Challenges in Virtual Reality Studies: Ethics and Internal and External Validity

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ABSTRACT

User studies on human augmentation nowadays frequently involve virtual reality (VR) technology. This is because VR studies allow augmentations of the human body or senses to be evaluated virtually without having to develop elaborate physical prototypes. However, there are many challenges in VR studies that stem from a multitude of factors. In this paper, we first discuss different types of VR studies and suggest high-level terminology to facilitate further discussions in this space. Then, we derive challenges from the literature that researchers might face when conducting research with VR technology. In particular, we discuss ethics, internal validity, external validity, the technological capabilities of VR hardware, and the costs of VR studies. We further discuss how the challenges might apply to different types of VR studies, and formulate recommendations.

CCS CONCEPTS

• **Human-centered computing** → **User studies**; **Virtual reality**.

KEYWORDS

Virtual Reality Studies, Virtual Reality, User Study, Challenges, Ethics, Validity

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1 INTRODUCTION

Virtual reality (VR) has been investigated for more than 25 years and is still an immensely popular topic [16]. Research on human augmentation especially profits from VR technology, since it allows to manipulate users' perceptions of their own body and its capabilities [4, 30, 36, 40, 57, 70]. Hence, VR studies provide means for evaluating virtual human augmentations that can be customized, altered, and implemented much easier than physical prototypes. VR studies can focus on diverse topics, ranging from hardware solutions [14, 63] to user experience [27, 44] and simulations of real-world situations [20, 30, 51]. While most VR studies are still conducted at laboratories, novel methods have risen for conducting studies remotely which e.g., allows evaluating virtual human augmentations in different contexts, like the user's home [37, 49, 58, 67, 82]. Such different VR study types pose different challenges with regard to ethical concerns, internal, and external validity.

However, we have not yet observed a *comprehensive discussion on challenges* in VR studies, especially in regard to *not only ethics but also internal and external validity* of different types of VR studies. Our research aims at 1) presenting an overview of different types of VR studies, 2) discussing potential challenges in VR studies, and 3) proposing recommendations for researchers that conduct VR studies in the future. Hence, this paper is primarily intended as an introduction to VR studies for researchers, developers, designers, and students, rather than a comprehensive literature review.

2 TYPES OF VR STUDIES

We establish *VR studies* as an umbrella term that includes any study that utilizes VR technology. We further distinguish VR studies based on (a) whether the study employs a *direct* or *indirect* use of VR and (b) whether the study takes place *on-site* or *remotely*. These factors function on their own spectrums. For example, direct VR studies can be either on-site or remote; remote studies can be either direct or indirect, etc. We do not intend our categorization to be exhaustive, but rather, to suggest high-level terminology to help navigate the diverse space of VR studies.

2.1 Direct vs. Indirect VR Studies

We distinguish VR studies by the applied use of VR technology. By *direct VR Studies*, we refer to studies with direct applications in VR (e.g., evaluating VR hardware). Contrary to this, *indirect VR Studies* seek to apply their gained knowledge outside of VR, where VR is used as a tool (e.g., using VR for real-world training).

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Direct VR studies include research on prototypes – like novel controllers [14, 86] or head-mounted displays [63, 69] – and interaction techniques [42], but also software applications like games or learning experiences [13, 15, 74]. Users' experiences and performances in VR have been also frequently investigated [1, 27, 44, 60, 77, 79] – i.e., experiences like *presence*, but also negative effects like *cybersickness* [17, 19, 47]. Other *direct VR studies* investigate the provision of sensory stimuli, such as haptics [60] or auditory cues [35, 56].

Indirect VR studies usually simulate real-world environments to gain knowledge from participants or apply skills to them to be later used in the real world. Research has shown that users' behavior in simulated environments is similar to their behavior in corresponding real-world environments [20, 80]. VR has been applied for medical training [2, 28] and emergency evacuation scenarios [22, 59, 64]. Hence, VR can enable the conduction of experiments that would be difficult or unethical in the real world [20, 34, 38, 59, 78] and the evaluation of virtual augmentations of the human body or its capabilities [4, 30, 36, 40, 57, 70].

2.2 On-Site vs. Remote VR Studies

On-site studies can take place in a lab or another specifically chosen and prepared location (e.g., a car [54] or a museum [66]), where researchers have a high degree of control over the study situation. In contrast, there are *remote studies*, where users attend the study remotely, typically via an internet connection, and without the (physical) presence of an experimenter.

On-Site VR Studies are conducted in a specific location (e.g., a lab), usually in presence of an experimenter, and with devices provided by the researchers [51, 78, 80]. This implies a largely controlled usage context, resulting in few confounding variables and highly reproducible results [9].

Remote VR studies (aka. *in the wild* or *crowdsourcing* studies) have emerged in recent years due to the increasing market size of VR devices worldwide [83]. These studies are conducted by the participants themselves, without the physical presence of a researcher. This frequently also implies that the participant can choose the timing and physical environment where the study is conducted. Remote VR studies enable ecologically valid evaluations with large sample sizes and high diversity [37, 49, 58]. Related work further suggests that the results of remote studies are comparable to others conducted in the lab [37].

3 ETHICAL CONCERNS

Using VR can cause moral and legal concerns regarding their multiple potential adverse effects on users [5, 43, 61, 81]. These potential effects include issues regarding mental health, physiological health, neglecting the real world, blurring of moral standards as well as loss of control over personal data and *personally identifiable information* (e.g., kinematic fingerprint) [81]. All these VR-induced symptoms and effects are commonly abbreviated as VRISE [17, 61].

3.1 Health Risks

Potential health risks related to VRISE need to be carefully considered before conducting any VR study [50]. The most investigated topic inside VRISE is *cybersickness*, a VR-induced motion-sickness potentially based on conflicting sensory perceptions [17, 21, 46, 61].

Table 1: Factors affecting cybersickness derived from related literature [3, 19, 46, 52] and grouped similar to [19].

Individual Factors	Device Factors	Task Factors
Age	Lag	Control
Gender	Flicker	Duration
Illness	Calibration	
Posture	Ergonomics	
Previous Usage	Tracking Errors	
	Field-of-view	

Cybersickness can cause symptoms ranging from disorientation (e.g., dizziness or vertigo), to nausea (e.g., stomach awareness, increased salvation) and oculomotor limitations (e.g., headache, blurred vision, eyestrain) [17, 19, 47]. Cobb et al. [17] found that *80%* of their 148 participants experienced some symptoms. While the effects were mild for most participants and subsided soon, *5%* of the participants had to abort the experiment, because they experienced severe effects. The factors influencing *cybersickness* can be divided into device, task, and individual factors (see Table 1) [19, 21, 47]. While the device and task-related factors can be strongly influenced by the design of the VR experience, individual factors are less controllable and avoidable.

Using VR technology can furthermore cause injuries [5]. There is a risk of falling triggered by VR experiences and users are worried about bumping into objects or hurting themselves [33, 51, 55].

Possible implications of the usage of VR devices on mental health represent a further risk. VR can, at least temporally, increase dissociative experiences, such as depersonalization and derealization [1]. In this regard, there are further concerns about a possible rejection of the real world, which could even cause the neglect of own body needs [81]. The implications on preexisting mental disorders constitute another risk that has to be thoughtfully considered [1, 81].

3.2 Privacy Risks of VR Usage

In addition to health risks in the use of VR devices, there are further concerns about privacy risks. Spiegel [81] states that such devices potentially record personal information, such as the users' patterns of eye movement, motor responses, and reflexes. This data could form a distinctive *kinematic fingerprint*. VR devices could additionally record information on the consumers' habits, interests, and tendencies (e.g., used software or games). Spiegel raises the concern that such information could be accessed by third parties (e.g., businesses, governments, hackers, and identity thieves).

3.3 Other Moral Implications

The usage of VR devices implies further ethical considerations. VR experiences are able to trigger negative emotions, which are even more intense than comparable emotions induced by 2D experiences [48, 50]. This technology could also intensify the blurring of moral standards relative to violence and aggression already observed in video games [81]. In addition, the general manipulative potential of VR is still poorly explored. Such manipulative virtual experiences could aim at influencing the beliefs, emotions, or behavior of the user [50, 81].

3.4 Specific Concerns on Remote Studies

While the above-mentioned health and privacy risks apply to all VR user studies [49], there are some additional ethical concerns about remote approaches. During the conduction of such studies, there is no evaluator present to assist participants in the case of sudden health issues (e.g., severe cybersickness symptoms or injuries due to falls) [58]. This is especially important to consider because VRISE can be reduced, as above mentioned, but not completely avoided for all participants. However, if the sample of a remote study consists only of owners of VR devices, one could argue that the conduction of the study is not riskier than the normal usage of such devices [82]. Another issue of remote studies is the implied need of transmitting the gathered data. This represents an additional possible entry point for attacks on the privacy of the participants, especially since the source of the transmission could provide further cues on the identity of a subject (e.g., mail address or IP) [67].

4 INTERNAL VALIDITY: CONFOUNDING VARIABLES

The internal validity of a user study largely depends on control over possible confounding variables. We discuss participants' potential biases in regard to VR technology and the control a researcher has over the environment in which VR studies are conducted.

4.1 Potential Biases

Harrison et al. [31] highlight the importance of gathering information on a study's subject, to understand their possible biases and motivations, especially when it comes to qualitative feedback.

4.1.1 Awareness and Access to Devices. Surveys on the awareness of VR indicate that between *63%* and *87%* of the general population have heard of VR [29, 33, 84]. Moreover, access to such technology has been constantly increasing in the last years, reaching *16* million installed VR headsets worldwide in 2021 [25]. In the US alone, *30.6* million people used a VR headset at least once a month, and *28.3* million people experienced VR regularly using other hardware (i.e., *17.7%* of the US population in 2021).

4.1.2 General Population's Opinions. O'Hagan et al [62] found that their survey participants (*N=210*) associated VR primarily with gaming applications and expressed a rather positive sentiment towards this technology. Herz and Rauschnabel [33] found a slightly positive attitude towards the usage of VR headsets among their 611 German participants (*Mean=3.70* on a 7-points Likert scale). The (re-)purchase intention was rated lower (*Mean=2.58*). The authors further investigated the perceived benefits and risks of this technology. Those benefits included the opportunity to explore different places (*Mean=5.21*), to have a fun experience, and to gain access to entertainment (*Mean=5.06*) as well as experience embodiment (*Mean=3.95*). The participants further confirmed to perceive privacy (*Mean=4.09*), physical (*Mean=3.89*) and health risks (*Mean=3.61*). A survey realized by Context [29] inquired what participants (*N=2511*) found most exciting about VR. In this regard, *61.7%* of the subjects mentioned immersive sports experiences, *53.17%* wanted to experience things they would physically never do (e.g., sky-diving) and *48.3%* desired to immerse in a film. While we could find indications of slightly positive attitudes toward VR, the general population's expectations of VR usage might not align with their experiences during a VR study. Hence, qualitative feedback could be, for example, influenced if a participant took part in the VR study hoping to experience fun virtual environments, but was then selected for a control group that involves no usage of such technology.

4.1.3 Personal Factors. Herz and Rauschnabel [33] found that previous experience with VR glasses ($p < .001$) and age ($p=.012$) had significant effects on the attitude towards such devices. Furthermore, they detected significant effects of previous experience ($p=.003$) and gender of the participants ($p=.03$) on the (re-)purchase intention. Thus, *previous experience* with such devices influenced both the attitude and the (re-)purchase intention [33]. Huygelier et al. [39] observed a more positive attitude of their 38 participants after being exposed to VR for the first time. However, previous experiences with VRISE (e.g., cybersickness of injuries) might have an even stronger effect on possible biases [61]. For *gender* effects, surveys found that virtual or augmented reality device owners and users are predominantly male [12, 18, 67], indicating a lower interest in VR devices in the female population. Moreover, usage of VR devices is not equally distributed across different *age* groups. The number of VR users decreases from 34% and 35% for the age groups 16-24 and 25-34 to 6% when it comes to ages 55-64 [12]. However, Huygelier et al. [39] found that their older aged participants' (ages from 57 to 94, *Mean=74.8*) initial attitude towards VR was neutral and found no clear significant effect between age and attitude. While it is difficult to derive a clear correlation between age and attitudes toward VR technology, the possible effects should be considered.

4.2 Control over the Context

The context in which a study is conducted represents another possible cause for confounding variables (i.e., influencing factors like interruptions, noisy environments, or malfunctioning hardware).

4.2.1 Limited Control Over Remote Studies. The largest challenge regarding *remote VR studies* is the missing control over the real-world context during the evaluation process. This strongly affects the internal validity of the results of such evaluations, since confounding effects can not be generally excluded. Even though researchers can provide specific instructions on the study procedure, they should also include controlling mechanisms to make sure that these instructions were executed correctly [49, 82]. This can be a difficult task, depending on the specific study design and requirements. It can also result in a high amount of data that has to be subsequently excluded from the evaluation. Researchers might consider implementing more flexible study designs that allow for different user postures (e.g., standing and sitting), devices, and confined spaces around the participant [49, 58, 71].

4.2.2 Internal Validity of Indirect VR Studies. Within *indirect VR studies*, the simulated environment can be easily controlled and manipulated by the researcher, allowing for meticulous and less effortful data collection, similar to on-site studies. The control can be even extended to the manipulation of virtual personas enabling also the manipulation of the social context [51]. This results in a high internal validity of the results of such studies since they exclude uncontrolled confounding variables.

5 EXTERNAL VALIDITY: RECRUITED SAMPLE AND NATURALISTIC CONTEXT

Two major factors might influence the external validity of user study results: non-representative samples and non-naturalistic cues [31].

5.1 Recruiting Diverse Participants

Many HCI user studies have poorly diverse samples of young, tech-savvy, and mostly male participants [6, 67]. Such samples potentially restrict the external validity of results since they do not represent the general population. Another potential issue is that sample sizes tend to be small, often only between 12 and 16 participants [6]. This can directly affect the effect sizes of results and, consequently, their practical significance [73].

5.1.1 Online Recruitment and Testing. To overcome the lack of diversity and small sample sizes, many authors proposed online recruiting and testing approaches. Reviews of such methods have shown results to be comparable to those achieved with directly recruited participants [7, 10, 41, 75, 85]. Nevertheless, those methods might exclude possible subjects who do not use specific platforms or can not access the internet [7]. Furthermore, the decision for a specific platform can affect the quality of the results [11, 41].

5.1.2 Reaching Owners of VR Headsets. *Remote VR studies* might specifically target users of VR devices to conduct fully online study procedures that participants can run without supervision. Such studies allow for larger sample sizes and more diversity [49, 67]. VR users could be recruited through online communities (e.g., Reddit [41, 67, 75]), individualized advertisements (e.g., Facebook adds [45, 72]), crowdsourcing platforms (e.g., Amazon Mechanical Turk or Prolific [49, 58, 67]) or specific VR platforms (e.g., VRChat, Steam or Rec Room [67, 71]). However, whether VR owners can be seen as a representative sample of the general population is questionable, due to the unequal demographic distribution of this population [12, 18, 26, 39, 67]. Rivu et al. found that VR users are predominantly young (mean age = 29.72, SD = 8.8), male (77%) gamers (91%). Ma et al. [49] found a slightly more diverse pool of 242 Amazon Mechanical Turk crowd workers with access to suitable VR technology (*61%* male; ages: *18-78, median = 32*). Thus, researchers have to assess if their specific sample is representative of the targeted population [82].

5.1.3 Sending VR Technology to Participants. To overcome these issues, an alternative approach to the execution of *remote VR studies* might be sending VR hardware to previously registered potential participants [58]. For example, Mottelson and Hornbæk [58] send cardboard VR glasses to 57 participants. However, sending materials to participants requires resources, and may not be feasible especially if the study requires high-end hardware.

5.2 Naturalism of VR

A major motivation for *indirect VR studies* is that a simulated environment may present a more naturalistic context than a traditional real-world lab environment [31, 51]. This implies an improved external validity of such approaches compared to traditional on-site studies. VR studies also allow researchers to develop new prototypes virtually instead of physically, which can reduce the implementation effort largely and also allows for easy adaptation. However, today's VR devices usually focus on supporting visual and auditory cues (i.e., through head- or gaze-tracking technologies, microphones, and headphones). Especially the provision of haptic feedback is still being investigated and poorly developed in commercial solutions where it usually involves game-like controllers [53, 76]. These controllers do not represent natural interactions and can influence the behavior of their users [51, 53]. The provision of naturalistic cues might also include real-world objects the users normally interact with. Hence, participants' behavior can be affected by the impossibility of interacting with e.g. their smartphones in VR [51, 53].

We argue that the incapacity of current VR devices to allow for naturalistic haptics and interactions with real-world objects is still a major factor that limits the external validity of *indirect VR studies*, and the potential topics of interest that these studies might address. Further research is needed to better understand the limitations and opportunities of indirect VR studies [51]. For *direct VR studies*, the lack of naturalism is less of an issue, as they do not necessarily rely on accurate portrayals of the real world. In fact, the current shortcomings are an excellent opportunity, as many such studies focus on developing and evaluating new technical and interactive capabilities for VR [14, 35, 86].

6 FURTHER CHALLENGES

Dependence on Capabilities of Technology. The differing capabilities of available devices can affect the data that can be gathered during a VR study, the naturalism of the experience, the design of the study, and the behavior of participants [49, 58, 82]. Device owners frequently perceive limited technical capabilities as a usability issue [53]. Performance metrics like task completion speed and accuracy are especially prone to be affected by this [58]. Moreover, smartphone-based devices usually lack hand- or body-tracking and other physiological sensing capabilities while also suffering from limitations like battery exhaustion, overheating, or lagged rendering for fast head movements [49, 82]. This especially affects *remote VR studies*, where smartphone-based devices are frequently used due to their low cost and widespread distribution [49, 58, 82].

Costs of VR Studies. *Indirect VR studies* aim at simulating a naturalistic usage context, resulting in an effortful and time-consuming implementation process. Moreover, high-end VR devices might be needed to display high-fidelity virtual environments. According to Mäkelä et al. [51], the development costs (i.e., monetary costs and effort) of indirect VR studies are still lower compared to field studies because developed virtual environments can be reused. The authors situate the costs of such studies between traditional field and lab studies [51]. *Direct VR studies* are not necessarily contrary to this. Even though the evaluation of, for example, some hardware prototypes can be independent of the used technology or the fidelity of the virtual environment, other research questions could depend greatly on specific capabilities. The costs of such studies strongly depend on the evaluated research question and study design. The monetary costs of *remote VR studies*, on the other hand, are reported as lower than *on-site approaches* since they require no present researcher, no specific space, and no device costs if participants' devices are used [49]. However, the required effort might be much higher in comparison to *on-site VR studies* because the developed procedure has to be of higher quality, more stable against unexpected participant behavior, and also clearly understandable without further support [82].

7 RECOMMENDATIONS FOR CONDUCTING VR STUDIES

7.1 Ethical Considerations

Ethical concerns about the usage of VR technology have moral implications for the design of VR user studies, especially since effects on the consumers' mental health and moral standards are still poorly investigated [1, 81, 82].

7.1.1 Reduce Health Risks. The risk of injuries can be reduced by avoiding moving, perturbing, surprising, or scary stimuli inside the virtual environments since they could cause falls or sudden movements of the user [48, 55]. Moreover, researchers should allow for stable postures of participants (e.g., sitting rather than standing) [46]. Designers of VR studies could also pre-screen their participants for temporal afflictions (e.g., flue, fatigue, or hangover), the influence of drugs or alcohol, or existing psychological disorders/vulnerabilities [19, 24, 50]. To avoid factors that contribute to cybersickness, VR devices with little lagging, not noticeable display flickering, and accurate position tracking should be used [8, 32, 65]. The Devices should also support efficient calibration and ergonomic adaption to the user [46, 52]. Study tasks should maximize the user's control over the virtual environment, and allow for a gradual adaption to VR [46, 52]. Moreover, researchers found that women are more likely to suffer from cybersickness, as well as children (i.e., aged 2-12) [8, 68] or first-time users [8, 17, 68]. However, these groups can not be simply excluded by the researcher without decreasing the generalizability of study results to the general population. Consequently, researchers need to find a compromise between reducing health risks and the validity of their results.

7.1.2 Privacy Protection. Participants' private information should be anonymized to prevent re-identification, protected, and reduced to the minimum necessary amount, especially when it comes to *personally identifiable information* [23, 67]. Furthermore, transparent communication of all health and privacy risks, the collected data, and of how and for what duration it is stored has to take place as part of the *informed consent* [50, 67]. In this regard, researchers might have to gain insights on hardware or software providers *Terms and Conditions* agreements, to be able to take thoughtful decisions on their integration into VR studies.

7.2 Internal and External Validity

Regarding the *internal validity* of VR studies, researchers should expect that especially qualitative results could be influenced by possible biases on VR technology. Those biases might even differ depending on individual factors like age, gender, expectations, and previous experiences with VR. These confounding effects could be identified by gathering information on the subject's attitudes towards and previous experiences with such devices. Counterbalancing possible personal factors could even eliminate their influence. However, since this measure might prove difficult in practice, researchers should measure confounding variables and evaluate their possible effects through data analysis.

When it comes to *external validity*, we propose weighing the choices on recruitment methods and study type. Similar to traditional user studies, the recruitment should result in a representative sample, while a well-chosen study design potentially increases the naturalism of cues. Especially *direct remote VR studies* could potentially increase external validity since they allow for the recruitment of large and diverse samples and provide a naturalistic usage context [58]. Depending on the application, researchers might opt for *indirect VR studies* instead of *direct on-site studies*, since they can achieve higher *internal and external validity* (i.e., controlled context and simulated naturalistic cues) [31, 51].

8 CONCLUSION

To fully exploit the potential of VR studies, researchers have to consider its multiple implications. Hence, we recommend thoughtfully examining the ethical implications of such studies since the usage of VR devices might imply risks to health and privacy. Those risks need to be minimized, whenever possible, and also transparently disclosed to participants. Furthermore, internal validity relates to participants' previous attitudes and experiences regarding VR technology. As controlling for these possible confounding variables might prove difficult, researchers should measure them and evaluate their possible effects through data analysis. Furthermore, we found the unclear generalizability of VR owners and the limited naturalism of virtual environments to be factors influencing the external validity of VR studies. However, if thoughtfully designed and conducted, VR studies represent a valuable research tool, especially in the field of human augmentation [30, 36, 37, 40, 49, 51, 57, 58, 70].

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