Ready Worker One? High-Res VR for the Home Office

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ABSTRACT

Many employees prefer to work from home, yet struggle to squeeze their office into an already fully-utilized space. Virtual Reality (VR) seemingly offered a solution with its ability to transform even modest physical spaces into spacious, productive virtual offices, but hardware challenges—such as low resolution—have prevented this from becoming a reality. Now that hardware issues are being overcome, we are able to investigate the suitability of VR for daily work. To do so, we (1) studied the physical space that users typically dedicate to home offices and (2) conducted an exploratory study of users working in VR for one week. For (1) we used digital ethnography to study 430 self-published images of software developer workstations in the home, confirming that developers faced myriad space challenges. We used speculative design to re-envision these as VR workstations, eliminating many challenges. For (2) we asked 10 developers to work in their own home using VR for about two hours each day for four workdays, and then interviewed them. We found that working in VR improved focus and made mundane tasks more enjoyable. While some subjects reported issues—annoyances with the fit, weight, and umbilical cord of the headset—the vast majority of these issues seem to be addressable. Together, these studies show VR technology has the potential to address many key problems with home workstations, and, with continued improvements, may become an integral part of creating an effective workstation in the home.

CCS CONCEPTS

• **Human-centered computing** → *Virtual reality*; *Empirical studies in HCI*.

KEYWORDS

Virtual Reality, Workstations, Remote Work, Field Study

1 INTRODUCTION

Software developers, perhaps more than any other profession, have long led the move towards working from home [14, 64]. Recent studies have shown that as high as 57% of workers in the computer and information systems field work remotely [60]. While this is partially due to the field lending itself well to remote work—work files can easily be transferred to and from a home office digitally—we posit that there are other contributing factors. Software developers themselves are often technologically savvy and able to configure their home network and supporting hardware and software to interface smoothly with those working in the main office. Working from home poses a number of challenges, with a recent study showed that physical conditions—adjustable furniture, lighting, space, etc.—impact work [23]. This is in addition to related factors, such as being disturbed by others at home [13]. Proposed solutions range from a dedicated home office room to, on the more extreme end, pre-made office pods which can be placed in backyards like a shed [58].

Many of these physical solutions require the one thing that most homes do not always have: extra space. With VR technology steadily progressing in affordability, comfort, and resolution (the Varjo XR-3 now touts 70 ppd and a 115° field of view [45]), we ask: should developers consider digital solutions to their space challenges? Imagine a small corner nook, just big enough for a chair, keyboard, and mouse, and being able to use this nook to work in an expansive environment, isolated from the sounds and sights of your home.

In this paper, we present two studies, 1) a large-scale glimpse into the current challenges of home workstations, and 2) a case study of developers swapping their home workstation for a VR office. They provide complementary perspectives for designing the VR office of the future. For 1) we used a digital ethnography approach [39] to investigate the current challenges developers face in setting up their physical workstations at home. We collected 430 images of home workstations that developers posted on public forums and analyzed them for common workspace problems [8, 57], finding that many home workspaces are impacted by a lack of appropriate space. After analyzing these workspaces we used speculative design [3, 67] to visualize them as they would be if VR technology replaced the display and audio equipment, and we saw that in many cases existing workspace problems could be alleviated with the help of VR. This speculative design peers into a future where VR is advanced enough to comfortably replace the physical setup for a full-day immersion.

However, easing into this "Ready Player One" [10] future with today's state-of-the-art hardware, we propose to use VR as a special session in the work day. Just as someone might step out of their home and work in a café for a few hours to get into a better headspace, we imagine donning on the headset for a "change of scenery" in an environment which can be anything you like. To explore the problems that using VR might introduce, we conducted 2), a field

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study in which we asked ten developers to set up a VR workstation in their own home and work in VR for approximately two hours per day, for four days, while completing normal work tasks. We then interviewed these developers, analyzed their responses, and discussed the self-reported challenges faced.

This work makes the following contributions:

- It presents findings from an ethnographic study of home workstations, identifying common challenges and applying speculative design to see how VR might overcome them.
- It presents findings from a multi-day field study of developers using a high-resolution VR for their work at home.

Altogether, we provide preliminary evidence that high-resolution VR can be used to create home workstations that support focused, productive work while overcoming many of the space challenges.

2 RELATED WORK

2.1 Working From Home

While working from home (WFH) has been a steadily growing trend since the advent of distributed work, the COVID-19 pandemic marked an unprecedented migration from offices to homes. Even after companies started to return to the office, many chose to seek remote work opportunities, finding that they enjoyed benefits such as shortened commute time or flexibility. Working from home comes with many advantages, but also challenges. For many, the home environment brings an array of distractions and interruptions - something which for knowledge workers is known to be detrimental to productivity [2, 24, 25, 32, 59]. Surveys of knowledge workers during the COVID-19 pandemic identified home office ergonomics as a primary factor for employee productivity and wellbeing, particularly when it came to monitor setups [17, 49]. This paper investigates in more detail the challenges which WFH knowledge workers face in their stations, and assesses the experience of using VR for homeworking.

2.2 Studies in VR

Past studies of in VR indicate a number of considerations for long-term immersion. A 2019 study by Guo et al. formalized a framework based on Maslow's hierarchy of needs, which was evaluated with a long-term exposure experiment to determine the physiological, psychological and cognitive effects on users [22]. Some studies focus on specific measures, such as visual fatigue [21] or mental fatigue [56], showing that working in VR can have a negative effect in both cases. Recently, a study asked users to work on their normal work tasks in VR for an entire, 40 hour work week [27], finding concerning levels of simulator sickness with two participants dropping out on the first day "due to migraine, nausea and anxiety". In consideration to these findings, we chose a more comfortable 2-3 hour timeframe for our study and used a headset with the highest resolution available.

2.3 Solving Ergonomics

VR offers to transform the future of work through custom work environments free from physical constraints [4, 18, 41]. Yet, its adoption comes with ergonomic challenges, especially regarding prolonged use and movement. McGill and Kehoe introduced techniques that minimize these ergonomic concerns by assisting users in viewing large virtual spaces more comfortably [36]. To optimize typing performance in VR, solutions have been developed which visualize the user's hands and physical keyboard [19, 29]. Furthermore, the adaptability of keyboards in VR has been explored, innovating methods of reconfiguring and augmenting keyboards to suit the immersive environment [35, 54]. While challenges exist, research is illuminating pathways to optimize VR for work-related endeavors.

2.4 Bystander - VR User Interactions

As VR is used increasingly in shared spaces, it brings to the forefront interactions between VR users and bystanders. There are several social considerations, such as being secretly observed when typing passwords [54] and ways to increase users' cognizance of their surroundings [31]. Similarly, O'Hagan et al. spotlighted the nuanced interplay and the pronounced impact of bystanders on VR immersion [46]. Analyses of user-generated content by Dao and Muresan highlighted real-world disruptions in VR [12]. Furthermore, the use of VR HMDs in public spaces can be accepted, but only when social interaction is not expected [15, 55]. Efforts to bridge the real and virtual dimensions have underscored the need for solutions that maintain both user immersion and spatial awareness [34, 42, 43, 46]. As the adoption and application of VR continues, so does the challenge of harmonizing immersive experiences with real-world interactions.

2.5 Benefits of VR and AR

While AR allows situational awareness, VR facilitates full immersion in the VR environment. The biophilia hypothesis [66] states that humans have an "urge to affiliate with other forms of life", and that interacting with nature is essential to well-being [20, 28, 62]. Studies show immersion in nature settings, as compared to urban settings, significantly improves the participant's affect and reduces stress [61–63]. A study by Ruvimova et al. used a calming beach environment to explore whether VR can enhance flow in a distracting open office. The comparison of different lab conditions showed that working on a virtual beach created a flow condition similar to that of working in a private office [53]. Other studies suggest that both AR and VR benefits users by providing unlimited virtual monitors which can be configured ergonomically, around the user [36]. We build on prior work, exploring the in-situ experience of developers working in VR. Considering past findings, we use several natural environments and a video pass-through function for a better experience.

3 STUDY: HOME WORKSTATIONS

While many developers prefer working at home, setting up a home workstation can be challenging due to the many other requirements of the space [13, 23]. Using *digital ethnography*, we first investigate the challenges in home workstations. In the second step, we apply *speculative design* to examine if VR as the primary display device can overcome the challenges in home workstations.

3.1 Digital Ethnography Study

Ethnography is a qualitative study of a cultural group that often involves prolonged observation (i.e., participant observation) or examination of the group's artifacts and documents [6]. Digital ethnography, or netnography, expands beyond these traditional modes of observation, leveraging online forums, blogs, and social media posts to access information that would otherwise be unobtainable [39].

To study developers' workstations, we collected self-documented workstation pictures, as artifacts, from an online platform used by our target group. These pictures, collected from the field by participants themselves, offer unprecedented insight into the home workstations of a wide variety of users. While the pictures certainly contain some bias from the participants, they represent data that would be nearly impossible to collect using traditional methods. To create our dataset, we curated a list of 430 images from public Reddit threads via the open API. This was done in accordance with the Reddit terms of service, approval from our institution's ethics board, and the guidelines from the HCI community for protecting pseudonymous research participants (e.g., [7, 33]). We focused on three sub-reddits on which users share and comment on high-quality pictures of complete workstations that they have created: `r/Battlestations`, `r/Workstations`, and `r/Workspaces`. To focus our dataset on software developers, we filtered these posts, only keeping pictures posted by users who *also* posted more than once on software development sub-reddits, such as `r/Programming`, `r/Java`, and `r/SoftwareDevelopment`. For reproducibility, we provide a detailed description of the image collection process and the entire data set on Github [1].

To identify current workstation challenges, one researcher labeled each curated picture with the challenges clearly visible in the picture, starting with a list of existing ergonomic issues commonly identified in workstation studies [8, 57]. To ensure a consistent coding, a second researcher independently labeled a randomly selected set of 40 pictures (inter-rater reliability $\kappa = 0.709$).

3.1.1 Results. Table 1 contains a list of all identified challenges in the curated set of workstation pictures. A representative example for each challenge is shown in Figure 1. Note that we added one code for the presence of a pet (Pet) that was not mentioned in prior studies on corporate workstations.

One of the most evident difficulties software developers face in setting up home workstations is **finding an appropriate space**. Some workers have to decide whether it is better to steal space from their bedroom or a common space such as the kitchen if no extra room is available. Due to the lack of appropriate space, we often find workstations in less-than-ideal spaces, such as in a living room nook Figure 1 (A), a kitchen table (F), or a cramped bedroom (L).

The lack of appropriate space creates many challenges, such as a lack of Desk space, general Clutter, and even a crowded Footwell at the workstations. A lack of choices in the home on where to locate the workspace also leads to lighting issues (Backlit and Sidelit), noise from a Public space or Shared space, restrained freedom of movement (Width of room and Awkward space), or a lack of work and life boundaries (Bedroom).

> Home workstation challenges mostly stemmed from smaller, irregular spaces with distractions, differing from spacious and organized corporate offices.

Of the 430 images, 359 (84%) were coded with at least one challenge, and most challenges were directly related to space constraints. Table 1 lists the challenges based on their frequency, sorted from most frequently (top) to least occurring (bottom). A lack of sufficient Desk Space was visible in 66% of the workstation pictures. We saw various ways in which developers tried to resolve it, from mounting high on the wall to hanging monitors off the side of desks. Another common challenge due to the lack of appropriate space is lighting issues, with 37% of pictures coded with Backlit or Sidelit, indicating an intense contrast in light within the worker's monitor view that can cause eye-strain [44]. And 19% of workstations had space issues in their Footwell or overall Clutter.

> Almost all workstations (84%) had challenges clearly visible in photographs, even though these photographs were usually taken to show off their workstation.

3.2 Speculative Design of Workspaces

We set out to identify which challenges can be addressed with VR. In many cases, VR cannot completely *solve* the challenge—a cluttered room will (unfortunately) remain cluttered even if its inhabitant puts on a headset. Rather, by replacing the visual field with another, VR has the potential to alleviate some of the consequences: it may reduce the anxiety or distraction in favor of calm and mental clarity. To determine which of the identified challenges in Table 1 are thus solvable with a VR workstation, we applied speculative design [3]. Speculative design is the process of envisioning future solutions to existing problems, "...the designing of artifacts to communicate what the future could hold...", grounding this vision with input from an interdisciplinary team to ensure potential feasibility. Common examples of speculative design are corporate concept videos (e.g., SpaceX's vision for Interplanetary Transport [11] and scenario planning exercises [67]). A key outcome of speculative design is a concrete artifact—a video, prototype, mockup, or rendering—that can be used as an object to critique and serve to identify remaining technical and social challenges with the envisioned solution.

We started the speculative design with a specific workspace from our dataset. We then worked with an artist to visualize the workspace from the same perspective, removing unnecessary hardware and inserting our speculative element, the VR headset. For instance, to explore solutions to the Desk Space challenge, we chose a typical workstation from our dataset that included that code (e.g., left of Figure 2a). We then removed unnecessary hardware, such as the monitors and speakers, and replaced them with a VR headset that we visualized in **context** (e.g., right of Figure 2a). We applied this approach to all of the challenges in Table 1, finding that we can resolve or partially address all but one of the identified challenges with VR. As many of the speculative designs were similar in concept, we present three more representative visualizations, and indicate in Figure 2 where they were similar (e.g., our Desk Space solution was similar to our Footwell solution, since the VR freed up physical space on the desk which could be used for equipment previously under the desk). In the actual workplace in Figure 2b (left), there is a window directly behind the main monitor, causing a backlighting effect. In the speculative design solution (right), lighting challenges are eliminated through the use of VR. Shared workspaces, such as Figure 2c (left), can lead to distraction. In the speculative design (right), the VR workstations with integrated headsets can increase visual and auditory privacy. Similarly, workspaces in a public space, such as a kitchen (Figure 2d (left)), can lead to many distractions and interruptions. When reimagined as a VR workstation (right), the worker can enjoy sound and sight isolation, facilitating productive work.

Figure 1: Examples of codes: (A) Desk Space, (B) Backlit, (C) Cluttered, (D) Sidelit, (E) Pet, (F) Public Space, (G) Width of Room, (H) Awkward Space, (I) Footwell, (J) Fixed Chair, (K) Shared Space, (L) Bedroom and Chair Space

Challenge / Code	**Description**	**Instances**		**Can Address with VR**
(A) Desk space	Desk with limited desk space, including smaller desks and larger ones that were clearly not large enough to hold all the user's equipment and supplies.	282	(66%)	Yes
(B) Backlit	Desk with window behind it, with the sun shining through, causing a back-lighting effect on the monitor. Back-lighting is known to cause eye strain [44].	106	(25%)	Yes
(D) Sidelit	Desk with a window beside it, which can make it hard for developers to view their screen [44].	52	(12%)	Yes
(I) Footwell	Desk with large equipment placed in the footwell, potentially causing ergonomic problems [65].	48	(11%)	Yes
(C) Cluttered	Desk with unorganized equipment and unrelated items. Clutter is known to increase stress [52].	33	(8%)	Yes
(F) Public space	Workplace in a common space of the home, such as a dining room table used as a desk, often leading to a noisy environment and impacting productivity [30].	30	(7%)	Yes
(E) Pet	Workspace shared with a pet. While pets can be a comfort, they can also be a distraction.	19	(4%)	Yes
(G) Width of room	Desk in a small nook. Limited width causes various space challenges for equipment and supplies.	17	(4%)	Yes
(H) Awkward space	Desk in an awkward, unsuited space for supporting work, such as an attic with a slanted ceiling.	15	(3%)	Yes
(I) Bedroom	Workplace in the bedroom making the separation between work and life difficult.	15	(3%)	Yes
(J) Fixed chair	Workstation with a fixed, not adjustable, chair, often leading to poor ergonomics [48].	10	(2%)	No
(K) Shared space	Two workstations for two people working side-by-side. Working in close proximity can lead to distraction and affect cognitive performance, especially with remote meetings [26].	9	(2%)	Yes
(L) Chair space	Workstation with insufficient space to move the chair properly.	8	(2%)	Maybe

Table 1: Workspace challenges, their frequency in the curated set, and their resolution using VR in the speculative design.

Using speculative design, we found that VR workstations can address most challenges of current home workstations.

4 VR FIELD STUDY

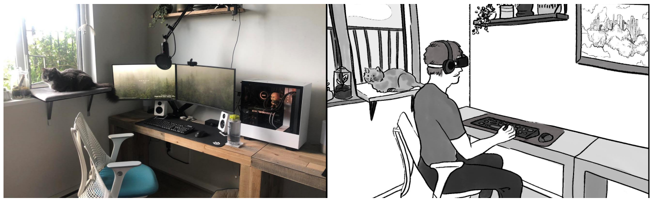
While studying home workstations and envisioning potential solutions offered a good first step, it would be imprudent to provide guidelines on using VR to facilitate home workstations without field testing with the actual hardware. Commonly available consumer VR hardware has been known to cause motion sickness, suffer from resolution issues, produce noticeable heat, and cause neck strain [9], so it was imperative that we performed a qualitative investigation to investigate the remaining technical, ergonomic, and social challenges that might keep VR technology from being adopted for this specific use case. We conducted a field study to investigate this question.

4.1 Participants

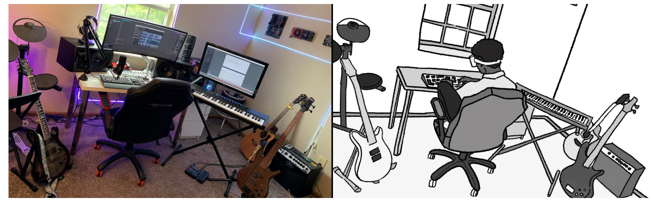
We recruited 12 knowledge workers with software development backgrounds, but only 10 completed the study (*mean age*=28.20, *sd*=8.42, 8 male, 2 female). The two participants that did not complete the study opted out due to technical issues; one did not have enough space to place the tracking equipment and the other could not remotely connect to their work laptop due to security constraints. All participants were compensated with a fitness watch.

4.2 Apparatus

With virtual reality hardware still maturing, one of challenges of this study was to design a VR workstation which would allow users to perform work in VR and be comparable to their current workspace.

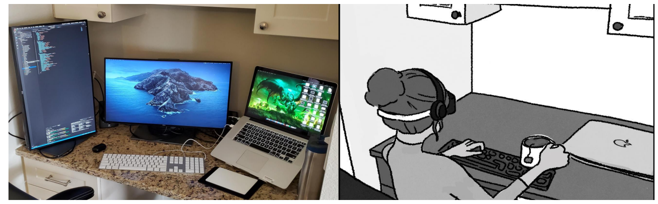


(a) Desk space (Cluttered, Footwell)



(b) Backlit (Sidelit, Pet)

(c) Shared space (Bedroom, Footwell)



(d) Public space (Width of Room, Awkward Space, Chair Space)

Figure 2: Actual workstation pictures exhibiting a challenge (left) and the speculative design VR workstation addressing it (right). Our speculative design solutions were similar for the challenges listed in brackets.

Figure 3: VR Experimental Setup

Physical Setup: Participants were seated at their own home desk and wore a headset for the duration of the session. A low-latency, full-color video pass-through camera allowed participants to view their surroundings in a small radius around them when looking directly down. Two tracking beacons (HTC Steam VR Basestation 2.0) were set up on tripods in front and behind the desk to track head movement and prevent visual lag. We provided a traditional keyboard and mouse, which users could see via this window. Though VR-specific input solutions have been developed, we aimed to keep the physical setup as similar as possible for a cleaner comparison. Figure 3 shows an in-lab picture of the configuration.

Hardware: Participants used the Varjo XR-3 headset (70 ppd and 115° field of view). This was operated via a high-end graphics processing workstation (DigitalStorm workstation with Intel Core i9-10900K and GeForce RTX 3090 24GB graphics card).

Software: Participants worked from the study computer and remotely accessed their work computer using commonly available remote desktop software—Remote Desktop Connection's client or TeamViewer client—depending on compatibility with their workstation. Though remote access introduced occasional lag, it was necessary to allow all participants to perform their actual work while using a high-resolution headset. In a future where hardware requirements for operating such VR headsets are hopefully reduced, we of course envision users working seamlessly from their own machines.

VR: Participants saw their rendered computer screen in one of three Unity environments, which they were free to switch between at any time. Two were nature settings: (1) a creek under a starry sky and (2) a mountain forest. The third was an urban office. The goal: allow the user to find an environment they felt comfortable in.

4.3 Study Protocol

In this section we describe the three phases of the study: the preparation, the four study days, and the wrap-up. The range of data collected is described further. Each session involved a *Screen-*, *VR-*, and *Webcam-Recording*, and *Post-Session Questionnaire*. The end of the study also included a *Final Interview* and *Demographics Survey*.

4.3.1 Pre-Study. Before the study start, we met each participant for an introductory interview. We introduced the study, addressing any questions and concerns. On the morning of the first study day, a researcher delivered the hardware to the participants' house and setup the necessary hardware and software, walking participants through the procedures they would be performing on their own.

4.3.2 Work Sessions. Participants were asked to work in VR for four days, for approximately two hours per day. More than two hours was allowed, but we were careful not to force participants into a longer-than-desired immersion. We gave participants schedule flexibility to accommodate their work schedule. Since participants performed the experiment from home with no researcher onsite, we included extra data collection in the form of recordings and surveys. This was not the primary data source, but rather gave the researchers a chance to cross-reference context of participant statements in the final interviews. For each session, participants were asked to activate the following recordings while in VR:

Screen-Recording captured the participant's monitor while they were in VR, as seen in the top right of Figure 3. **VR View Recording** captured the participant's first-person view in VR, including the monitor, virtual environment, and camera-thruput if they looked down at their desk, shown in the top middle. **Webcam Recording** captured the participant's head movements and the room behind them, shown (with participant obfuscated) in the top left of Figure 3.

After each session, participants filled out a *Post-Session Questionnaire*. The aim of this survey was two-fold: 1) to allow the cross-reference of notes from specific sessions when analyzing interviews and 2) to test out a quantitative methodology which could be repeated with a larger participant pool. This questionnaire asked what activities the participant performed, which virtual environment(s) they used, general impressions and possible issues. It also captured flow state [50], perceived affect and valence, and perceived focus and productivity. Since this iteration of the study offers too few datapoints for statistical significance (ten participants times four sessions), we do not include it in the scope of this analysis. However, the full questionnaire is included for replication [16].

4.3.3 Wrap-up. Our primary focus was to understand how participants experienced working in VR. At the end of the week, we conducted semi-structured *Final Interviews* of ∼25 minutes with each participant. We began with an open question of "How was your experience in this study?" Subsequent questions asked about the tasks or activities done in VR, environments used, and aspects the participant found particularly enjoyable or frustrating. Finally, we asked if the participant could envision working in VR regularly and if there were potential barriers that needed to be addressed. For the full interview guide, see the online supplement [16].

4.4 Data Analysis

Our mixed-methods approach emphasized a qualitative case-study of the experiences of participants working in VR, the core of which was a thematic analysis of all interviews. For context, we also analyzed a sample of video recordings for a glimpse of session activities.

4.4.1 Qualitative Analysis. The *Final Interviews* were analyzed using inductive thematic analysis [5] with a focus on broad thematic patterning across the data. The interviews comprised a total of 4.10 hours, or ∼25 minutes per participant. The ten interviews were audio-recorded, transcribed and coded in full. The first author, who conducted the interviews, took charge of the analysis process. The transcripts were first reread for familiarization, then coded using an inductive, data-driven approach which focused on identifying salient themes repeated across and within transcripts. The codes were iteratively revised and finally combined into larger themes. Three more authors looked at a sample of forty quotes (of 1-5 sentences each) and independently coded and thematically grouped on a smaller scale. The major patterns were then discussed as a group and distilled into six themes which we present in section subsection 4.5.

4.4.2 Quantitative Analysis. For context of how participants spent their time in VR, we coded 12.17 hours of video recordings across all participants. The third day (of four) was coded for each participant: this was a point at which some familiarity had been gained while avoiding Fridays, which may not represent the workweek [51]. For the coding, the first author watched and manually coded each video, which included the screencast and VR view, noting down start times and duration for each app used (or if the user was looking around at the VR scenery) and what category the activity fell into (e.g., work or recreation). The activity categories were coded based on the author's observation of how the participant was using the app; thus, 'Notepad' is coded as 'work' since it was only used in a work context, while some activities (e.g., 'Email') spanned multiple categories. We reached saturation of activity codes with the third-session sample, so did not further code more sessions. It should be noted that some recordings (P03, P05, and P07) are incomplete due to a recording failure or the participant ending the recording early.

4.5 Qualitative Results

Six themes were generated through the thematic analysis of the *Final Interviews*. Many of the comments expressed an experience of heightened flow (4.6.1) and biophilia (4.6.2) in using the headset, though differing preferences indicate the need for tailoring the environments (4.6.3) and workspace (4.6.4) to each user. The final themes highlight the ways in which VR changes the user's interactions with the outside world, both for the physical workspace (4.6.5) and household members (4.6.6). Overall, these comments indicate several potential benefits of using VR for working, while highlighting outstanding areas for improvement. We elaborate below.

4.5.1 Heightened Flow. We set out to learn about participant's experience in VR: how did it feel to work in VR? How was it different from their normal work? In answer to the intentionally open question of "How was your experience in VR?", we heard a recurring sentiment that VR helped foster a better state of mind. Specifically, these descriptions echoed a sense of **improved flow** – a psychological state of engagement associated with heightened focus, immersion, and changed sense of time (emphasis ours):

*I liked how **immersed** I feel in whatever I'm doing (P08)*

*It was very effective and I found myself being very **focused** into what I was doing (P03)*

***Time passes super quick** once you put it on. That was something that blew my mind was how fast an hour seemed (P03)*

Several participants noted that the VR **blocked distractions**. With the real-world distractions out of sight and out of mind, the users could more easily focus on the task at hand.

*Working from home, I have so many distractions around me already, so it **eliminates those [distractions]**. It creates some new ones, but getting rid of all the existing ones is big (P10)*

*Normally I have **my phone** on the other side of the room, but that day I was able to have it on my desk and I was fine (P01)*

Interestingly, others related this engagement with the VR environment itself – the surroundings led participants to feel more **engaged in work**, even when working on relatively boring tasks.

*Reading is kind of the most boring tasks for me, but [. . .] it was like reading in a forest, so I actually **enjoyed it** (P05)*

*I think the VR definitely did **brighten up my mood** a little bit while I was working [. . .] looking at that mountain environment was definitely way better than looking at my desk all day. (P04)*

4.5.2 Biophilia Stems Enjoyment. Participant comments indicate that the virtual environment is instrumental to the VR experience, with the most common theme centering on enjoyment of the nature environments—a sentiment reflecting *biophilia*. Indeed, many participants noted that they enjoyed virtual nature because they already **loved outdoor activities**. Several participants mentioned nature as being likewise central to their real-world hobbies:

*Well, I'm very big in nature. Most of my hobbies are spending time outside or rock climbing outside in the forest and **hiking**,*

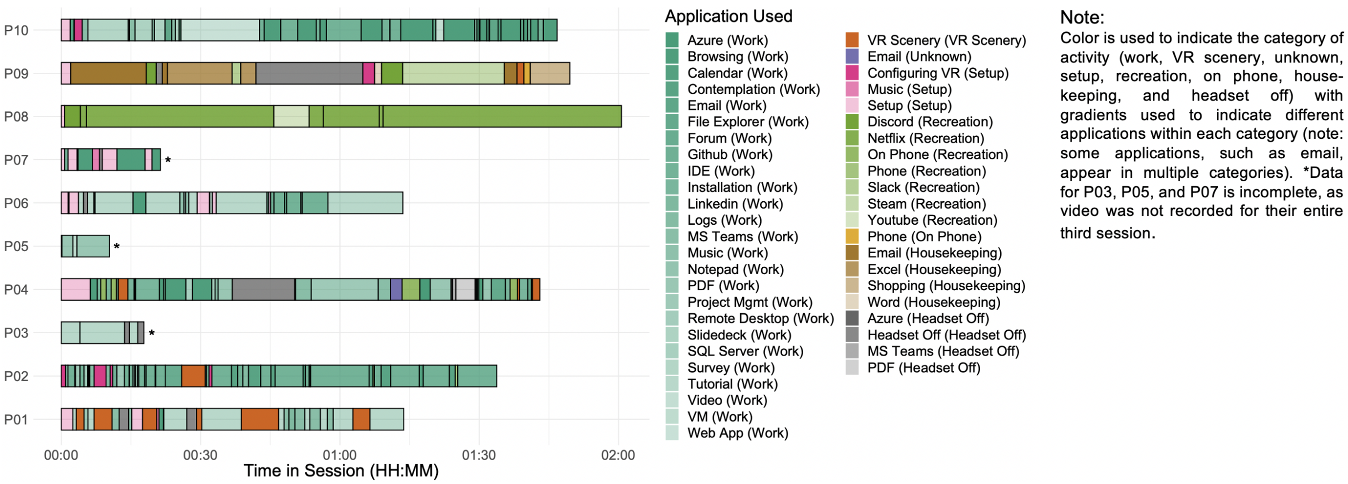


Figure 4: Timeline of apps used in the third VR session per participant, manually coded from videos. (See [16] for visualization script).

__camping__. So it felt like I was doing something that I normally would be doing, __being out in nature__, but not having to go out and find a place to be, to do my work. And there's no sun beaming down on you. And no wind wrestling around your papers (P03)

I like the waterfall one because __I like being in places like that__. I personally like to go in forest and being close to water (P05)

For participants who seek out communion with nature in their leisure time, VR offers something similar during the worktime. It seems that for these users, VR allowed them to get a taste the outdoors while in the confines of their home office. They often mentioned that they **appreciated sunlight**, even when it was virtual.

It's been cloudy and rainy the past couple of days. So even if I do get sunlight where I'm sitting, it's kind of gray and dull. So, you know, having that VR on, in the mountains where it was __sunny__ the entire time definitely helped out tremendously (P04)

For this study, we offered participants only three virtual environments, but we can imagine extending this to any range of environments that could be selected based on the user's wishes. Indeed, the importance of tailoring environments to the user is evident in our next theme: participants' varying preferences for environments.

4.5.3 Differing Environmental Preferences. While there was a general consensus on enjoying the nature environment, participants expressed varying opinions on the finer points of the environment. For example, what amount of detail is appropriate.

Both nature scenes included environmental details intended to increase the *fidelity*, or realism, of the environment. Some examples include ambient sounds (e.g. birds chirping) and movement (e.g. rustling leaves and flowing water). Participant reactions to these environmental stimulants fell into three groups. In the first and largest group, participants enjoyed these details and the realism which they added. Some participants called special attention to certain elements, such as the rustling of foliage—"the trees moving was great" (P06), the "ambiance of the nature sounds" (P07), or seeing the sunshine (P04). Indeed, fidelity is often a goal of environment design, as it can create a stronger immersion (to an extent [37]).

However, participants in the two other groups either found the environmental stimulants to be too much, or – conversely – not enough. Participants that were overwhelmed by the environment noted that it **distracted them**:

I would take lots of breaks and I would just kinda look around at the environment and see all the little details and the VR space [. . .] it definitely __distracted__ me a bit from my work (P04)

While these participants might benefit from a simpler, more minimalistic setting, other participants wanted more from the environment: in particular, more signs of liveliness. Although the scenes featured bird calls, there were no actual animals (or people) present. The **absence of life was unnatural**, almost eerie.

In the wilderness one, I think it would have been cooler if animals were to come by occasionally. It'd be kind of a distraction, but I just feel like it makes it feel a little more __natural__ (P01)

[If] you're at a cafe in the future and you're overlooking a city skyline or something like a cafe on a rooftop, that would be really cool. And then you can see a bunch of __liveliness__ going on (P09)

These contrasting preferences indicate a need for tailoring the environment to each user (and possibly even to the user's current mood or task). VR grants users agency to easily swap one setting for another. Indeed, we find in our next theme reports of participants practicing their agency not only in choosing the environmental scenery, but also in controlling the workspace layout.

4.5.4 Tailoring the Workspace. Workspace flexibility was not a focus of this study: indeed, the setup was intentionally simple to standardize conditions. Participants were given one screen and we did not expect them to **make adjustments**. However, several of the more VR-savvy participants reported adjusting the screen, in size and position, to make it more comfortable or convenient for their work. One participant particularly appreciated the ability to position the screen however they liked (e.g. higher and tilted down) because it allowed them to lean back in their chair while they worked:

Going back to being able to __place the workspace wherever I wanted__. If I wanted to __lean back__ in the chair and just kind of read that was easily done, not [having to] to lean up to scroll (P07)

Several participants enjoyed the large screen, which could fit many lines of code or text and reduced the need for frequent scrolling.

(a) The participant uses the video pass-through feature to offer their dog a treat. **(b) The large headset makes drinking difficult and the participant is forced to take it off.** **(c) The participant uses video pass-through feature to respond to texts on their phone.**

Figure 5: Stills from the video recordings of the field study, depicting how users interacted with objects in their physical environment.

Coding was pretty cool because, with the one monitor, it didn't matter. 'Cause it was giant and ***I could make the text size really small****. And so I could see hundreds of lines like a giant screen, which was nice. So for writing code, it was really good (P09)*

We can imagine that with a more customizable VR environment these possibilities would be even greater: for example, in VR a user might have dozens of windows positioned around them to their taste, without the need for a dozen physical monitors and a large space.

4.5.5 Interactions Between the Virtual and Real Worlds.

While VR may allow greater flexibility via a virtual workspace, participants indicated that the integration between the virtual and physical spaces is not always smooth. To allow participants to view their desk, the VR setup included a camera **video pass-through feature** that allowed users to see their surroundings when they looked direclty down (see videostills in Fig. 5a - 5c). Most participants enjoyed this feature, because it offered them a window into the real world. However, for some the feature actually had a disorienting effect:

[When] I would have to look down and write something physically, it would kind of ***break the entire immersion*** *of the headset. And then it would be like, this isn't the middle of the forest (P03)*

When I had to go down to the keyboard, that was ***difficult and disorienting****. If I was doing it for a longer time, it might be more comfortable, but it was* ***awkward*** *just seeing the window (P06)*

One participant even tried to improve their touch typing in order to avoid looking down at the keyboard:

I didn't really know where the equal sign was. So I had to [...] learn what those buttons were more. It's just ***too much energy*** *to have to look down all the time (P09)*

The **bulky, wired headset** complicated other common actions, such as drinking. Figure 5b shows a participant trying to take a sip of water. Having successfully located the cup using the video pass-through feature, the participant attempts to take a sip but the cup hits the headset with a loud clang. The participant has to take the headset off, take a sip, and put the headset back on. It takes a few moments for the VR to start up again. When asked about advancements they would like to see in the setup, many participants wished for a lighter, more compact headset and for the headset to be wireless.

These comments point towards a need to better integrate the virtual and physical spaces. On the physical side, we can imagine VR-focused ergonomic adjustments (e.g. using a close-lid cup with a straw). On the virtual side, we could render physical devices (e.g. the keyboard and beverage cup) within the VR. Participant experiences also indicate the challenge balancing immersion in the VR space while retaining awareness of the physical space. This balance especially plays a role when other household members—such as family and pets—come into play, as discussed in the following theme.

4.5.6 Effects on Socializing with Outside Members.

The HMD affects interactions not only with inanimate objects, but with members that share the space as well—both human and not. We expected the VR to minimize the interactions participants had with the outside world and it was surprising to see how participants adapted to the **need for awareness** of members outside. Several participants used the video pass-through window to check in on their pets. One used it to give their (confused) dog a treat, as seen in Figure 5a. Another used it to monitor their cat.

If I hear the cat around me, I used [the pass-through feature] for that as well [...] so I wasn't going to like ***accidentally punch her*** *while trying to reach for the mouse (P07)*

Some participants were comfortable conversing with their family members and housemates without taking off the headset, essentially talking to a disembodied voice. Others had blocked out the physical world so thoroughly that the occasional intrusion surprised them:

There's a part where my husband comes in and actually like ***scares the crap out of me****. 'Cause I didn't hear him come in. He laughed like hysterically for five minutes (P08)*

The difficulty of social interactions with members outside the VR is a known issue, but one that is an area of ongoing research.

4.6 Quantitative Results

Figure 4 visualizes the coding of 12.17 hours of video recordings in VR, showcasing the third session for each participant. The analysis of the coded data shows that **participants spent a big part of their time in the VR working on their tasks** even though they were allowed to dictate how they spend their time. In total from the coded sessions, participants spent 53.2% of their time on work, 21.8% on recreation, for 6.9% the headset was off, 6.5% was spent on housekeeping, 5.7% on setup, 4.4% on the VR scenery. The predominance of work-related application usage (color green within Figure 4) for all but two participants indicates that developers can use the VR to complete their work tasks. Only P08 spent the session on recreation activities, and P09 spent most of the time on housekeeping (personal admin) tasks. While participants were in the VR, they **frequently switched between different applications, reflecting typical workflows** outside the VR, such as between the IDE, browser, logs, and more. At the same time, the timelines also show that some participants (P01, P02, P04) took advantage of the VR scenery to get

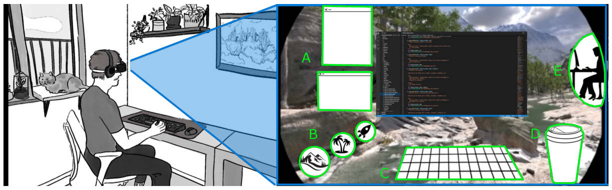


Figure 6: Extending the speculative design: we add to the original VR workspace the features most needed for improving the experience: A) multiple customizable windows, B) choice of virtual environments, C) rendered keyboard, D) rendered beverage cup, and E) a video pass-through window to see others in the space.

some breaks in between work. Over the 12.17 hours, participants performed 250 application switches, roughly one every 3 minutes, with fewer switches during recreation and housekeeping (P08 and P09), and participants engaged in a wide range of activities. The *work* category includes professional activities, such as coding or answering work emails, *housekeeping* refers to personal administration tasks, such as personal finances, and scheduling appointments, *setup* includes configuring the VR or workspace, *VR scenery* refers to looking around at the virtual environment, and *unknown* includes activities that span multiple categories. Interestingly, participants rarely chose to work more than two hours, if that. This may be related to the comfort issues and challenges mentioned by participants in subsection 4.5. In the supplementary materials [16], we also include the raw data and analysis from the post-session questionnaire, which were not a focus of this study but may be interesting for context.

5 DISCUSSION

5.1 Putting it Together

We have presented a diptych of studies which, put together, offers a few lessons for developing the VR office of the future. The first study investigated the reality of working in the home office and presented major challenges of the physical workspace. These challenges can be roughly grouped into two categories (1): physical constraints, such as awkward spacing and poor lighting, and (2): environmental distractions, such as clutter and a shared/public space. VR offers a solution to both categories by (1) providing ample virtual space (e.g. removing the need for multiple monitors) and (2) blocking out visual distractions. Given this promise, we set out to test a VR home work setup in the real world. Having used VR for work for a week, participants reported many positive benefits. Some touched on the first issue (1): enjoyment of the virtual sunlight, the large screen, and the prospect of limitless monitors. Touching on issue (2), many participants also reported being less distracted, less drawn towards checking their phones and less aware of others in their space (for better or worse). Other benefits included boosts in mood and focus. However, the interviews point to a need for customizing the setup, in terms of both environment and workspace layout. Further, in solving the above challenges, VR introduces its own set of challenges. The HMD and hardware pose challenges in terms of ergonomics (e.g. headset discomfort, the chord getting in the way) and interactions with the physical space (e.g. typing or drinking beverages). Interacting with household members can likewise be awkward. We therefore extend the previous speculative design (the physical setup) with an improved virtual setup, as envisioned in Fig. 6, sketching out the features which would boost the VR working experience the most.

5.2 Physical World Coordination

Fortunately, solutions for many physical coordination challenges mentioned by participants have been or are being developed. Already, there are headsets which are chordless, lightweight and/or offer cooling. Research has investigated optimizations for interfacing with VR, such as rendering typist hands on keyboards [34] or retargeting the tablet and user's hands to lie in the user's field of view [19]. Helpful solutions for long VR sessions, such as rendering the beverage cup in VR and pass-through window into a shared space were successfully tried in a long-exposure study [22]. Best practices for VR workspace design are also being actively investigated [38, 40, 47]. We therefore have reason to hope that with continued improvements in VR hardware and workspace design, the benefits of working in VR will begin to significantly outweigh the challenges.

5.3 Threats to Validity

The workstations study was based on user-submitted photographs and may contain a sampling bias—for example, with users only posting workstations they were proud of. The actual frequency of challenges may thus be under-reported (though it is interesting to note how often we did see challenges). Since the demographic data of Reddit users is private, we could not report it; a replication with another sample is required to understand generalizability.

The intensive nature of the VR field study (1 week per participant) meant that the population was small and not representative of all users; these findings must be confirmed with a larger sample. The methods we proposed for tracking VR usage and session experience could then be applied with numeric power. Another limitation is the time required to adjust to a VR workstation: a true longitudinal study of two weeks or more would be necessary to eliminate the learning period. Finally, participants had to work on our high-resolution workstation and remotely access their work computer, which sometimes caused a slight delay between mouse and keyboard actions and may have affected satisfaction with the VR experience. Once VR hardware becomes less demanding users will be able to work directly on their own workstation, avoiding such frustrations.

6 CONCLUSION

In this work, we examined the challenges developers face when working from home and studied how a high-resolution VR may help to overcome these challenges. In our digital ethnography study, we saw that most people, even those who wanted to show off their home workstation pictures, have difficulty finding appropriate space and often face visual and auditory distractions. The findings from our field study with ten developers showed not only that using a high-resolution VR could overcome many of the space-related challenges and participants were able to properly work in it, but also that participants frequently experienced an increased flow and appreciated the nature experience in the VR. This paper outlines a VR field study methodology and interesting points for continued exploration, potentially with an extended VR setup. While there are remaining challenges with VR, the results show the potential that the future of VR can hold for software developers working from anywhere.

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