Exploring the relationships between the usability of a medium and the sense of Spatial Presence perceived by the user

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Abstract

In this paper the relationships between the usability of Virtual Reality inducing technology and the sense of Spatial Presence perceived by the user are discussed from a theoretical perspective. After an explication of both constructs, joint prerequisites are identified and discussed: media factors, user factors and features of the context of use. Furthermore, some mutual effects between the two constructs are hypothesized. The paper aims to provide inspiration for further empirical work on the relationships between usability and Spatial Presence.

Keywords: Presence, Spatial Presence, Usability, Virtual Reality

1. Introduction

With the advent of enhanced interactive communication interfaces the immersive potential of electronic media has increased enormously [1]. Today, even common interactive media technologies like computer games or home cinemas have the potential to 'catch' the user in the virtual worlds they are providing, creating Presence experiences. In general, Presence research deals with the user's "perceptual illusion of non-mediation" [4], which occurs when users of media systems temporarily become unaware of the fact that they are using a medium. One important facet of this phenomenon is the state of Spatial Presence that relates to the psychological sensation of the user to be located in a mediated environment, despite the fact that the environment is only an illusion affected by the medium [cf. reviews 5; 6; 7; 8; 9].

In future, the diffusion of new immersive technology might lead to a wide-spread accessibility of sophisticated Virtual Reality (VR) systems which today still are subject to laboratories of researchers. Whenever a technology is intended to be distributed to a large market, the usability of the product becomes an important issue. Accordingly, keywords like "usability engineering" [2] and "user-centered design" [3] reflect the efforts to design hardware and software in order to meet the needs of the user and enable a comfortable and effective human-technology-interaction.

In this paper, relationships between the usability of a medium and the sense of Spatial Presence perceived by its user are discussed. First, the central terms are explicated by introducing conceptualizations of usability and Spatial Presence. Building on these assumptions, the joint prerequisites of both constructs are identified and hypothetical mutual effects are discussed. The paper concludes with an outline of scenarios in which the interplay of usability and Spatial Presence becomes practically relevant.

2. What is Usability?

Early conceptualizations of usability were inspired by graphical user interfaces of personal computers which were primarily used for office applications like word processing and data-base calculations. In this context, several definitions of usability were introduced of which the one provided by the international standard ISO 9241-11 [11] has received the greatest acceptance [cf. 3]: *Usability is the "extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use"* [11 p. 2].

According to this definition, usability is a construct consisting of three dimensions: effectiveness, efficiency and satisfaction. These dimensions are framed by a specific context of use which reflects the particularities of users, tasks, equipment and the physical and social environments in which a product is used [cf. 11 p. 2].

Effectiveness is defined as the accuracy and completeness with which users achieve specified goals [11 p. 2]. Accuracy refers to the extent to which the quality of the output corresponds to specified criteria, whereas completeness stands for the proportion of the target quantity which has been achieved [11 p. 12]. Thus, the interaction with a media technology can be considered as effective when it enables the user to achieve his/her intended goals. For example, a training session in a flight simulator is effective when it enables the user to successfully replicate the actions performed in the VR in reality.

Efficiency refers to the relation between the expended resources (e.g. cognitive effort or time) and the effectiveness of the interaction [11 p. 2]. Thus, the interaction with a media technology can be considered as efficient when it enables the user to achieve his/her intended goals with reasonable effort. An example for an efficient interaction with a media offering providing VR experiences would be a VR system that enables the user to successfully navigate through the depicted surrounding without taking up all mental resources, i.e. keeping mental resources free for the completion of additional tasks.

Satisfaction stands for the user's freedom from discomfort and positive attitudes towards the use of the product [11 p. 2]. According to this definition, the interaction with a media technology can be considered as satisfactory if the user feels free from discomfort or even enjoys the experience. For example, users of a highly immersive computer

game feel satisfied when they can successfully control the avatar representing themselves in the virtual environment without distracting malfunctions of the interface.

Recently, the concept of the traditional graphical user interface usability has been extended to fit the particularities of VR technology. According to Biocca and Delaney [1], VR technology can be considered as an "extension of body and mind": it features sophisticated input devices (e.g. data gloves, eye movement, audio input, psychophysiological input) as well as multi-modal output devices like head-mounted displays, aural displays, haptic output, force feedback devices, whole body movement displays or even nasal displays, providing the user with continuous streams of highly realistic mediated information as well as the ability to interact with the virtual environment.

Research on the usability of VR technology has already covered various aspects like the usability of virtual environments in general [12; 13; 14], interactive systems [15], shared space virtual conferencing [16] and collaborative virtual environments [12]. The common ground of all these approaches is that the specificity of VR technology prompts specific criteria for the assessment of usability which go beyond traditional understandings.

Stanney et al. [12] for example argue that common tasks in virtual environments are wayfinding, navigation, object selection and object manipulation – tasks that are not typical for non-immersive technologies. Furthermore, the integration of visual as well as auditory and haptic system outputs confine VR systems from traditional graphical user interfaces, which are generally limited to audio-visual output.

3. What is Spatial Presence?

Simply spoken, Presence refers to a "perceptual illusion of nonmediation" [4]. Presence has been differentiated into various subtypes like "Social Presence" and "Co-Presence" [cf. 18]. A more specific concept is "Spatial Presence", which has been described as "a sense of being there" occurring "when part or all of a person's perception fails to accurately acknowledge the role of technology that makes it appear that s/he is in a physical location and environment different from her/his actual location and environment in the physical world" [19].

Spatial Presence is closely related to the phenomenon "situation awareness" as explicated by Endsley [20; 21]. Endsley [21] defined situation awareness as "the perception of the elements of the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future" (p.97). Situation awareness refers to the perception of situations of any kind, thus we understand Spatial Presence as a kind of "mediated situation awareness".

Wirth et al. [22; see also 23] conceptualize Spatial Presence as a two-dimensional construct: The core dimension is the sensation of being physically located in a mediated environment, the second dimension is the perception of actions possible in this environment. The model suggested by Wirth et al. [22; 23] is designed to explain the occurrence of Spatial Presence in different media settings, and of course it covers VR systems. It explains the formation of Spatial Presence as a process affected by the interaction of personal, situational and media factors. The model is organized in two levels of processes that are involved in the emergence of Presence: The first level refers to the formation of a spatial situation model (SSM), which is a mental model of the perceived spatial (media) environment. On the model's second level, the transition from the mere existence of an SSM towards the actual state of experiencing Spatial Presence is facilitated through the (successful) test of a perceptual hypothesis. The hypothesis states that the mediated environment is the user´s "primary ego-reference frame" (PERF). If it is confirmed, users assign their self-location and perceived possible actions to the mediated environment (i.e., they feel spatially present).

Both levels are influenced by media and user factors. Media factors attracting the user´s attention or supporting the construction of an SSM, for example spatial cues like motion parallax, contribute to the first level of the model. User factors influencing the construction of an SSM can be divided into user traits and user states and actions. Traits influencing the construction of an SSM are the domain specific interest and the user's spatial ability. States and actions are the situational motivation and the activity of spatial thinking which are corresponding to the user's traits. The allocation of attention to the presentation as a prerequisite of constructing an SSM depends on those media and user factors. Having constructed an SSM, the user may take the step to the experience of Presence, which is again influenced by media and user factors. Media factors related to the perceptual hypothesis testing like realism and meaning of the presented environment contribute to the formation of Spatial Presence. The most important user trait influencing the formation of Spatial Presence is absorption, which refers to the individual's motivation and skill in dealing with an object in an elaborate manner. The corresponding user states and actions are involvement, defined as active and intense processing of the mediated world, and the suspension of disbelief, defined as the intentional elimination of external stimuli and internal cognitions that (might) contradict the medium-as-PERF-hypothesis.

The model of the formation of Spatial Presence experiences is visualized in figure 1.

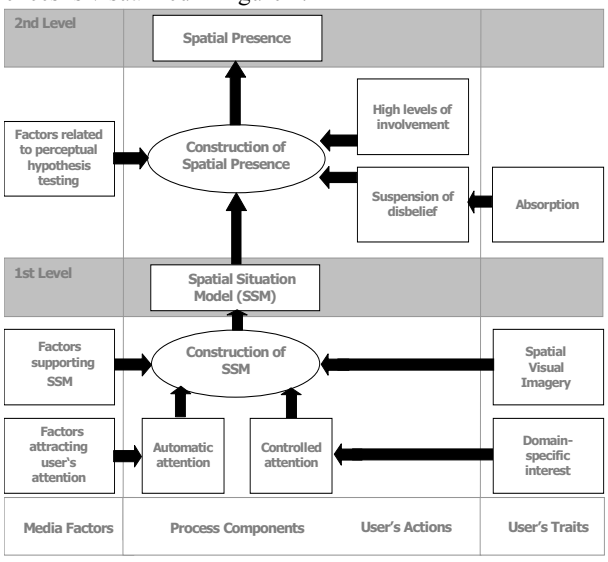

Figure 1. Visualization of the two-level-model of Spatial Presence experiences by Wirth et al. [22]

4. Joint prerequisites of usability and Spatial Presence in human-media-interactions

As explicated above, Spatial Presence is a psychological state that occurs in interaction with a medium when certain media and user factors are given. Usability, however, describes the quality of such a human-media-interaction in terms of its effectiveness, efficiency and satisfaction. Thus, both phenomena occur during human-media-interactions featured by specific conditions. These conditions can be differentiated into three categories: media factors, user factors and the context of use.

Media factors include all features of the technology (i.e. input- and output-devices and their specifications). User factors relate to the traits and states of the media user (e.g. absorption or domain-specific interest). The context of use, however, consists of the task which has to be solved in the VR (e.g. navigation through a building) and factors describing the physical and social environment in which the medium is used (e.g. external noise, room temperature or the attendance of other people). This conceptualization of human-media-interactions is visualized in figure 2.

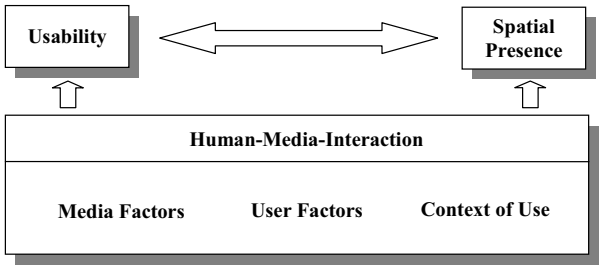

Figure 2: Conceptualization of human-media-interactions

We suggest that – when using VR technology – there are several prerequisites that foster the experience of Spatial Presence and enable high levels of usability at the same time. These joint prerequisites will be explicated in the following.

4.1 Media factors

One important factor fostering usability as well as Spatial Presence is the allocation of attention to the virtual environment. If the user is not paying attention to the mediated environment, s/he will neither be able to solve tasks in an effective, efficient and satisfactory manner nor create an SSM, which is a necessary prerequisite for the experience of Spatial Presence. Media factors can foster processes of attention allocation and thus contribute to Spatial Presence as well as to usability. Terms like "vividness" [26] refer to media factors contributing to the allocation of attention. The more sensory information a medium emits, the more likely it is that a user will persistently allocate his/her attention to the media offering. Media content is also an important factor that can affect the persistence of attention allocation: Narration, drama, and plot have been reported to increase the user's interest in media products [35; 36].

Media factors are also important for the way the mediated information is processed. The usability of a VE as well as the occurrence of Spatial Presence depend on the user's perception of spatial arrangements. If the user does not have the sensation of a spatial environment, s/he will not be able to form an SSM and thus will not experience Spatial Presence. On the other hand, the performance of tasks including navigation and wayfinding in a spatial environment will not be solved effectively and efficiently if the user does not experience the environment displayed by the medium as spatial. A broad range of so-called "spatial cues" fostering the perception of space within a media offering has been introduced in the literature [e.g. 28; 6]. Many spatial cues are linked to the visual modality. Static monocular cues include occlusion, height in the visual field, relative size, relative density and texture effects, aerial perspective and relative brightness, foreshortening and accommodation [28]. Binocular cues include for example stereopsis [29]. Spatial information can also be mediated by spatial audio [30], haptic cues [31] or vestibular cues [32]. The spatial information has to be displayed concise and consistent in order to enable the user to discriminate different elements and to assemble these elements into meaningful objects ["sensory integration"; 33].

In sum, media offerings that display a variety of concise spatial cues within different perceptual channels, which are linked in a consistent and plausible manner are more likely to evoke precise and coherent SSMs than those presenting only a few, diffuse or inconsistent cues. If users of VR systems are confronted with limited, constrained, or incoherent sensory inputs, they may not only have problems in forming an SSM, but may also experience some sort of confusion or impairment. The most prominent phenomenon of this kind is motion sickness, which has also been labelled cyber sickness [34], which is usually experienced as very unpleasant. VR systems fostering motion sickness have a limited usability because of poor satisfaction.

Media factors can even affect the formation of Spatial Presence directly, because they contribute to the confirmation of the medium-as-PERF-hypothesis. The mediated place should display many similarities with real places and be coherent in terms of structure, components, and dynamics, which increases the likelihood of a confirmation of the medium-as-PERF-hypothesis [22; 23]. Interactivity can also provide strong support for this hypothesis. The degree of interactivity depends on the adequacy of the given feedback and on breadth of possible interactive actions [33; 26]. Inappropriate configurations like, for example, high response latencies, will remind the user of the artificial nature of the VR system and the medium-as-PERF-hypothesis will be weakened. Interactivity does also have an impact on usability. Improper configurations will hamper effectiveness. If acting in the VR is complicated, cumbersome, and not appropriate to the task, the user will have to spend a lot of effort in order to perform the task with high quality and in an suitable time period. This task performance will not be efficient due to the additional efforts and usability can be considered as rather poor.

4.2 User factors

Several user characteristics have been identified to foster Spatial Presence experiences [cf. 37]. Some of these are likely to promote the usability of VR technology simultaneously. Wirth et al. [22; 23] propose four user traits to influence Spatial Presence experiences positively: spatial ability, absorption, domain-specific interest and the willingness to suspend disbelief.

Spatial ability, defined as "the capability to produce vivid spatial imaginations" [22 p.9], fosters the construction of an SSM and therefore supports Spatial Presence experiences. Simultaneously, a user's spatial ability can enhance the usability of a VR system, as this trait is likely to support the user completing wayfinding and navigation tasks in an effective and efficient manner.

Several studies showed that absorption fosters Spatial Presence experiences [cf. 37]. One possible explanation for this effect is that users with a high tendency to get absorbed allocate significant amounts of attention on the media stimulus. The allocation of attention is a prerequisite for high usability, too, as it enables users to perform tasks effectively.

The same argument can be applied to the role of the user's domain-specific interest in the mediated environment: Such an interest is likely to foster Spatial Presence experiences, as it supports the allocation of attention to the VR content. Simultaneously, it can be assumed that users who are interested in the mediated environment perform tasks more effectively and with greater satisfaction.

Suspension of Disbelief, defined as the intentional elimination of external stimuli and internal cognitions that (might) contradict the medium-as-PERF-hypothesis [22], fosters Spatial Presence experiences. It can also enhance usability, as users with a high willingness to suspend disbelief may be able to compensate disturbances of the human-media-interaction (e.g. response latencies of input devices) cognitively, fostering the efficiency and satisfaction with which tasks are solved.

4.3 Features of the context of use

In addition to media and user factors, human-media interactions are characterized by the context of use, which includes the task which has to be solved as well as the physical and social environment in which the medium is used.

We assume that two specific task characteristics can be joint prerequisites for Spatial Presence experiences and usability: The relevance of spatial cues for task completion as well as the relevance of the task for the user.

In order to be solved effectively, many tasks require information about the spatial structure of the virtual environment. This applies for all tasks that demand orientation, e.g. navigation and wayfinding but also for complex tasks like the accomplishment of tele-operated surgeries. The presentation of spatial cues fosters Spatial Presence experiences, as they help the user to create an SSM. Simultaneously, the presentation of spatial cues is a necessary condition for the effective completion of tasks demanding orientation in the virtual environment.

A high relevance of the task for the user is another joint prerequisite. Some tasks have a high relevance for the user, e.g. the realization of tele-operated surgeries, where the success of the task completion judges over the life or death of the patient. In cases of high relevance, it can be assumed that media users allocate striking amounts of their cognitive resources on the task. As explicated above, the allocation of attention is a major precondition for the experience of Spatial Presence. Simultaneously, it can be hypothesized that the allocation of attention on the task will enhance the usability of the medium, as focused users are likely to solve tasks more efficiently.

As far as the physical and social environment in which the medium is used is concerned, the absence of disturbing stimuli can be considered as a joint prerequisite of Spatial Presence experiences and usability. Disturbing stimuli, defined as stimuli not generated by the VR technology, can disturb or even impede Spatial Presence experiences, as they distract the user's allocation of attention on the mediated environment. Coevally, a lack of attention lowers the efficiency with which tasks are solved and therefore confines the usability of VR technologies.

5. How usability can have a particular effect on Spatial Presence

In addition to the identification of joint prerequisites of the two constructs, we will also 'dare' a brief closer look on possible effects of the usability of VR systems on the experience of Spatial Presence. We assume that all three core aspects of usability (i.e. a high satisfaction, a high efficiency, as well as a high effectiveness) can positively influence the psychological processes involved in the formation of Spatial Presence.

First, a high satisfaction should motivate the user to extend the exposure to a stimulus or environment [cf. 38]. Thus, the attention allocation onto a depicted spatial scenery could be prolonged, which in turn should increase the likelihood of Spatial Presence experiences (see section 3).

Second, a low efficiency implies that many resources (i.e. cognitive workload, time, etc.) need to be invested by the user in order to achieve a given task. It might be argued, in turn, that in special cases a lack of cognitive resources can impede the formation of Spatial Presence. For example, this could be true if the user encounters a poor media offer with insufficient or ill-defined spatial cues and thus has to invest a relatively high amount of cognitive resources (in terms of visual spatial imagery or suspension of disbelief; see section 3) if he wants to feel spatially present. However, with much resources being bound to task achievement, the user might abandon processes to advance the 'spatial illusion' in order to avoid a cognitive 'overload'. A low efficiency, then, would hinder or impede Spatial Presence experiences. This means, in turn, that a high efficiency enables the user to invest additional cognitive workload to the spatial illusion, if necessary.

Third, it can be argued that effectively solved tasks lead to mastery experiences or feelings of self-efficacy [39].

Given that a typical task conducted in a VR (e.g. navigating a robot through a labyrinth to an exit) builds on a chain of subtasks (e.g. moving the robot, turning the robot, reaching a room with the robot, etc…), it might be argued that effectively solved tasks lead to persistent feelings of mastery, which closely resemble a specific meta-experience that has been described as flow [40]. One typical aspect of flow is the absorption of the user in the experience, causing that he or she temporarily forgets about the outer world, space and time. Given the general similarity to Presence experiences and with specific regard to the role of absorption in the formation of Spatial Presence (see section 3), it seems reasonable to think of flow experiences as promoters of Spatial Presence [41]. In sum it can be argued, then, that a chain of effectively solved tasks result in flow experiences, which in turn could contribute to the sensation of Spatial Presence [for empirical evidences for a positive contribution of task performance on Presence cf. 42 - 43].

6. How Spatial Presence can have a particular effect on usability

We assume that one can also distinguish a particular effect Spatial Presence might exert on usability. When experiencing Spatial Presence, objects and other entities are perceived in direct relationship to the own egocentric position [44]. Thus, users can directly assess distances, sizes, and 'action possibilities' in the virtual space. In contrast, without feeling physically present, users have no 'direct' reference point in the spatial scenery. Thus, if they want to construe the environment, they need to 'reconstruct' the spatial arrangement in their mind by implementing a reference point on a virtual basis. Thus, cognitive resources are bound if users do not feel spatially present, but set free, if they feel located in the environment.

Building on this assumption, it can be argued that usability might benefit from states of Spatial Presence, as users can allocate more cognitive resources for an effective and efficient task performance.

7. Conclusions

The theoretical analysis of the concepts usability and Spatial Presence showed that there are several joint prerequisites. In addition, it has been argued that a high usability should positively affect the experience of Spatial Presence and, in turn, that the experience of Spatial Presence should enhance the usability of VR technology. These assumptions, however, have been derived out of a theoretical conceptualization and have to be tested empirically in the future.

From a practical point of view, taking the joint prerequisites into account can be useful for researchers, designers and engineers working on VR-technology-interfaces that need to provide Spatial Presence experiences and enable high degrees of usability at the same time like vehicle simulations (e.g. aircraft and ship simulators), physical simulations (e.g. the simulation of magnetic fields for students of physics) or medical applications (e.g. tele-operated surgeries and anatomy instruction) [cf. 45].

From a scientific point of view, this means that research on Spatial Presence should include usability variables and VR-usability research should include the assessment of Spatial Presence – the interrelation of both constructs calls for interdisciplinary research.

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