What We Don't Know. The Effect of Realism in Virtual Reality on Experience and Behaviour

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Abstract This study addresses the question how realistic Virtual Worlds should be designed in order to create engaging experiences and stimulate 'natural' behaviour. Creating high realistic worlds is time consuming and expensive and it is unclear whether it is always needed. With the aim of gaining insights about questions related to presence and realism, an experiment involving 72 participants was set up upon a Virtual Reality cycling apparatus in which different levels of realism were created. Users were observed and evaluated regarding their experience (engagement, presence, naturalness and negative effects), awareness of realism and behaviour. The results indicate that, despite that differences in realism were observed, differences in realism do not have an effect on experience and behaviour. There seem other variables involved that can affect the whole experience in an enough intensity to obliterate the effects of a better sense of presence and realism. In addition, an increase in a perceived higher level of realism seems to be depended on a congruent increase of different elements within the virtual world. Merely increasing the level of realism of one element does not alter levels of perceived realism of users.

Keywords Virtual reality · Realism · Experience · Presence · Behaviour

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1 Introduction

As Virtual Reality (VR) technology, e.g. processing power and screen resolutions, advances rapidly, high realistic and high-fidelity worlds become possible in VR as well. It seems somewhat intuitive that a more realistic environment, able to achieve a higher fidelity with the actual environment which the VR is emulating, would elicit a better sense of presence and experience from the users. However, creating high realistic worlds is time consuming and expensive and it is unclear whether it is always needed in order to engage users and let them behave in a natural manner. VR studies seem to produce mixed results and indicate a more subtle and complex relationship between level of realism and experience. Moreover, the level of realism in most studies seem, despite hard work in development, relatively low compared to what is possible with technologies of today and what is used within the context of current entertainment films and games. In addition, none of these studies analysed experience (presence, naturalness, engagement and negative effects) and VR behaviour when the VR environment represents a real (city) environment in which the realism and resemblance is altered on multiple aspects. With the aim of gaining insights about questions related to presence and realism, an experiment was set up using a VR cycling apparatus developed within Breda University of Applied Sciences in collaboration with Atlantis Games. The virtual world represented a bike experience within a street in a Dutch city (Breda), which differed in level of realism. The subjects were observed and evaluated regarding their awareness of level of realism, the VR experience and physical responses to events within the virtual world. Several studies have been conducted concerning virtual reality and cycling, however, these were mostly focused on the topics of rehabilitation and exercise purposes (Hagen, Chorianopoulos, Wang, Jacceri, & Weie, 2016; Song, Kim, & Kim, 2004). This study tries to contribute to determine optimal levels of realism to a given VR application in order to optimize the cost and time needed to develop it by. As such we might avoid creating levels of realism that won't be perceived by the users or do not improve their VR experience significantly.

2 Theory

Presence and realism are important concepts regarding VR experience (Rettie, 2004, Yu, Mortensen, Khanna, Spanlang, & Slater, 2012). They also seem to become more important, as the technology of displays, miniaturization and computational power evolves making it possible to (re)produce more realistic Virtual Worlds. A combination of four technological dimensions (sensory, interaction, control and location) are expected to increase a sense of realism or presence and enhance an experience within VR (van Gisbergen, 2016). However, realism is a construct with many different meanings. On the one hand it refers to resemblance, in which realism is operationalized as reproducing something that is known and

familiar for the observer. The object, environment or event in that case also exists in the 'real', non-mediated, world. On the other hand, realism can refer to something that is perceived as real without any knowledge or reference to an object or event that is known to the observer. Even to the extent that the object or environment does not exist in the 'real' world (van Gisbergen, 2016). In this study we focus on the latter, meaning users "subjective sense of being in the place depicted by the Virtual Environment" (Yu et al., 2012) without knowing the (resemblance with the) real situation but instead reproducing a feeling in which the VR experience is like the real world (Rettie, 2004). However, it remains unclear how much effort should be put in creating high levels of realism (Bailenson et al., 2005).

On the one hand theories, such as gestalt, claim that high realism increases experience and natural behaviour. Users will behave more real when the world is perceived as more real (Pertaub, Slater, & Baker, 2002). On the other hand, there are theories, such as the uncanny valley (Slater and Steed, 2000), that propose that too much realism (resemblance) brings about a very strong drop in believability and comfort and as such may be forcefully rejected by humans as a defence mechanism (Bryant, 2001; Dautenhahn, 2002; Reichardt, 1978). It has been acknowledged by Brenton, Gillies, Ballin, and Chatting (2005) that there is hardly any research regarding manipulated realism as an experimental condition, and further research needs to be conducted in this area. Studies that have been conducted show mixed results. Research on the effect of realism in VR worlds indicated positive effects of increased realism on presence, arousal and liking (e.g. Barlett & Rodeheffer, 2009; Bailenson & Yee, 2006; Bailenson, Yee, Merget, & Schroeder 2006; Ivory & Kalyanaraman, 2007; Nowak, 2001; Nowak & Biocca, 2001; Zanola, Fabrikant, & Çöltekin, 2009), as well as no effects or negative effects of higher realism in games or avatars on emotions, presence and behaviour (e.g., Anderson, Rothbaum, & Hodges, 2001; Bailenson, Blascovich, Beall, & Loomis 2001; Garau, Slater, Pertaub, & Razzaque, 2005; Ivory & Kalyanaraman, 2007; Slater & Steed, 2000). This leads to the first research question (RQ1): What is the effect of realism in virtual worlds on user experience and behaviour? As it is unclear whether realism has an effect on experience, it also remains unclear whether it will affect user behaviour in VR towards more 'natural' behaviour. Leading to the second research question (RQ2): will a more realistic environment cause a more natural response in a virtual world compared to less realistic environment? Although the effect of realism on experience and behaviour remains unclear, we do expect that users will notice differences in level of realism even when they have not used virtual reality before, leading to the following hypothesis (H1): A more realistic virtual environment will cause a higher perceived feeling of realism than a less realistic virtual environment.

3 Method

A between-group (low versus high realism) design experiment was carried out which included an online questionnaire after the VR experience. Figure 1 shows an overview of the research design and data collection method.

The research took place at Breda University of Applied Sciences (June 2017). The VR gear was connected to a regular bike mounted in an intelligent trainer, able to interact with the virtual environment (e.g. back-pedal brake). The virtual environment was presented to the users by means of immersive goggles (an Oculus Rift DK2 head-mounted display). The bicycle was placed in the middle of a silent room (Fig. 2).

The virtual environment used in each virtual ride could be switched between a low realistic and a high realistic one (Fig. 3). A video camera recorded all sessions to observe the behaviour of the participants and a researcher was constantly present in the room. Participants were invited in the room and had to sign the informed consent form and read the information sheet. They were orally briefed about the procedures of the experiment and we asked to act as natural as possible on the

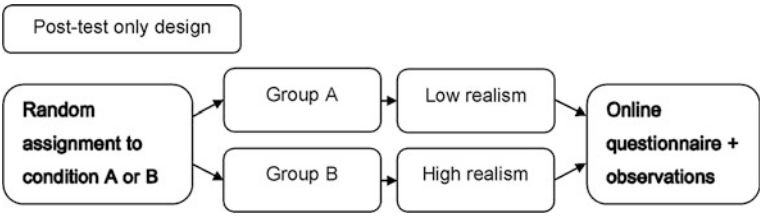

Fig. 1 Overview of the research design and data collection method

Fig. 2 Bike connected to the VR system

Fig. 3 Low and high Realism VR environment. *Source* CycleSpex

bicycle as if they were cycling outside. Each participant was able to observe the virtual environment for 30 seconds to become acclimated to the assigned virtual environment. The VR experience lasted for approximately two minutes. The online questionnaire took approximately 10–15 minutes. In the end, the participants were thanked and little treats were present to show gratitude for their participation.

3.1 Materials

The virtual world consisted of a simulation of a straight-ahead bike path within a city in the Netherlands (Breda). At the end of each VR cycle experience, a dangerous intersection with a traffic light was created. The traffic light would turn orange when a participant would approach the traffic light, and it would subsequently turn red. After approximately three to four seconds the traffic light would turn green again. A low and high realistic world was created. Both conditions contained the same environmental sounds (e.g. wind and bird sounds). Also, the following items were the same: characters, billboards, bicycle, traffic lights, and leaves on the ground. However, the following items were more detailed and in depth in the high realistic condition: buildings, street, lighting, sky, lighting, textures. In addition, only the high realistic condition contained street lights, shadows and graffiti.

3.2 Participants

The participant sample of the study consisted of 72 BA and MA students that were recruited at Breda University of Applied Science. The mean age was 23 years (SD = 3.465) and did not differ between groups. Per condition, 36 people participated in the experiment following the criterion of a minimum of 30 participants used in many VR experimental studies (e.g. van den Boom, Stupar-Rutenfrans, Bastiaens, & van Gisbergen, 2015; North & North, 2016). The number of female participants was the same for each group (50%). In the low realism condition, there

were 10 people who originated from abroad, while in the high realism condition there were 8 foreign people. None of the participants were familiar with the bike route in the city.

3.3 Measures

Presence
We measured presence using the ITC-Sense of Presence Inventory (ITC-SOPI) scale developed by Lessiter, Freeman, Keogh, and Davidoff (2001). A scale commonly used to measure VR experiences (e.g. by Baños et al., 2004; Bruce & Regenbrecht, 2009; van den Boom et al., 2015). The questionnaire consists out of four factors: *Spatial presence*, *Engagement*, *Naturalness* and *Negative effects*. All items were measured using a 5-point scale (1 = *strongly disagree*, 5 = *strongly agree*). Presence was measured using 19 items (using statements such as "*I felt I could interact with the displayed environment*", 13 items were used to measure Engagement (e.g. "*I felt sad that my experience was over*"), Naturalness was measured using 5 items (e.g. "*The displayed environment seemed natural*") and for Negative effects 6 items were used (e.g., "*I felt disorientated*"). For all four factors separately, the items were averaged to form a scale which showed reliable results for the low and high realism conditions: Presence ($\alpha = 0.86$ and $\alpha = 0.90$), Engagement ($\alpha = 0.65$ and $\alpha = 0.75$), Naturalness ($\alpha = 0.66$ and $\alpha = 0.77$) and Negative effects ($\alpha = 0.77$ and $\alpha = 0.63$).

Overall Perceived Realism
Overall realism was measured using two subscales of the German VR Simulation Realism Scale (Poeschl & Doering, 2013; Witmer & Singer, 1998). This scale has been used in many other studies (e.g. Fromberger, Jordan, & Müller, 2014; Reuter, 2015). The scale consists out of two items *Scene Realism* (5 items, e.g. "*Reflection in virtual space seemed to be natural*", $\alpha = 0.70$ and $\alpha = 0.82$) and *Audience behaviour* (4 items, e.g. "*Behaviour of virtual humans in the virtual environment was authentic*", $\alpha = 0.84$ and $\alpha = 0.85$). All items were measured on a 7-point Likert scale (1 = *strongly disagree*, 7 = *strongly agree).*

Item Perceived Realism
Perceived realism was measured for 15 elements within the virtual world such as shadows, traffic lights and cars using 7-point scales (1 = *strongly disagree*, 7 = *strongly agree,* e.g. "*The cars seemed very realistic to me*"). The items were analysed separately as well as combined as one factor showing reliable results for the low and high realism condition ($\alpha = 0.87$ and $\alpha = 0.92$).

VR Attention
Attention was measured for the dangerous traffic light condition using three recall questions. The first question was whether the traffic light was noticed, the second

was whether the colour of the traffic light was noticed, and the third question was whether the colour change of the traffic light was noticed.

VR Excitement
VR Excitement was measured by means of the question: did your excitement level change when you approached the traffic light? (answer options were I did not see a traffic light, yes and no).

VR Behaviour
Observed VR behaviour was first measured by asking the participants what they did during the dangerous traffic light situation that turned red. Participants indicated whether they did not stop (because they did no see the traffic light or colour change or did see it but not stopped) or did stop cycling (as they observed the traffic light turned orange or red). In addition, using video footage and live observations it was checked whether the participants stopped or not. Also, VR behaviour was categorized into an active level behaviour (1 = *passive*, 2 = *active*) as participants themselves are often unaware of their physical behaviour as it is difficult to detach themselves from the interactions they performed (Kumar, 2014). The footage was watched numerous times before interpretations were made. Two researchers coded the behaviour as either being passive or active based on physical movement and how they communicated when approaching the dangerous traffic light situation. Participants in the passive stage did not physically react (e.g., stop for traffic light) and/or spoke out loud about the traffic light situation while participants in the active stage reacted to the traffic light with a physical reaction (such as expressions of surprise, laughter or alertness) or by mentioning the traffic light situation.

4 Results

Presence
The results showed no differences between the low and high realism conditions on all four factors of presence: Spatial presence (M_{low} = 3.11, SD = 0.49, M_{high} = 3.12, SD = 0.56, t(70) = 0.34, p = 0.74), Engagement (M_{low} = 3.56, SD = 0.38, M_{high} = 3.61, SD = 0.41, t(70) = 0.57, p = 0.57), Naturalness (M_{low} = 3.31, SD = 0.64, M_{high} = 3.39, SD = 0.70, t(70) = 0.50, p = 0.62) and negative effects (M_{low} = 2.37, SD = 0.73, M_{high} = 2.16, SD = 0.52, t(70) = 1.40, p = 0.17).

Overall Perceived Realism
The low and high realism conditions seemed not to be perceived as different in their amount of reflecting reality. No differences were found between low and high realism conditions for Scene realism (M_{low} = 4.70, SD = 1.02, M_{high} = 5.14, SD = 1.02, t(70) = 1.83, p = 0.04, 1-sided) but not for VR Audience behaviour (M_{low} = 4.08, SD = 1.32, M_{high} = 4.24, SD = 1.35, t(70) = 0.51, p = 0.31, 1-sided).

Item Perceived Realism
Participants experienced differences in realism between the items within the two conditions. Although both conditions were perceived as real, the high realism condition was perceived as more real when combining the evaluation of all elements that were altered in realism between the conditions (M_{low} = 4.15, SD = 1.13, M_{high} = 4.76, SD = 1.10, t(2) = 2.33, p = 0.023). Closer inspection reveals that five out of eight items were perceived as more real in the high realism condition: the buildings, the street, the lighting, the textures and the bicycle path. Shadows, Sky and cars showed the same direction, however not significant. All elements that were identical in both conditions, such as traffic lights and characters, were as expected not perceived as different on their level of realism from each other.

VR Attention
The results indicate no effects of realism on attention for VR objects within a virtual world. In the low as in the high realism condition, no differences were found in the percentage of participants that noticed the traffic light (M_{low} = 81%, M_{high} = 78%, χ^2(1, N = 72) = 0.08, p = 0.77), the colour of the traffic light (M_{low} = 72%, M_{high} = 70%, χ^2(2, N = 72) = 0.46, p = 0.79) and observed the traffic light colour change (M_{low} = 64%, M_{high} = 56%, χ^2(2, N = 72) = 0.76, p = 0.68). In both conditions most of the participants were aware of the traffic light situation although many also missed the fact that the colour changed right in front of them.

VR Excitement
Realism changed feelings of excitement. More participants within the high realism condition felt a change in excitement when having to all of a sudden stop in front of a traffic light compared to the low realism condition (M_{low} = 57%, M_{high} = 78%, χ^2(3, N = 72) = 7.90, p = 0.04).

Observed VR behaviour
No differences were found between the low and high realism condition concerning behaviour in front of the dangerous traffic light situation. In both conditions most participants stopped in front of the traffic light (M_{low} = 67%, M_{high} = 61%, χ^2(5, N = 72) = 2.68, p = 0.75). Almost none (3%) kept on cycling when seeing the traffic light was orange or red. This result was confirmed in the observations as an equal number of participants stopped in front of traffic light in both conditions. In addition the video footage showed no significant differences in percentage of active participants between the low (53%) and high (67% realism conditions χ^2(1, N = 72) = 1.44, p = 0.23).

5 Conclusions

The aim of this research was to gain a deeper understanding about the effects of different levels of realism in virtual worlds on VR experience and behaviour. Two levels of realism were created within a VR city cycling experience and contrasted to

each other. Participants were able to cycle, while sitting on a stand-alone bicycle with a VR headset on. As expected (H1), VR users notice differences in realism. More effort in creating high realistic worlds will be observed and seen by VR users. However, the results also reveal that merely increasing specific VR elements is not enough create a higher experience or change behaviour. As indicated in the study of Bailenson et al. (2006), to generate more engagement and excitement there also need to be congruency in levels of realism between elements that create a virtual avatar or in our case a virtual world. Indeed, participants in our study for instance observed that the characters used within the high realism virtual world were not as real as other elements. As such participants proclaimed that this stops further feelings of a high overall perceived realism of the virtual world even when putting more realism effort in those elements. If one 'stays behind' (in our case the characters) this hinders the overall perceived feeling of realism. This is for instance indicated in one of our results in which the high and low realism conditions did not differ on (character) human behaviour realism.

On the other hand, a higher perceived level of realism also does not immediately result in more natural behaviour (RQ2). The low and high realism condition seemed to stimulate the same natural VR behaviour. Both levels of realism elicited the same looking behaviour, resulting in noticing the same elements within the VR world. Also, user behaviour was the same for the high and low realism condition. Meaning that in our study users in low and high realism conditions seemed to cycle in the same realistic manner, for instance by stopping in front of a red or orange traffic light that reflected a relative dangerous situation. An explanation for the similar behaviour in VR worlds that differ in level of creative realism, seems to be connected to a generic level of VR experience that is elicited. No differences were found in experience between a low and high level of realism measured by means of presence, negative effects, naturalness and engagement (RQ1). A reason for the similarity in experience might be that several elements within the VR world already create a high level of experience. As such increasing realism of some elements within the virtual word might not do much more on experience. In particular, the relative new and innovative experience of cycling in a virtual world, might already have created a large feeling of experience and presence. Indeed, a study conducted by Slater, McCarthy, and Maringelli (1998) demonstrated that the greater participants would move their bodies, the greater the sense of presence was felt. This also explains why these results seem to contradict the finding of another study conducted by Slater, Khanna, Mortensen, and Yu (2009), which indicated that more realism in VR causes a higher sense of presence. As in the study of Slater et al. (2009), users were not physically active in VR. Being active in an innovative way in VR, like cycling through a virtual city, might create a VR presence ceiling effect, especially for those who have little experience in VR. Previous studies did indicate that new VR users are highly immersed and feel very present in virtual worlds often leading to probably unnatural VR behaviour such as observing a VR world more intense compared to experienced users (Stupar-Rutenfrans, Ketelaars, & van Gisbergen, 2017; Syrett, Calvi, & van Gisbergen, 2017).

The outcome that more realism not always leads to increased experiences and more natural behaviour might be good news for some VR applications. A very expensive highly realistic virtual environment does not always seem necessary to achieve results. For our case this would mean that the cycling VR application could be used to create and test new cycling roads without having to invest a lot of money in a high realistic world. The same might go for other VR applications developed in other areas such as health, retail or culture. And even within the domain of robotics, where experts also believe that a certain level of realism is needed to create meaningfull experiences (Dautenhahn & Werry, 2004). However, more needs to be investigated and theorized on in order to extend these results to other domains.

First there is the question how real our environments were. Where are we on the realism continuum with these tested VR worlds? Of course much more effort could have been put in creating even more realistic words up to a level they use in the gaming triple A industry. And although with current VR technology that would maybe not be very useful (e.g., the resolution in VR is not as good as used in non VR simulations), VR technology developments go fast. It would be wise in past and future studies to somehow be clearer about the level of realism and fidelity used in VR worlds used for research in order to be able to better understand results acquired using VR worlds. However a judging system in how and where to position VR worlds on the VR realism continuum does not exist yet.

In line with the level of realism, it is also unclear how to create virtual worlds that can be compared on level of realism for research purposes. The level of realism in this study was manipulated by means of altering elements (creating more fidelity) and adding realism in the environments by adding objects or elements (such as shadows) or even the way it is possible to navigate and manipulate the VR world (e.g. by adding more stirring options). It is unclear how different elements create realism and it might be the case that adding other elements or altering different elements (such as the characters) might create more differences or higher levels of realism. However, it is difficult to research the different roles of different elements or to not add (or leave out) specific elements as the congruency between the different elements is important to create high perceived levels of realism. More research should be conducted on how different elements affect realism in order to also better be able to compare results from studies that (different level of realism in) virtual worlds.

Finally, a relevant possibility to explain the contradictions among the different studies could be the existence of unknown variables influencing the phenomena. Some of these variables could potentially overshadow the influences that a better level of realism would provoke. Preliminary studies indicate that delay and expect experience can influence significantly the perception and opinions of the users regarding the evaluation of VR applications.

Although more studies are needed to extend the reach of being able to apply the outcomes of this study, it is clear that investing effort and costs in creating a higher level of realism to obtain a better VR experience and more natural VR behaviour is not always needed. VR users observe realism differences in virtual worlds but not always experience them differently or act different based on those (unconscious) observations and experiences. In order to be able to pinpoint ideal levels of realism

attached to the purpose of the VR world and the experience of the VR users, more research is needed as well as a joint effort to classify VR worlds used in research on level of realism.

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