Guidelines for Immersive Virtual Reality in Psychological Research

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Abstract

Virtual reality (VR) holds immense promise as a research tool to deliver results that are generalizable to the real world. However, the methodology used in different VR studies varies substantially. While many of these approaches claim to use “immersive VR”, the different hardware and software choices lead to issues regarding reliability and validity of psychological VR research. Questions arise about quantifying presence, the optimal level of graphical realism, the problem of being in dual-realities and reproducibility of VR research. We discuss how VR research paradigms could be evaluated and offer a list of practical recommendations to have common guidelines for psychological VR research.

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Introduction

The number of annually published articles in peer reviewed academic journals with “virtual reality” as a keyword has doubled between 2016 and 2019 from around 6000 entries to over 12 000, according to EBSCO Information Services. The excitement is understandable as VR holds a huge potential for both basic science [1**,2**,3] as well as therapeutic approaches [4*].

While the field of contemporary VR research emerged already in the early 90s, the recent surge in publications is associated with the release of several affordable and high-quality VR head-mounted displays (HMDs) [1**,5]. Off-the-shelf consumer-oriented systems like the HTC Vive and Oculus Rift have given more researchers the opportunity to pursue psychological experiments with immersive VR setups - that is, integrating computers, HMDs, body-tracking sensors, special interface devices and 3D graphics [4*]. Given recent advancements in computational power, software and optics, these “new generation” devices offer low latency, wide field of view and unprecedented level of both interactivity and data gathering [6**,7,8*], differing clearly from “non-immersive”, “desktop” or projection-based VR solutions. However,

there still exists a large heterogeneity among various contemporary approaches. We argue that considerations regarding hardware capabilities and software limitations should be taken into account when conducting and reporting psychological VR studies to resolve the situation that some experts have described as the “Wild West” with a “lack of clear guidelines and standards.” [9**].

Ensuring Reliability

The ultimate aim of a VR system is to technologically immerse the user into virtual worlds, inducing a sense of presence - the illusion of being in the virtual world and behaving accordingly [5]. A basic modern VR lab is relatively easy and affordable to set up with minimal prior knowledge [1**,6**]. However, not all immersive VR systems provide the same level of presence [10]. This is a problem, as two studies, both using “immersive VR” might arrive at different results because the setups provided a different level of presence. Unfortunately, presence is hard to quantify. State of the art methods for measuring presence are mainly subjective self-report questionnaires and many popular scales developed before the new generation VR era are incapable of assessing qualitative differences between various modern immersive techniques [11**].

An immersive VR setup can physically have many different configurations in various labs, some likely resulting in sub-optimal performance of the VR system, as technological knowledge of VR is not yet widespread in experimental science [6**]. The current immersive VR “gold standard” experience implements a room-scale solution, where the user can roam freely in a given play area of many square meters [6**,12,13]. This allows for actual walking and exploration, crouching and other large movements. Such devices with consumer-optimized positional tracking solutions can introduce a possible interaction between the particular physical lab space and digital experience - while the user moves around in the virtual space, there might be specific moment in the study (e.g. user covering the tracking sensor while performing some motion) or problematic spots in the room where positional tracking is not guaranteed [14]. As a solution, experimenters should test each paradigm exhaustively and also be aware and design around the possible hardware limitations [15]. Information regarding the exact setup of the physical space should also be mentioned in the methods section of published papers. This would also answer calls to enhance reproducibility and transparency of VR research [16**].

Content wise, questions about reliability arise regarding the level of realism one should strive for in development. This could pose potential reliability problems when comparing two immersive VR methods that claim to study the same phenomenon, yet fail to attain a similar level of graphical fidelity [15,17*], for example if one study does not provide shadows and realistic colouring of objects. The advent of powerful graphical processing units and game engines have certainly made achieving a high graphical fidelity easier than ever [18*]. Although perceptually convincing VR scenarios are becoming the norm in VR development, it is still debated whether the effort to increase visual realism actually improves VR experiences and study outcomes

[1**,4*,19**]. However, we think that most studies comparing the effect of different graphical quality levels suffer from a floor effect due to limited technological capabilities in the past. Some types of studies may even benefit from purposefully “impoverished” visuals [17*,20]. Realistic graphics may certainly raise face validity and user buy-in of virtual experiences [4*]. Higher resemblance of reality can make the participants feel more present in the VR world [21*], with simulations high in context-realism and perspectival-fidelity producing “virtually-real experiences” [17*]. Still, many scientific VR experiments even today are visually sub-standard when compared to contemporary content created for entertainment purposes that participants have become well accustomed to in their daily lives. Rendering virtual humans should not be semi-realistic, as this can induce the unwanted “uncanny valley” effect, whereby quasi-human characters can lead to revulsion [18*]. Many studies compare real-life situations with “identical” virtual copies, meticulously recreating physical testing laboratories in VR [22*,23]. However, digital copies often lack the most basic crucial properties of our everyday experience, such as object shadows and the user’s correct head height. Some researchers, admitting shortcomings in the technical abilities of many academic developers, have proposed using commercially available games with high production value for research [24] and borrowing game design concepts from the entertainment sector [25]. More enjoyable content could also help draw in more study participants.

Validity pitfalls

Immersive VR research can potentially study and unravel processes that are closer to reality than classic laboratory experiments [1**,2**]. This is important as generalizability to everyday life is critical for psychology as a science [2**]. However, ecological validity of behavioural studies in VR is not a given even when immersive VR is used [26].

One prominent feature of VR that should not be ignored in psychological research is that of being in “dual realities” [27]. It is unclear whether VR engages the same cognitive processes as the real world, if the participant has top-down knowledge that the virtual world is not a substitution of the real world, but an add-on. The act of donning a HMD to enter the virtual world has been referred to as the device-gap, providing a clear and present demarcation between reality and VR [19**]. Some researchers have proposed to measure the persistent duality by counting self-reported “breaks in presence” [28] or drawing presence fluctuations post-experience [29*]. A theoretical exception to this problem would be perfect simulation of all possible senses, where the user truly becomes unaware of the base reality [30], a state called superrealism [19**].

Another problem is that different types of users get immersed differently [31] and the feeling of presence in a virtual environment relies heavily on suspension of disbelief, which is difficult to control [26] and may be a trait rather than a state [32]. Individual differences could be caused by differences in prior experience of VR [1**]. As a general rule of thumb, people with excessive

VR experience should not be recruited as participants. Care should be taken to avoid gender bias towards male participants, a problem present in current VR research [33].

Specific components of the virtual experience can influence the phenomenon under investigation. For example, the presence of a realistic and believable virtual body can be critical to many studies [1**,34**]. To minimize possible confounds, standardized, validated and VR optimized libraries of 3D objects have become available [35,36]. However, due to fewer binocular cues and conflicting depth information inherent in current VR display technologies, it is questionable whether objects in VR elicit fine-tuned neural and behavioural responses representative of real objects [34**].

Many VR studies implement artificial movement for example by smooth virtual locomotion while the user remains physically stationary, which can be a source of cybersickness [6**,13,37]. Designing around this pitfall should be kept in mind, as cybersickness substantially decreases cognitive performance and confounds physiological data [6**]. However, given the recent advancements of developer knowledge, cybersickness can be largely avoided without decreasing the level of presence [1**,6**,13,37,38]

Finally, effects established in a classical highly controlled non-VR environment could disappear in a more complex virtual setting [25]. This direct comparison between VR and classical setups can be enabled in two ways - some researchers have conducted laboratory-like experiments in an endless uniform gray VR void [39], while others have gone to great lengths in reproducing the exact laboratory environment digitally [22*].

While VR gives experimenters the power to create faithful copies of reality, it also allows researchers to modify and break the basic laws governing our world in order to gain new insights into the workings of the human mind. Recent studies have flipped visual feedback to study visuomotor adaptation and sensory recalibration [40], modified gravity to assess physical judgments [41], turned participants hands invisible to study sensory attenuation of self-generated movements [39,42], observed non-Euclidean navigation [43] and allowed participants to embody elongated arms and virtual cardboard boxes [44]. We have no doubt that this represents just the beginning of the many possibilities offered by “Virtual Unreality”.

Evaluating VR paradigms

As the consumer VR content market has expanded greatly in recent years, some basic “comfort rating” systems have emerged¹. However, these simple criteria might be inadequate to capture the complexities of experimental VR paradigms comprehensively [45**]. More systematic evaluation approaches have recently been proposed.

¹ <https://support.oculus.com/comfort/> (accessed on 25.04.2020)

The VR-Check framework [45**] evaluates ten main dimensions: cognitive domain specificity, ecological relevance, technical feasibility, user feasibility, user motivation, task adaptability, performance quantification, immersive capacities, training feasibility, and predictable pitfalls. While the work focuses on VR paradigms for neuropsychological assessment, many of the dimensions are also crucial for experimental research. Another similar framework has been proposed by an international working group of VR clinical outcomes research experts (VR-CORE). Their approach features three study phases (VR1-VR3) similar to the phase I-III model of pharmacological intervention studies [9**]. The focus is set on human-centered content development, feasibility, acceptability, tolerability, and clinical efficacy. Immersive VR also creates challenges for evaluation of user experience, and a model has been proposed to assess the interconnections between presence, engagement, immersion, flow, usability, skill, emotion, experience consequence, judgement, and technology adoption [46]. On the content side, VR software seeking high reliability should also include an ergonomic locomotion system, tutorials, in-game instructions and interactions similar to real-life [6**].

Based on the issues discussed in previous sections, we offer a list of concrete practical recommendations for designing and reporting of VR experiments to complement these general evaluation frameworks. Figure 1 presents a graphical summary of the guidelines.

Guidelines for immersive VR research

1. Play VR games

It is useful to learn what actually works in commercial practice [25], as game developers design their content so that a wide range of users would be able to enjoy the experiences comfortably and with high motivation for extended periods of time. With some luck, one might even find a ready-made game that can be easily used in an experiment.

2. Beware of dual realities

Consider the cognitive effects of “dual realities”, as the knowledge that the virtual world is not actually real can have a confounding effect on the research phenomena of interest [27] and presence levels should be measured throughout the experiment [29*].

3. Choose your setup

Consider immersive VR as seated, stationary or free-roam experiences with new generation 6 degrees of freedom HMDs and high level of natural interaction [6**]. The particular choice of the VR paradigm and the level of immersion must ultimately depend on the research question [45**].

4. Design with human-centric principles

Human-centric design principles must be kept in mind at all times, following VR industry best practices and avoiding cybersickness [9**]. An exception is for studies aiming to “break” some facet of virtual reality.

5. Beautify

Modern VR experiments should be up to participants’ expectations about contemporary computer graphics seen in various games or movies, unless the goal of the study specifically states otherwise. Most modern game engines allow adding optimized shadows and anti-aliasing (smoothing of jagged edges), in fact they are the default settings. Complex and believable scenes increase ecological validity [17*].

6. Gamify

Add entertainment value or gamification aspects to increase the motivation of participants to wear the HMD for extended periods if needed. Top games in VR arcades can achieve an average session duration of around 30 minutes. Engaging content can help recruit a larger sample for statistical rigor [16**].

7. Pick your participants

Keep in mind that individual differences in achieved levels of presence could be attributed to prior experience of VR [1**]. When recruiting participants, it is worth inquiring about the frequency of prior VR use.

8. Test often and extensively

Frequent pilot testing with participants is an unavoidable process of back-and-forth between different iterations of the study paradigm [9**].

9. Freeze updates

Freeze software and hardware updates during the data gathering period of the main experiments if possible, as consumer VR middleware can introduce new unexpected features or break dependencies within the experimental software [7].

10. Be real

When interpreting study results, be realistic about the applicability of the VR study to real-world context [1**,16**,26].

11. Foster replication

The methods section of research papers should include information on play area size and exact physical setup. Source data, code and ideally the executable of the experience should also be available with the results to foster replication, review of data and procedures [16**].

Figure 1. A graphical summary of the guidelines for immersive VR research

Conclusions

While there is a plethora of experimental VR studies published, caution must be taken regarding the generalizability of these results to real-world interactions [1**,16**,26]. At the same time it is clear that immersive VR can provide novel insights about human behaviour and the workings of the brain given that the experiments are designed carefully. We hope that the proposed guidelines can steer the field from a “wild west” towards a scientific “gold rush”.

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Conflict of interest statement

Nothing declared.

CRedit authorship contribution statement

Madis Vasser: Conceptualization, Writing - original draft.

Jaan Aru: Writing - review & editing

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