Examining Design Choices of Questionnaires in VR User Studies

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ABSTRACT

Questionnaires are among the most common research tools in virtual reality (VR) user studies. Transitioning from virtuality to reality for giving self-reports on VR experiences can lead to systematic biases. VR allows to embed questionnaires into the virtual environment which may ease participation and avoid biases. To provide a cohesive picture of methods and design choices for questionnaires in VR (INVRQ), we discuss 15 INVRQ studies from the literature and present a survey with 67 VR experts from academia and industry. Based on the outcomes, we conducted two user studies in which we tested different presentation and interaction methods of INVRQS and evaluated the usability and practicality of our design. We observed comparable completion times between INVRQS and questionnaires outside VR (OUTVRQS) with higher enjoyment but lower usability for INVRQS. These findings advocate the application of INVRQS and provide an overview of methods and considerations that lay the groundwork for INVRQ design.

Author Keywords

Virtual reality; VR; user studies; in-VR questionnaires; inVRQs; research methods.

CCS Concepts

•**Human-centered computing** → **Virtual reality; HCI design and evaluation methods;** *Empirical studies in HCI;* User studies;

INTRODUCTION

The notable rise of a new generation of virtual reality (VR) systems in recent years opened up new methods and interventions for researchers across many different areas. These range from highly immersive stimulus-response studies [36, 60] over spatial navigation [147, 175] and embodied cognition [149, 154]

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to exposure therapies [47, 56, 146], exercising [165, 202], education [18, 104], work collaboration [7, 97], and other forms of social interaction [5, 99]. Typically, mid- and post-experience measures are collected via subjective responses on questionnaires [103]. Furthermore, the development and evaluation of VR experiences for entertainment or serious purposes also frequently relies on questionnaires. To fill out conventional paper- or computer-based forms, the subjects need to take off the head-mounted display (HMD) and change the domain from virtual to physical reality [83]. This often leads to temporal disorientation and loss of sense of control [91]. Accordingly, questionnaire results are likely biased to a degree that is difficult to quantify and likely varies from case to case. Such undetermined bias is highly problematic for many types of research and evaluations.

In contrast to the physical domain, alternate reality technologies allow for the embedding of questionnaires directly into the environment. While the transition from VR to answering, for example, paper-based questions presents a drastic change of context, embedding question-items in VR offers an opportunity to stay closer to the context of an ongoing exposure than out-of-VR research setups and avoid a break in presence (BIP) [83, 137]. Especially for measures where the self-reporting needs to be administered as soon as possible after the treatment and may be especially sensitive to differences in study setups, such as common measures for presence [155], immersion [82] or flow [35, 183], it appears crucial to give careful consideration to the interaction modalities around delivering question-items and gathering responses in order to foster the adequate interpretation of individual research outcomes and for fostering replicability.

Schwind et al. observed a higher consistency of self-reported presence when administering questionnaires in VR. The authors highlight that the effects of using questionnaires in VR are unclear, pointing out that the commonly applied measures were not validated for VR studies [159]. These considerations motivate our investigation on questionnaire practices in contemporary VR user research. We investigate whether authors employ comparable terminology and reflect their choices with regard to questionnaire presentation and response collection mechanisms. To date, VR user research does not have a shared range of common administration procedures, well-defined classification schemes, or standardized toolkits for presenting questionnaires in VR user studies that could guide

such considerations and make it easier to contrast against other work.

To build an understanding of the current practices and to lay the groundwork for future efforts around developing practical toolkits, we based this work on the following research questions:

RQ1 *How are questionnaires and individual question-items applied in contemporary VR user research?*
RQ2 *What are the considerations around – and possible advantages of – administering questionnaires in VR?*
RQ3 *What are appropriate design choices for presentation and interaction with in-VR questionnaires?*

To approach the research questions, we conducted: (i) a literature review of 123 publications on VR user studies, (ii) a survey with 74 VR experts, (iii) a preliminary design study to compare different presentation and interaction methods, (iv) a user study (n=38) of a revised iteration of our in-VR questionnaire tool, comparing it to a on-screen response system. This aggregated examination of the literature review and expert survey allows us to extract a detailed picture of proceedings of VR user research, compensating for incomplete reporting in publications and for sampling effects [123]. Based on these insights, we iteratively implemented an in-VR questionnaire tool and applied it in 2 user studies to investigate design options and effects of questionnaire administration in VR.

This work focuses on self-reporting methods. Other more objective measures (e.g. behavioural or biosignals) provide more reliable data [79] and are less likely to be affected by BIPs. We also did not take qualitative analyses into account since the procedures differ notably from quantitative studies. By providing a coherent survey of questionnaire methods in VR through a literature analysis, expert interviews, and an empirical investigation of in-VR questionnaire (INVRQ) designs, our research can inform the discourse around questionnaire methods in VR research, structure design considerations on VR user research and also inform the design and implementation of practical questionnaire toolkits that are relevant to both research and industry.

STATE OF THE ART
Due to its immersive nature and a wide variety in technical setups, VR with HMDs requires careful deliberation by researchers aiming to conduct studies with human subjects. In this section, we review methods and practices for questionnaires in human-subject research followed by a consideration of the VR-specific technicalities around moving between worlds and their effects on question asking.

Questionnaires in Human Subject Research
Questionnaires are an important source of information for evidence-based research [12, 45, 103]. They embody self-reports and therefore gather the participants' subjective experiences [45]. Question types in surveys can be divided into unstructured and structured questions [144]. Structured questions allow for a clear classification of the responses (see [152] for a more detailed discussion), while unstructured or open-ended questions allow the subjects to respond freely. This type of question is more exploratory and allows for a broader understanding of phenomena [103], while also requiring more effort from the respondents. Survey methodologies received much attention in the literature and their advantages or drawbacks are widely explored [13, 17, 163]. *Reliable* (consistency of the measurement) and *validated* (measuring the right construct) questionnaires are vital for reproducible and consistent research [17]. Choi and Pak [32] list 3 groups of potential biases: *design of the question*, *questionnaire design*, and *administration*. Question design covers the effects of poor wording, such as double-barreled questions, negative phrasing or wording that enforces choices [12, 32, 103]. Biases of questionnaire design are due to formatting and length of the surveys [4, 32] as well as length and structure of the questions [23]. Context-dependent forgetting [1, 58] due to environment change [136] biases the responses. We argue that especially in immersive scenarios, a series of random errors can be minimized through consistent administration of questionnaires. Notably, these considerations on questionnaire design are typically contextualized against paper-based or screen-based questionnaires not considering aspects around BIPs or switching between different realities [159].

Moving Between Virtual and Physical Reality
When individuals are deeply engaged with an activity or absorbed in a virtual environment (VE), they completely block out the world around them [35]. Brown and Cairns [26] identified 3 levels of immersion in games as a scale of involvement: (i) *engagement*, the lowest level of immersion, (ii) *engrossment*, when players become emotionally affected by the VR and (iii) *total immersion* where players are detached from reality. This phase is also associated with empathy for the characters in the game and transfer of consciousness [150] and is linked to the state of flow [35]. A sudden interruption or transition between realities can invoke negative feelings and affect the emotional state [91]. Accordingly, assessing presence during immersive experiences results in more reliable measurements [21, 49]. In contrast to immersion, presence is a state of mind, describing the feeling of being part of the VE [82, 201]. Presence relies on involvement and immersion [201]. When "returning" from a state of presence in VEs, a real world task is impaired to the degree of immersion and one's ability to re-engage with the "real world" is decreased [82, 171].

Thus, leaving the VE is likely to interrupt the presence perception. Schwind et al. [159] investigated the effect of filling out a questionnaire directly in VR. They replicated their lab in VR and asked participants to fill out presence questionnaires in physical reality and in VR after exposing participants to a VE at varying degrees of realism. Schwind et al. could not find significant differences of presence between the 2 questionnaire modalities. However, the data revealed a lower variance and, thus, higher consistency of the data when the questions were answered in VR. This is in line with evidence from the literature that support the assessment of questions in VR [83, 91].

Frommel et al. observed a significant effect on presence when questionnaires are integrated in the game context [53]. Similarly, Shute discussed how to embed questionnaires into games without disturbing the game flow [169]. These considerations

With Q, not reported: [2, 15, 16, 20, 27, 30, 31, 33, 34, 38, 42, 43, 50–52, 54, 63, 67–70, 73–76, 86, 89, 90, 92, 93, 95, 101, 105–107, 109–111, 115, 117, 120, 122, 124–126, 130–132, 134, 135, 139–143, 145, 151, 156, 164, 167, 173, 174, 178–181, 184–186, 188, 190, 192, 193, 195, 199, 200, 204]
OUTVRQS: [3, 8, 29, 77, 84, 94, 98, 114, 121, 138, 157, 162, 176, 177, 187, 191, 196, 197]
INVRQS: [6, 28, 37, 44, 55, 66, 85, 100, 108, 127, 148, 158–160, 198]
Without Q: [9, 11, 19, 22, 40, 59, 71, 91, 133, 153, 182, 194, 205]

Table 1. Overview of all papers reviewed, organized by whether a questionnaire was used and how it was presented

can guide the choice of adequate levels of *embeddedness*, and a general decision whether to remain in VR or to exit VR when asking study participants to respond to questionnaires or individual question-items.

LITERATURE REVIEW

For our literature review we searched in digital libraries [10, 80] that host proceedings of high quality conference series about human-centric methods and VR applications. Namely, we scanned ACM CHI, ACM CHI PLAY, ACM VRST, IEEE VR and IEEE 3DUI for the years 2016–2019. We deliberately chose this timeframe to gain consistent insights on contemporary resarch methods and the release of the HTC Vive in June 2016 [78] substantially changed HMD use in VR user studies. The search included publications until July 2019, considering papers categorized with any of the keywords "virtual reality", "head mounted display", "virtual environment", "user study", and "questionnaire". Only papers with abstracts that mention a VR application with HMDs and explicitly mention some form of evaluation with users or empirical user study were added to the list.

In total, we reviewed and evaluated 123 research papers, see Table 1. The papers are organized following whether they use questionnaires for measurement or not. We also categorized the different representations of questionnaires: in-VR questionnaires (INVRQ), out-VR questionnaires (OUTVRQ) and those who did not include a report of the presentation method.

Analysis

To investigate common procedures of questionnaires in VR user research, we analyzed both the system design and the study design. We paid special attention to the treatment of questionnaires or individual question-items and to the description regarding transitions between VR and physical reality. Further, we looked at the nature of the VR experience. These factors were considered as discriminatory for VR user research from classic, less immersive interventions. Each paper was examined by 2 of the authors. Disagreements were resolved in discussions.

Uses of VR Hardware

Established desktop VR devices, such as the HTC Vive (63) and Oculus Rift (42), are most commonly used in the papers reviewed followed by mobile device powered HMDs, e.g. Samsung Gear VR (9) and Google Cardboard (4). 3 publications did not report the device used. The input modalities and devices used in the VR applications are mainly native VR controllers (e.g. Oculus Touch, HTC Vive Controller) (49)

	Interaction	Presentation	Questionnaire (Extent)
[6]	Gamepad	n.a.	well-being [44] (SI)
[28]	Gamepad	HUD (Fig. 1b)	well-being [44] (SI)
[37]	Orally	HUD	custom (MI)
[44]	Gamepad	World (Fig. 1e)	well-being (SI)
[55]	n.a	n.a.	presence rating [21] (SI)
[66]	VR controller	World	well-being [44] (SI)
[85]	VR controller	HUD (Fig. 1a)	custom (SI)
[100]	VR controller	World	custom (SI)
[108]	Full body	n.a.	IAT [64] (MI)
[127]	VR controller	World (Fig. 1d)	NASA-TLX [72] (MI)
[148]	Freehand	n.a.	custom (MI)
[158]	Freehand	World (Fig. 1c)	PQ [201] (MI)
[159]	VR controller	World (Fig. 1f)	SUS [189], IPQ [155], PQ [201] (MI)
[160]	Freehand	World (Fig. 1c)	PQ [201] (MI)
[198]	Freehand	Body (Fig. 1g)	PANAS [96] (MI)

Table 2. Examples of INVRQS with their realization (interaction and presentation), the questionnaire used and its extent (multi-items (MI) vs. single-item (SI)), if reported in the publication (n.a. otherwise)

followed by freehand interaction (e.g. Leap Motion or Microsoft Kinect) (35) and general purpose input devices (e.g. game controller, keyboard, mouse, stylus, smartwatch, and touch screen) (25).

Questionnaire Assessment

110 out of 123 papers report having used questionnaires in their VR user studies. Since the use of VR devices entails design decisions regarding the presentation of questionnaires and individual question-items, we surveyed the documentation of such decisions in the respective papers. 77/110 do not report how they presented the questionnaires to their users. 13 papers report that the participants filled out the questionnaire after leaving the VE but do not describe whether they used paper- or screen-based questionnaires. 15 papers report on the usage of INVRQS – either for the whole question asking procedures in the user-study (3) or in combination with OUTVRQS (12).

Cases of In-VR Questionnaires

15 papers report the use of INVRQS. Some describe the design in more detail. Figure 1 depicts 7 different realizations of INVRQS. Kang et al. (Fig. 1a) used a 2D heads-up display (HUD) overlay with a single question about the user's motion perception between multiple trials in their VE [85]. The user interface (UI) shows a single question with a multi-line question text and 3 buttons for answering choices. As input device, they used a native VR controller [85]. Schwind et al. (Fig. 1c) included the full 32-item PQ [201]. The participants stayed in the VE for the whole duration of the study: on average 58.6 min [160] and 75 min [158]. The authors designed a 3D floating UI which appears in front of the subjects showing a one-line text instruction and 4 items on 7-point Likert-scales. Users select answers and navigate the questionnaire with freehand gestures using a Leap Motion [158, 160, 161]. In another study, Schwind et al. (Fig. 1f) placed single questions on presence on a virtual PC in the VE, with which a user interacts with the trackpad of a VR controller [159]. Oberdörfer et al. (Fig. 1d) presented the NASA-TLX [72] using a virtual world-referenced representation of the paper-based version. The users interacted using a VR controller with pointing [127].

(a) Kang et al. [85]   (b) Cao et al. [28]   (c) Schwind et al. [161]   (d) Oberdörfer et al. [127]

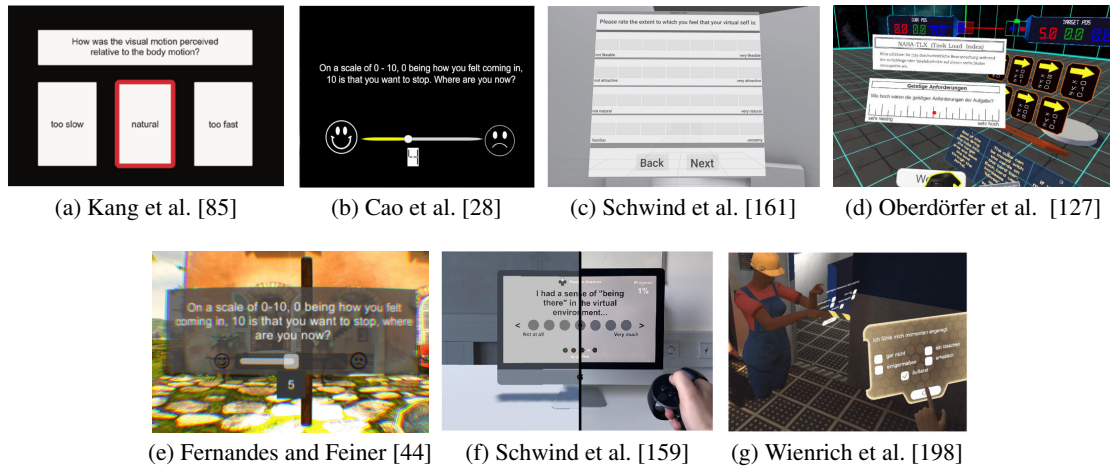(e) Fernandes and Feiner [44]   (f) Schwind et al. [159]   (g) Wienrich et al. [198]

Figure 1. Examples of different realizations of INVRQ: (a) and (b) present the questionnaire using a HUD, (c)-(f) use a world-referenced questionnaire, and (g) presents the questionnaire attached to the body.

Wienrich et al. (Fig. 1g) presented a body-referenced INVRQ [198]. The questionnaire was displayed on a 2D floating UI with a 20-items PANAS [96] attached to the hand of the virtual character. They combined the in-experience measurement with further out-VR measurements and oral answering of the Fast Motion Sickness Scale (FMS) [88]. Fernandes and Feiner (Fig. 1e) is the earliest example of INVRQS in our sample. The authors applied a 10-point Likert-scale slider on well-being where subjects could stop the experiment by selecting the maximum value of discomfort [44]. [28] (Fig. 1b), [6] and [66] adapted this method in their works in different realizations.

All INVRQ designs differ in their presentation (HUD, world-reference, body-referenced), their extent (single-question vs. multi-item questionnaire), question-item presentation (text-based vs. scales) and interaction modality (pointing, free-hand, trackpad). Table 2 summarizes the variation of the INVRQ designs. The applications of INVRQS cover questions about the subject's well-being, their sense of presence and task-specific questionnaires, e.g. about task workload or affect.

Discussion

Our literature analysis shows that comprehensive reporting of questionnaire usage in VR research is frequently neglected. Only Schwind et al. [159] compare INVRQS and OUTVRQS and discuss their effects. This indicates that the field may benefit from building awareness and providing guidelines. We identified 15/123 cases of INVRQS applied in VR user studies. The realizations differ substantially in their presentations and interaction methods. The majority of cases used presentations that contextualized the questionnaires in the VE, either attached to the user, or anchored in world space in a stationary manner. The participants used predominantly native controllers to interact in VR, directly followed by free-hand interaction. In order to better contextualize these literature findings and to collect details about the design of INVRQS and their potential shortcomings, we discuss a further investigation through an online expert survey in the following section.

EXPERT SURVEY

To augment the insights gained from the literature review, we conducted an expert online survey that evaluates general proceedings of VR user studies and attitudes towards INVRQS. With this additional analysis of the state of the art, we aimed to capture an impression of the actual procedures employed by the researchers independent from possible biases present in publications with space limitations.

Survey Dissemination and Pre-Processing

We developed a custom survey to capture the general reporting of proceedings of VR user studies as well as experiences and attitudes of the study designers regarding INVRQS. The complete survey is provided in an OSF project[1]. Following informed-consent, it consisted of 22 questions grouped into 5 categories (demographics, general research practice, VR research practice, INVRQ experience and OUTVRQ experience). The survey was designed and distributed using Google Forms. For recruiting expert participants, we extracted a list of authors from the papers (2016–2018) we analyzed in our literature review and sent them personal invitations. We also advertised the survey via social media channels. Over 6 weeks in July and August 2018, we collected 74 replies.

Since the online survey focused on researchers and VR experts, we excluded 4 participants who were not directly involved in VR user studies in the last 24 months and 3 participants who indicated that they do not generally use questionnaires as measures in their VR user studies. Moreover, we corrected obvious spelling mistakes to facilitate accurate counts of established terms (e.g. hardware or questionnaire names). For anonymized analysis, we removed time stamps and added unique identifiers (E1–E74). The reported analysis focuses only on questions that are most relevant to our research questions.

Analysis

After data cleaning, the analyzed data set consisted of 67 full set responses. Based on participant indication, we sampled

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[1]**https://osf.io/f5qy7/**

responses from 13 different *countries of residence* (Q3). With 20 participants from Germany, 9 responses each from the USA and Portugal and 4 responses each from Denmark and France, the majority of our sample came from northern-hemisphere countries. As a result of the sampling strategy, the expert sample stems predominantly from academia. The participants indicated to be holding the following positions (Q2): 22 Ph.D. students, 16 professors (full, associate, assistant or equivalent), 10 undergraduate students, and 8 Postdocs. The remaining 11 participants provided individual answers, such as research engineer or research fellow. On average, the participants indicated to be rather experienced with designing user studies (Q4). On a 6-point Likert-scale (0 to 5): $M=3.76$, $SD=1.18$. The majority (56) were directly involved with conducting $1-5$ VR user studies in the last 24 month while 8 experts indicated involvement with between 6 and 10 studies. Only 3 indicated more than 10 VR user studies (Q9). Our sample consists of a diverse spectrum within the group of academic researchers who have a sound background on VR user research allowing us to interpret the responses as an expert evaluation.

VR research
The experts' *most commonly used VR devices* (Q10, multiple choice) in the last 24 months were *desktop VR devices* (HTC Vive (55) and Oculus Rift (37)) or *mobile VR devices* (Samsung Gear VR (15) and Google Cardboard (11)). Other devices were mentioned occasionally. Only 4 participants used neither HTC Vive nor Oculus Rift. The most commonly used input modalities (Q11, multiple choice) reported for the general interaction with VR are mainly *native VR controllers* (50) and *freehand interaction* (e.g. Leap motion or Microsoft Kinect) (31) followed by *gaze interaction* (19) and *general purpose input devices* (e.g. game controller, keyboard, mouse, stylus or smartwatch) (34). 6 participants reported using custom controllers that were not further defined.

Questionnaires
We asked our participants how they *usually present questionnaires* in their user studies. 29 use a separate screen outside the VR, 21 paper questionnaires, 6 embed the questionnaire in VR, 2 use oral answers and 9 use mixed methods (Q13). Validated questionnaires (OUTVRQS) are very common in VR user research (Q12). Independent of the form of presentation, the experts reported they *encounter some difficulties with questionnaires in VR user studies* (Q16): 14 experts reported problems with the questionnaires in general, such as ambiguous question items in validated questionnaires, e.g. PQ, or the length of questionnaires, e.g. SSQ [87], NASA-TLX [72], especially for use in measurements between trials. 7 experts reported problems of their participants when moving from VR to reality for answering the questionnaires, namely the lack of immersion (4) and the temporal effort (3).

29/67 experts have tried in-VR questionnaires (INVRQ *users*). Most of them (25) tried fully interactive questionnaires that are both presented and answered in VR (Q18, single choice). All experts rated the usefulness of INVRQS (Q17) on a 6-point Likert scale ($0-5$). They rated the usefulness with $M=2.97$, $SD=1.58$ which is significantly higher than the midpoint 2.5 (one-sided independent sample t-test $t_{65}=2.41$,
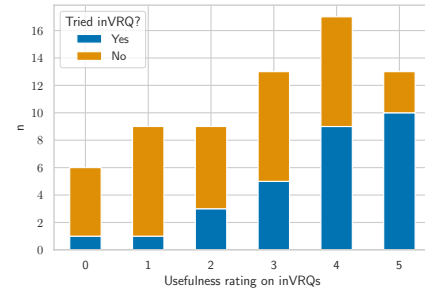

Figure 2. Ratings of the usefulness of INVRQS (Q17, scale: 0 to 5, 5 being highest) separated by INVRQ experience (Yes/No).

$p<.01$). For further analysis, the experts were split into 2 sub-groups according to whether they have tried an INVRQ in their research setups (Q18) or not ($M_{Yes}=3.72$, $SD_{Yes}=1.33$ and $M_{No}=2.39$, $SD_{No}=1.55$), cf. Figure 2. A two-sided independent sample t-test showed a significant difference between prior INVRQ experience and the usefulness rating ($t_{65}=3.69$, $p<.01$, Cohen's $d=.45$). To appropriately weight the responses we further split the experts according to their scientific seniority. Group A: post-docs and professors, Group B: all other participants (presumably more junior researchers). The experts in group A tend to rate the usefulness higher than the other participants: With $M_A=3.46$, $SD_A=1.74$ and $M_B=2.70$, $SD_B=1.46$). But the difference was not significant $t_{65}=1.91$, $p=.06$.

In-VR Questionnaires
14/29 INVRQ *users* presented the questions in world space as floating displays and 4 used a 2D UI (probably replacing the virtual world) (Q19). 4 experts responded that they presented only 1 question at a time. 14 experts did not observe any difficulties of their participants using INVRQS (Q20). Usability and the "amount of time for filling out the questionnaires" (E44) were major challenges experts came across (4× each). Further, "completing long questionnaires can be (...) annoying" (E18) and participants are "impatient (...) and hence made mistakes in the scaled questions" (E5).

Out-VR Questionnaires
Using Q18 as a branching question, 38 OUTVRQ *users* were asked to provide reasons for not embedding the questionnaires into the VE (Q21). 19 from that group reported that they do not suspect to benefit from INVRQS. 9 experts reported technical difficulties and 3 exceeding time effort in setting up the embedding for INVRQS. "Time effort to embed into VR much higher than doing the same on paper and harder to change/make additions" (E48). 6 experts mentioned usability problems and 1 sees problems in all these categories. The experts explained their critical opinions of INVRQS further (Q22): They argue, it would reduce the "willingness to answer the questions" (E31) because interaction with the UI in VR is more frustrating and takes longer than on desktop. Especially text entry is seen as a major issue. The experts reason that this might bias the results "towards the choices that are easiest to make through the interface" (E31). Additionally, they mentioned the time effort for implementation and usage:

"My last study took 45 minutes including questionnaires. It gets very hot and inconvenient under a Vive for such a long time – especially if it's your first time" (E71).

Discussion

The responses to the survey indicate that experts generally appear to have a positive attitude towards INVRQS. Both our literature review and expert survey demonstrate that there is no common standard for using questionnaires in VR user studies. While the reporting of the presentation type of the questionnaires in the literature is mostly imprecise, our expert survey did not surface a clear standard method for presentation. Thus, regarding RQ1, the state of the art for delivering questionnaires in VR user studies is quite heterogeneous. Also, we found inconsistencies between the literature analysis and the online survey: While only 15/123 papers reported on the usage of questionnaires embedded in VR, 29/67 experts reported that they have tried INVRQS before. Possible reasons for the contrast between the positive attitude of the INVRQ user group and the rare reporting of INVRQS are not intuitively clear. The difference could indicate that a shift may be taking place in the community with many applications of INVRQS not having been published yet. There is, however, the possibility of increased variance due to publication bias that warrants control in future work. Alternatively, the authors of the analyzed corpus may have considered the presentation type to be irrelevant. In contrast to these outcomes, there are experts who have a strong opinion against embedding questionnaires and argue that INVRQS could bias responses. In response to RQ2, the broad range of *reasons provided for or against using* INVRQS indicate technical challenges, implementation effort, and fear of biases and participant overload. In the following section we investigate these objections from the users' viewpoint and design and evaluate an INVRQ tool.

DESIGN STUDY

Although many guidelines from "traditional" HCI, cf. [41, 168], can be applied to VR, the third dimension brings its own challenges for UI designers. LaViola et al. [102] point out that there are no standards for 3D UIs yet, such as the ISO 9241-110 [81] standards for 2D GUIs. The results from the literature review and from the expert surveys are heterogeneous and do not allow for a definite answer of the usefulness and realization of INVRQS. With regard to RQ3, the goal of this design study was to identify the most usable interface design.

In-VR Questionnaire Design

Based on the results of our expert survey and general guidelines on traditional UIs [41, 168] as well as UIs in VR [40, 62, 128, 203], we implemented 4 variants of INVRQS. The interfaces differ in 2 dimensions: *anchoring* (world-referenced and body-referenced) and *interaction modality* (pointer and trackpad). The world-referenced UI is anchored in the VE and users can freely move around the interface. A body-referenced UI is attached to a hand-held controller.

To enhance readability, we applied guidelines from research and industry which recommend *signed distance field* fonts [61, 128]. In line with Dingler et al. [40], we used light glyphs on a dark background. Oculus best practices recommend to avoid HUDs (cf. Fig. 1a, 1b) in favor of UI elements that are settled in the VE, as it overcomes the binocular disparity and allows to contextualize the UI in VR [102, 128]. This is in line with the statements from the experts who applied INVRQS, as the majority (32/67) implemented questionnaires in the world space (see Fig. 1c–1f). In contrast to world-referenced UIs, body-referenced interfaces, as in Fig. 1g, take advantage of the user's proprioceptive sense and can significantly enhance the interaction with the UI [102, 118].

The interaction with the UI varies between a laser pointer – as Oberdörfer et al. [127] applied for their INVRQS – and a clicking interaction where the trackpad of the controller is used to navigate through the questionnaires, similar to Schwind et al. [159]). Oculus guidelines [128] suggest a laser pointer with a visible ray-cast and a cursor projected on the UI as an appropriate and intuitive method to interact with UI in VR. This is reflected in general guidelines which suggest better performance in terms of speed, accuracy and cognitive demand [112, 113, 119]. In contrast, navigating a UI using a trackpad promises to be more efficient when the UI is close to the users since they are not required to twist their arms for aiming.

The 4 designs that emerge from the 2 dimensions anchoring (world, body) and interaction (pointer, trackpad) cover a wide range of designs that are applicable to INVRQS. We developed all 4 designs iteratively following the same usability guidelines and paying particularly attention for comparability. Our interface supports continuous values (slider), checklists, radio lists, drop downs; and switches. The prototype is implemented in Unity3D with OpenVR. Their interaction and design is demonstrated in the accompanying video figure.

Study Design, Procedure and Tasks

The study has a 2×2 within-subject design where users filled out INVRQS using the 4 different versions of the interface: world-pointer (WP), world-trackpad (WT), body-pointer (BP) and body-trackpad (BT). The order of the condition was counterbalanced using Latin Square. First, the subjects were welcomed and informed about the study. The experimenter fit the HMD (HTC Vive) and explained the interaction in the current condition with the native controllers. To provide a context to the VE, we used a sci-fi scene.

To investigate the usability of all response types, we developed a questionnaire which asks for common knowledge facts to ask subjects easy-to-answer but objective questions to calculate correctness. Each condition consisted of a questionnaire that comprised all 5 question types once. Each participant answered 20 questions in total with each question type once per condition. After each condition in VR, the participants took off the HMD and filled out a paper-based System Usability Scale (SUS) [25]. When the participants finished all 4 conditions, the experimenter asked them to put the 4 interfaces into a ranked order and conducted an interview.

Participants
10 male (age M=29.9, SD=2.9) subjects from a game jam at the campus participated in the study. For their experience in VR and as VR developer or researcher, the participants gave

a score on a Likert scale from 1 (no experience) to 5 (high experience). All participants had prior experience in VR and game development (*M*=3.6, *SD*=.84). 6 participants developed VR applications or conducted studies in VR (*M*=2.3, *SD*=1.33). Although this sample lacks representative diversity, it allows for a deep discussion of the design space while avoiding general issues that could have come up with novices.

Results and Discussion

For the quantitative metrics (SUS [25] and duration), we conducted a repeated measures ANOVA with condition as factor. The descriptive statistics and the results of the analysis are in Table 3. Bonferroni corrected pairwise comparisons of the SUS [25] scores revealed significant differences between BP and BT ($p<.01$), between BP and WP ($p<.01$), and between WP and WT ($p<.01$). For the required time, Bonferroni corrected pairwise comparisons revealed significant differences between BP and BT ($p<.01$), BT and WP ($p<.01$), and between WP and WT ($p<.05$). On the subjective rankings, the participants rated the world-pointer setup significantly higher ($F_{3,36}$=13.27, $p<.001$).

6/10 subjects stated that the laser pointer is easy and intuitive to use. In contrast, the majority perceived the trackpad as tedious and confusing. 3/10 participants liked being able to move the questionnaire. But 4/10 participants reported they were confused by the body-referenced interface and stated the movement as unpleasant. The world-anchored UI was stated as less demanding than the body-referenced (3/10).

Completion time, SUS scores [25] and the interviews clearly show the world-referenced anchoring with the laser pointer interaction is easiest to use and therefore the best candidate to investigate the concerns raised by the experts.

USER STUDY

To assess whether usability and duration concerns about IN-VRQS raised by the experts hold true and to provide guidance on question-asking methods in VR, we conducted a user study in which the participants shot balloons with bow and arrow in a VR archery game and then filled out INVRQS as well as questionnaires presented on a notebook (OUTVRQ). The aim of this study was to evaluate adequate design choices of INVRQS we identified in the design study and to capture the users' perspectives on INVRQS. In contrast to previous work by Schwind et al. [159], our user study applies the questionnaires in a realistic study setting without replicating the lab space virtually.

The Questionnaire Tools

We implemented the INVRQ with world-based anchoring and laser pointer interaction (Fig. 3). We refined the overall readability, i.e. font size, contrast, spacing and positioning

Figure 3. Screenshots of the archery task. The world space-anchored INVRQ is filled out using the HTC Vive controller as a laser pointer.

of the UI in the VE. The tool supports sliders, radio lists, radio grids and check lists. We omitted drop downs and free-text fields since these elements rarely appear in standardized questionnaires, as the literature review shows. If needed, drop downs can be represented using a radio list, and free-text input can be approximated with voice recording.

The OUTVRQS were realized using the questionnaire tool LimeSurvey [57]. It was presented on a 15" notebook with external keyboard and mouse with default speed.

Measurements

After the archery game, we measured presence in the VE using IPQ [155] on a Likert scale with the subscales *general presence (GP)*, *spatial presence (SP)*, *involvement (INV)* and *experienced realism (REAL)*. Furthermore, we asked the participants to rate the game and the perceived control over the bow on a 10-ticks slider. For demonstrating a greater variety of question types, we additionally included questions about the VE (1*x* numerical, 4*x* single choice with 2–5 items, 4*x* multiple choice with 5 and 16 items).

To evaluate the workload and the usability of the INVRQ tool, we employed the raw NASA-TLX [72], using a 20-ticks slider to measure physical, cognitive and temporal demand, as well as performance, effort, and frustration. Usability was measured with the UMUX [46], a four-item questionnaire providing comparability with the SUS [25] (r=.96). As an objective performance metric, we logged the exact time. To get detailed insights from the users' perspective, we conducted a semi-structured interview at the end of a session.

Study Design and Procedure

The study compares the usage of INVRQS to digital OUT-VRQS. To provide a realistic study setting, we designed a

	WP (M, SD)	WT (M, SD)	BP (M, SD)	BT (M, SD)	F(3,27)
SUS [25]	91.25, 8.99	64.25, 24.09	79.00, 14.49	52.25, 19.52	11.15**
t (min)	0.61, 0.12	1.00, 0.27	0.69, 0.33	1.19, 0.23	14.92**

Table 3. Descriptive statistics and RM-ANOVA of the design study for the 4 conditions world-pointer (WP), world-trackpad (WT), body-pointer (BP) and body-trackpad (BT) on SUS [25] and time. **p<.01.
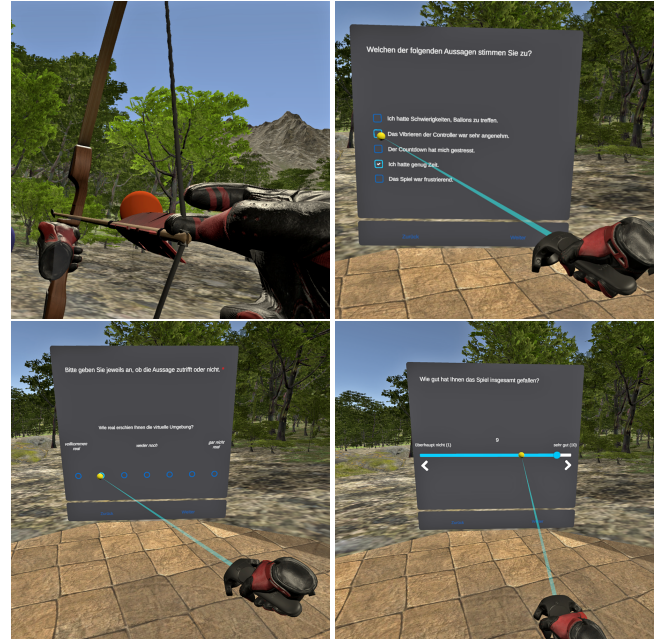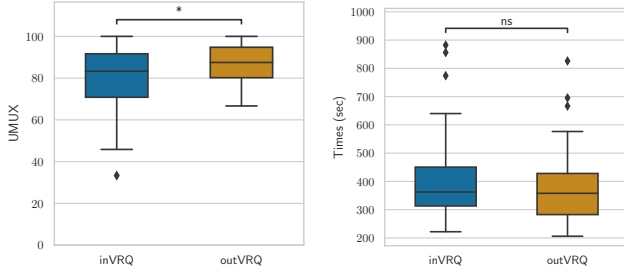
Figure 4. Ratings of usability on UMUX [46] (left) and of completion times (right) for both conditions.

balloon archery game as an immersive VR experience (see Fig. 3). We chose this task because (i) it is engaging and requires the participants to focus, promising an immersive VR experience, (ii) the interaction is easy to learn but differs from the pointing interaction used for answering the INVRQS; thus, the task is less likely to produce carry-over learning effects. For the archery task, we used free Unity3D assets and implementations from the SteamVR Interaction System. The VE consists of a round platform with 3 pillars that display instructions that guide through the experiment. The platform is surrounded by 12 spawn points for the balloon targets and it is situated in a realistic environment with mountains, trees, a river and high resolution textures. The questionnaire interaction builds on the laser pointer by SteamVR and the GUI interaction by HTC Vive.

The study followed a within-subject design with the conditions INVRQ and OUTVRQ in randomized order. After the participants were informed about the procedure, they signed a consent form. The experimenter fitted the HTC Vive Pro HMD. Then the participants played a tutorial round in which they had to hit 5 balloons followed by a 90 s round where they should hit as many balloons as possible. After the archery task, the participants filled out questionnaires using the corresponding tool for their first condition (INVRQ, OUTVRQ). Afterwards, the participants repeated the game and questionnaires using the other questionnaire method. We encouraged them to take a 2 min break in between. After both conditions, the experimenter conducted a semi-structured interview followed by a paper-based demographics questionnaire. Finally, the participants were orally debriefed. The study, including game, questionnaires and interview, was conducted in German and took around 45 min ($\approx$11 min in VR).

Participants
We advertised the study on campus, social media and in lectures and conducted it in July 2019. In total, 38 participants (age: M=27, SD=10.8; 16 f, 22 m, 0 other; 20 started with the INVRQ condition) volunteered for our study. Most participants were students. 21 participants used vision aids in VR, 1 participant has a light dyschromatopsia. The sample has a broad range of prior VR experience: 6 participants use VR regularly, 27 occasionally and 5 never used VR before. 19/38 participated in other VR user studies previously and 3 participants used INVRQS before. We detected no outliers regarding demographics and task completion times.

Results

Performance, Presence and Rating of the VR Experience
On average, participants shot 24.71 balloons (SD=10.33) in the first round and improved by 6.34 (SD=6.01) balloons in the second round. We obtained presence on the IPQ [155] on a 7-point Likert scale (0–6). To determine if the measures deviate from neutral, we performed a two-sided one-sample t-tests against the midpoint 3. The results show a positive difference for GP (t_{37}=14.93, p<.001), SP (t_{37}=22.53, p<.001) and INV (t_{37}=5.99, p<.001), but no difference for REAL (t_{37}=−48, p=.63). There was no significant effect of condition on any IPQ subscales (see Fig. 5a). Like Schwind et al. [159], we performed a t-test to compare the variances of both conditions on all IPQ subscales; the differences were not significant (GP_{var}: t_{37}=-.52, p=.60, SP_{var}: t_{37}=-.05, p=.96, INV_{var}: t_{37}=1.47, p=.15 $REAL_{var}$: t_{37}=.17, p=.87).

Further, the participants rated the interaction with the bow (M=7.89, SD=1.70) and how they liked the game (M=8.0, SD=1.73) on a 10-ticks analog scale from 1 (not at all) to 10 (very much). A one-sample t-test revealed significant differences against the midpoint (5.5) for bow control (t_{37}=15.01, p<.001) and game ratings (t_{37}=14.86, p<.001), but no effect of conditions neither for bow control nor game rating.

Duration and Self-reports on Usage of the Questionnaires
Figun 4 shows plots of UMUX scores and answering time. On average, participants required 6.77 min (SD=2.69) to fill out the questionnaires in VR and 6.30 min (SD=2.26) on the notebook (without the time for taking off the HMD). There was no significant difference of condition on duration of filling out the questionnaires (t_{37}=-1.05, p=.29). Nevertheless, in the post-experiment interviews, 5 participants perceived filling out the questionnaires in VR as faster. 2 had the impression the questionnaires in VR would be shorter. The IPQ completion times did not differ significantly (INVRQ IPQ: M=146.39 s, SD=65.46) in comparison to the ones reported by Schwind et al. (VR IPQ: M=146.94 s, SD=63.2) [159]: t_{37}=.04, p=.97. On the UMUX, the participants rated the questionnaire tools' usability. Both systems were rated positively (INVRQ: M=77.35, SD=18.35, OUTVRQ: M=86.21, SD=9.4). The difference between the conditions was significant (t_{37}=2.82, p<.01). In accordance with Grier [65], the participants experienced low to medium workload on the NASA-TLX [72] (INVRQ: M=18.64, SD=11.38, OUT-VRQ: M=14.40, SD=9.42). Paired t-tests revealed significant differences on physical demand (t_{37}=4.14, p<.01) and effort (t_{37}=3.00, p<.01) subscales but not on mental demand (t_{37}=1.42, p>.05), temporal demand (t_{37}=1.15, p>.05), performance (t_{37}=1.48, p>.05) or frustration (t_{37}=1.76, p>.05). The results are depicted in Figure 5b. We contrasted the mean TLX-scores against Schwind et al.'s values (VR: M=33.16, SD=20.96, PC: M=37.77, SD=19.26) [159]. Our data show a significantly lower workload for both corresponding comparisons INVRQ (t_{72}=3.50, p<.01) and OUTVRQ (t_{72}=6.57, p<.01) conditions.

Qualitative Results
We collected relevant statements from the interviews and dynamically generated categories emerging from the material.
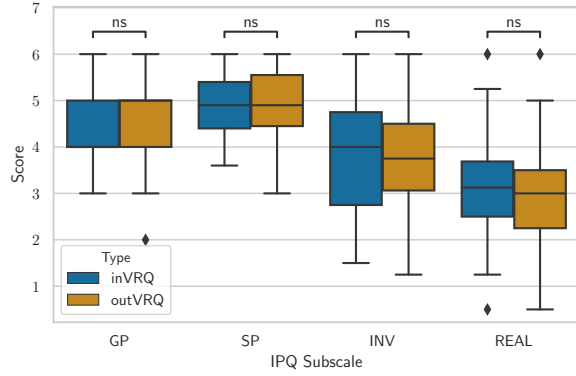
(a) Ratings of presence on IPQ [155] subscales general presence for (GP), spacial presence (SP), involvement (INV) and realism (REAL) split by INVRQS and OUTVRQS conditions.
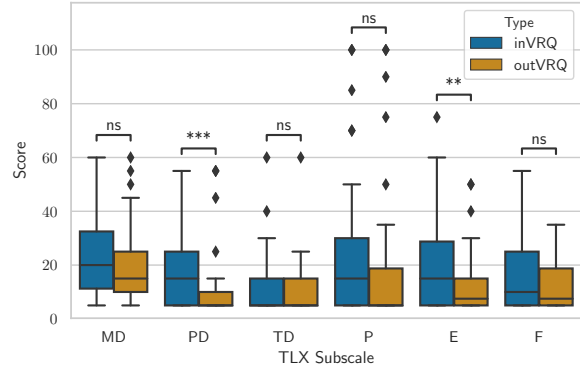
(b) NASA-TLX [72] results on the subscales: mental demand (MD), physical demand (PD), temporal demand (TD), performance (P), effort (E) and frustration (F) split by questionnaire conditions.

Figure 5. Boxplots of presence and workload split by questionnaire type

We indicate how many participants agree with the central statements made by others. Exact quotes were translated by the authors and are labeled with an ID in parentheses.

The majority of the participants (27/38) stated their *VR experience* as "fun" or "enjoyable". 17 found the INVRQS easy to use and the interaction intuitive. 4 participants preferred the directness of input with the VR controllers. However, 16 reported that sometimes the UI did not respond to their input; 4 described this as frustrating. 26 referred to the OUTVRQS as the "common" and "normal" questionnaires. 4 participants reported higher effort using the mouse and 12 participants would have preferred a faster mouse movement in OUTVRQ. Although the participants highlighted the advantages of familiarity using the mouse, we observed that all users instinctively understood the pointing interaction.

17 users criticized changing from VR to physical reality and stated that not having to switch the system feels more fluent and "better integrated" (P12). 4 users addressed the BIP due to the change of medium and how it might affect data quality.

Regarding *presentation*, 31 participants confirmed that readability and font size of the INVRQS were good and the questionnaire canvas was positioned well. P34 disliked not having a full overview of the displayed content in contrast to the notebook screen. 13 users mentioned that blurred edges in the HMD required head movement for reading. 8 users found it strenuous to fill out the questionnaires in VR. 5 of them suggested to provide a chair, P38 sat on the floor. Concerning *data validity*, 4 participants hypothesized that maintaining the immersion is "better for the results" (P11). When answering how they feel, 14 participants found it beneficial to do so in VR, because they still were in the situation: "You don't need to recall how you just felt." (P9). Correspondingly, 8 valued the immediacy of the surveying in VR.

12 stated the INVRQS were entertaining: "I didn't know filling out questionnaires can be fun!" (P33). Accordingly, OUT-VRQS were referred to as "dryer" (P4) or boring by 12 users, and P35 stated that a pleasant setting can be motivating to fill out the survey. At the same time, such positive excitement may influence certain measures (e.g. affect).

Finally, we asked the participants how they would like to answer questionnaires if the they would have to repeat the study. A majority of 31/38 would prefer to do it in VR, 5 on a computer and 2 had ambivalent opinions.

Discussion

The high ratings on the IPQ [155] with positive differences against neutral on all subscales but REAL, the ratings of the game and the control over the virtual bow, as well as the qualitative statements indicate that the game provided a high sense of presence. This indicates that our experiment design, which intended to simulate a realistic VR user study scenario, was successful. In alignment with results by Schwind et al. [159], we could not find any differences between the conditions on presence. However, our data show no differences in consistency and we cannot confirm their findings of lower variances of presence when surveying in VR. This supports prior findings that presence questionnaires are inadequate to assess BIPs [171]. Further, literature suggests that presence should be assessed behaviourally [48, 166, 172] or physiologically [24, 39, 116, 170].

With the UMUX, we measured high usability scores for both questionnaire tools (INVRQ: M=77.35, SD=18.35, OUT-VRQ: M=86.21, SD=9.4). However, the OUTVRQS were rated higher with a medium effect size (Cohen's d=.60). A possible explanation was given in the interviews: The participants sometimes had to repeatedly click on a UI element of the INVRQ for selection. The UMUX score allows a comparison with the SUS [46]. According to Bangor the scores are in a highly acceptable range [14], discarding the concerns of the experts. Similarly on the TLX, we measured a comparatively low workload [65]. However, the physical demand and effort are significantly higher in the INVRQ condition. As 5 participants stated, this could be attributed to the fact that they were standing and using the VR controller in mid-air rather than sitting on a chair and using the mouse with a resting hand on

the desk. The comparable duration is consistent with the TLX ratings for temporal demand and allows to infer that answering questions in VR does not affect the duration of a user study.

Limitations and Future Work
Our research only investigates the design aspects of the anchoring and interaction modality with INVRQS. This first step was essential to establish a convenient INVRQ design that can be applied in VR user research. Due to small sample size and non-diverse participants in the pre-study our design recommendations are not conclusive. However, the high UMUX scores in the user study confirm the prior results. In future work, we aim to systematically examine further design options (e.g. HUDs, freehand interaction) at different degrees of contextualization and embeddedness as previous work showed for games [53, 169] and VR [52, 198].

We only considered a short assessment of an INVRQ ($\approx$6.5 min) at the end of 1 exposure. Future work should examine the effects of long VR exposures and the effect of IN-VRQS for repeated between-trials measurements. We also did not evaluate open-ended questions which allow the subjects to respond freely, but require sophisticated methods for text-entry in VR. Although such methods exist [92, 129], they are often less accurate and efficient than out-VR settings, especially for untrained users [92]. In future work, we aim to investigate text-entry and oral assessment of open-ended questions in VR as [37], [121] and 4 surveyed experts suggested. The slightly lower UMUX rating suggests room for improvements for the in-VR questionnaire components and the increased TLX physical demand and effort, together with participant comments and behaviour suggest that investigations into "middle-ground" approaches (e.g. remaining in VR but being seated) could lead to more practical solutions.

CONCLUSION
Subjective self-reports are frequently used in VR user studies and administered in the physical domain. This can lead to a break in presence [83], disrupt the immersive experience [91] and bias the responses [159]. Embedded questionnaires in the VE reinforce the association of VR and the subjective responses. Although different presentation methods of the questionnaires may affect the results, contemporary research has no shared agreement or validated assessment methods of self-reports in VR user studies. This work aggregates the contemporary body of research, VR expert perspectives and the user experience of INVRQS.

Our first research question (RQ1) investigates current applications of questionnaires in VR user research. From the literature analysis, we identified 15 instances of INVRQS. These few examples differ substantially in visualization and interaction, emphasizing the lack of validated surveying procedures in VR user research. For a comprehensive understanding of the advantages and challenges of INVRQS (RQ2), we conducted an online survey with 67 VR experts. 43/67 of researchers see the importance of embedding questionnaires directly into the VE. To explore presentation and interaction modalities suitable for INVRQS (RQ3), we conducted 2 user studies, in which we first identified world-anchoring and pointing as

most adequate design choices to administer questionnaires in VR and then contrasted an INVRQ against a common screen-based OUTVRQ. Although the results show lower usability and higher physical demand and effort of INVRQS, the ratings are within tolerable range and the majority of participants stated a positive attitude towards INVRQ.

24/67 of the experts rated the usefulness of INVRQS below neutral and raised concerns regarding usability (10) and the required time for answering (5). The high UMUX-scores and comparable completion time between INVRQS and OUT-VRQS defy these objections. Moreover, the majority of the participants (31/38) would choose INVRQS over OUTVRQS. This result may be partially attributed to a novelty effect of VR and might weaken with a wider dissemination of VR technology. Similarly, our online survey showed that 29/67 of the experts have already applied INVRQS in user studies and mainly consider them as useful and effective. Based on our findings from the literature review, the survey and the user studies, we advocate that presenting questionnaires in the VE helps the participants to report their experience in a convenient, non-interruptive manner.

Based on the results from the 4 presented studies we conclude: (i) researchers should to apply INVRQS in their user studies, (ii) pointing and world-anchoring are usable ways to realise INVRQS, (iii) participants prefer using INVRQS over OUT-VRQS and (iv) researcher should be aware of slightly raised physical and mental demands when using INVRQS.

Similar to the establishment of standardized questionnaires that are empirically validated, we propose moving towards standardizing questionnaire implementation and presentation methods in VR, similar to a quasi-standardization that has already occurred in more traditional screen-based questionnaires due to the prevalence of selected survey tools, such as Google Forms or LimeSurvey [57]. Future work will need to seek for comparative experimental evidence on how the questionnaire modality affects the reliability of the the measurements. As with most design choices, there is no absolute right or wrong. However, researchers should be aware how their measurement methods influence the data. This research lays the groundwork for a design theory of INVRQS to provide validated and standardized methods of question-asking in VR.

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