Feeling Alone in Public – Investigating the Influence of Spatial Layout on Users' VR Experience

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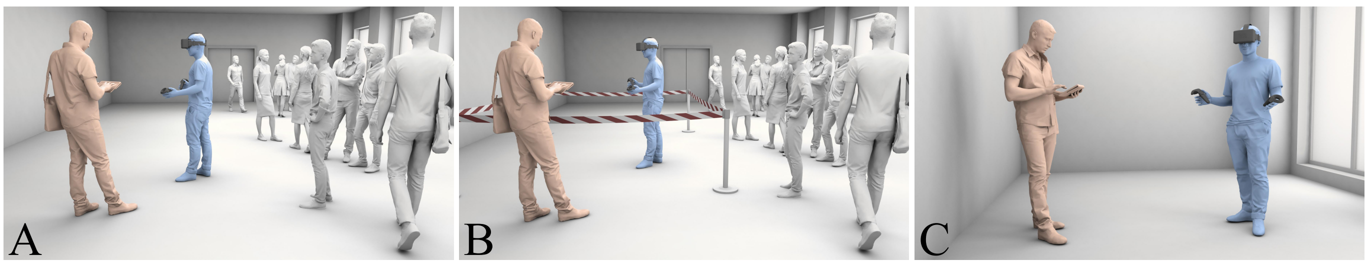

Figure 1. In a user study we examined how the spatial layout influences the UX when using a fully immersive HMD. We compared the HMD user (A) surrounded by random bystanders, (B) separated by a barrier tape and (C) being in a separated room. The examiner was present (orange).

ABSTRACT
We investigate how spatial layout in public environments like workplaces, fairs, or conferences influences a user's VR experience. In particular, we compare environments in which an HMD user is (a) surrounded by other people, (b) physically separated by a barrier, or (c) in a separate room. In contrast to lab environments, users in public environments are affected by physical threats (for example, other people in the space running into them) but also cognitive threats (for example. not knowing, what happens in the real world), as known from research on proxemics or social facilitation. We contribute an extensive discussion of the factors influencing a user's VR experience in public. Based on this we conducted a between-subject design user study (N=58) to understand the differences between the three environments. As a result, we present implications regarding (1) spatial layout, (2) behavior of the VR system operator, and (3) the VR experience that helps both HCI researchers as well as practitioners to enhance users' VR experience in public environments.

Author Keywords
Virtual Reality; Public Spaces; Head-Mounted Displays; User Experience

ACM Classification Keywords
H.5.3 Information Interfaces and Presentation: Group and Organization Interfaces

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INTRODUCTION
The advent of consumer-grade head-mounted displays (HMDs), like Oculus Rift or HTC Vive, make high-quality virtual reality (VR) an affordable technology for many application areas. Example areas include, but not limited to, car companies[1], health and fitness[2], or hotel groups[3]. In these cases, VR is for example used to showcase products to potential customers. A particular challenge arises, as demonstrations happen in environments, where mutual strangers act in parallel. This can be shops, museums [40], exhibition halls, as well as public spaces like a crowded city [3].

From research on proxemics [28] and social facilitation [24] we know that the mere presence of other persons has a strong influence on the user's experience as well as on their behavior which we discuss in more detail in the following section. When using HMDs in public environments the user is usually surrounded by different people. This includes the system operator but also strangers (e.g., other visitors). In particular, the presence of strangers not only imposes a constant physical threat to the user (since these could incidentally collide with the VR user), but also cognitive arousal and behavior changes as described by proxemics [28] and social facilitation [24].

Imagine the following scenario: A sales representative for kitchens might present the company's portfolio in VR at a trade fair. Customers wearing an HMD stand in front of the booth and experience the design of their future kitchen in VR. At the same time, bystanders and passersby occupy the surrounding space. Due to the strong immersion, the HMD user neither sees nor hears the real world anymore.

[1]https://audi-illustrated.com/en/CES-2016/Audi-VR-experience, received 08/2018
[2]https://www.icaros.com, received 08/2018
[3]http://framestorevr.com/marriott, received 08/2018

From this, the following implications can be derived. From a *commercial perspective* there is the risk of creating a negative experience for the HMD user. An example known from earlier research is the *butt brush effect* [52], which describes the decreased likeliness of retail decision when being touched by others during examining goods. As the HMD covers the eyes, additional effects influencing the user can be expected [34]. From a *research perspective*, behavior changes can be expected and consequently impact on study results. Creating a safe environment for the HMD user by creating a separated space with barriers or walls, might help the user to have a better experience (see Figure 1). Yet, space is often limited and infers extra costs, for example at a fair where exhibitors are typically charged per square meter.

To enhance the design of public HMD experiences, we conducted a between-subject user study with 58 participants and three factor levels (Figure 1). We compared three conditions: (A) the HMD user acting while being surrounded by people (*surrounded*); (B) the user acting next to other people, but being separated by a barrier (*barrier*); (C) the user acting in a separated room (*separated*), without other people present but a supervising person (referred to as examiner). We investigate the influence of the different conditions of physical and visual separation to strangers on the user's experience regarding feeling of being present in the VR, the feeling of personal security, and the emotions during the study. We also report on the influence of the system operator on the HMD users experience.

Our paper makes the following contributions:

- We introduce, discuss, and confirm a design space when using HMDs in public spaces.
- We provide Insights from a user study (n=58), exploring the interplay of factors influencing the UX during HMD usage under different spatial conditions.
- We derive implications for designers of future HMD experiences for public environments. Our results help to make them an informed decision as to which spatial layout should be used and how they could compensate for the drawbacks of a certain environment.

BACKGROUND AND RELATED WORK

Our work draws from several strands of prior research. In this section, we motivate our study design by reporting the effect of bystanders from existing work in behavioral, communication research and the research on Virtual Reality systems.

The Mere Presence of Others in the Real World

HMD users might be visually and auditory separated from surrounding bystanders. However, communication happens all the time two humans are co-existing [55]. In our case, the HMD user might hold a reminiscence of people surrounding in mind. Reminiscence and loss of control about interaction with bystanders might influence HMD users' VR experience.

Proxemics describes the human use of space as well as humans' behavior, communication, and social interaction [28]. This research got considerable attention from the HCI community and had been applied to interaction with technology before [6]. The theory of proxemics classifies space around a person into the public, social, personal and intimate distance. Depending on the distance two humans will change their behavior.

A mismatch between one's behavior and others' expectation creates arousal for the latter, described by the *expectations violations theory* (EVT) [9] – for example, as a person raises their voice when coming closer, this may make the approached person anxious. This further leads to a shift of attention of the person whose expectations were violated towards the source of violation [23]. As an HMD user might expect violations from the bystanders, this would mean a distraction from VR to the real world. The sounds of passersby might enforce the HMD user's distraction, as s/he cannot accurately interpret the sounds.

Violating proxemic distances can be interpreted as positive or negative, where only negative violations create arousal [23]. The perception of a violation depends on the *communicator reward valence*, that is the sum of all positive and negative expectations a person might have for the encounter. For example, passersby unknown to the HMD user might create a negative experience and bystanders touching the HMD user might cause a bad feeling. In contrast, a friendly VR system operator might give the HMD user a feeling of safety and guidance. A positive violation of proxemics would be the operator touching the HMD user to guide him/her around an obstacle [2]. The communicator reward valence persists over longer periods of time. Hence, the image of the surrounding passersby might influence the HMD user's experience even after putting on the HMD and not seeing the passersby anymore.

The *social facilitation* theory, in contrast to EVT, does not look into the expectations of one person towards another. It describes how the presence of others influences a person. The central assertion of this theory is that mere presence of others alters the performance of a person. Guerin and Innes give a summary of the theories created and expanded for decades under the umbrella term social facilitation [24]. As with the EVT, the mere presence of others is expected to increase the general level of arousal. One explanation among others is the shared attention to the surrounding environment between people. The shared attention reduces cognitive load on the person engaged with the task as others take care for possible secondary tasks. In our example scenario, the salesperson engages with the role of an observer for the environment in order to protect the HMD user from real world threats. The HMD user trusts the salesperson and therefore does not need attentional resources to monitor the environment, resulting in a better focus on the virtual content. This might lead to better user experience regarding the sense of being Safe and present in VR.

Two examples from actual implications for the influence of bystanders on a person in the field are the *butt brush effect* [52] and the *staging effect* [21]. The *butt brush effect* [52] originally refers to situations in a retail shop where a shopper is 'brushed' from behind by a person or display table while examining retail goods. It is hypothesized that the likeliness of the 'brushed' person making a purchase decreases [52]. A similar effect may occur in a VR environment, as users are 'brushed' by bystanders. The *staging effect* occurs in public places as technology provides a stage for the user [21]. A common example from the 90s is Dance Dance Revolution[4], a game that requires the player to perform in front of a display, while bystanders are cheering at him/her. Public interaction in VR may create a similar stage, resulting in a negative experience.

From the presented research we learn that HMD users might react to others depending on their spatial distance. Further users expectations towards the upcoming experience, the social relationship to bystanders and the personality of HMD users might have an influence. In contrast to our work, existing research accounts for situations in which people can see each other in the same environment. As HMD systems are thought to separate the user from the real world completely, there will only be a reminiscence about it left, which we expect to have an influence on the user's experience. There are two possible extreme reactions by the HMD users. HMD users forget about the real world and have an excellent experience. Alternatively, the HMD user has no more visual control over the environment, while still holding an imaginary impression of surrounding people. Intermediate states are not predictable yet, due to the mentioned lack of knowledge about the impact of proxemics, social facilitation, and the mere presence of others.

Influence of Mere Presence of Others in VR

Related work took into account the described theories above, either to show that they hold in VR or to use VR for research on these theories. Some examples from research include studies on social inhibition [29], social phobia [42], fear of public speaking [47], influence of racial bias [39], the physical state of activity of the other [18] or the influence of avatar representation on the users walking path [5]. Contrasting to our scenario, in these studies, a second person or avatar is visible in VR and not as a bystander.

Interplay Between VR and the Real World

In this work we focus on an HMD user and a real world bystander acting in parallel. We summarize work that investigates this situation in the following.

Mixed presence describes a situation in which two persons are acting together, either collocated or remote, with different cognitive states of presence. Remote mixed presence systems for collaboration can be summarized as Collaborative Virtual Environments [12]. In collocated scenarios, real world bystanders surround an HMD user and interact with him/her. The purpose of existing related work is to design for interaction in these situations [25, 30, 38, 49]. Results of conducted studies do not offer insights into HMD users' experience.

Telepresence scenarios are another form of VR-real world interaction, looking either into two persons having a remote communication, or teams working on both sides of the telecommunication system [35, 51]. The cognitive disparity is the same in our scenario, as HMD users are acting in the virtual space while being surrounded by people acting in the physical space. Our scenario is different from that, as both are still co-located in one physical space. Work on telepresence introduced the so-called *presence disparity* [51]. It means that people tend to interact with their co-located workers instead of the remote ones. Unlike for remote collaboration, this effect can be seen as positive for the sense of being present, as the user can concentrate on the VR and is not on bystanders.

[4] https://en.wikipedia.org/wiki/Dance_Dance_Revolution, received 08/2018

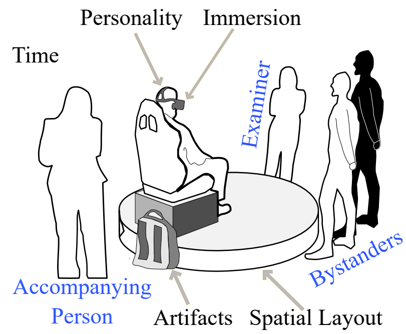

Figure 2. The factors influencing an HMD user in a public environment. In our study we focus on the factor spatial layout. Blue factors are summarized under presence of others.

ShareVR is a system that includes real world bystanders in an HMD based VR experience for entertainment in living room environments [26]. They could show that the integration of bystanders can improve the experience.

Dose of Reality presents and evaluates concepts on how to incorporate the real world into the VR, as users reported to have severe issues of awareness for the real world [36]. One of their concepts integrates real world bystanders in VR, conducting unspecific tasks. The results indicate that the feeling of being present in VR is stable, but the users feel distracted by the sudden appearance of the real world bystanders avatar. In contrast to our work, the effect of the real world on the experience was not explored in a field study but an online survey. Furthermore, they were proposing a connection between the real and the virtual world by augmentation of the real world bystander in an office context. In contrast to *ShareVR* and *Dose of Reality* we want to foster immersion in the HMD by separating the user, instead of constantly reminding the user about the surrounding real world.

DESIGN SPACE AND STUDY CONCEPT

A number of different factors influence user experience when using HMDs in public spaces (see Figure 2). These factors need to be taken into account and controlled for the study design and future research. Therefore we summarized the literature introduced above, discussed and conducted brainstormings with experts in research on interaction in public spaces and VR. For each dimension of the design space, we start with a short description of the term, discuss the expected influence and close with a short discussion.

Personality and Immersion

The primary goal is to immerse the HMD user into technology to enable them to develop the feeling of being present in VR. However many definitions for the term presence exist and especially how the mental model to create the feeling of being presence looks like [7, 43, 48, 56]. As the term presence is central to our argumentation of the factors influencing the design space we describe this in the following in detail.

Presence and Immersion

We describe our understanding of the concept of being present as: "Presence is a state of consciousness, the (psychological) sense of being in the virtual environment." [48]. The term immersion is a measurable property of a VR system, like screen resolutions, latencies, and further [48]. Therefore immersion is part of the influencing variables in public environments. Important to our work is the general assumption that (1) "Cognitive processes mediate the impact of immersion on the development of presence." [43]. That leads to the conclusion that (2) higher immersion does not necessarily lead to a higher state of presence, as there are cognitive processes in between [43, 46]. These cognitive processes are individual and have the purpose to (3) suppress conflicting stimuli, like noise from the real world and the allocation of attention to the virtual stimuli [10, 46].

Multidimensional factors influence presence in a public environment (see Figure 2). In general these can be categorized into *internal* (subjective) and *external* (objective). *Internal* factors are the cognitive processes that generate the feeling of being present. They vary between users as individual factors come into play. An example is personality traits like people being introverted or extroverted. *External* factors correspond partly to the term Immersion, and therefore the VR system belongs to the external factors. We define a VR system as the software and hardware used to create an interactive virtual reality experience, which is needed by the user to create the feeling of being present in the experience. The requirements for the technical implementation of a highly immersive VR system – e.g., ergonomics[27], interaction [43], avatars, rendering and plausibility [48] – are summarized in the section *System Requirements: Hardware* of the *Handbook of Virtual Environments* [27] or the work of Cummings and Bailenson [14]. Immersion, therefore, is a dimension of the design space.

Because this is a highly complex topic in itself, we argue that it is adequate to use currently available consumer hardware and software. Studies using these systems already proofed the ability to create a strong immersion (e.g., [15, 26, 36]).

Furthermore, external factors might become internal factors, as the memory of the real world environment can stay in the users head during the VR experience (see discussion on *time* below).

Personality

Cognitive processes generate the feeling of being present in the VR. Further effects like the *staging effect* are highly depended on users' personality. Therefore the personality of the user has a strong influence on the experience. We use the BIG–Five personality traits that describe a person based on a common language [22]. Prior work shows that introverted people feel more present in VR [4]. The authors also recommend generating emotional VR environments, as they create a higher immersion for the user. Kober and Nuper [31] were able to show differences in the presence feeling among users with diverging Big-Five personality traits, but also report that these dependencies vary between the used presence questionnaires. Other studies confirm dependencies of personality traits and presence [32], the emotional involvement, and conscientiousness of people [19]. They assume a correlation between spatial ability and spatial presence [13]. Personality, therefore, is a dimension as users are different concerning (1) acceptance of the hardware itself, (2) their VR experience, (3) perception of the real world environment and the surrounding people during the experience including (4) the relation to the examiner.

Spatial Layout

We define the spatial layout as the physical structure around the user, including all movable or immovable objects like walls, staircases or furniture. The physical structure can match or differentiate between the real world and VR. The spatial layout also defines the user interaction with other beings concerning physical, visual, auditory and olfactory interaction. E.g., it was shown that people tend to walk more careful when a threat caused by the spatial layout is matched in the VR compared to the real world [17, 45]. However, movement trajectories do not alter between VR and real world if they have the same layout [45].

The spatial environment influences the auditory stimuli from the real world and creates a mismatch between the perceived room size in the VR – e.g., a mountain peak – and the physical room – e.g., an office space. The haptic stimulus in a pure VR environment is only the floor. The physical floor in the real world and the optical visualization in VR should match the relative position to the user and the perceived texture. However, the physical surface can deviate from the virtual representation within certain limitations [45].

Presence of Others

We distinguish between the examiner, a person accompanying the user and bystanders as *others* being around the HMD user (Figure 2). The expected influence of each role is described in the section *Mere Presence of Others in the Real World*.

Bystanders are strangers being present, but are not intended to take part in the VR experience actively or passively [1]. Bystanders in a public scenario are expected to either pass by or stand and watch the HMD user. We do not assume that the HMD user will focus on a specific person but perceive passersby as a group of people. This group might have specific attributes that are reflected by the HMD users creating a mental image of the surrounding group. There might be systems designed to include bystanders in the experience, but with that, they get part of the VR system.

The *examiner* is a person that is guiding the HMD user through the VR experience. The examiner can be exchanged with different roles like a salesperson or a system operator. They are mostly unknown to the HMD user. We assume that the contact to the *examiner* has timely stages – *before* and *during* the VR experience. *Before* the session there might be an introduction into the system and task. The introduction alters the expectations of the HMD user and therefore the experience and behavior [8, 33]. In the introduction phase, the examiner creates an individual relationship with the HMD user which needs to correlate with the experience one wants to create for the VR user. As discussed, a positive relation between the HMD user and the examiner might lead to a better experience. *During* the session the examiner can be physically present or not and can get in interaction with the HMD user or not. As described in the chapter *The Mere Presence of Others in the Real World*, we expect changes in behavior or the experience of the HMD user due to the mere presence of the examiner during a VR experience. For instance, social facilitation theory suggests that HMD users might feel monitored by the examiner and therefore stick to a possibly dull task in VR instead of exploring a fun environment.

A person might be accompanying the HMD user. This person has a closer social relationship to the HMD user than the other roles defined above. The influence of this person is unpredictable as s/he might either be positive to the HMD experience and support the HMD user or negative which might lead to a stop of the experience and makes all persons leave.

Time

It was shown that it takes some time, to adapt to the incoming stimuli from the VR system and create a feeling of being present in the VR. During the progress of the VR experience, the feeling of being present can alter in intensity due to breaks in presence or have temporal fluctuations, but the behavior in the VR stays consistent [20]. While time itself is not a factor influencing a user, the progress in time affects all other variables. For example, internalized factors like a memory of the real world vanishes over time, as it is dependent on the user's personality and the cognitive processes active during the HMD experience. Alternatively, a task executed for a shorter period might involve the user very much as it is exciting and fun, but after a certain point of interaction gets boring. Boredom might let the user's focus drift away from VR towards more appealing stimuli in the real world. Time, therefore, is a further dimension.

Personal Artefacts

People are likely to carry personal items with them. Examples are different kinds of bags, electronic devices or umbrellas. While wearing the HMD, users cannot monitor their belongings. This might influence the users' experience since they are constantly distracted by worries about their belongings.

Implications for the User Study

The factors presented in this section can vary in many ways. For the apparatus of our study, we decided on a particular combination of factors that all follow the goal to create the best possible immersion and feeling of being present.

Space should be varied regarding visual (to address social facilitation) and physical (to address proxemics) layout and in whether or not HMD user and bystanders are separated.

The HMD user needs to be represented by a random sample. The influence of the different personalities will be controlled by using the Big-Five personality questionnaire [41].

Passersby need to be present all the time as the effects we assume are related to the mere presence of others.

The examiner might introduce a bias in two opposing ways. Firstly, in the condition *surrounded*, the HMD user might expect the examiner to care for the safety and therefore pass monitoring of the environment to the examiner without comment. This attention sharing would lead to a better experience for the HMD user than expected from the environmental situation. Secondly, in the condition *separated*, the user is alone with the examiner while having the eyes covered. In this situation, users might feel intimidated, as they are not able to monitor the examiner's behavior towards them. To address this the examiner will be trained to behave in the same way for every participant.

The VR experience needs to support all immersion factors that influence the feeling of being present as described above.

Time needs to be long enough to create a maximum feeling of being present and let users experience natural variations during the experience as described by Garau [20]. Personal artifacts will be secured before the experience, and the participants will be asked not to bring an accompanying person.

USER STUDY

In order to explore the influence of the spatial layout around the users in a public environment on the feeling of being present, the emotional state and the sense of security in the VR, we conducted a user study.

Participants

We advertised the study through university mailing lists and social media. 58 participants (33 female) with a mean age of 25 years (SD= 5). 60% of the participants had prior experience with HMDs. Participants were compensated with 10 Euro. 21 participants participated in the *surrounded*, 21 in the *barrier* condition and 16 in the *separated* condition (see Figure 3).

Apparatus

The VR system consists of the HMD Oculus Rift CV1[5], two Oculus sensors for room size positional tracking, two Oculus Touch controllers. We used a VR ready computer with Nvidia GTX 1080, IntelCore i5 6600k and 16GB RAM. The smartwatch Motorola 360[6] was used as an alarm clock by the HMD user in order to communicate the end of the experience. The fenced off area in the public space was about 3.5 m $\times$ 3.5 m during the *barrier* condition.

Materials

Based on the idea of Garau and colleagues we let people draw so-called *time graphs* [20]. These drawings support users' memory when recalling their experience. The template we gave the users showed the timely progression on the horizontal axis. In contrast to Garau's suggestion, our template showed a positive change of the parameter in the upper and the negative change in the lower direction instead of only one direction. We did so to allow participants to reflect also negative moments. Three diagrams with the parameters emotion (positive up and negative down), presence (virtual up and real down), and a general sense of safety (feeling safe up and feeling threatened

[5] https://www.oculus.com/rift, received 08/2018
[6] https://www.motorola.in/products/moto-360, received 08/2018

down) were presented to participants. For presence, participants in this way could easily describe when they felt to be rather in the real world and when in VR.

The semi-structured interview was composed of four key questions. Each participant was asked to "Summarize the study and tell me about your experience", "How have your emotions changed over time?", "How did you perceive your real environment?" and "What else did you notice about the study?". Following questions were dependent on the answers, the drawings of time graphs and purposed to get unexpected insights.

Study Design

A between-subject design for the factor spatial layout with the three levels *surrounded*, *barrier* and *separated* was used to which the participants were randomly assigned.

Measures – For behavior analysis, we logged orientation and position coordinates of the users' head and recorded the view of the user. We argue that users with fear of colliding with others or objects will move less and slower regarding speed and acceleration. Additionally, we considered physiological measurements like heart rate or skin conductance which are supposed to be related to feeling present [37]. However, we expect disturbing variables like movements or arousal due to the experience and given task itself to influence the measurements. A dependency of the measurement and a specific factor, therefore, is not explicit, as also discussed by Diemer and colleagues [16].

To record the emotional state of the participant, we used the PANAS questionnaire [54] which consists of two scales with ten items. The PANAS measures the positive and negative effects on the user and was presented to the participants before and after the experience. The presence was measured with the established IPQ questionnaire [43] after the experience. To analyze the data towards personality and control for a group with varying personalities, we used the BFI–10 [41].

A semi-structured interview was conducted after the study, recorded, and transcribed. In a next step all claims regarding the topics *bystanders*, *sense of safety*, *presence* and *emotions* were collected by the topics. We clustered similar statements and counted the numbers of statements for each group.

The Examiner – During the experiment, the examiner – male, 25 years old – was present all the time. This is according to our example scenario, as there was always a system operator or salesperson present. The examiner acted as a neutral person in order not to bias the user in advance. In particular, the examiner acted the same for each participant without being exceptionally friendly, e.g., taking time for small talk, nor being negative by saying things like we are conducting a *small* study. His behavior was trained in advance and discussed with other experts from the department. He did not state any expectations on the user's behavior or success in the VR. He did not interact with the HMD user during the study.

Task – The Task should be as immersive as possible according to Slaters defined needs for a highly immersive environment which claim cognitive and physical stimulation of the user.

Figure 3. We compared three environments: an environment where participants were surrounded by passersby (left), one where they were separated from passersby (middle) and one where they ran the study in a separated room (right).

Therefore we chose the VR game *Job Simulator*[7]. The users had to follow the tasks given by the game *Job Simulator* within the level *Store clerk*. It contained short social interactions with avatars who had to be served by preparing and selling typical store products. For example, the participants had to prepare hot dogs or sell lottery tickets. Participants were presented store music and voices of the avatars through a headset.

Procedure

The conditions in public took place in a university hallway near a library (Figure 3 left, middle). The study for the *separated* condition took place in an empty classroom of the university.

Participants were greeted and requested to fill in a consent form followed by the demographic, BFI-10 and PANAS questionnaires. They were told that they will have to play a VR game and that the tasks will be presented in the game. They were asked to fulfill the tasks without any further requirements. No attention to the spatial setup or the actual purpose of the study were given. The examiner explained the VR system by describing the setup with the position sensors and the controllers. The participants were introduced to the usage of the controllers, then the HMD was put on and straps, as well as lenses, were adjusted. After this, they took off the HMD and were told about the smartwatch and the vibration alarm going off after 15 minutes of being in the experience, indicating the end of the experience. We told them that the instructor would be present but silent during the experience. They then started the experience. Following the experience, the PANAS, the IPQ, and the time graphs were filled out. After that, we conducted the semi-structured interview.

RESULTS

In the results section, we present the quantitative data from the analysis of the IPQ and PANAS questionnaires, the recorded movement data and evaluation of the interviews. To quantify the number of people during the public conditions, we counted the people being present in the hallway during the user's interaction on the recorded video that showed the users surrounding. We did so every 5 seconds. On average 2 persons were around participants at any time.

Quantitative Data

The results from the IPQ, the PANAS questionnaires, and the movement data are summarized in Figure 4.

Movement data was cleaned by removing 5% of the highest values in the measurements speed and acceleration from each

[7] https://jobsimulatorgame.com/, received 08/2018

		surrounded		barrier		examiner	
IPQ	Spatial	4.5	0.9	4.3	0.8	4.6	0.6
	Involvement	4.2	1.1	4.3	1.1	4.5	0.9
	Realness	3.2	0.9	2.8	1.2	2.7	1.3
PANAS	Before Positive	3.2	(0.6)	3.1	(0.6)	3.2	(0.5)
	Before Negative	1.5	(0.5)	1.4	(0.5)	1.4	(0.4)
	After Positive	3.5	(0.6)	3.4	(0.7)	3.3	(0.5)
	After Negative	1.5	(0.4)	1.5	(0.5)	1.5	(0.4)
Space	Head Travel Distance (m)	102	(26)	102	(26)	102	(22)
	Used Area (m²)	1.0	(0.22)	1.0	(0.25)	0.9	(0.26)
Speed/	Average (m/s)	0.1	(0.1)	0.1	(0.08)	0.1	(0.07)
	Max. Speed (m/s)	0.47	-	0.44	-	0.42	-
Accelaration	Max. (m/s²)	4.7	-	4.4	-	4.7	-

Figure 4. Results for the IPQ, PANAS and movement measures for the three conditions surrounded, barrier and separated.

condition, in order to exclude possible errors of the tracking system. We compared the results conducting a one-way between-subject analysis of variance (ANOVA) to compare the effect of spatial layout on the movement parameters. The Levene statistic showed homogeneity of variance in all cases. Normal distribution was evaluated by visually analyzing a histogram of the data and did not show a violation in any case.

The igroup presence questionnaire data was analyzed using an ANOVA, as the scales fulfill the criteria of being symmetric around the middle and having equidistant formulations on each side of the scales [11]. With the null hypothesis that there is no difference between the conditions, no significant difference at a $p<.05$ level could be shown for spatial presence ($F(2,55)=.376$, $p=.688$), involvement ($F(2,55)=.741$, $p=.481$) and realness ($F(2,55)=1.474$, $p=.238$). Therefore the null hypothesis can not be rejected in any case. The overall feeling of being present shows high values in all conditions.

The same statistical test was used to compare the movement results. With the null hypothesis that there is no difference between the conditions, no significant difference at a $p<0.5$ level could be shown for the used space ($F(2,55)=.922$, $p=.404$), the average speed ($F(2,55)=.148$, $p=.863$) or the mean acceleration ($F(2,55)=.995$, $p=.376$). Therefore the null hypothesis can not be rejected in any case.

As we could not show significant differences in our measurements, we analyzed the interviews in order to understand if those results are reflected in the users subjective feeling.

Interviews

The interviews had the purpose to get insight on the HMD users' experience regarding bystanders, the examiner, and sense of security and presence. The interviews were conducted in German language. Relevant quotes are translated into English by the authors.

Presence of Others – The interview results can be divided in utterances belonging to physical and cognitive threats.

Users in the *separated* condition did not report physical threats of possible bystanders. In the public conditions the fear of colliding with somebody else was apparent but without considerable difference between the conditions – *surrounded* (6) and *barrier* (5). In both public conditions, there was the fear of bumping into objects. In the *surrounded* condition the fear of being touched is reported additionally. For example, participant 34 commented to feel *"[...] being at the mercy of the (real world) environment[...]"*. All participants diluted their statements. They explained that they just forgot about passersby, as they were deeply involved in the task in VR. Two of them said that passersby would take care, as they understand the blindness of the HMD user, or they felt safe as it was a study situation which is suspected to be secured by the examiner.

Cognitive threats triggered by bystanders were present in all conditions. In the *separated* condition 1 participant reported being happy to be alone in the room, as there was nobody else to monitor him. One participant mentioned that a stranger could enter the room, but he feels safe as he would realize it. It should be emphasized that participants from the *separated* condition did not perceive the examiner as being in the room or being a threat.

Social embarrassment was reported in all conditions. With a high number in the *barrier* condition, the possibility of being watched by strangers was reported to create feelings like shame or uncertainty (*surrounded* = 4, *barrier* = 9, *separated* = 1). In the public conditions even fear or intimidation was reported (*surrounded* = 4, *barrier* = 8, *separated* = 3), as we expected it from the related work on proxemics. Some participants felt ashame only during the first minute of the experience and then forgot or ignored it. In all conditions, there were reports of constant behavior change or the wish to take of the HMD to escape the situation. Participant 33, condition *surrounded*, reported *"[...] there could have been 1000 people standing around me [...] this is unsettling [...], lets say funny"*. The influence of feeling pressure to perform well in the task mainly introduced by the examiner was reported (*surrounded* = 1, *barrier* = 3, *separated* = 1).

Sense of security – The sense of security was interpreted by the participants when discussing and drawing it, as either the feeling of mental and bodily safety or as certainty in actions during the game. If the later was the case, the examiner asked if they could *"[...] tell something about their sense of security related to the real world [...]"*.

Corrected by asking again, the majority of participants had no issues with their sense of security (*surrounded* = 11, *barrier* = 15, *separated* = 13). The reasons why they felt secure were trust in others (*surrounded* = 6, *barrier* = 3, *separated* = 1), knowing the VR system and knowing the real room (*surrounded* = 3, *barrier* = 1, *separated* = 2).

The trust in others could be separated in trust in the examiner and trust in the surrounding people. One participant of the *surrounded* condition reported: *"We are in the faculty for mathematics [...]. The people around here are not that dangerous, but they might try to explain the parabolas to me."*. Still, there was the anxiety of getting touched or hit for 5 users in the public conditions.

Knowing the VR system created confidence for some users. They felt more secure when they were familiarized with the hardware of the VR system, the interaction with the VR, the VR space and their task in VR. 7 users reported anxiety. They did not know what to expect in the experience and the HMD blocking the visual connection to the real world.

Knowing about the real room was helpful by being assured for physical safety, but also in order to trust the people acting in the environment. Firstly the knowledge that the size of the real space was big enough to fit in the VR space they experienced took the fear of colliding with physical objects. Still, 6 participants from all conditions reported the fear of colliding with a physical object. In the condition *barrier* three participants reported feeling secure because of the barrier tape. Secondly, a general feeling of trust is generated in the environment as the participants had been at the place before and felt familiar.

Presence – Sounds like voices originating from the real world was the main difference in the participants reports between the public conditions, *surrounded* and *barrier*, to the *separated* condition (*surrounded* = 7, *barrier* = 11, *separated* = 0). In the public conditions, people diminish the effect of noises from the real world by saying not to be affected. Discussing their drawings on the state of presence during their experience, they answer contrarily. They describe noises and voices from the real world as forcing them to shift their focus from VR to real world. E.g., they described this shift as if *"[...] you just woke up[...]"*(*surrounded* = 5, *barrier* = 5, *separated* = 0). The reported reasons, in the public conditions, why the noise was not observed consciously were integration of the stimuli into the VR experience (5), masking out of the noises from the real world (19), the focus on the task in VR (4) and the involvement in interaction in VR (15). Another issue originating from the voices in the real world was a non sequitur position of the voice's origin. It was reported that the sound came through the wall behind the user in VR, which was logically impossible for them and created irritation (2).

Physical threats from the real world environment were reported to be influencing, as some people had the physical objects from the real world in mind in order to prevent collision (*surrounded* = 5, *barrier* = 4, *separated* = 4).

Time spent in the VR helped the users to forget about the real world more and more (*surrounded* = 7, *barrier* = 3, *separated* = 4). One participant answered the question about how he perceived the real world: *"Not at all. Only in situations in which I was uncertain (about the task), I remembered the surrounding[...]. I did not really perceive something, I did not feel, hear, see or something like that, but I sensed that there is somebody and that I am somewhere else then what I see in front of me"*.

Due to different events over time, the feeling of being present in the VR can alter. During the phase of familiarization and the further progress of the study, people reported a shift of their attention to the real world, when the task seems to be not solvable, are hard to understand, or interaction fails (6). In these situations, the users felt uncertain and/ or frustrated. 44 participants from all conditions reported experiencing these feelings during the first minutes of the VR experience.

The vibration of the smartwatch at the end of the session was a pleasant interruption and attention shift for the users. The communicated vibration was perceptually integrated into the VR experience for a moment until the participant recalled its meaning for the end of the session (2).

Limitations

We chose the game job simulator in order to create a highly immersive environment for the user. The game has a predefined walkable area. From this, the non-significant difference in the movement area being used might have been originated. However, we would have expected slower movement speed and acceleration especially in the *surrounded* condition which has the danger of colliding with physical objects. This effect might be created due to the large movement space in the hallway and the examiner being present, which we discuss in the following section.

DISCUSSION

Our study aimed at examining the impact of the spatial layout of a VR system on the HMD users experience between the conditions *surrounded* by others, being separated by a *barrier* and acting in a *separated* room without others being around. Only slight differences were apparent between the two public conditions. The barrier tape mainly introduced additional physical security compared to not having a separation. It prevents the danger of bumping into physical objects and people from entering the walkable area. The two public conditions are discussed as one in the following.

Presence of Others – No differences in the measures for speed and acceleration of movements between the conditions could be found. We assume that the general positive attitude of the HMD users towards the examiner, the familiar location and bystanders took away some fears. The findings in the separated condition support this. There are no reports about the fear of being touched and social embarrassment.

Cognitive threats due to bystanders in the public condition were reported to affect the users' experience in the first minutes. Surprisingly after some time, all the participants forgot about their real-world surrounding including other people. We assume that the positive attitude towards the examiner, the fact that users knew to be in a user study and the familiar environment created a trustful environment. We expected this effect, as it is described by social facilitation and the communicator reward valence (Section 1). The positive attitude is reflected by the users' reports about feeling protected in the study context. No reports about a possible threat due to the examiner in the private condition was recorded. However, they could have felt disturbed by the examiner, as there was nobody else in the room when they covered their eyes. This result can either be interpreted as influencing the studies outcome as the study context itself had an outcome on the results. Alternatively, as we argued in the background section, it shows the positive influence a supervising person can have on the usage of HMDs in public environments.

Physical threats were also reported but not regarding getting hurt, but the fear of being unwillingly touched by a stranger. Fear of more severe damage might not have been a problem for the participants in our study as (1) available space in the hallway in combination with the low number of bystanders reduced the risk to bump into each other, compared to a situation on a fair. Users reported, that knowing about the walkable physical area to be much bigger then the virtual play area helped to feel secure. (2) Bystanders surrounding the HMD users are reported to be familiar – they are also students – and categorized as not being dangerous and caring towards the HMD user. This reflects the influence of the space itself. Interestingly not the barrier tape is the element introducing the possibility to immerse into the VR system. It is the combination of a positive attitude towards others and the familiarity with the surrounding.

In summary, our design space is confirmed concerning the examiner playing a different role than bystanders for the HMD user. Further users also discriminated between the role of bystanders and the space around them. Based on these findings we expect varying results in less familiar places. Additional less familiar bystanders might be present, and the supervising person fulfills a different role than the examiner in our study. The combination of these factors might have a more negative effect on the user experience and the feeling of being present.

Feeling of being Present in VR – Besides sounds coming from the real world in the public conditions, we could not find a difference between the conditions. Sounds in the public condition were reported as an interruption of the feeling of being present. However, most of the users reported not to have an issue with that. They integrated the sounds into their VR experience or did not perceive them as they were focused on the VR.

Users needed some time to forget the real world, trust the situation and gain control over the VR. However due to events over time their feeling of being present altered between the VR and real world. We expected these variations similar to the findings of Garau [20]. Intrinsic reasons for these variations are boredom, unlogical events in the VR, not understanding the task and interaction and feeling being at the mercy of bystander. Extrinsic reasons are sounds from the real world and being watched at by bystanders. This is by definition a reduction on the users feeling of presence, although the users did not report this as such. As a consequence, we assume that amateur users could not rate the experience as precise as a professional. We discuss this in more detail in the following section.

Novelty Effect and Expectations Mismatch – The IPQ Data did not show any difference, and further, the PANAS did not give any hints for a negative influence of the conditions on the user. We expect a novelty effect and expectations mismatch. In contrast to our expectations of negative effects of public environments, positive emotions even raised slightly after the experience. All participants reported that playing the Job Simulator made much fun. This is in contrast to some reports by the users about negative feelings and fears. They reported getting touched, hit something and the breaks in presence described in the subsection above as negative effects. However, they diminish their report by saying that this did not affect their experience and the feeling of being present. Based on this we assume an expectations mismatch as the users were inexperienced in using VR systems. We assume that the scales used in the standard questionnaires are not extreme enough on the positive side. Users expectations might be very low in comparison to immersive quality a state of the art VR system is capable off to provide.

Design space – In the section above we could show that the user recognized all the aspects of our introduced design space. We could not identify other factors. It needs to be mentioned that we did not include the factors *Accompanying Person* and *Artifacts*. We know from previous work that these factors also exist in public environments [34].

Implications

In this work, we focused on effects introduced by variations of spatial layout in a public HMD experience. With our proposed implications, we contribute to supporting design decisions. Practitioners and scientist can benefit from this either to design for a specific situation or to understand the effects that might arise under specific system layouts.

Full Separation not Mandatory – In all conditions a very appealing VR experience is possible. However, there are slight differences between public and separated conditions. Disruptions of the VR experience by stimuli from the real world in the public conditions, result in a diminution of spatial presence and plausibility of the VR for the HMD user. However, HMD users can still be involved very well in the experience. Giving an exciting task, possibilities to explore and interact with the VR help the user to focus on the VR. In experiences offering only a few involving elements, threats origin from the real world might get dominant. An example could be the reviewing of architecture. From this we conclude that the fewer involving elements are existing in an experience, the more spatial, visual and auditory separation should be set up in the environment.

Physical separation helps to overcome the fear of colliding with others, as it might happen in very crowded situations. Alternatively to the barrier tapes used in this study, one can use objects like big flower pots or other forms of decoration in order to lead the stream of bystanders around the walkable area. A recommendation for all spatial layouts is to make the user assume that the walkable area in real world is much bigger than the space needed in VR. Visual separation of the HMD user fosters confidence of the user, in particular in the first minutes of the experience. Therefore short experiences or experiences that create an emotional involvement of the user can benefit from a physical and visual separation of the HMD user. In environments with a low likelihood of hitting another person, it might be sufficient for the user to have a trustful system operator around.

System Operator as Protection – The system operator is an important factor for user experience in the usage of HMDs in public environments. If s/he is a trustworthy person and the HMD users trust him/her to take care of their physical safety, a good experience is possible. From this, we conclude that a system operator can help in experiences that demand a separation of the user, but specific reasons do not allow a physical separation. Also, s/he is needed as a helping hand during the experience. Therefore a system operator should be trained on how to be a trustful person for the user in order to foster positive social effects like shared attention. Further, the system operator can improve the users experience in public by communicating clear rules. Exemplary rules are communicating expectations to the user, explain what the user can do and how s/he should do it. Further, a start and end of the experience should be defined. In our study we introduced an alarmwatch to inform the user about the end, which helped the users. The definition helps to avoid situations in which the user might interpret a challenging or unclear situation as an error in or the end of an experience. A clear explanation of how and when the system operator can be contacted helps the users to maintain certainty in their actions. This avoids negative effects as it might be embarrassing to the user to speak into a room s/he can not see.

Make Users Look Good – The participants reported that they felt insecure in the first minutes of interaction due to not knowing what to do and expect, how to interact, when the task starts, the experience ends and how/ whom to communicate to or ask for help during the experience. Failing in understanding these basic rules, creates a feeling of insecurity. This feeling is enforced when being watched at by bystanders. Therefore the primary goal in the experience design should be to make the users believe that they are in control of the situation all the time. An instructional part could be beneficial to guide the users into the VR. Helping the user out of VR by guiding him/her back is also important, as getting back to reality is as demanding as adapting to the VR.

During the first minutes the interaction should be simple – adjusted to the experience of the user group – in order not to make the users fail in front of bystanders [44]. Creating a transition for the user from the real world environment to the VR environment was shown to be beneficial [53, 50] and might be especially beneficial in public environments. The user should not be overwhelmed with functionalities and especially avoid complicated tasks or even mistakes in the implementation. These frustrating moments are reported by the participants to break the presence feeling. Do not put the interesting or important topic of the experience in the first minutes, as the user might miss it.

CONCLUSION AND FUTURE WORK

In this paper, we presented a study on the influence of spatial layout on the HMD users experience during a VR experience in public. A design space is introduced by us and showed to include all relevant factors influencing a VR experience in public environments. Based on the theoretical discussion of the design space we conducted a between-subject user study (N=58) comparing the conditions *surrounded*, *barrier* and *separated*. We show that HMD users in these environments are affected by physical – getting hit by others or objects – or cognitive – e.g., being watched at by strangers – threats. Based on our theoretical and findings from the user study we give implications for future design of public HMD experiences. We argue that a good VR experience is possible in all spatial layouts when all factors influencing the VR experience are taken into account. For example, the engagement of the user on the VR experience can be fostered without any additional separation. Possible actions to increase engagement are the introduction of a highly involving task and a system operator communicating clear rules for the experience. The introduced design space creates new research opportunities as we only addressed the spatial layout of the system. Further our results give practitioners and researcher the possibility to improve the design of future HMD experience and better understand the effects created due to certain system layouts.

Future Work

In future usage of HMDs, e.g., unsupervised public display of HMDs [34], the system operator will not be present anymore. We want to research these situations in order to find out if users can maintain a good experience and work on VR systems for these types of environments. Our work focused on the topic from a UX point of view. Using performance-driven task approaches could give additional insights into the influence of factors in public HMD experiences. We argue that there are differences possible, as the feeling of being present is a cognitive process and therefore any disturbance might lead to corrupted task performance in the VR. Practical tools need to be developed that help to analyze the reported variations in presence feeling over time. Short-term interruptions are not reflected precisely in questionnaires but showed to be the primary threat during the HMD experience.

REFERENCES

1. 2018. *bystander*. Oxford University Press. `https://en.oxforddictionaries.com/definition/bystander`
2. Walid Afifi and Sandra Metts. 1998. Characteristics and Consequences of Expectation Violations in Close Relationships. *Journal of Social and Personal Relationships* 15, 3 (1998), 365–392. DOI: `http://dx.doi.org/10.1177/0265407598153004`
3. AFP Relax News. 2014. Virtual reality booth whisks users to Hawaii and London in 4D. (2014). `https://www.yahoo.com/news/virtual-reality-booth-whisks-users-hawaii-london-4d-163207143.html`

4. Ivan Alsina-Jurnet and José Gutiérrez-Maldonado. 2010. Influence of personality and individual abilities on the sense of presence experienced in anxiety triggering virtual environments. *International Journal of Human-Computer Studies* 68, 10 (2010), 788–801. DOI: http://dx.doi.org/10.1016/j.ijhcs.2010.07.001

5. Fernando Argelaguet, Anne-Hélène Olivier, Gerd Bruder, Julien Pettré, and Anatole Lecuyer. 2015. Virtual Proxemics: Locomotion in the Presence of Obstacles in Large Immersive Projection Environments. In *Proceedings of IEEE Virtual Reality (VR)*. DOI: http://dx.doi.org/10.1109/VR.2015.7223327

6. Till Ballendat, Nicolai Marquardt, and Saul Greenberg. 2010. Proxemic interaction. In *ACM International Conference on Interactive Tabletops and Surfaces*, Antonio Krüger, Johannes Schöning, Daniel Wigdor, and Michael Haller (Eds.). ACM, New York, NY, 121. DOI: http://dx.doi.org/10.1145/1936652.1936676

7. Frank Biocca, Jin Kim, and Yung Choi. 2001. Visual Touch in Virtual Environments: An Exploratory Study of Presence, Multimodal Interfaces, and Cross-Modal Sensory Illusions. *Presence: Teleoperators and Virtual Environments* 10, 3 (2001), 247–265. DOI: http://dx.doi.org/10.1162/105474601300343595

8. Stéphane Bouchard, Julie St-Jacques, Geneviève Robillard, and Patrice Renaud. 2008. Anxiety Increases the Feeling of Presence in Virtual Reality. *Presence: Teleoperators and Virtual Environments* 17, 4 (2008), 376–391. DOI:http://dx.doi.org/10.1162/pres.17.4.376

9. Judee Burgoon and Jerold Hale. 1988. Nonverbal expectancy violations: Model elaboration and application to immediacy behaviors. *Communication Monographs* 55, 1 (1988), 58–79. DOI: http://dx.doi.org/10.1080/03637758809376158

10. Karl-Erik Bystrom, Woodrow Barfield, and Claudia Hendrix. 1999. A Conceptual Model of the Sense of Presence in Virtual Environments. *Presence: Teleoperators and Virtual Environments* 8, 2 (April 1999), 241–244. DOI:http://dx.doi.org/10.1162/105474699566107

11. James Carifio and Rocco Perla. 2007. Ten Common Misunderstandings, Misconceptions, Persistent Myths and Urban Legends about Likert Scales and Likert Response Formats and their Antidotes. 3 (03 2007).

12. Elizabeth Churchill and David. Snowdon. 1998. Collaborative Virtual Environments: An Introductory Review of Issues and Systems. *Virtual Reality* 3, 1 (1998), 3–15.

13. Matthew Coxon, Nathan Kelly, and Sarah Page. 2016. Individual differences in virtual reality: Are spatial presence and spatial ability linked? *Virtual Reality* 20, 4 (2016), 203–212. DOI: http://dx.doi.org/10.1007/s10055-016-0292-x

14. James Cummings and Jeremy Bailenson. 2016. How immersive is enough? A meta-analysis of the effect of immersive technology on user presence. *Media Psychology* 19, 2 (2016), 272–309. DOI: http://dx.doi.org/10.1080/15213269.2015.1015740

15. Parth Desai, Pooja Desai, Komal Ajmera, and Khushbu Mehta. 2014. A Review Paper on Oculus Rift– A Virtual Reality Headset. *CoRR* abs/1408.1173 (2014).

16. Julia Diemer, Georg Alpers, Henrik Peperkorn, Youssef Shiban, and Andreas Mühlberger. 2015. The impact of perception and presence on emotional reactions: a review of research in virtual reality. *Frontiers in psychology* 6 (2015), 26. DOI: http://dx.doi.org/10.3389/fpsyg.2015.00026

17. Philip Fink, Patrick Foo, and William Warren. 2007. Obstacle Avoidance During Walking in Real and Virtual Environments. *ACM Transactions on Applied Perception* 4, 1, Article 2 (Jan. 2007). DOI: http://dx.doi.org/10.1145/1227134.1227136

18. Jesse Fox, Jeremy Bailenson, and Tony Ricciardi. 2012. Physiological responses to virtual selves and virtual others. *Journal of CyberTherapy and Rehabilitation* 5, 1 (2012), 69(4).

19. Iris Galloso, Juan Palacios, Claudio Feijóo, and Asunción Santamaría. 2016. On the Influence of Individual Characteristics and Personality Traits on the User Experience with Multi-sensorial Media: An Experimental Insight. *Multimedia Tools and Applications* 75, 20 (2016), 12365–12408. DOI: http://dx.doi.org/10.1007/s11042-016-3360-z

20. Maia Garau, Doron Friedman, Hila Widenfeld, Angus Antley, Andrea Brogni, and Mel Slater. 2008. Temporal and Spatial Variations in Presence: Qualitative Analysis of Interviews from an Experiment on Breaks in Presence. *Presence: Teleoper. Virtual Environ.* 17, 3 (2008), 293–309. DOI:http://dx.doi.org/10.1162/pres.17.3.293

21. Erving Goffman. 1959. *The presentation of self in everyday life*. Anchor Books, New York.

22. Lewis Goldberg. 1990. An alternative "description of personality": The big-five factor structure. *Journal of personality and social psychology* 59, 6 (1990), 1216–1229.

23. Emory Griffin. 2012. *A first look at communication theory*. McGraw-Hill, New York.

24. Bernard Guerin and John Innes. 1984. Explanations of social facilitation: A review. *Current Psychology* 3, 2 (1984), 32–52. DOI:http://dx.doi.org/10.1007/BF02686548

25. Jan Gugenheimer, David Dobbelstein, Christian Winkler, Gabriel Haas, and Enrico Rukzio. 2016. FaceTouch: Enabling Touch Interaction in Display Fixed UIs for Mobile Virtual Reality. In *Proceedings of the 29th Annual Symposium on User Interface Software and Technology (UIST '16)*. ACM, New York, NY, USA, 49–60.

26. Jan Gugenheimer, Evgeny Stemasov, Julian Frommel, and Enrico Rukzio. 2017. ShareVR: Enabling Co-Located Experiences for Virtual Reality Between HMD and Non-HMD Users. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems (CHI '17)*. ACM, New York, NY, USA, 4021–4033. DOI: http://dx.doi.org/10.1145/3025453.3025683

27. Kelly Hale and Kay Stanney (Eds.). 2014. *Handbook of virtual environments: Design, implementation, and applications* (second edition ed.). CRC Press.

28. Edward Hall. 1966. *The hidden dimension*. Anchor Books, New York.

29. Crystal Hoyt, Jim Blascovich, and Kimberly Swinth. 2003. Social Inhibition in Immersive Virtual Environments. *Presence: Teleoperators and Virtual Environments* 12, 2 (2003), 183–195. DOI: http://dx.doi.org/10.1162/105474603321640932

30. Hikaru Ibayashi, Yuta Sugiura, Daisuke Sakamoto, Natsuki Miyata, Mitsunori Tada, Takashi Okuma, Takeshi Kurata, Masaaki Mochimaru, and Takeo Igarashi. 2015. Dollhouse VR: A multi-view, multi-user collaborative design workspace with VR technology. In *SIGGRAPH Asia 2015 Posters, SA 2015*. Association for Computing Machinery, Inc. DOI: http://dx.doi.org/10.1145/2820926.2820948

31. Silvia Kober and Christa Neuper. 2013. Personality and Presence in Virtual Reality: Does Their Relationship Depend on the Used Presence Measure? *International Journal of Human-Computer Interaction* 29, 1 (2013), 13–25. DOI: http://dx.doi.org/10.1080/10447318.2012.668131

32. Yun Ling, Harold Nefs, Willem Brinkman, Chao Qu, and Ingrid Heynderickx. 2013. The relationship between individual characteristics and experienced presence. *Computers in Human Behavior* 29, 4 (2013), 1519–1530. DOI:http://dx.doi.org/10.1016/j.chb.2012.12.010

33. Donat Luigi, Rebecca Tortell, Jacquelyn Morie, and Aimee Dozois. 2005. Technical Report. University of Southern California Institute for Creative Technologies (ICT).

34. Christian Mai and Mohamed Khamis. 2018. Public HMDs: Modeling and Understanding User Behavior around Public Head-Mounted Displays. In *Proceedings of the 7th ACM International Symposium on Pervasive Displays (PerDis '18)*. ACM, New York, NY, USA. DOI: http://dx.doi.org/10.1145/3205873.3205879

35. Gregor Mcewan, Markus Rittenbruch, and Tim Mansfield. 2007. Understanding Awareness in Mixed Presence Collaboration. In *Proceedings of the 19th Australasian Conference on Computer-Human Interaction: Entertaining User Interfaces (OZCHI '07)*. ACM, New York, NY, USA, 171–174. DOI: http://dx.doi.org/10.1145/1324892.1324924

36. Mark McGill, Daniel Boland, Roderick Murray-Smith, and Stephen Brewster. 2015. A Dose of Reality: Overcoming Usability Challenges in VR Head-Mounted Displays. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems (CHI '15)*. ACM, New York, NY, USA, 2143–2152. DOI: http://dx.doi.org/10.1145/2702123.2702382

37. Michael Meehan. 2001. *Physiological Reaction As an Objective Measure of Presence in Virtual Environments*. Technical Report. Chapel Hill, NC, USA.

38. Kjetil Nordby, Stian Børresen, and Etienne Gernez. 2016. Efficient Use of Virtual and Mixed Reality in Conceptual Design of Maritime Work Places. In *15th International Conference on Computer and IT Applications in the Maritime Industries*.

39. Tabitha Peck, Sofia Seinfeld, Salvatore Aglioti, and Mel Slater. 2013. Putting yourself in the skin of a black avatar reduces implicit racial bias. *Consciousness and cognition* 22, 3 (2013), 779–787. DOI: http://dx.doi.org/10.1016/j.concog.2013.04.016

40. Juno Rae and Lizzie Edwards. 2016. Virtual reality at the British Museum: What is the value of virtual reality environments for learning by children and young people, schools, and families?. In *MWA2016: Museums and the Web 2016*.

41. Beatrice Rammstedt and Oliver John. 2007. Measuring personality in one minute or less: A 10–item short version of the Big Five Inventory in English and German. *Journal of Research in Personality* 41, 1 (2007), 203–212. DOI:http://dx.doi.org/10.1016/j.jrp.2006.02.001

42. Stéphane Roy, Evelyn Klinger, Patrick Légeron, Françoise Lauer, Isabelle Chemin, and Pierre Nugues. 2003. Definition of a VR-based protocol to treat social phobia. *Cyberpsychology & behavior : The impact of the Internet, multimedia and virtual reality on behavior and society* 6, 4 (2003), 411–420. DOI: http://dx.doi.org/10.1089/109493103322278808

43. Thomas Schubert, Frank Friedmann, and Holger Regenbrecht. 2001. The Experience of Presence: Factor Analytic Insights. *Presence: Teleoperators and Virtual Environments* 10, 3 (2001), 266–281. DOI: http://dx.doi.org/10.1162/105474601300343603

44. Ben Shneiderman. 2004. Designing for Fun: How Can We Design User Interfaces to Be More Fun? *Interactions* 11, 5 (Sept. 2004), 48–50.

45. Adalberto Simeone, Ifigeneia Mavridou, and Wendy Powell. 2017. Altering User Movement Behaviour in Virtual Environments. *IEEE transactions on visualization and computer graphics* 23, 4 (2017), 1312–1321. DOI: http://dx.doi.org/10.1109/TVCG.2017.2657038

46. Mel Slater. 1999. Measuring Presence: A Response to the Witmer and Singer Presence Questionnaire. *Presence: Teleoper. Virtual Environ.* 8, 5 (Oct. 1999), 560–565. DOI: http://dx.doi.org/10.1162/105474699566477

47. Mel Slater, David Pertaub, Chris Barker, and David Clark. 2006. An experimental study on fear of public speaking using a virtual environment. *Cyberpsychology & Behavior : The impact of the Internet, multimedia and virtual reality on behavior and society* 9, 5 (2006), 627–633. DOI:http://dx.doi.org/10.1089/cpb.2006.9.627

48. Mel Slater and Sylvia Wilbur. 1997. A Framework for Immersive Virtual Environments (FIVE): Speculations on the Role of Presence in Virtual Environments. *Presence* 6 (1997), 603–616.

49. Aaron Stafford, Bruce Thomas, and Wayne Piekarski. 2009. Comparison of Techniques for Mixed-space Collaborative Navigation. In *Proceedings of the Tenth Australasian Conference on User Interfaces - Volume 93 (AUIC '09)*. Australian Computer Society, Inc, Darlinghurst, Australia, Australia, 61–70.

50. Frank Steinicke, Gerd Bruder, Klaus Hinrichs, Anthony Steed, and Alexander Gerlach. 2009. Does a Gradual Transition to the Virtual World increase Presence? (2009).

51. Anthony Tang, Michael Boyle, and Saul Greenberg. 2004. Display and Presence Disparity in Mixed Presence Groupware. In *Proceedings of the Fifth Conference on Australasian User Interface - Volume 28 (AUIC '04)*. Australian Computer Society, Inc, Darlinghurst, Australia, 73–82.

52. Paco Underhill. 2000. *Why we buy: The science of shopping* (1st ed.). Touchstone, New York.

53. Dimitar Valkov and Steffen Flagge. 2017. Smooth Immersion: The Benefits of Making the Transition to Virtual Environments a Continuous Process. In *Proceedings of the 5th Symposium on Spatial User Interaction (SUI '17)*. ACM, New York, NY, USA, 12–19.

54. David Watson, Lee Clark, and Auken Tellegen. 1988. Development and validation of brief measures of positive and negative affect: The PANAS scales. *Journal of personality and social psychology* 54, 6 (1988), 1063–1070.

55. Paul Watzlawick, Janet Bavelas, and Don Jackson. 1967. *Pragmatics of human communication: A study of interactional patterns, pathologies, and paradoxes*. W. W. Norton, New York.

56. Bob Witmer and Michael Singer. 1998. Measuring Presence in Virtual Environments: A Presence Questionnaire. *Presence: Teleoper. Virtual Environ.* 7, 3 (1998), 225–240. DOI: http://dx.doi.org/10.1162/105474698565686