. (2015) also found that these three personality traits were positively associated with immersive tendency. Whereas neuroticism was found to be most strongly related in the former study, openness was found to exert the strongest influence in the latter. In line with Witmer and Singer (1998), several findings indicate that immersive tendency is related to presence (Ling et al., 2013; Kober & Neuper, 2013). Kober and Neuper (2013) investigated whether different personality characteristics were related to presence. They found no significant correlations between the FFM personality traits and presence, with the exception of openness which showed mixed results for different measures of presence. Sacau et al. (2005) reported that presence was related to agreeableness, but did not find significant correlations with the other FFM traits. Agreeableness encompasses tendencies to be generous, cooperative, and trusting (McCrae et al., 2012).

The potential influence of related personality traits have also been examined. Empathy broadly refers to how an individual respond to the experiences of others, and include emotionally responding to the experiences of other people and taking others perspective (Davis, 1980; Davis, 1983). Agreeableness and empathy overlap conceptually, and they have also been found to be associated empirically (Melchers et al., 2016; Mooradian et al., 2011). Like agreeableness, studies of the association between empathy and presence have revealed mixed results (Kober & Neuper, 2013, ; Ling et al., 2013; Sas & O'Hare, 2003). Absorption is characterized as a tendency for having episodes of total attention that fully engages a person's available perceptual, motoric, imaginative, and ideational resources (Tellegen & Atkinson, 1974). Sacau et al. (2005) found that absorption and openness were positively correlated. Results of studies investigating absorption in relation to presence have been mixed, with some finding a relationship (Kober & Neuper, 2013; Sacau et al., 2005; Sas & O'Hare, 2003) and others finding no association (Ling et al., 2013). Similarly to research on simulator sickness, the inconsistent findings regarding the role of individual factors in presence could potentially be due to the use of different VR devices and environments.

Association Between Simulator Sickness and Presence

Weech et al. (2019) reviewed studies investigating the relationship between simulator sickness and presence, and concluded that the balance of available evidence favored a negative association. However, previous findings have been inconsistent and negative correlations have generally been found in previous studies (e.g. Knight & Arns, 2006; Nichols et al., 2000; Witmer & Singer, 1998). Results of more recent studies using modern HMD-mediated VR have yielded somewhat mixed results. Weech et al. (2020) reported finding a negative correlation, while other studies have reported null correlations (Clifton & Palmisano, 2019; Ling et al., 2013; Servotte et al., 2020). In addition, some of the recent studies measuring both presence and simulator sickness have not reported whether they are related (Coxon et al., 2016; Melo et al., 2018; Sagnier et al., 2020).

Present Study

Previous research on individual differences in simulator sickness and presence has yielded heterogeneous findings, and no consensus has been reached regarding which specific factors are related to these phenomena. Therefore, one goal of the present study was to explore whether previously proposed individual factors were related to simulator sickness and presence in the current generation of HMD-driven VR systems. Specifically, the first aim was to investigate whether sex, age, mental rotation ability, previous experience with VR and video games, and the personality traits neuroticism and extroversion, were related to simulator sickness. The second aim was to investigate whether sex, age, mental rotation ability, previous experience with VR and video games, and the personality traits neuroticism, extroversion, openness, and agreeableness, were related to sense of presence. In addition, findings regarding the regarding the relationship between simulator sickness and presence have been mixed. Therefore, the third aim was to investigate whether simulator sickness and presence were associated. The present study was an explorative study and part of a larger research project.

Method

Choice of Method

The present the study was based on a post-positivist paradigm. The fundamental assumption of post-positivism is that there is one reality that can be studied through the scientific method, but that it is not possible to achieve perfect objectivity and reality cannot be known with certainty (Chilisa & Kawulich, 2012). A quantitative methodology was chosen, which is typically utilized within this paradigm, with the aim of investigating the relationship between the variables of interest. Moreover, in order to investigate individual differences in simulator sickness and presence, it was necessary to elicit these sensations. Therefore, a lab experiment in which participants were exposed to VR was conducted, and the data were collected with questionnaires and a test.

Participants

Fifty-five students and recent graduates at the Norwegian University of Science and Technology participated in the study. Participants reported that they met the following inclusion criteria: they were generally healthy adults between the ages of 18 – 45; they declared not taking any psychotropic drugs and not suffering from a psychiatric/psychological illness. Two participants were removed from the dataset. One as data from questionnaires was missing and one as their age was more than three standard deviations away from the mean. Therefore, 53 participants (32 females and 21 males) between the ages of 18-30 (M = 23.6, SD = 2.22) were included in the data analyses.

Sampling Procedure

The participants were recruited through multiple methods including; announcements in university courses and on social media, by directly approaching potential participants, and through recruited participants informing their acquaintances. Data was mainly collected September 2nd – October 1st 2019, with the exception of a few subjects who participated in May and July of the same year. The goal was to have roughly 50 participants by October 1st. The number of participants was established considering the sample size employed in similar studies (see e.g. Kober & Neuper, 2013). The study took place in a laboratory at the Norwegian University of Science and Technology. No payments or rewards were offered for participation in the study. The study was approved by the Norwegian Centre for Research Data (NSD).

Apparatus

The VR environment was presented via an Oculus Go, which is a lightweight (355 g) stand-alone HMD system with built-in speakers and one handheld controller. The HMD is equipped with a 5.5 inch LCD screen with a resolution of 2560 x 1440 pixels (1280 x 1440 per eye), yielding a field of view of about 110 degrees with a refresh rate of up to 72 Hz (Hillmann, 2019). Participants were exposed to a VR roller coaster ride (see Figure 1; B4T Games, 2017), lasting approximately 5 minutes. The VR scenario was primarily chosen in order to induce simulator sickness symptoms. An acceptable level of presence was also expected due to the technological qualities of the Oculus Go, and because the VR roller coaster ride was assumed to evoke emotional reactions. A written permission of use of the software for scientific purposes was obtained from the copyright holder prior to the experiment.

Figure 1

Screenshots from VR Environment

Joystick Years

To assess previous experience with video gaming and VR use, we used Kühn and Gallinat's (2014) joystick years measure. Joystick years refers to an individuals' lifetime amount of video gaming. The questionnaire consists of three questions: "How many days per week do you play video games?", "How many hours do you play videogames on these days on average?", and "How many years have you been playing video games on a regular basis?". An individual's joystick years is calculated by multiplying hours x days per week x 52 (weeks per year) x years (Kühn & Gallinat, 2014). To account for previous experience with both video games and VR, the original set of questions and one altered set regarding VR use were included.

Motion Sickness Susceptibility

Participants rated their motion sickness susceptibility using the short motion sickness susceptibility questionnaire (MSSQ-short; Golding, 2006). The questionnaire assesses previous experience with motion sickness in nine nausogenic environments, including cars, aircrafts, ships, and funfair rides. Participants are asked to rate the degree to which they have felt sick or nauseated in each mode of transportation and entertainment over the last 10 years on a scale from 1 (“never felt sick”) to 4 (“frequently felt sick”). If they had no experience with a given environment, there was also an option of “not applicable”, which was scored as 0. A total sickness score was calculated for each participant by adding their scores, meaning the total scores could range from 0 – 36.

Positive and Negative Affect

The positive and negative affect schedule (PANAS) is a 20-item measurement of positive and negative affect (Watson et al., 1988). Positive affect refers to the extent to which an individual experiences positive moods, including enthusiasm and alertness. In contrast, negative affect reflects the extent to which an individual experiences aversive mood states, such as anger, fear, and nervousness. Low positive affect is associated with feelings of sadness and lethargy, while low negative affect is associated with feeling calm and serene. PANAS comprises one positive affect scale and one negative affect scale, consisting of ten mood states each. Each mood state is rated on a scale from 1 (“slightly or not at all“) to 5 (“very much“). The PANAS questionnaire was administered prior to and after the VR simulation, and participants were instructed to rate each mood state based on how they felt at that moment. Mean scores for the positive affect and negative affect scales were then computed.

Personality

The NEO Five-Factor Inventory-3 (NEO FFI-3; McCrae & Costa, 2007) was administered to assess personality characteristics. This is a 60-item measurement of the dimensions of the FFM of personality: neuroticism, extroversion, openness, agreeableness, and conscientiousness. Examples of items include: “I often feel tense and jittery” (N), “I like to have a lot of people around me” (E), “I often enjoy playing with theories or abstract ideas” (O), “I tend to assume the best about people” (A), and “I pay my debts promptly and in full” (C). The items are assessed on a 5-point likert scale, from “strongly disagree” (1) to “strongly agree” (5) (McCrae & Costa, 2007). The test is scored by summing the scores of the six items pertaining to each factor.

Mental Rotation Ability

Mental rotation ability is most commonly measured with the Mental Rotations Test (MRT) by Vandenberg and Kuse (1978), which uses drawings provided by Shepard and Metzler (1971; Casey, 2013). In the present study, a redrawn version (Peters et al., 1995) of the original test was administered. The test consists of problem sets with one target image of a 3D object to the left, and four additional images of 3D objects to the right. Two of these images are rotated versions of the target and the other two do not match it. One point is given for identifying both of the correct images, while no points are given for identifying one of them. 12 problem sets were administered using pen and paper with a time limit of 3 minutes. As such, participants could obtain a score of 0-12.

Simulator Sickness

The Simulator Sickness Questionnaire (SSQ; Kennedy et al., 1993) is the most widespread measure of simulator sickness (Brooks et al., 2010). The questionnaire consists of 16 symptoms which are rated on a four-point scale, from 0 (“none”) to 4 (“a lot”). Based on a factor analysis, the symptoms are clustered into three subscales: oculomotor, disorientation, and nausea (Kennedy et al., 1993). Oculomotor include symptoms such as fatigue and eyestrain, disorientation include dizziness and vertigo, and nausea include sweating and nausea. Each subscale consists of seven symptoms. As such, five of the symptoms, for instance general discomfort, are included in two of the subscales. The score for each subscale is calculated by summing the corresponding item scores and multiplying this score by a weight (Kennedy et al., 1993). The oculomotor sum is multiplied by 7.58, and scores can therefore range from 0 to 159.18. The disorientation sum is multiplied by 13.92, with scores ranging from 0 to 292.32. The nausea sum is multiplied by 9.54, with scores ranging from 0 to 200.34. A total severity score is calculated by adding the unweighted sum of each subscale and multiplying this sum by 3.74, meaning it can range from 0 to 235.62.

Presence

The Slater-Usoh-Steed Questionnaire (SUS; Usoh et al., 2000) is a 6-item questionnaire of presence. The questions are centered around three themes: the sense of being within the VR environment, the extent to which the VR environment is experienced as the dominant reality, and to what extent the VR environment is remembered as a place. SUS includes questions such as “To what extent did you think you were really in the simulated situation?” and “Does your memory of the simulated situation feel like the memory of a real place?”. Each item is assessed on a scale from 1 to 7, with a higher score indicating greater presence. A mean score of presence was then computed across the six questions.

Procedure

Upon arrival in the laboratory, participants were asked to read the information letter and fill out an informed consent form (see Appendix). Following the informed consent procedure, participants were asked to fill out a pre-simulation questionnaire. The pre-simulation questionnaire included demographic questions about the participants’ age and sex, the two sets of questions regarding experience with VR and videogames, motion sickness susceptibility (MSSQ-short) and positive and negative affect (PANAS pre). A Norwegian version of the NEO-FFI-3 personality test was then administered. After completing the questionnaires, the participants received the instructions for the Mental Rotations Test (MRT-A), as well as four sample sets to practice on. Once stating they understood the task, participants were handed the test and given three minutes to complete as many problem sets as possible. After completing the test, participants were seated in a comfortable chair and fitted with the Oculus Go. They were informed that the VR roller coaster ride would last approximately 5 minutes and reminded that they could discontinue participation at any time. Participants were then handed the controller and instructed on how to start the simulation once ready. After being immersed in the VR environment, a post-simulation questionnaire was administered. The post-simulation questionnaire consisted of measures of positive and negative affect (PANAS post), presence (SUS), and simulator sickness (SSQ). Each session lasted approximately 35 minutes, including instructions and debriefing. Lacking a validated version in Norwegian, all the questionnaires had been translated to Norwegian and back-translated into English by the researchers involved in the study, to obtain a reliable (however not validated) version of the questionnaires in the Norwegian language (except for NEO-FFI-3, in which a validated Norwegian version exists).

Included and Excluded Measures

Mental rotation scores and the demographic variables sex and age were included in the analyses. 26 participants (49.1%) did not play video games regularly and reported 0 joystick years. On the basis of the large proportion reporting 0 joystick years, the variable was not included in the analyses. None of the participants used VR on a regular basis, meaning all of them reported 0 joystick years for VR.

Based on previous work, the personality traits neuroticism, extroversion, openness, and agreeableness were included in the analyses. Conscientiousness, which is associated with organization and purposefulness (McCrae et al., 2012), was not included as previous theorizing and research has not indicated a role of this trait in simulator sickness or presence.

Positive and negative affect prior to experiencing the VR roller coaster ride were excluded, because extroversion has been found to correlate with positive affect, and neuroticism with negative affect (Costa & McCrae, 1980). Positive and negative after were included to investigate whether they were related to experienced simulator sickness and presence.

Data Analysis

All statistical procedures were performed in IBM SPSS Statistics (Version 26.0). Spearman's correlations were performed to assess the relationships between the measured variables. This non-parametric statistic works on ranked data, meaning it does not rely on the assumption of normality and reduces the impact of outliers (Field, 2013, p. 271), which are typical for simulator sickness scores (Mittelstädt et al., 2019). Following the work of Kober and Neuper (2013), stepwise regression was used to investigate whether the individual factors predicted presence and simulator sickness. Whereas hierarchical regression relies on past research for selecting variables, stepwise regression is suitable for exploratory research (Field, 2013, p. 323). Four stepwise multiple regressions were conducted to investigate whether sex, mental rotation score, neuroticism, and extroversion predicted scores on the three simulator sickness subscales (nausea, oculomotor, and disorientation) and the simulator sickness total score. Another stepwise multiple regression was conducted to investigate whether sex, mental rotation score, neuroticism, extroversion, openness, and agreeableness predicted sense of presence. Independent samples t-test was used to investigate whether there was a sex difference in simulator sickness and presence. Positive and negative affect (PANAS post) was not included, as it was measured after VR exposure and thus could not be a predictor of simulator sickness and presence.

Results

Descriptive Statistics

Means, standard deviations, and range for the questionnaires are provided in Table 1. McCrae and Costa (2007) reported the following norm scores on NEO-FFI-3 for adults between the ages of 21-30 years: neuroticism = 21.8 (*SD*=7.9), extroversion = 29.6 (*SD*=5.7), openness = 29.6 (*SD*=6.7), agreeableness = 30.1 (*SD*=6.4). The raw scores in the present study (see Table 1) were similar, although scores on neuroticism, extroversion, and openness were slightly higher. Means for the SSQ subscales and total score provided by Kennedy et al. (1993) came from data collected after exposure to traditional flight simulators, which tend to produce a different symptom profile and lower scores compared to VR technology (Stanney & Kennedy, 1997). VR devices are typically associated with a D > N > O profile, meaning the most severe and frequent symptoms are disorientation symptoms, followed by nausea symptoms, and the least exhibited are the oculomotor symptoms (Stanney & Kennedy, 1997). The same profile was identified in the present study (see Table 1). In contrast, flight simulators tend to show a O > N > D profile and Kennedy et al. (1993) reported the following means: nausea subscale = 7.7 (*SD*=15), oculomotor subscale = 10.6 (*SD*=15), disorientation subscale = 6.4 (*SD*=15), total score = 9.8 (*SD*=15). Mean scores in the present study were considerably higher (see Table 1). The mean presence score in the present study (see Table 1) was comparable to the mean Usoh et al. (2000) reported for participants exposed to VR, of 3.8 (*SD*=1.3).

Table 1

Descriptive Statistics for Study Variables

	M	*SD*	Range
Neuroticism	24.0	6.7	3-42
Extroversion	30.9	8.1	14-44
Openness	31.9	6.4	18-45
Agreeableness	29.9	6.8	13-41
Motion sickness susceptibility	17.7	5.1	9-34
Mental rotation score	5.4	2.6	0-12
PA post	32.2	7.2	17-45
NA post	17.6	6.0	10-31
Presence	3.7	1.1	2-6
Nausea subscale	60.3	36.3	0-162
Oculomotor subscale	41.9	32.4	0-136
Disorientation subscale	105.8	69.1	0-264
SS total score	72.8	44.9	7-187

Note. PA = positive affect; NA = negative affect.

Correlations

There was a significant positive correlation between neuroticism and the nausea subscale (see Table 2). No other significant relationships were found between the simulator sickness scores and the personality traits. Significant negative correlations were found between positive affect (post) and the nausea subscale, disorientation subscale, and total score. Significant positive correlations were found between negative affect (post) and all simulator sickness scores.

There was a significant negative correlation between sex and presence. This indicated that females experienced more presence, compared to males. Positive affect and negative affect (post) both showed significant positive correlations with presence.

No relationship was found between presence and the simulator sickness scores. There was a significant negative correlation between neuroticism and sex. This indicated that females scored higher on neuroticism, compared to males. There was a significant positive correlation between sex and mental rotation score. This indicated that males had higher mental rotation scores, compared to females.

Motion sickness susceptibility significantly correlated with the nausea subscale, disorientation subscale, and simulator sickness total score. Simulator sickness and motion sickness are related phenomena, and the relation between them does not explain why there are individual differences in susceptibility. Motion sickness was therefore excluded from further analysis.

No relationship was found between age and the other variables. The sample was homogenous with regard to age, and age was therefore removed from further analysis.

Table 2

Correlations for Study Variables

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. Age	-														
2. Sex[a]	.25	-													
3. MSS	-.16	-.30*	-												
4. Neuroticism	-.03	-.29*	.13	-											
5. Extroversion	-.27	-.13	.05	-.42**	-										
6. Openness	-.12	.06	-.17	-.05	.09	-									
7. Agreeableness	.04	-.25	.10	.11	-.00	.14	-								
8. MRT	-.02	.37**	-.10	-.22	.03	.17	-.09	-							
9. PA post	-.15	.11	-.07	-.31*	.41**	.15	-.06	.13	-						
10. NA post	.06	-.25	.11	.31*	-.21	.06	.02	.05	-.22	-					
11. Presence	.08	-.31*	.05	.07	.21	.10	-.00	-.19	.32*	.29*	-				
12. SSQ-N	-.11	-.26	.43**	.28*	-.05	-.09	-.05	.08	-.35*	.59**	.10	-			
13. SSQ-O	-.18	-.11	.21	.14	-.08	.06	-.01	.12	-.15	.32*	.05	.70**	-		
14. SSQ-D	.01	-.01	.33*	.14	-.11	.10	.13	.21	-.30*	.45**	.03	.75**	.80**	-	
15. SSQ-TS	-.09	-.15	.35*	.19	-.10	.04	.03	.17	-.28*	.49**	.08	.88**	.91**	.94**	-

Note. MSS = motion sickness susceptibility; MRT = mental rotation; PA = positive affect; NA = negative affect; SSQ = Simulator Sickness Questionnaire; SSQ-N = Nausea; SSQ-O = Oculomotor; SSQ-D = Disorientation; SSQ-TS = Total Score.

[a] 0 = female and 1 = male. * $p < .05$. ** $p < .01$.

Regression Analyses

The regression model for the nausea subscale was significant, ($F[1, 51]=4.61$, $p=.036$). This model included neuroticism and excluded all other variables. Neuroticism explained approximately 7% of the variance in nausea (${}_{Adj}R^2= .07$, $b^*=.29$). No variables were entered into the regression models for the oculomotor subscale, the disorientation subscale, or the SSQ total score. The regression model for presence was significant ($F[1, 51]=5.95$, $p=.018$). This model included sex and excluded all other variables. Sex explained approximately 9% of the variance (${}_{Adj}R^2= .09$, $b^*=-.32$).

T-tests

On average, females scored higher on the nausea subscale ($M = 67.97$, $SE = 6.86$), compared to males ($M = 48.61$, $SE = 6.35$). This difference, 19.36, was significant $t(50) =2.1$, $p = .043$. No significant differences were found for the oculomotor subscale, the disorientation subscales, or the SSQ total score. On average, females reported experiencing higher levels of presence ($M =4$, $SE = 0.2$), compared to males ($M = 3.25$, $SE = 0.22$). This difference, 0.74, was significant $t(46) = 2.5$, $p = .016$.

Discussion

The use of VR for professional training will likely increase as the availability of VR devices increases, but the outcomes of such training could be influenced by the level of simulator sickness and presence experienced by users. Susceptibility varies across individuals, and knowledge about the role of influential individual factors could help inform how VR use can be optimized. The present study investigated whether simulator sickness and presence were related to various individual factors, as well as whether there was an association between simulator sickness and presence. The main findings were that neuroticism was associated with nausea symptoms of simulator sickness, females scored higher on the nausea subscale than males, and sense of presence was higher among females compared to males. Significant negative correlations were found between positive affect (post) and all simulator sickness scores except oculomotor, and significant positive correlations were found between negative affect (post) and all simulator sickness scores. Positive and negative affect (post) both revealed significant positive correlations with presence.

Simulator Sickness and Individual Factors

In the following, I will first present a framework and previous findings that could provide insight into the association found between neuroticism and nausea. Then, I will present potential explanations for the sex difference found in nausea. Finally, I will briefly mention the individual factors that were not related to simulator sickness.

Neuroticism and Nausea

In the present study, neuroticism was positively correlated with and a significant predictor of nausea symptoms. Balaban and Yates (2017) developed a framework of how nausea is perceived and how it progresses, as a result of interactions between sensorimotor, interoceptive, and cognitive-behavioral processing. Following this framework, neural pathways (i.e. vestibular, somatosensory, visual, or visceral pathways) are activated in response to internal or external triggers, for instance, an aversive visual motion stimulus. This activation elicits sensorimotor responses that produce neurological signs of nausea, such as cold sweating and altered heart rate, as well as interoceptive mechanisms. Interoception refers to a bodily perception of the symptoms, and is depicted to influence the neurological signs of nausea, and the expressed symptoms resulting from cognitive-behavioral processing. Specifically, at the cognitive level, perception of the symptoms affect interpretation of the trigger stimulus and symptoms themselves, emotional states, and arousal. Fear and anxiety responses may be generated and can lead to, for instance, rumination and worrying about the symptoms. These processes can, in turn, influence interoceptive and sensorimotor processing.

This framework also incorporates comorbid features that might influence nausea, including anxiety. Clinical research on anxiety and vestibular disorders has indicated that anxiety, visual, and vestibular systems may interact during balance control (Staab et al., 2013). The sensorimotor component in Balaban and Yate's (2017) framework incorporates postural control mechanisms, and defines a reference frame for which sensory input are interpreted. As previously presented, there is evidence that neuroticism influences the processing of visual and vestibular stimuli (Indovina et al, 2014; Riccelli et al., 2017). Based on their findings, Indovina et al. (2014) proposed that the vestibular systems of individuals with high neuroticism might differ in two ways when processing vestibular stimuli, compared to those with low scores. First, their vestibular system might be more reactive to vestibular stimuli. Second, their vestibular-anxiety reactions to vestibular stimuli might be amplified. Relatedly, the findings of Riccelli et al. (2017) could indicate that neuroticism is associated with increased susceptibility to visual motion stimuli and sensitivity to balance threats. Given the interconnectivity between sensorimotor, interoceptive, and cognitive processes (Balaban & Yates, 2017), it is possible that these neurological differences might be associated with a higher susceptibility to nausea.

Weech et al. (2018) investigated various measures of sensorimotor processing in relation to simulator sickness and found that individual differences in postural control predicted simulator sickness. Specifically, their results indicated that increased postural sway was associated with decreased simulator sickness, in response to VR simulated self-motion. According to the postural instability theory (Riccio & Stoffregen, 1991), motion sickness might arise if ineffective postural control strategies are used. In Balaban and Yate's framework (2017), altered postural control is incorporated as a defensive response to perceived nausea. It is plausible that individuals with high neuroticism scores might face more difficulty when attempting to adjust their posture during VR simulations. Clinical studies have indicated that anxiety disorders adversely affect postural control (Staab et al., 2013). Grounded in the conceptualization of neuroticism, another possibility is that individuals with high scores might have been more attentive to their nausea symptoms.

Mittelstädt et al. (2019) suggested the association they identified between pain catastrophizing and simulator sickness, might be explained in terms of the cognitive-behavioral processes proposed by Balaban and Yates (2017). Specifically, they pointed out that pain catastrophizing is a corresponding concept to illness worry and rumination, and similarly affect the way bodily discomfort arising from aversive stimuli is interpreted. According to Balaban and Yates's (2017) framework, illness worry and rumination is associated with emotional arousal and can alter the neurological signs and interoceptive bodily perception of nausea. Mittelstädt et al. (2019) postulated that individuals with high pain catastrophizing scores appear to pay more attention to simulator sickness symptoms, and find it difficult to disengage from them. This tendency to focus on the symptoms could in turn intensify the symptoms or result in more symptoms developing. Neuroticism is also associated with a tendency to focus on, amplify, and interpret bodily sensations as signs of illness (Costa & McCrae, 1987). It is possible that individuals with high neuroticism scores were more attentive to their nausea symptoms, and prone to a similar reinforcement effect. Participants with high neuroticism scores might also have been more likely to report discomfort. However, if this were the case, one might expect that neuroticism would also have been associated with disorientation symptoms, oculomotor symptoms, and the total simulator sickness score. In summary, the presented framework and studies offer potential explanations why neuroticism was positively associated with nausea symptoms.

Sex and Nausea

A null correlation was found between sex and nausea symptoms, and sex was excluded from the corresponding stepwise regression. However, the independent samples t-test was significant, indicating that females on average experienced more nausea symptoms compared to males. Munafo et al. (2017) found evidence that sex differences in postural sway preceded sex differences in simulator sickness. While they found that the incidence in simulator sickness was higher among females, specifically 2.33 females for each male, the severity did not differ. However, only the SSQ total severity score was included in the analyses, meaning potential differences in nausea symptoms were not investigated. As discussed above, differences in postural control could be related to nausea susceptibility. In contrast with Munafo et al. (2017), Weech et al. (2018) found that females experienced significantly more simulator sickness than males, when comparing total severity scores. However, while sway path length was found to be the strongest predictor of simulator sickness, it did not differ between males and females (Weech et al., 2018). Relatedly, Stanney et al. (2020) found no significant difference in postural stability between males and females.

As briefly mentioned in the introduction, it has been suggested that the female hormonal cycle might be involved in the greater motion sickness susceptibility of females (Golding, 2016). Susceptibility to motion sickness (Golding, 2005) and simulator sickness (Clemes & Howarth, 2005) have been found to vary across the menstrual cycle. However, Golding et al. (2005) concluded the magnitude of this susceptibility fluctuation is not large enough to fully account for sex differences. In addition, in a recent study Hemmerich et al.

(2019) found no significant correlations between the estimated levels of four sex hormones and simulator sickness.

Hemmerich et al. (2019) did however find that perceived menstrual pain was positively associated with simulator sickness susceptibility. In addition to this, the peak simulator sickness scores of females with severe menstrual pain differed significantly from those of females with low pain and males. Significant differences in simulator sickness incidence and severity has also been found to be significantly higher among individuals with neck pain, compared to asymptomatic individuals (Tyrrell et al., 2018). Hemmerich et al. (2019) suggested their findings could indicate that variability in pain sensitivity and pain perception might account for individual differences in simulator sickness. The proposed role of pain perception is in supported by the finding that pain catastrophizing and simulator sickness are associated (Mittelstädt et al., 2019). Research on sex differences in pain has indicated that for most pain modalities, pain sensitivity is greater among females compared to males (Fillingim et al., 2009). Furthermore, brain imaging studies have indicated there are sex differences in the processing of nociceptive stimuli (Fillingim et al., 2009). Taken together, these findings indicate a potential role of pain in individual susceptibility to simulator sickness, as well as sex differences. Another related explanation is that neuroticism could have accounted for the sex difference in nausea symptoms. Specifically, females were found to score higher on neuroticism than men, and neuroticism was in turn found to predict nausea symptoms.

In a recent study, Stanney et al. (2020) conducted two experiments to investigate whether a variety of individual factors might account for sex differences in simulator sickness. Their results indicated that interpupillary distance non-fit was the main contributor to sex differences in simulator sickness. Adult males tend to have a wider interpupillary distance, compared to adult females (Dodgson, 2004). Most HMDs can be adjusted so that the center of users' eyes can be aligned with the center of the VR lenses, within a limited range. Based on a comparison of the interpupillary distance range of seven currently available HMDs, Stanney et al. (2020) found that they accommodate considerably fewer females than males, and may not fit 30% or more. When comparing males and females whose interpupillary distance could be fit, no sex differences in simulator sickness were found. In contrast to the majority of other current HMDs, the Oculus Go has a fixed interpupillary distance (Hillmann, 2019). Although not investigated in the present study, it is possible that females experienced greater interpupillary distance mismatch, and in turn more nausea symptoms.

Most of these explanations are focused on simulator sickness in general, rather than nausea symptoms specifically. In contrast with Weech et al. (2018) and Stanney et al. (2020), the SSQ total severity score did not significantly differ between males and females in the present study. Clifton and Palmisano (2019) proposed that potential sex differences in simulator sickness might have been masked by the provocative VR environment they used. This could have been the case in the present study as well, or it might be that females are particularly susceptible to nausea symptoms. It is also important to note that the majority of evidence that there is not a sex difference comes from studies only comparing SSQ total scores (Clifton & Palmisano, 2019; Knight & Arns, 2006; Ling et al., 2013; Melo et al., 2018; Weech et al., 2020), although some have reported finding no significant sex difference in nausea symptoms (Gamito et al., 2008; Sagnier et al., 2020).

Other Individual Factors and Simulator Sickness

Mental rotation has been proposed as an individual factor that might reduce simulator sickness (Parker & Harm, 1992). The potential influence of mental rotation ability on simulator sickness has not been investigated previously, but the findings of the present study indicate there is no association. This might have something to do with the technological capabilities of HMD-driven VR systems, which I will get back to when discussing mental rotation and presence.

No relationship was found between extroversion and simulator sickness in the present study. The findings of Indovina et al. (2014) showed that the anxiety systems of individuals with low extroversion scores might be more reactive to vestibular stimuli, compared to others. In contrast, Riccelli et al. (2017) did not find any evidence that low extroversion correlated with brain connectivity or activity during simulated self-motion. The present findings indicate that low extroversion scores were not associated with simulator sickness. Furthermore, individuals who score high on extroversion have a tendency to be energetic, fun-loving, and optimistic (McCrae et al., 2012), which could cause high scorers to enjoy the VR rollercoaster more, and therefore have a reduced susceptibility to simulator sickness. However, this interpretation was not supported by this study, since there was no significant correlation between simulator sickness and extroversion.

Presence and Individual Factors

In the next section I will present potential explanations for the finding that females experienced more presence, compared to men. Then, I will discuss the null correlations between presence and the other individual factors, as well as potential reasons for the heterogeneity of studies investigating individual differences in presence.

Sex and Presence

The findings of the present study indicated that females experience higher levels of presence compared to males. More specifically, this was indicated by the findings that sex and presence were significantly correlated, that sex was a significant predictor of presence, and that average presence significantly differed between males and females. This is in contrast with several previous findings indicating that males experience more presence (Gamito et al., 2008; Felnhofer et al., 2012; Felnhofer et al., 2014; Sagnier et al., 2020) or that there is no sex difference (De Leo et al., 2014; Schwind et al., 2019; Weech et al., 2020). Regarding previous findings that males experience higher levels of presence compared to females, potential explanations include that males tend to have more video gaming experience (Gamito et al., 2008) and score higher on spatial abilities (Felnhofer et al., 2012). Previous gaming experience was not included in the present analysis, however none of the participants had regular experience with VR. The findings of the present study indicated that males scored higher on mental rotation compared to females, which is commonly found (Casey, 2013). As such, it appears that spatial abilities did not account for sex difference in presence in the present study.

A sex difference was also found for neuroticism, namely that females scored higher compared to males. Several previous studies have examined the potential influence of anxiety on presence. Alsina-Jurnet and Gutiérrez-Maldonado (2010) and Alsina-Jurnet et al. (2011) investigated whether presence was related to anxiety in a VR university exam scenario and non-stressful VR environments. Their findings show that presence was not associated with anxiety in the neutral VR environment for the non-test anxiety group nor the high test anxiety group. In the stressful VR environment however, presence was associated with anxiety for both groups, and most strongly among the high test anxiety group. Relatedly, Weibel et al. (2010) found an association between neuroticism and emotional involvement, and suggested that individuals with high neuroticism scores might experience more presence when they are exposed to negative media contents. The VR roller coaster ride used in the present study was likely experienced as stressful by at least some participants, and even more so by those who were high in neuroticism and developed simulator sickness. As such, it might be that the tendency of females to score higher on neuroticism, in combination with a provocative VR scenario, was associated with a higher sense of presence.

Felnhofer et al. (2012) and Gamito et al. (2008) also intentionally chose anxiety inducing VR environments. Felnhofer et al. (2012) used a VR speech scenario and measured trait anxiety of social interaction. Their results indicated that anxiety was related to a single item measure of presence, but not a more comprehensive measure. In addition, they reported that females expressed more anxiety, although males and females did not significantly differ. They suggested that this non-significant finding was likely due to small sample size. Similarly, Gamito et al. (2008) selected a VR classroom test scenario and measured trait and state anxiety. However, both anxiety and presence scores were lower compared to normative data. They proposed that anxiety scores might have been lower because the VR scenario was not perceived as a real life test. Drawing on the findings of Alsina-Jurnet and Gutiérrez-Maldonado (2010), it might be that the VR scenarios in the aforementioned studies were not perceived as considerably stressful. Various VR systems, VR environments, and measures of presence and individual factors have been used across different studies, which makes comparison difficult. At the same time, it appears that anxiety-related traits might come into play when VR environments are perceived as sufficiently stressful and, as suggested by Felnhofer et al. (2012), could be a confounding variable for sex differences in such instances.

Other Individual Factors and Presence

It has been proposed that mental rotation ability might be associated with an increased sense of presence. However, no relationship was found in the present study, which is consistent with the findings of several previous studies (Alsina-Jurnet & Gutiérrez-Maldonado, 2010; Coxon et al., 2016; Ling et al., 2013). These findings are inconsistent with the hypothesized role of spatial abilities by the process model of spatial presence (Wirth et al., 2007). Similarly to the present study, no association has been found in studies where mental rotation tests were administered and HMD-driven VR systems were used (Alsina-Jurnet & Gutiérrez-Maldonado, 2010; Coxon et al., 2016; Ling et al., 2013). In contrast, the evidence of an association comes from studies measuring self-reported spatial visual imagery and using desktop computers (Hartmann et al., 2016; Hofer et al., 2012). Coxon et al. (2016) used a HMD and three measures of spatial ability in order to investigate the heterogeneity of previous studies. Their results indicated that self-reported spatial visual imagery, but not the scores on two spatial ability tests, correlated with presence. Therefore, they suggested that some aspect of spatial abilities might be related to presence, but which and how they can be measured remains unclear. In summation, the findings of the present study provide additional support that, at least the mental rotation aspect of spatial skills, is not associated with increased presence. The consistency of this finding across studies using different VR environments could also indicate it was not related to the type of VR content used, although spatial abilities might influence presence in yet other VR environments. A potential explanation for the finding could be that mental rotation abilities may not be necessary for processing stimuli provided by HMDs, and therefore did not influence participants' susceptibility to experiencing presence and simulator sickness.

As discussed above, it is possible that neuroticism could explain the sex difference in sense of presence, but no direct associations with presence were found. Similarly, no relationship was found between extroversion, openness, or agreeableness, and sense of presence. One potential explanation for the heterogeneous findings of studies investigating the relationship between personality factors and presence, is that different types of VR systems have been used. Sas and O'Hare (2003) postulated that during exposure to immersive VR systems, most users become immersed regardless of individual differences in personality. Users are assumed to experience presence because of the advanced technological capabilities of immersive VR systems, such as HMDs. By contrast, individual differences are expected to account for users' sense of presence in non-immersive VR systems, because they are not prevailed by the less advanced technological capabilities (Sas & O'Hare, 2003). In line with this suggestion, Sas and O'Hare (2003) used a non-immersive VR system and found that empathy and absorption correlated with presence, whereas Ling et al. (2013) used a HMD and found these personality traits were not associated with presence. It is possible that null correlations were found in the present study because the technological factors of the Oculus Go, rather than personality traits, created a sense of presence. However, because the types of VR systems, VR environments, presence measures, and personality questionnaires used have varied across studies, a variety of factors might have influenced the results.

Kober and Neuper (2013) employed various presence and personality questionnaires to investigate whether the relationships depended on the presence measure used. Their results revealed that, with the exception of one null correlation, the four presence measures were significantly correlated. Nevertheless, several personality factors revealed heterogeneous correlations with presence, across the different presence measures. Kober and Neuper's (2013) results regarding the relationships between different personality factors and presence may be limited because they used a 3D projection screen, which is less immersive than HMD systems, and their sample size was small and exclusively consisted of females. Their results do however indicate that correlations between presence and personality factors can vary from one presence measure to another.

The influence of individual factors on sense of presence might also be influenced by the type of VR environment used. For instance, the results of Alsina-Jurnet and Gutiérrez-Maldonado (2010) showed that personality characteristics were more relevant in the VR university exam scenario, compared to the non-stressful VR environments. Based on this finding, they suggested that personality characteristics may exert a larger influence on presence in emotional VR environments, whereas technological factors are far more important in eliciting a sense of presence in non-emotional VR environments.

Emotions

Unsurprisingly, simulator sickness was found to be negatively associated with positive affect and positively associated with negative affect, after VR immersion. Presence, on the other hand, was positively associated with both positive and negative affect. VR environments may evoke the same types of emotions that an individual would experience in a corresponding real-world situation (Hodges et al., 1994). The results of the present study indicate that experiencing presence during the VR roller coaster ride was associated with both positive and negative emotions. Some participants may have enjoyed the simulation, while others did not. Baños et al. (2005) compared an emotional VR environment to a neutral one, and found that participants experienced the emotional as more natural, believable, real, and engaging. Similarly, Alsina-Jurnet and Gutiérrez-Maldonado (2010) found that presence scores were higher in an exam scenario compared to a neutral VR environment, indicating a role of emotions in presence. Furthermore, the high test anxiety group experienced a greater sense of presence, compared to the low test anxiety group. The authors suggested that a VR environment needs to be emotionally relevant for a given user, in order to elicit a high level of presence (Alsina-Jurnet & Gutiérrez-Maldonado, 2010).

Neuroticism was negatively correlated with positive affect and positively correlated with negative affect after VR exposure. This could be related to the finding that individuals with higher neuroticism score tended to experience more nausea in the present study. In contrast, extroversion was positively correlated with positive affect, but the correlation with negative affect was not significant. Weibel et al. (2010) found that neuroticism and extroversion were positively correlated with emotional involvement, indicating individuals might be positively or negatively involved. As proposed by Weibel et al. (2010), and in line with the trait conceptualizations (McCrae et al., 2012), the positive correlations found in the present study could indicate that participants with high neuroticism scores were prone to negative reactions, and individuals with high extroversion scores to positive reactions, towards the VR environment.

Simulator Sickness and Presence

In line with several recent studies (Clifton & Palmisano, 2019; Ling et al., 2013; Servotte et al., 2020), a null correlation was found between simulator sickness and presence in the present study. Servotte et al. (2020) suggested the nonsignificant correlation in their study could be explained by participants experiencing relatively low simulator sickness, and that high levels could decrease or suppress users' sense of presence. Similarly, Witmer and Singer (1998) proposed that experiencing symptoms of simulator sickness could disrupt users' sense of presence through distraction or by reducing their involvement in the VR environment. The findings of the present study indicate this might not the case, as simulator sickness scores were high and no association was found between the total score nor the subscales and presence. Clifton and Palmisano (2019) also reported a high incidence of simulator sickness in their study, but failed to find an association. A potential explanation for these findings is that recent HMD-driven VR systems generate a stronger sense of presence, that is not easily influenced by simulator sickness. In previous generations and less immersive VR systems, users' sense of presence might be more sensitive to disruption by simulator sickness symptoms. Relatively few of the studies reviewed by Weech et al. (2019) employed HMD VR, so this could also explain why the balance of previous findings favored a negative association. In contrast, Weech et al. (2020) found a negative association between simulator sickness and presence in two experiments where a current generation HMD VR was used. However, this association was dependent on the narrative participants were provided prior to being immersed in the VR environment. When conducting separate analyses for the group who listened to a rich narrative and the group provided with minimal narrative context, the negative relationship was found only for the rich narrative group. As such, it is possible that other factors might modulate the association between simulator sickness and presence.

Strengths and Limitations

The predetermined sample size was recruited for the present study, and deemed sufficiently large to investigate the relationship between the measured variables. However, the sample was relatively homogenous and the generalizability of the results might be limited. The sample may also have consisted of individuals with a particular interest in technology or the research topic. Because simulator sickness and presence are influenced by the VR system and VR environment used, it is also possible that the findings of the present study might not be applicable to other settings. In addition, the findings are correlational and no causal links can be established. It is possible that associations were found due to the influences of a third variable.

Another potential weakness is that self-report measures were used, which are prone to certain biases. For instance, participants may have attempted to guess what was being investigated and the expected results of the study, and responded in a socially desirable manner. Several issues concerning the measurement of simulator sickness and presence have been raised. Simulator sickness symptoms have been found to correlate with anxiety, and there is concern that the SSQ items may be confounded by anxiety (Bouchard et al., 2011). As such, the reported scores might reflect experienced symptoms and feelings of anxiety. In addition, there is evidence that symptom onset can be delayed until after VR immersion (Smart et al., 2002; Stoffregen et al., 2010). Therefore, it is possible that some participants might have developed symptoms after leaving the laboratory, or that symptoms could have worsened. There is also evidence that the subjective evaluation of simulator sickness is slightly delayed, compared to physiological responses (Min et al., 2004). However, it remains unclear which physiological variables are the best indicators of simulator sickness (Dużmańska et al., 2018).

Skarbez et al. (2017) reviewed commonly used presence questionnaires, and recommended the SUS questionnaire on the basis that it is among the shortest and a direct measure of users' sense of presence. One limitation of the presence measure is that the questionnaire was completed after the VR roller coaster ride, meaning participants were required to recall the experience. Another possibility would have been to provide an assessment during VR immersion, but this might disrupt users' sense of presence. In addition, there is evidence that sense of presence reported during and after immersion do not significantly differ (Wissmath et al., 2010). Presence is a complex phenomenon, and a limitation pertaining to presence questionnaires in general is that they rely on participants' interpretation of the concept (Skarbez et al., 2017). Various physiological and behavioral measures have been proposed as means for assessing presence objectively. For instance, arousal is the most commonly proposed physiological representation of presence, which can be assessed through skin conductance or heart rate (Skarbez et al., 2017). Similarly to simulator sickness, no agreement has been reached concerning objective measures of presence (Wissmath et al., 2010). Additionally, which physiological indicators are suitable might vary across different VR environments.

It should be noted that the joystick years measure might not have reflected the participants true gaming experience. Several participants verbally reported that they used to play video games on a regular basis previously. However, as long as they did not play video games or use VR on a weekly basis at the time the experiment took place, they received a score of 0 years.

Future Research

The level of simulator sickness and presence VR users experience appear to be influenced by various individual and technological factors, and the interplay between them.

One challenge within VR research in general is that a variety of VR systems and environments have been used. In research investigating individual differences in simulator sickness and presence, this is further complicated by the use of different measures across studies. Taken together, this is likely an important source of the heterogeneity of previous findings, and also hinders comparison of results. Thus, comparable research designs and replication studies are needed in future research, in order to establish the role of individual factors.

The present study provides evidence that during VR simulations, individuals with high neuroticism scores and females tend to experience more nausea symptoms, and that females experience more presence compared to males. More research is needed in order to validate these findings, and to explore the underlying mechanisms and causal chains that account for these differences. As pointed out by Weech et al. (2019), conducting power analyses to determine sample size could benefit future studies. Modifications might be made to further investigate the associations found in the present study. For instance, it could be interesting to implement additional VR environments and investigate how the influence of individual factors might differ. With a larger sample, conducting separate analyses for males and females could generate valuable information regarding sex differences in nausea symptoms and presence. It is also important to note that neuroticism accounted for seven percent of the variance in nausea symptoms, and that sex accounted for nine percent of the variance in sense of presence. Given that a large proportion of the variances were not accounted for, this indicates that other individual factors that were not measured in the current study could be important.

The prevalence of simulator sickness can vary significantly between different VR environments (e.g. Munafo et al., 2017), and appears to have been relatively high in the present study. The results do however demonstrate that VR users may develop symptoms of simulator sickness even after short exposures (i.e. approximately 5 minutes). VR roller coaster simulations appear to be suitable for investigating simulator sickness, and relatively high incidences of symptoms have been reported in several previous studies (Davis et al., 2015; Gavgani et al., 2017; Nesbitt et al., 2017; Stanney et al., 2020). One issue that was not investigated in the present study is the potential after-effects of the VR simulation. In a recent review, Dużmańska et al. (2018) concluded that simulator sickness symptoms appear to persist for some time after VR exposure. For instance, Gavgani et al. (2017) measured simulator sickness every hour for three hours following a 15 minute VR roller coaster ride, and found that participants still reported experiencing symptoms after three hours. Stanney et al. (2003) reported that some symptoms might linger for more than 24 hours after VR exposure. Since symptom onset additionally could be delayed (Smart et al., 2002; Stoffregen et al., 2010), future studies should consider measuring simulator sickness at several points in time following VR simulations.

One important implication of the present study, is that future studies measuring simulator sickness with the SSQ questionnaire should not omit the subscales from analyses. In several previous studies, only the total score was included (e.g. Moss & Muth, 2011; Munafo et al., 2017; Weech et al., 2018). The SSQ is widely used to assess simulator sickness, but given its limitations a new or modified measure might be warranted. It has been pointed out that, in addition to some SSQ items potentially reflecting anxiety rather than simulator sickness symptoms, the questionnaire was developed for training in traditional simulators among physically fit military personnel (Bouchard et al., 2012). Bouchard et al. (2012) had participants complete the SSQ after being exposed to different VR systems and environments, and conducted a factor analysis. The results indicated that the SSQ comprised of two factors, oculomotor and nausea, rather than the three factor solution identified by Kennedy et al. (1993). It would have been interesting to attempt to replicate the SSQ factor structure (Kennedy et al., 1993) in the present study, but the sample size was not sufficiently large (Field, 2013, pp. 683-684).

A number of conceptualizations and measures of presence exist, and it appears to be a particularly challenging phenomenon to measure. The correlations Kober and Neuper (2013) found between different presence questionnaires indicated that they measure a similar construct. However, on the basis that they revealed heterogenous correlations with personality variables, the authors recommended that it might be beneficial to include several measures in future studies and calculate an overall mean presence score. However, this also suggests that more research into the presence questionnaires, and how to optimally measure this subjective feeling, is needed. Since it also remains unclear which objective measures are most suitable for assessing sense of presence, and simulator sickness, a solution could be to use self-report measures in combination with physiological measures.

Future studies including a measure of the FFM personality traits might want to consider using the 240-item NEO-PI-3, instead of the NEO-FFI-3. The big five traits are relatively broad, and the more comprehensive questionnaire also measures the six facets underlying each trait (McCrae & Costa, 2007). Thus, it could provide more detailed insight into the specific aspects of neuroticism that are related to simulator sickness. It is also possible that some of the facets of the other traits could be associated with simulator sickness or presence.

Implications for Organizations

The present study has several implications for the use of VR for professional training. In order to optimize training, evaluations should be done in advance, in order to identify employees' susceptibility to simulator sickness and presence. Personality questionnaires can be distributed to assess employees neuroticism scores. In Norway, the Working Environment Act posits several requirements regarding the working environment. Section 4-1 (2) states that the organization, arrangement, and management of work "shall be arranged in such a way that employees are not exposed to adverse physical or mental strain and that due regard is paid to safety considerations" (Working Environment Act, 2005). Concern surrounding the potential consequences of VR use on health and safety have been raised (Cobb et al., 1999; Rebenitsch & Owen, 2016), and should be considered when planning VR training. Section 4-2 (2a) states that employers are obligated to organize and arrange work with regard for the individual employee's situation (Working Environment Act, 2005). This implies that attempts should be made to individually tailor VR training when needed.

Based on the findings of the present study, females and individuals with high neuroticism scores appear to be more prone to simulator sickness. Thus, if no adjustments are made, they may benefit less from and become more reluctant to participate in VR training. Generally, it would be advisable to provide information regarding potential side effects in advance, give employees sufficient time to become familiar with the technology prior to training, and offer support. VR training should be terminated if any symptoms are reported, since simulator sickness appears to increase with exposure time (Dużmańska et al., 2018).

There is evidence that adaptation to VR environments can occur with repeated exposures (Dużmańska et al., 2018; Kennedy et al., 2000). For instance, Gavgani et al. (2017) found that by the third consecutive day participants were exposed to a VR roller coaster, the onset of nausea symptoms was slower and the other simulator sickness symptoms were reduced. McCauley and Sharkey (1992) proposed using exposure times short enough to avoid symptom onset repeatedly until adaptation occurs. Furthermore, they suggested that adaptation programs should be designed on an individual basis. Hence, a possible solution could be to implement such programs for employees at risk. Although the results of several studies indicate that VR users can become adapted, the adaptation pattern and to what extent it occurs has varied across studies (Dużmańska et al., 2018). In addition, employees need to be committed to going through repeated exposures (Gallagher & Ferrè, 2018). However, Stanney et al. (2020) pointed out that habituation programs may not be effective if HMDs do not fit users' interpupillary distance.

The evidence of sex differences in the effects of VR technology are a cause for concern. Within an organizational context, it could be a hindrance to the implementation of VR training or be a source of discriminatory treatment toward employees. As highlighted by Munafo et al. (2017), consequences could occur at a societal level if the use of HMD driven VR becomes widespread enough. Based on the higher incidence of simulator sickness among females than males in their study, they called for manufacturers to make design changes. Stanney et al. (2020) concluded that if the adjustable interpupillary distance range is changed, sex differences in simulator sickness might be eliminated. Their results indicated that if these changes are not made, the consequences could be significantly higher simulator sickness and longer recovery time among females.

In the present study, males reported experiencing less presence than females. However, it is possible that this finding might be specific to the VR environment used in the present study. Furthermore, although the mean scores differed between the sexes, this does not necessarily mean that sense of presence among males was too low. In addition, no clear link has been established between presence and task performance, meaning more presence is not necessarily desirable (Skarbez et al., 2017). Thus, further research is needed to investigate the influence of presence on the effectiveness of VR training. If it appears to be important for training outcomes, it is necessary to identify why sex differences in presence exists and what might be done. Although the consequences of less or more presence on VR training outcomes are non-conclusive, organizations should be aware that sex differences might occur.

Conclusion

Simulator sickness and sense of presence are central to VR user experience, but how they can be minimized and optimized, respectively, remains a challenge. Susceptibility varies across individuals, and the present study investigated whether sex, personality factors, and mental rotation ability were associated with simulator sickness and presence. The findings indicated that neuroticism correlated with and was a significant predictor of nausea symptoms. Furthermore, females, on average, reported experiencing significantly more nausea symptoms than men. In addition, females were found to experience a higher sense of presence, compared to men. The potential link between simulator sickness and presence was also investigated, but it was not significant.

The use of VR technology in organizations will likely increase as these systems become increasingly accessible, but outcomes could be limited if employees develop symptoms of simulator sickness or experience low presence. Organizations should take individual differences into account, in order to optimize VR training. The findings of the present study could help identify individuals who are more and less susceptible, so that VR training can be individually tailored.

Previous research on individual differences has yielded mixed results, which could be a result of the use of various VR systems, VR environments, and measures, across studies. More research on individual differences in simulator sickness and sense of presence is needed in the current generation of HMD-driven VR systems.

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Appendix

Informed Consent Form

Er du interessert i å delta i forskningsprosjektet *«Virtuell virkelighet og velvære»?*

Dette er en forespørsel om deltagelse i et forskningsprosjekt der hovedformålet er å undersøke menneskelig generell velvære under bruken av virtuell virkelighet (VR) teknologi. I dette skrivet vil vi gi deg informasjon om formålet med prosjektet og hva din deltagelse vil innebære.

Formålet med prosjektet

Formålet med denne studien er å undersøke hvordan mennesker interagerer med VR-teknologi og hvordan virtuell virkelighet påvirker generell velvære. I denne studien vil menneskelige faktorer som individuelle forskjeller og generell velvære måles, for å kunne forstå menneskelige interaksjoner med virtuell virkelighet. Det endelige målet med prosjektet er å bidra til å utvikle innovative teknologier og evaluere påvirkningen av forbrukerorientert virtuell virkelighet på sluttbrukerne.
Denne studien er del av et større forskningsprosjekt, som er finansiert av EU-kommisjonen (ImmerSAFE) og vil være del av en doktoravhandling.
De innsamlede dataene vil, i anonymisert form, benyttes til vitenskapelige formål, inkludert vitenskapelige publiseringer og undervisning.

Prosjektet vil være del av en masteroppgave ved institutt for psykologi på NTNU.

Hvem er ansvarlig for forskningsprosjektet?

NTNU er institusjonen som er ansvarlig for prosjektet.

Hvorfor blir du bedt om å delta?

Utvalget av deltagere ble selektert på grunnlag av de følgende seleksjonskriteriene:
Friske voksne (18-45).
Ingen inntak av psykofarmaka.
Ingen psykiatriske/psykiske lidelser.
Villige til å delta på frivillig basis blant studentmassen ved NTNU.

Dersom du ikke fullstendig oppfyller kriteriene som er nevnt ovenfor, vær vennlig og informer eksperimentatoren om dette før du fyller ut og signerer dette skjemaet. I dette tilfellet vil ikke dataene dine samles inn og ingen informasjon om deg vil arkiveres.

Hva innebærer deltagelse for deg?

- *Dersom du velger å delta i prosjektet vil dette innebære at du fyller ut et spørreskjema elektronisk/i papirformat. Dette vil ta omtrent 20 minutter og svarene vil oppbevares elektronisk/i papirformat. Spørsmålene du vil bli stilt omhandler din subjektive oppfatning av de simulerte omgivelsene, for å for eksempel måle kvaliteten på simuleringen. Videre vil det bli stilt generelle spørsmål om din velvære og følelser under simuleringen. Alle spørsmålene må besvares på en mest mulig oppriktig og naturlig måte, og det kreves ingen forkunnskaper for å svare.*

- *Spørsmål som omhandler emosjoner, legemlige følelser opplevd under simuleringen, generell velvære, tidligere erfaringer og personlighet vil også være inkludert i spørreskjemaene.*
- *Dersom du velger å delta i prosjektet vil dette innebære at du vil bruke et forbrukerutviklet VR-headset (Oculus GO) og oppleve simulerte «immersive» omgivelser i ca. 5 minutter.*

Til dette prosjektet vil informasjon om psykososiale forhold/helse samles inn.

Deltagelse er frivilling
Deltagelse i prosjektet er frivillig. Dersom du velger å delta kan du trekke tilbake samtykket ditt når som helst uten å oppgi en grunn. All informasjonen om deg vil da anonymiseres. Det vil ikke være noen konsekvenser for deg dersom du velger å ikke delta eller senere bestemmer deg for å trekke deg.

Ditt personvern – hvordan vi vil oppbevare og bruke dine personlige data
Vi vil kun bruke dine personlige data til de formål som er spesifisert i dette informasjonsskrivet. Vi vil prosessere de personlige dataene dine konfidensielt og i henhold til Personvernordningen (GDPR) og Personopplysningsloven.

- *Dataene vil være tilgjengelige for prosjektlederen (Karin Laumann, karin.laumann@ntnu.no) og forskeren som er direkte involvert med dataanalysene (Simone Grassini, simone.grassini@ntnu.no).*
- *Navnet og kontaktinformasjonen din vil erstattes med en kode. Listen over navn, kontaktinformasjon og de respektive kodene vil oppbevares separat fra resten av de innsamlede dataene. Digitale data vil oppbevares på en PC på universitetet og være passordbeskyttet. Data som er i fysisk format vil bli låst inne i en sikret boks på kontorene til de ansvarlige forskerne.*

Deltagerne vil ikke på noen måte være gjenkjennbare fra dataene.

Hva skjer med dine personlige data ved forskningsprosjektets slutt?
Ved prosjektets slutt (31.08.2021) vil de personlige dataene anonymiseres. Innsamlede data vil oppbevares uten noen forbindelse til deltagernes personlige opplysninger.

Dine rettigheter
Så lenge du kan identifiseres i de innsamlede dataene har du rett til:
- tilgang til dine personlige data som prosesseres
- be om at dine personlige data slettes
- be om at ukorrekte personlige data korrigeres
- motta en kopi av dine personlige data (data portabilitet), og
- sende en klage til personvernombud/Data Protection Officer eller Datatilsynet angående prosesseringen av dine personlige data

Hva gir oss rettigheter til å prosessere dine personlige data?
Vi vil prosessere dine personlige data basert på ditt samtykke.

Basert på en avtale med NTNU har Norsk senter for forskningsdata (NSD) vurdert at prosesseringen av personlige data i dette prosjektet skjer i overenstemmelse med regelverket for datavern.

Hvor kan jeg finne ut mer?
Dersom du har spørsmål om prosjektet, eller ønsker å utøve dine rettigheter, ta kontakt med:

- *NTNU* via Simone Grassini (simone.grassini@ntnu.no) og via prosjektlederen, Karin Laumann (karin.laumann@ntnu.no).
- Personvernombud/Data Protection Officer: *Thomas Helgesen (thomas.helgesen@ntnu.no).*
- Norsk senter for forskningsdata, via mail: (personverntjenester@nsd.no) eller telefon: +47 55 58 21 17.

Med vennlig hilsen,

Prosjektleder	Stipendiat	Masterstudent
Karin Laumann	Simone Grassini	Ann Kristin Luzi

Samtykkeskjema

Jeg har mottatt og forstått informasjonen om prosjektet Menneskelig prestasjon og faktorer i virtuell virkelighet, og har blitt gitt muligheten til å stille spørsmål. Jeg gir samtykke:

☐ til å delta i innsamlingen av data gjennom bruk av spørreskjema.
☐ til å oppleve VR omgivelser i en laboratoriesetting.
☐ til at dataene mine oppbevares anonymt ved prosjektets slutt til oppfølgingsstudier.

Jeg gir samtykke til at mine personlige data prosesseres til prosjektets slutt, omkring *[31.08.2021]*

(Deltagers signatur, dato)

Norwegian University of
Science and Technology