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INTERACTION AFFECTING THE SENSE OF PRESENCE IN VIRTUAL REALITY

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PREFACE

This report presents the results from a research task that is part of the M.Sc.-thesis at the Delft University of Technology with the same subject. The M.Sc.-thesis is performed under supervision of Charles van der Mast and Martijn Schuemie at the Department of Information Systems and Software Engineering, Faculty of Information Technology and Systems at Delft University of Technology. The M.Sc.-thesis originates from an overall project by the Delft University of Technology and the University of Amsterdam on the treatment of phobias using the so-called Virtual Reality Exposure Therapy (VRET, see also Schuemie et al. 2000a and http://is.twi.tudelft.nl/~schuemie/vr.html).

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SUMMARY

Virtual Reality (VR) has been proposed as a new tool for treating phobias. Using the so-called Virtual Reality Exposure Therapy (VRET) it is thought to be possible to treat patients more effectively and/or efficiently than with common methods of therapy. For such treatment the VR experience should be able to evoke fear, and for this the sense of being present in the virtual environment (VE), i.e. the sense of presence, is believed to be a prominent factor. Furthermore, the interactivity in a VE is believed to be a crucial factor for the sense of presence. This report will therefore investigate the effect of interactivity on the sense of presence in a VE. It is the result of a research task, which is part of a M.Sc.-thesis that originates from a project on VRET by Delft University of Technology and University of Amsterdam.

The report reviews different views on presence, briefly reviews what effects the sense of presence in VE's can have, and how presence can be measured. It looks into the concept of interactivity, following a definition that is rather unusual in presence research but that seems more promising; interaction as a cycle of our actions and the reactions by the environment. Furthermore, the report reviews our mental models and the affordances of the environment, i.e. what the environment offers or affords us, and the role these concepts have in the interaction of a human with its environment. It also proposes a new model, the PPMC-Model, that sees interaction as determined by four components of a VR experience: the Purpose, the Participant, the Medium, and the Content. Finally, this report examines its main topic: how the interactivity of a VE can affect presence. It will contend that interaction in VE affects the sense of presence by its role in shaping and maintaining the so-called virtual mental model, and by its possible effect on a person's attention and involvement. The report will discuss that interaction has to comply with two constraints to enable these effects: interaction has to be engaging and interaction has to be comprehensible. These two constraints are then reviewed in relation to the four PPMC-components, and from this the report suggests the possible usefulness of activity modeling and user study in the design and application of VR.

The report reviews available literature on presence, on interactivity in VR, but also on Human-Computer Interaction (HCI) and on human interaction in the natural world.

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INTRODUCTION

This report presents the results of a survey of the literature on the sense of presence and interactivity in virtual reality (VR), and more importantly the relationship between these two concepts. The survey is a research task and is a preparation for a M.Sc.-thesis at the Delft University of Technology with the same subject. Earlier, this preparation also led to the article 'Research on Presence in VR: A Survey' (Schuemie et al. 2000b) which was submitted for publication in CyberPsychology & Behavior.

This M.Sc.-thesis originates from an overall project by the Delft University of Technology and the University of Amsterdam on the treatment of phobias using the so-called Virtual Reality Exposure Therapy (VRET, see also Schuemie et al. 2000a and http://is.twi.tudelft.nl/~schuemie/vr.html). In exposure therapy patients are subjected to situations that evoke their anxiety. For VR, the concept of presence is thought to be an important factor in evoking emotional responses such as anxiety, and therefore seems valuable for VRET. Furthermore, many scholars have argued that in creating this sense of presence, interactivity plays a prominent role. Therefore, this report, and the M.Sc.-thesis in general, hopes to supply more insight into the nature of presence and interaction, and their relationship.

In the first chapter the concept of presence will be discussed, reviewing different views on presence, the effects that the sense of presence can have, and the measurement of presence. In the second chapter interactivity will be dealt with, more specific its definition, the interaction cycle, and the role of our mental models and affordances for interactivity. Furthermore, a new model of VR experiences will be proposed to analyze the relationship between presence and interactivity. This main topic, the effect of interactivity on presence, is discussed in the last chapter.

1 PRESENCE

This chapter on the sense of presence in virtual environments will describe different views on presence that have a prominent place in presence research or which are thought to be important for future research. In paragraph 1.2 it will shortly review possible effects of presence, such as stronger emotional responses or improved task performance. In paragraph 1.3 it will look into the measurement of presence in summary. The effects and measurement of presence are described in more detail in the accompanying article (Schuemie et al. 2000b) as given in appendix A. That article also looks into other causes of presence besides interactivity. The review of views on presence in paragraph 1.1 will also touch on subjects such as interactivity and mental models, subjects that will be covered in more detail in the next chapter.

1.1 ONTOLOGY OF PRESENCE

An ontology of presence, such as presented here, has a prominent place in presence research. It drives the way we initiate and set up our research, what we look for and find, and indeed the way we measure, interpret and describe things (Sheridan 1999). This paragraph will review the Traditional View or Rationalistic Stance and the Ecological View. Finally, it will review two theories that in a way combine the

Traditional and Ecological View: the Estimation Theory and the Embodied Presence Model.

The Traditional View

What in this report will be called the Traditional View involves several prominent views in current research and literature on presence. These different ideas on what presence is and how it develops are described in the following paragraphs. They share some common characteristics that set them apart from the Ecological View, which will be described later on.

Presence by Immersion

In the application and research of immersive virtual reality, many see the sense of presence mainly as a result of the immersion in a virtual environment (see for example Schubert et al. 1999a, 1999b, Slater et al. 1995, Slater & Wilbur 1997, Witmer & Singer 1998). Slater & Wilbur (1997) see the immersion as an *objective* description of the technology applied, and thereby clearly distinguish it from the *subjective* sense of presence resulting from this immersion (see below). They define immersion as the extent to which a display is capable of enabling an illusion that is inclusive, extensive, surrounding and vivid. Furthermore, they state, the immersive quality of a system is affected by things such as a virtual body, a plot and the matching of display and proprioceptive feedback. In this report this definition of immersion will be used and not the less common definition of Witmer & Singer, as discussed in the subparagraph Presence by Involvement below, according to which immersion is seen as a psychological state.

A less often used but often cited taxonomy is that of Zeltzer (1992), who argues that a VR system can by characterized by the following:

- Autonomy, the extent to which the VE is more than just passive geometry.
- Interaction, the degree to which VE parameters can be modified at runtime.
- Presence, as measure for the number and fidelity of available sensory input and output channels.

Here, Zeltzer uses the term “presence” in a way that closely resembles the term “immersion” defined by Slater. As discussed elsewhere, the term “immersion” is sometimes also used, unfortunately, in a way closely resembling the subjective definition of presence as for example by Bangay & Preston (1998) and Witmer & Singer (1998, see below). As mentioned earlier, this report will use Slater's definitions of the terms “immersion” and “presence”, unless stated otherwise.

Presence as Transportation; Being-In and Being There

The earliest conceptions of presence as a kind of transportation appear in the first issue of the journal *Presence*. In that issue both Sheridan and Zeltzer describe the sense of presence as the sense of being somewhere else than the current physical location (Sheridan 1992, Zeltzer 1992). Zeltzer sees the sense of presence as 'the sense of being in and of the [virtual or simulated] world.' Sheridan defines two kinds of presence, namely *virtual presence* and *telepresence* to distinguish between respectively presence from virtual reality and presence from teleoperation. He sees virtual presence as a subjective sensation or mental manifestation in which someone has the sense of being 'physically present with visual, auditory, or force displays generated by a computer' (Sheridan 1992). In his later work the idea of transportation is even more explicit when he states that it's about a sense of being present at a synthetic location created by a computer and various displays (Sheridan 1996).

Many scholars have in the recent years adopted, less or more explicitly, this view of presence as transportation in their research. Steuer (1992) follows this conception but makes a distinction between the natural perception and the mediated perception of an environment. For this, he defines *presence* as 'the sense of being in an environment' and *telepresence* as 'the experience of presence in an environment by means of a communication medium.' Witmer & Singer (1998) also adhere to the conception of presence as transportation: 'Presence is defined as the subjective experience of being in one place or environment, even when one is physically situated in another (Witmer & Singer 1998).'

Heeter (1992) identifies three dimensions to this conception of presence: personal, social and environmental presence. Personal presence follows from experiencing your own presence in virtual reality. Heeter states that this is like the process of 'discerning and validating the existence of self in the natural world (which humans have engaged in since birth).' The environmental presence develops from the perception of the existence of an immersing environment that reacts to you and seems to know you are there. Social presence develops from the existence of other beings in the environment that react to you and seem to know you are there.

Some scholars have taken the view of presence as transportation a step further. Slater's group has conceptualized it as a transformation from one environment to another (Slater et al. 1994). They propose that this transformation can be applied several times during a virtual reality session, firstly from the real to the virtual environment, and next from this virtual environment to another by, for example, again donning a now virtual HMD. With this view they propose the concept of *stacked environments*, i.e. environments at ever "deeper" levels of presence. They suggest that this concept could be used for the classification of levels of presence, thus introducing equivalence classes for the concept of presence.

Exclusive Presence

It is thought that presence occurs in an "instant by instant" manner, and that at some instant someone can only be present in one environment (Biocca 1997, Lombard 2000). Lombard states that it is undetermined whether presence appears continuous because presence varies in degree at each instant or that this continuity is the result of cumulating the instants of being present in a place.

> 'Presence occurs in an "instant by instant" manner. Although it appears that presence is a continuous rather than dichotomous variable, it has not been determined whether 1) presence can exist in varying degrees at each instant (as it seems) or 2) our sense that presence is continuous is the result of the cumulative effect of instants, which may be as short as milliseconds, in which presence either does or does not exist (Lombard, 2000).'

Biocca (1997) states that 'at one point in time, users can be said to feel as if they are physically present in only one of three places: the physical environment, the virtual environment, or the imaginal environment. Presence oscillates among these three poles.'

However, it can be said that presence can be experienced in several environments at the same time, if a longer period of time is considered. Slater et al. (1994, 1998), for example, claim that a person will experience a sense of presence in both the physical and virtual environment. Slater et al. (1994) point out that a high sense of presence in a VE requires a simultaneous low level of presence in the real world, and vice versa. This view is also apparent in Slater & Steed's view who state that the level of presence experienced during an interval is dependent on the relative amount of time of being present in the virtual world (Slater & Steed 2000).

This issue of where and to what degree a person experiences presence might be explained by the focus of attention by that person. Witmer & Singer (1998) state that presence in a virtual environment depends on 'one's attention shifting from the physical environment to the virtual environment, but does not require the total displacement of attention from the physical locale.' They state that people can concurrently attend to aspects of both worlds, and that the amount of attention, among other things, will determine the amount of involvement and presence. They also refer to the varying degree of presence in everyday (non-virtual) situations, where attention is divided between the physical world and the 'mental world of memories, daydreams, and planned activities.' We will now go into Witmer & Singer's (1998) view on presence by involvement in some more detail.

Presence by Involvement

Witmer & Singer (1998) relate presence in part to the concept of attention: 'presence may vary across a range of values that depends *in part* on the allocation

of attentional resources.' They argue that to experience presence both involvement and immersion are necessary, and see these factors as psychological states:[1]

> '*Involvement* is a psychological state experienced as a consequence of focusing one's energy and attention on a coherent set of stimuli or meaningfully related activities or events.
>
> …
>
> *Immersion* is a psychological state characterized by perceiving oneself to be enveloped by, included in, and interacting with an environment that provides a continuous stream of stimuli and experiences.' (Witmer & Singer 1998, italics in the original)

The authors state that by focusing the attention a person will get more involved and will as a consequence experience a higher sense of presence. They call presence similar to the concept of selective attention which "refers to the tendency to focus on selected information that is meaningful and of particular interest to the individual." According to Witmer & Singer research has shown that attention is guided by the meaningfulness of the information presented.

Presence as Non-Mediation

Lombard & Ditton (1997), and recently Lombard (2000) have tried to get to a better explication of the concept of presence. Lombard & Ditton (1997) gave an overview of the different conceptualizations proposed on presence, and tried to get to a definition of the concept that encompassed these conceptualizations. The authors defined presence as 'the perceptual illusion of non-mediation.' In Lombard (2000) this definition was further explicated:

> 'Presence (a shortened version of the term "telepresence") is a psychological state or subjective perception in which even though part or all of an individual's current experience is generated by and/or filtered through human-made technology, part or all of the individual's perception fails to accurately acknowledge the role of the technology in the experience (Lombard 2000).'

The different conceptualizations as identified in Lombard & Ditton (1997), reappear in a somewhat modified form as the dimensions of the presence concept in (Lombard 2000). These dimensions, which are in many cases non-orthogonal and overlapping, have been termed "spatial presence," "sensory presence," "social realism," "engagement" and "social presence." Some scholars have argued that these types of presence should be divided into those that involve perceptions of physical environments, those that involve perceptions of social interaction, and those that involve both of these. We will shortly go into the dimensions of

[1] Witmer & Singer's definition of immersion is not the one that is used in this report. For the definition of immersion used in this report see the paragraph Presence by Immersion.

presence below, as they provide a good overview of the different presence concepts that have been proposed in recent years.

- "Spatial presence," "physical presence," "a sense of physical space," "perceptual immersion," "transportation" and "a sense of being there" occurs when someone believes that she or he is in *another physical location*, and she or he fails to acknowledge the role of the technology making it appear as such.
- "Sensory presence," "perceptual realism," "naturalness," "ecological validity", and "tactile engagement" occur when someone believes that she or he is in a physical location in which the *sensory characteristics correspond to those of the physical world*, and she or he fails to acknowledge the role of the technology making it appear as such.
- "Social realism" occurs when someone believes that she or he is in a physical location in which the *social characteristics correspond to those of the physical world* – that is the objects, events, and people do or could exist in the real world – and she or he fails to acknowledge the role of the technology making it appear as such.
- "Engagement," "involvement," and "psychological immersion" occur when someone's *perception is more or less directed toward the virtual environment*.
- "Social presence" occurs when someone believes that she or he is *communicating with other people or entities*, and she or he fails to acknowledge the role of the technology making it appear as such. Examples of social presence are "social actor within the medium" or "parasocial interaction" when one-way communication is thought to be two-way communication, "co-presence" or "transportation: shared space" when someone believes she or he is in the same physical location as someone else, and "medium as social actor" when someone believes she or he is communicating with an entity when it is in fact technology or medium.

The explication of the concept of presence given in (Lombard 2000) has some further remarks on the nature of presence. First of all, it states that in a way all experience of the physical world is mediated, namely by the human senses. This experience, also known as "first order" mediated experience, is our "normal" perception of the physical world. In this terminology, presence occurs when a person misperceives an experience mediated by technology, a so-called "second order" mediated experience, as a first order mediated experience.

Furthermore, the explication statement sees presence as a property of an individual and hence it will vary across people and time. Presence is not a property of technology, although similar technologies will generate similar sets of presence responses across people and time.

Lombard (2000) goes on to state that presence varies in degree depending on how much someone acknowledges the role of technology. It is also thought to occur "instant by instant." However, the manner in which presence varies at a certain instant, in a continuous or more in a dichotomous fashion, is still unclear (see the paragraph on "exclusive presence" for more detail).

The Ecological View

The following paragraphs will describe the Ecological View by first going into the basic ideas behind it. Then the Ecological View will be presented by comparing its ideas to those of the Traditional View. Finally, some explications of the Ecological View by different authors will be given.

Basic Ideas

Recently presence research has taken interest in what could be called the phenomenological or ecological stance, based on Gibson's ecological approach to visual perception (Gibson 1979) and Heidegger's phenomenal existentialism on the nature of human existence (Flach & Holden 1998, Zahorik & Jenison 1998, Mantovani & Riva 1999). O'Brien et al. (1998) gave a summary of the fundamental ideas that lay at the heart of this approach; they revolve around the idea of interactions with objects being "ready-to-hand," the environment offering situated affordances and the idea of perception and interpretation being one intersubjective activity. We will now elaborate somewhat on these fundamental ideas of this approach.

Interactions with objects are "ready-to-hand" The idea that our interactions with objects, are "ready-to-hand" is based on Heidegger's view on the nature of existence as "being-in-the-world" (Zahorik & Jenison 1998). In this view we are "thrown" into everyday situations, continually acting and interpreting and thereby not being able to 'represent the situation at hand in a detached analytical fashion.' During "concernful" interactions with objects, we do not have stable representations of these objects. The objects become transparent to us, or in Heidegger's terms "ready-to-hand." O'Brien et al. (1998) also mention our *social* interactions, and the role of practice and experience in this subject:

> 'We are a member of a social and a *physical* world. Many aspects of both our social interactions and our interactions with the material world are known *tacitly* or *bodily*. This is a result of practice and lived experience. The situated nature of practice and experience allows tools, objects, and spaces to "melt" into the activity, to become "ready-to-hand".' (O'Brien et al. 1998, italics in the original)

The environment offers situated affordances The term affordance was coined by Gibson (1979) and is meant to describe the possibilities or opportunities that the environment[2] offers or affords the animal.[3] For example, the ground affords walking, a chasm affords falling and hurting, an apple might afford eating and a

[2] Gibson defines the environment as the surroundings of an animal, containing substances, surfaces and their layout, enclosures, objects, places, events and the other animals.

[3] Gibson explicitly uses the term "animal" to include all organisms that perceive and behave (thus excluding plants).

tiger affords being eaten. Gibson states that in this 'theory of affordances' perception not only serves and controls what to do or not to do, i.e. behavior, but also depends on it. In other words, animals perceive the environment in terms of the possible interactions with it (Schuemie 1999).

Gibson emphasizes that his term affordance means to express the complementarity of the animal and the environment; that is, a particular affordance is dependent on both environment and animal. The surface of water in a ditch does not afford support or walking for humans, but it does for water bugs. O'Brien et al. (1998) stresses the situated nature of affordances:

> 'The affordances of the material world (environments, objects, tools, etc.) are the physical and interpretative constraints and possibilities we find. They, too, are situated – tied to the here and now of activity and practice.' (O'Brien et al. 1998)

Perception and interpretation as one intersubjective activity O'Brien et al. states that in this view, perception and interpretation are seen as one activity, tied to 'grammars' of interaction, which is also social and intersubjective.

> 'We do not simply "soak up" stimuli from the material world through our sensory apparatus, process them, and put together a representation of the situation at hand and *then* act. Rather, perception and interpretation are one activity. This activity is tied to "grammars" of human interaction and sense making …. It is part and parcel of us being, continuously and inescapably, a member of a social world. It is itself social. Like any other knowledge, practice, or habit, perception is intersubjective. There are ways of finding out about or even create new "grammars," which means that we are creative in what and how we perceive and experience things, but *within* the social, intersubjective world.' (O'Brien et al. 1998, italics in the original)

The Ecological View Compared to the Traditional View

Flach & Holden (1998) propose Gibson's ecological theory as a 'possible foundation for understanding and measuring the reality of experience (i.e. presence or immersion).' They state that the approach implies that the perception/action coupling becomes central in design for virtual reality. In this view the fidelity of a simulation is determined by 'the dynamic interplay between visual, acoustic and tactile feedback and the actions of looking around and manipulating objects' and not on 'the quality of visual or acoustic images.' Also, the experience of space is determined by 'degrees of freedom on action, rather than by the resolution or dimensionality of the displays.'

Zahorik & Jenison (1998) provide the Heideggerian/Gibsonian view as an alternative to the "rationalistic orientation" in presence research, what in this article has been called the Traditional View. They argue that this alternative view provides 'needed guidance and simplification for the evaluation of presence.'

Zahorik & Jenison give the following observations in proof of the rationalistic underpinnings of presence research:

- The subject / object distinction in presence measurement with subjective and objective measurements and considerations as to the possibility of differences between the results from these two types of measurement.
- The assumption in a number of works on the 'existence (and primacy) of mental representations, a further rationalist mainstay.' From this 'it is clear that common consensus holds a strict distinction between mental and physical worlds, and further, it is representations that bridge the gap between these two worlds.'
- Virtual reality research may be criticized similarly as artificial intelligence research (rationalist) has been criticized 'for assuming that it is possible to specify all relevant environmental information atomistically.' Zahorik & Jenison argue that this is the case when presence is being conceived 'as being contingent upon transfer of a sufficient amount of information so as to properly specify the geometry and kinematics of the particular environment being modeled to the user.'
- Finally, Zahorik & Jenison provide another clue to a rationalistic orientation when they contend that the term *virtual reality* seems to suggests that there is no doubt about the existence of "real reality" and next refer to the 'never … successfully disproven' solipsism, 'the view that the physical world does not truly exist, all that exists are subjective, mental worlds.'

Zahorik & Jenison identify some problems that would be inherent to this rationalistic view;

> 'Researchers are forced to continually relate subjective feelings of presence to objective facts of presence …, both through theory and measurement. Further, appeal to representations as the relational engine gains nothing, arguably, since such representations are not subject to independent confirmation. The atomistic formalization of relevant environmental properties is additionally problematic.' (Zahorik & Jenison 1998)

The authors propose an alternative view, based on Heidegger's phenomenal existentialism and Gibson's perceptual theory, which would avoid these problems.

They define presence by stating that 'Presence is tantamount to successfully supported action in the environment.' They state that actions are "successfully supported" when the response of the environment to an action is lawful, that is, 'commensurate with the response that would be made by the real-world environment in which our perceptual systems have evolved.' They note that where others see action as *one* of the presence determinants, in this view successfully supported action is a necessary and sufficient condition.

According to Zahorik & Jenison 'Gibson and Heidegger deny that any type of subjective component of presence exists … under conditions of concernful action in the environment.'

Furthermore, the authors state that virtual reality systems 'by design … have formalized environmental responses to the actions of the perceiver / actor.' They propose that presence examination is then possible by assessing the lawfulness of the perception / action coupling, or the actions of an actor by comparing the actions to those in a similar real-world analogue.

They state that a virtual reality system, with its formalized environmental responses to the actions of the perceiver / actor, which is truly similar to the real-world in respect to its actor dynamics, is actually a formalization of lawful ecological perception / action coupling and thereby of presence.

Mantovani & Riva (1999) also argue for the importance of the perception / action coupling inherent to the ecological approach: 'More than on precise presentation of static, computer-generated scenes, sense of presence may depend on the availability of information about spatial and temporal changes related to actor's movements in the simulated environment … Emphasis shifts from quality of image to freedom of movement, from the graphic perfection of the system to the actions of actors in the environment.' This might explain, as Mantovani and Riva suggest, the sense of presence experienced in MUDs (Towell & Towell 1997 as cited by Mantovani & Riva 1999).

Presence as Extended from the Real World to the Virtual World

As a continuation to the ecological view, O'Brien et al. (1998) concluded from ethnographic fieldwork in a multimedia art museum that the sense of presence 'is not "split off" from presence in "real world" but, rather, *extended* from the real to the virtual space' (italics in the original). They emphasize that real world activities and events and virtual world activities and events are relevant to each other, and argue that real world competencies of orientation, movement and interaction in space are drawn upon and 'transposed' into virtual worlds. This transposing, they argue, happens when strategies of working around difficulties are used, which takes place 'through the adjustment of everyday practices to the affordances of the mediating technologies.' Transposing also arises 'from possibilities that exceed the affordances of real situations.'

O'Brien et al. go on to state that the principle of intersubjectivity is a basis for interactions between people and between people and their material environment.

> 'What we say, perceive, or do is part and parcel of a world known in common (Schutz, 1962). In our actions, we assume that others know the world and the situation at hand in ways that are similar to how we know them, and we assume that the material world is arranged in a way that draws on and refers to such common knowledge. Thus, not only do we assume to see the same objects and events that others see, we also take for granted that we

> interpret them – for all practical purposes – in the same way as they do (O'Brien et al. 1998).'

From all this the authors come up with a somewhat different definition of presence, which they consider to be 'a constructed phenomenon where users draw upon resources within the environment to construct some sense of presence within the environment.' They argue that we can design and interpret a diversity of environments and that for a sense of presence facilitation of intersubjectivity is more important than 'visual appearance and "material" structure of an environment, its physical laws, and the affordance it provides.'

Finally, O'Brien et al. claim that for intersubjectivity 'some of the factors [people] could be seen to rely upon include an understanding of:'

- The sequence of action / events in the environment and their effect.
- Continuity of material arrangements, sensory clues, people's and agent's actions.
- Reciprocity of perspective across and between users sharing the environment.
- Membership of the environment and different forms of interaction users have with this environment.

Presence as Social Construction

Mantovani & Riva (1999) also discuss the prominent conceptualization of reality, which they call ingenuous realism (which Zahorik & Jenison (1998) termed the rationalistic tradition) and state that this view 'could reduce the potential of virtual environments as cultural tools intended to support human knowledge and action.' Their 'cultural perspective' sees presence as a social construction. "Reality", they argue, is not 'out there in the world, somewhere "outside" people's minds, escaping social negotiation and cultural mediation; reality is co-constructed in the relationship between actors and their environments through the mediation of the artifacts ….'

The authors state that their approach takes up and expands the ecological approach in presence research that neglects, to their opinion, the social and cultural dimension of experience. The approach, contrary to the ecological one, does recognize that experience is culturally mediated and immersed in a social context, and does emphasize the ambiguity of everyday situations and culture's function of clarification of this ambiguity. As an example they state that everyday action is 'part of a strategic game' (March 1991) and as such a joint effort with goals and several actors, which is based on distributed knowledge and coordinated actions embedded in cultural modes, that is the ways of doing things.

Mantovani & Riva (1999) break down their concept of presence into the following formulas:

- 'Presence is always mediated by both physical and conceptual tools that belong to a given culture.'

- ‘The criterion for presence does not consist of simply reproducing the conditions of physical presence but in constructing environments in which actors may function in an ecologically valid way.’
- ‘Action is essentially social (as knowledge in everyday situations is often distributed among various actors and various artifacts).’

The authors state that the quality of presence depends more on ‘the capacity to produce a context in which social actors may communicate and cooperate,’ a social context which for virtual reality is mainly composed of ‘symbolic references that allow actors to orient and coordinate themselves.’

Estimation Theory

Sheridan (1999) states that the uncertainty we have about the reality of perceptions of VE's are closely related to those of perceptions of reality. In an attempt to combine ecological and traditional rationalistic theory Sheridan proposes the estimation theory, which states that we can never truly know objective reality but are continuously making and refining a mental model which estimates reality, based on our senses and interaction with that reality. In Sheridan’s view, objective reality is ‘what one converges to in a sufficiently stable environment,’ using the proper methods and measurements. It is the limiting case of the estimation model, and thus, the “real” reality is a ‘best practical refinement of the virtual reality.’

Sheridan believes that this estimation theory could, as far as man’s interactions with the environment is concerned, accommodate both the traditionalistic rationalist position and the Heidegger-Gibson position. He contends that in our interactions with the world we make use of both mental models in the brain, based on experience, and of the affordances in the environment.

The Embodied Presence Model

Schubert et al. (1999a, 1999b) also stress their belief that not so much the presentation of stimuli is what causes a sense of presence, but rather the user’s interaction with the virtual environment on various levels, i.e. ‘the bodily and cognitive activity of the user.’ They have therefore proposed a theory and an accompanying model in which two popular ideas in presence research, related to this belief, could be combined: the idea on the importance of the body and the idea on the role of mental models for the development of a sense of presence. The first idea on the emphasis of the body in presence research, with the emphasis of ‘bodily action and motor processes for perception,’ was discussed earlier with the review of the ecological view in presence research. The view that mental representations play a role in the development of a sense of presence is also

visible in a lot of work on presence research, as may become evident from this report.[4]

Schubert et al. (1999b) base their theory and the so-called embodied presence model on the embodied cognition framework of Glenberg (1997) which, according to the authors, incorporates the two aforementioned ideas on the importance of mental models and the emphasis on the body. They state that 'the cognitive representation of an environment consists of possible patterns of actions' thereby capturing our relation with objects in the environment, and thus 'forming the meaning of a situation.'

With the embodied presence model, Schubert et al. (1999a, 1999b) propose an interpretation of presence as 'embodied presence' in the sense that they see presence as the outcome of mentally representing possible actions in the world. They state that 'presence develops from the representation of navigation (movement) of the own body (or body parts) as a possible action in the virtual world (Schubert et al. 1999b).' In this development of presence a mental model is constructed of the virtual space and possible actions herein. They see this mental model as an outcome of the active interpretation of the virtual environment.

The embodied presence model would predict two components for presence; one for the focus on the virtual environment and one for the mental construction of a space.

> 'On the basis of the presented theoretical model, the following predictions can be made. Presence should involve at least two components: One component related to the suppression of the actual environment and the focusing on the VE, and a second component related to the mental construction of a space out of the VE in which the body can be moved.' (Schubert et al. 1999b)

In an experimental study involving 246 users of mainly game-based virtual environments these two predicted components were confirmed. However another component, "realness", for the sense of reality attributed to the virtual environment, also emerged from the study although it was not predicted from the model (Schubert et al. 1999a). The Embodied Presence Model and especially the related questionnaire will be described in some more detail in the paragraph on the Measurement of Presence and Presence Components.

1.2 EFFECTS OF PRESENCE

This paragraph tries to answer the question why a sense of presence is desirable in the first place, or in other words what it can be used for. For presence to be useful

[4] Zahorik and Jenison (1998) provide a good review of the manifestation and role of the mental model concept in presence research.

and applicable in practical situations it is important to understand the effects or consequences of presence. As mentioned earlier, this subject has been dealt with in more detail in the accompanying article (Schuemie et al. 2000b) as given in appendix A; from that article a short summary of the usefulness of presence, and thus its relationship to other constructs will be given here. In this it will focus on the relationship that is relevant for this report: the relationship of presence on emotional responses such as fear.

Emotional Responses

Perhaps one of the most important consequences of presence is that a virtual experience can evoke the same reactions and emotions as a real experience. Because this effect is most relevant for this report some experiments on this subject will be reviewed.

Hodges et al. (1994) in a between-subject experiment with 10 subjects on a wait-list and 10 subjects being treated for fear of heights in VR showed that the subjects, who were all acrophobic, did show increased subjectively reported anxiety when confronted with height in the VE. They further showed that treatment in VR reduces acrophobia when compared to the waiting list. Later experiments around the world confirmed their findings, also for other phobias.

Regenbrecht et al. (1998) investigated the relationship between presence and fear of heights, both measured by questionnaires. In an experiment with 37 non-phobic subjects they did not find a significant correlation between presence and fear. A regression analysis did show that presence was the best predictor of fear. Schuemie et al. (2000a), in an explorative study with 10 subjects being treated for fear of heights, did find a significant correlation between fear and presence reported on questionnaires, but no significant correlation between presence and reduction of acrophobia (also measured through questionnaires).

North et al. (1998) found that people can show signs of fear of public speaking when confronted with a virtual audience. Slater et al. (1999) in a between-subject study with 10 subjects and 2 conditions (positive and negative audience) showed that, in a regression analysis, presence tended to amplify subject's response to the audience. In other words: People experiencing a higher level of presence were prone to report more negative reactions to a negative audience and more positive reactions to a positive audience.

When confronted with visual cues suggesting motion, a person will tend to correct for the perceived motion by adjusting their body posture. Freeman et al. (2000) in an experiment with 22 subjects investigated the relationship between reported presence and postural responses. No significant correlation was found however.

In conclusion it can be argued that the usefulness of presence for evoking emotional responses such as fear, and thus its usefulness for phobia treatment of for example fear of heights or public speaking, has a reasonable amount of empiric evidence, but that the relationship remains somewhat disputed. Another problem here is that only weak evidence for a relationship between presence and emotional responses such as fear has been found, and that no study has yet addressed the causality of this relationship. In other words, it is still unclear whether higher measured presence causes stronger emotional responses in a VE or the other way around. Nevertheless, the prevailing belief is that the sense of presence does have a positive effect on these emotional responses.

Other Effects

Based on the current status of presence research much uncertainty remains as to other effects that presence can have. Presence, when defined as a subjective sensation such as "being there," can be a goal in itself for certain applications such as games and movies. Another important research area in this respect is whether presence can contribute to better task performance in VR, for instance in lecturing and memorizing. This relationship between presence and task performance has been the subject of many studies but despite this remains controversial. Still another consequence of using VR is that it can cause nausea and dizziness, a phenomenon known as "simulator sickness." However, the relation between presence and simulator sickness is disputed as well.

1.3 MEASUREMENT OF PRESENCE AND PRESENCE COMPONENTS

For the measurement of presence we refer again to Schuemie et al. (2000) and give a short summary from that article below. However, the view and questionnaire by Schubert et al. (1999a) will receive more attention here, because of the importance the Embodied Presence Model has for this report.[5]

For the measurement of presence a distinction can be made between subjective measures, requiring introspection by the subjects, and objective measures. Objective measures can further be divided into behavioral and physiological measures. These types of measurement will shortly be reviewed below.

[5] Reasons for the relatively detailed treatment of the Embodied Presence Model were given in the conclusion of the paragraph Ontology of Presence.

Subjective measures: Questionnaires

The most commonly used measures in presence research are based on subjective ratings through questionnaires. Presence questionnaires are all originally developed from certain theoretical views on the concept of presence. This basis determines the scope of the questionnaires as well as the relevant application domain. In turn, the measures are used to refine the theories on which they are based. Techniques such as factor analysis show that there are several major components in reported subjective sensations on presence, and that these components are related. However, the relationships between these components and the concept of presence may not be assumed as given, and depends in part on the definition of presence used. Also, the components found depend very much on the original scope of the study and its related questionnaire. This is obvious for instance in the non-interactive design of Lombard & Ditton's experiment (2000). Another example is the Kim & Biocca (1997) questionnaire with its limited number and diversity of questions, which therefore was limited in the number and diversity of factors found. And finally, subjective measures can be prone to errors. For instance, prior experience in VR can affect the rating of presence (see for example Freeman et al. 1999, and Welch et al. 1996).

The Igroup Presence Questionnaire (IPQ)

This paragraph will review the Igroup Presence Questionnaire (IPQ), and will also present the components of presence that have been found through the combination of this questionnaire with the factor analysis method. The IPQ is given in appendix B of this report. Schubert et al. (1999a) constructed the IPQ by combining previously published questionnaires, among which those of Witmer & Singer (1998) and Slater & colleagues (Usoh et al. 2000), with a questionnaire from earlier research (Regenbrecht et al. 1998) and some newly developed questions on technological and context variables. The resulting 75-item questionnaire was submitted to 246 volunteers, most of who were male subjects using desktop-based VR game systems. From a factor analysis eight factors were extracted; three of these were found to be concerned with presence itself, and five were identified as immersion factors. The presence factors, which entailed only subjective reports of how users experienced the VE, were:

- *Spatial presence* (SP), the relation between the VE as a space and the own body.
- *Involvement* (INV), the awareness devoted to the VE.
- *Realness* (REAL), the sense of reality attributed to the VE.

The immersion factors, which the authors describe as the factors concerned with descriptions of the interaction of the user with the VE or with descriptions of the technological side of the VE, were:

- *Quality of immersion* (QI), the sensory quality for richness and consistency of the multimodal presentation.
- *Drama* (DRAMA), the perception of dramatic content and structures.
- *Interface awareness* (IA), the awareness of interfaces that distract from the VE experience.
- *Exploration of VE* (EXPL), the possibility to explore and actively search the VE.
- *Predictability* (PRED), the ability to predict and anticipate what will happen next.

The authors contend that the factor analysis provides supporting evidence for a distinction between reports on subjective experiences - the presence factors - and reported evaluations of the technology - the immersion factors. Furthermore, the two factors spatial presence (SP) and involvement (INV) support the distinction between a spatial-constructive and an attention component. This distinction was postulated earlier by Witmer & Singer (1998) and was also derived by the authors from the Embodied Presence Model. Finally, Schubert et al. (1999a) state that the two factors SP and INV together load on a first second-order factor, which thus might be a general presence factor. Though not predicted by the model and to the authors' surprise a third factor "realness" also loaded on this general presence factor. Schubert & colleagues calculated the internal consistency of IPQ over two studies to be 0.85 and 0.87 (Cronbach's α; N = 264, N = 296).

Other subjective measures

Instead of administering a questionnaire only after a virtual experience, IJsselstein & De Ridder (1998) proposed a continuous measure of presence during the experience using a slider operated by a participant. Slater & Steed (2000) proposed another measure of presence, a presence counter which measures the number of transitions in presence, that is, the number of times a participant indicates that the sense of presence is broken. Based on a simple Markov Chain model, this counter is used to estimate the relative time the person was present in the virtual world. Finally, Freeman & Avons (2000) used Focus Group Exploration, to gain more qualitative insight into the concept of presence. This method requires small groups to discuss a topic, in this case people's experience while watching stereoscopic TV. Results show that non-experts describe sensations of presence, and are relating presence to involvement, realism and naturalness.

Objective measures: Behavioral

As mentioned in the section on effects of presence, people tend to respond to mediated stimuli as if they were unmediated when they experience a high level of presence. Examining people's reaction to mediated stimuli could provide an

objective measure of presence. Sheridan (1996), for example, proposes measuring reflex responses, such as automatically trying to catch a ball or trying to avoid a rapidly approaching object. Prothero et al. (1995b) propose "class A" measures of presence, which measure subjects responses to virtual cues when subjects are also presented with conflicting real cues. O'Brien et al. (1998) used an ethnographic approach to study user's behavior, analyzing human to human interaction in multi-user VEs. This lead to more qualitative insight in the nature of presence, linking presence to the concept of intersubjectivity, i.e. the things people know in common.

Objective measures: Physiological

Sheridan (1992) warns that presence is a 'subjective sensation, much like "mental workload" and "mental model" – it is a mental manifestation, not so amenable to objective physiological definition and measurement.' However, several experiments found a significant correlation between the physiological measurement of skin conductance and the sense of presence. Still, it is important to note that skin conductance, like most physiological measures, is related to arousal and not directly to presence.

1.4 SUMMARY

This chapter introduced the theories and ideas on the nature of presence that have an important place in immersive virtual reality research. Three important views were presented; the Traditional View, the Ecological View, and the Embodied Presence Model. The Traditional View sees presence mainly as a result of immersion or involvement, emphasizing the quality of the visual or acoustic display of the VR experience. It also has a certain rationalistic orientation, which is visible for example in its subject / object distinction and its reference to mental representations. The Ecological View, on the other hand, sees presence more as a result of successfully supported action and as a social construction, emphasizing the importance of a lawful perception / action coupling.

However, it can be seen that these two views do not necessarily contradict each other, although they can have different implications. This is apparent, for example, in the view by Schubert et al. (1999a, 1999b) with the Embodied Presence Model, but also in Sheridan's Estimation Theory (1999). These two theories have tried to combine the Traditional and the Ecological View, referring to the use in interaction of both mental models and affordances in the environment, and the importance of the perception / action coupling.

It seems that in much of the work on the sense of presence human's interaction with the environment is seen as an important, or even the prominent cause. This is more or less evident, for example, in the description of the traditional view given before, particularly in Slater & Wilbur's (1997) definition of immersion, and in the proposed dimensions of presence by Heeter (1992) and Lombard (2000).

However, the belief that interaction is crucial for a sense of presence is especially visible, and naturally so, in those views that adhere to the described ecological view. This was evident in this report from Flach & Holden's (1998) view on the importance of interaction in the experience of space and the fidelity of a simulation, as well as from Zahorik & Jenison's (1998) definition of presence as successfully supported action. Furthermore, it is visible from Mantovani & Riva (1999) emphasizing freedom of movement and actions of actors in the virtual environment and from the Embodied Presence Model of Schubert et al. (1999a, 1999b) in which presence develops from mentally representing bodily actions.

The description of the ecological view given above already touched upon the main subject of this report, that is the relationship between interaction and a sense of presence. Zahorik & Jenison's (1998) view on the lawfulness of 'feedback' by the environment, the principle of intersubjectivity of O'Brien et al. (1998), and Mantovani & Riva's (1999) social context all give clues as to the nature of this relationship.

This relationship will be examined in more detail later, after the concepts of interaction and interactivity have been dealt with in the next chapter. In that examination, and in following research, the Ecological View, and especially the Embodied Presence Model, will have an important place. The main reason for this is the focus of both on the importance of human's interaction with the environment. Furthermore, the Embodied Presence Model also seems to be one of the more elaborated and complete models, and has seen a fair amount of empirical testing. Finally, the model seems to accommodate two important subjects in presence, namely involvement and spatial presence.

In the paragraph on effects of presence a short summary of different effects or consequences of presence were reviewed, while special attention was paid to the effect of presence on emotional responses. The review also described the effect presence is thought to have on other things such as task performance, and simulator sickness. As said, these effects determine the usefulness of presence. However, after several empirical studies and theories, the relationship between presence and these effects remains a subject of many disputes. Nevertheless, relevant for this report is that the general belief remains that the sense of presence does have an effect on emotional responses such as fear.

This chapter also shortly described several methods of measurement used in presence research today. It reviewed the subjective method of questionnaires. The

Igroup Presence Questionnaire was explicated because it seems one of the more elaborated and tested questionnaires in the field. Next to some other subjective methods of measurement, the objective methods of behavioral and physiological measurement were presented in summary. It was noted that the measurement of presence is done almost exclusively via questionnaires. Such questionnaires are used to refine the theories on presence and, surprisingly, to validate objective measures. A reason for this is the fact that presence theory is still being developed, and questionnaires offer rich feedback required to aid in the understanding of the phenomenon being measured. However, the measurement of presence, just as the concept presence itself, appears to be a complicated subject that still needs quite some research.

2 INTERACTIVITY

This chapter will introduce the second important concept of this report: interactivity. Heeter (2000) qualifies interactivity as overused and underdefined, so it is necessary to start with a clear definition of it, which is given in paragraph 2.1. The human action cycle, i.e. the continuing cycle of our action and reaction by the environment, will be described in paragraph 2.2. In this cycle we use our mental models to make sense of things, as is presented in paragraph 2.3. Paragraph 2.4 then describes how the affordances of the environment tell us what the possibilities for action are. Paragraph 2.5 will then present a new model of four components that determine our interactivity in VR experiences. This PPMC-Model, which emphasizes that not only the medium, but the purpose, the participant, and the content have a crucial effect on interactivity as well, forms the framework for the analysis of the relationship of presence and interactivity in the next chapter.

2.1 DEFINITION OF INTERACTION AND INTERACTIVITY

This paragraph will review the common definition of interaction in the field of VR, that is interaction as modification of, and navigation in the VE. Then it will review another definition, interaction as action and reaction that seems more suited for the design and application of state of the art VR. Finally, this paragraph will define the term interactivity.

Interaction as Manipulation and Navigation – The Predominant Definition

The earliest definitions of interaction in VR research are related to the ability of the user to modify the VE. Zeltzer (1992) calls interaction 'the degree to which VE parameters can be modified at runtime.' Steuer (1992) calls it 'the extent to which users can participate in modifying form and content of a mediated environment in real time.' Lombard (1997) follows this definition, but Slater & Usoh (1994) also emphasize the role of navigation in VR and see interaction as 'the ability of the participant to move through and change the world, that is, navigation and manipulation.' This definition of interaction as navigation and manipulation seems to have become the predominant one in VR research today.

Interaction as Action – Reaction

The above-described definition of interaction as manipulation and navigation seems to have two main objections.

First of all, this view seems to miss the importance of seeing the interaction as a continuous loop of action and reaction. It seems to pull apart the action and reaction parts of interaction, and focus on interactivity being mainly the action component, i.e. the modification or manipulation. This is also more or less visible in Steuer's (1992) categorization of presence into vividness[6] and interactivity factors, and his definition of the contributing factors of interactivity of speed, range and mapping.[7] Arguably, the view of interaction in its completeness, i.e. as action and reaction, provides a better foundation for the view presented in the next chapter. That view, of interaction being engaging and comprehensible, seems

[6] Steuer (1992) defines vividness as the 'representational richness of a mediated environment as defined by its formal features, that is, the way in which an environment presents information to the senses.'

[7] These factors will be described in the paragraph The Effect of the Medium in the next chapter.

to be better founded on a definition of interaction as action and reaction than on interaction as manipulation of the VE and navigation in the VE.

Second, with the growing popularity of multi-user implementations and artificial beings (avatars) for VR in recent years it could be argued that the definition of interaction as manipulation of, and navigation in the VE is somewhat limiting.

For these two reasons this report will instead use Heeter's definition (2000) of interaction as actions and reactions of a user with the environment:

> 'An interaction is an episode or series of episodes of physical actions and reactions of an embodied human with the world, including the environment and objects and beings in the world. These actions and reactions are actual interactions, a subset of the range of potential interactions of the human and the world at that time and place. (Heeter 2000)'

Heeter also identifies a number of physical aspects and accompanying internal dimensions of interaction. As examples of physical aspects she names the direction of gaze, focal point, body position and motion, speech, and facial expression. For internal dimensions of interaction with the world and ourselves she names selective attention, perception, interpretation, intent, thinking, feeling, imagining, wanting, and anticipating.

Notably, interaction can happen consciously or subconsciously, as we can be more or less aware of our interactions with the environment. Actually, Norman (1998b) states that *much* human behavior is done unconsciously. Examples of interactions that we mostly perform subconsciously or automatically are walking, driving, and eating, but also things like pushing certain door handles *down* to open doors, turning faucets a certain way, or turning a steering wheel clockwise or anti-clockwise to turn right or left. More in general it concerns activities that do not ask too much of our mental competencies, which we always perform the same way, and which we therefore have become used to.

Interactivity

Like interaction, the term interactivity also has many different meanings. In the field of human-computer interaction there are two prominent and almost similar uses of the term. For one, the term is used to indicate the amount of interaction *actually* taking place during a certain period, another more important one is its use to indicate some kind of amount of *potentially available* interaction. This report will use this last definition, and it will be used to qualify the experience with VR; this report thus investigates how interactivity of a VR experience affects the sense of presence.

2.2 THE INTERACTION CYCLE

There is limited knowledge on the nature of the human action cycle, the continuing cycle of action and reaction which in this report will be referred to as the interaction cycle. Not much has changed since Norman noted that at the time 'surprisingly little' was known about the nature of 'action sequences' (1988, p.221). The recent republication of his work still has this note (Norman 1998b).

Published work on the organization of activities has mostly been based on work by Newell & Simon (1972) about Human Problem Solving (Newman & Lamming 1995). There is much similarity, therefore, between the proposed models on this subject; they all basically have a functional form with 'parts that store *knowledge* about the domain of activity, parts that keep track of the *goal* of the current activity, and parts that make *choices* about the next action' (Newman & Lamming 1995, italics in the original).

This report will use one of these models, Norman's action model and the accompanying theory on action to provide more insight in the nature of the interaction cycle. Norman's action model sees human action as a seven stage cycle. The stages, one involving goals, and three each for execution and evaluation, are:

- Forming the goal.
- Forming the intention, the intention to act so as to achieve the goal.
- Specifying an action, the actual sequence of actions that we plan to do.
- Executing the action, the physical execution of that action sequence.
- Perceiving the state of the world.
- Interpreting the state of the world, interpreting the perception according to our expectations.
- Evaluating the outcome, evaluation of the interpretations with what we expected to happen.

It is important to note that these execution and evaluation phase of Norman's action model relate strongly to the action and reaction phase of interactions.

2.3 INTERACTION AND MENTAL MODELS

Mental models, the models we have of ourselves and the world around us, play a vital role in the interaction between human and the environment. In relation to the interaction cycle described above they are especially important in the stages of forming of the intention, in specifying an action, in interpreting the state of the world and in evaluating the outcome (Newman & Lamming 1995). The models are essential to humans for understanding experiences, predict outcomes of actions and handle unexpected occurrences (Norman 1998b).

Norman states that people form mental models of 'themselves, others, the environment, and the things with which they interact.' The models are a conceptual representation of the way objects work, events take place, or the way people behave. The models result, he states, from our tendency to form explanations of things. They are formed through experience, observation, training, and instruction.

Norman notes that our mental models are rather limited in nature, and correspond only partly with reality:

> 'We base our models on whatever knowledge we have, real or imaginary, naïve or sophisticated.
>
> Mental models are often constructed from fragmentary evidence, with but a poor understanding of what is happening, and with a kind of naïve psychology that postulates causes, mechanisms, and relationships even where there are none. (Norman 1998b p.38)'

Furthermore, Norman states, we base our explanations of things we perceive on analogy with past experience. However, this experience may not apply in the current situation (Norman 1998b p.45).

2.4 INTERACTION AND AFFORDANCES

In Norman's view, people form their mental models in their experience with objects, entities and events, by interpreting the perceived actions and affordances.[8] However, mental models and affordances are co-dependent, since the mental model itself is used to perceive the affordances. In this respect, Norman states that affordances result from 'mental interpretation of things, based on our past knowledge and experience applied to our perception of the things about us.'

Heeter (2000) calls VR a designed experience, which is a 'human attempt to structure an environment to create affordances for a human participant.' She also emphasizes that in the design of these experiences, real or intended affordances are not nearly so important as perceived ones.

Smets (1995) stresses that affordances are in a way dimensionless variables, 'not bound to any particular sort of body but to the interaction between mover and

[8] Strictly, Norman's work mainly concerns devices; his view has been applied here for objects, entities and events in general. Furthermore, while this report uses the term affordances, Norman differentiates between affordances, constraints and mappings. For Norman, affordances, constraints and mappings are the possibilities that a device affords and constrains, and the mappings of these possibilities onto visible (or otherwise recognizable) properties of this device. Norman's concepts all fall, arguably, under the wider conceptualization of Gibson's affordances; this report uses Gibson's terminology.

environment.' As an example, the affordance door-passability is thought to be 1.3 times the body width, including any container we may be sitting in.

2.5 INTERACTIVITY DETERMINED BY THE PPMC-COMPONENTS

Interactivity in VR can be described as being dependent on four components that have a role during a VR experience. This paragraph will firstly explicate this new PPMC-view and describe its components. Then, some common views on interactivity in VR, different to this PPMC-view will be reviewed. Finally, it will be argued why the PPMC-view seems to provide better insight in VR interaction than these more common views.

The PPMC-View

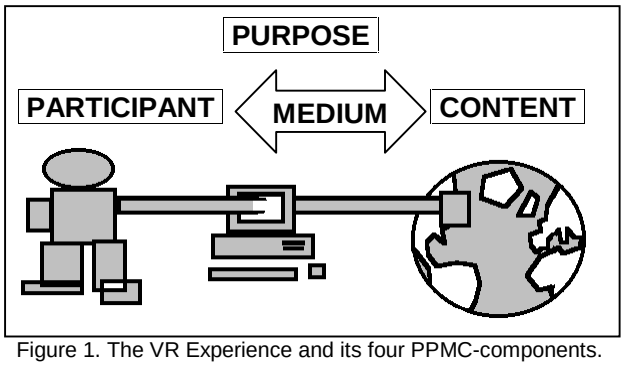

Figure 1. The VR Experience and its four PPMC-components.

The relationship between interactivity and presence is analyzed in this report in terms of VR experiences and four components that are involved in these experiences. The components that can be identified are the Purpose, the Participant, the Medium and the Content of a VR experience, which will also be referred to as the PPMC-components. As will be explicated later, these components have an important and clearly distinguishable role in the effect of interactivity on presence. The model, as depicted in figure 1, is similar to Heeter's PCE model for interaction in designed experiences with Participant, Channels and (Designed) Experience components (Heeter 2000). The main difference with Heeter's model is that the PPMC-model focuses on the purpose and the content of a VR experience as separate components that have distinct characteristics and that have a different effect on each other, on the participant, and on interactivity. Moreover, this report will explore in more detail the effect of these PPMC-components on interaction in VR.

In the PPMC-model, the *Purpose* relates to the purpose or goal of the experience, that is, what the experience is for. This can be, for example, performing a certain task, training people, applying some therapy for treating anxiety disorders, or possibly just for enjoyment. This component has been termed the purpose component instead of, for example, the task component so that it also accommodates VR experiences that do not really involve a task. For some VR experiences, such as when VR is used for enjoyment, but arguably also for therapy

of fear of heights etc., it seems less legitimate and effective to see the experience as a task, which in general is thought to have a certain goal and a rather fixed set of actions in a certain order, and/or clear deliverables. The *Participant* is the person who takes part in and perceives the VR experience, while the *Medium* is the mediating technology applied, that is the display technology such as the Head-Mounted Display and the sound system, and input systems such as a trackers, dataglove, or 3D mouse. In other words, the medium is the system that mediates the content of the experience to the participant, and that transmits the input or commands of the participant to the content. Finally, the *Content* of the VR experience is what is commonly know as the VE, the virtual environment, consisting of virtual objects, entities and events, usually with a virtual representation of the participant as well, but possibly also with representations of other participants. The content also consists of the actions by objects and entities, thus including reactions of these objects and entities to actions by the participant. Notably, much of the content in many cases resides on the same system that makes up the medium, and is often part of, or even intertwined with it. However, the distinction between content and medium, and more in general, the distinction of the four components, will prove to be valuable for the analysis of the effect of interaction on presence.

Alternative Views on Interactivity in VR

Some scholars in the field of VR research have characterized interactivity mainly as a medium trait. For example, Steuer (1992) sees it as something determined by the technological structure of the medium. Lombard & Ditton (1997) in their categorization of factors determining presence, describe interactivity as a factor of the form of the medium. Notably, Lombard & Ditton use the term medium in a broader meaning than used in this report. What will be called medium in this report, that is the mediating technology, seems to be called the form of the medium by the authors. Furthermore, what in this report will be called the content of the VR experience, is seen, in their terminology, as the content of the medium. Also, Lombard & Ditton describe the nature of the task or activity as a variable of the content of the medium, but as stated earlier, in this report the task or activity in a VR experience will be described as part of the purpose of the VR experience.

It seems that much of this difference in terminology poses no real differences in views. However, there seems to be an important difference in the view on interactivity as a variable of the mediating technology or, as will be described below, more as a variable that is determined by all four of the PPMC-components of a VR experience. As will be argued in the following, the view by Steuer and

Lombard & Ditton seems to be too limiting in the analysis of the interaction-presence relationship.

Arguments for the PPMC-View

To begin with, Heeter has argued, more from a communication research point of view, that activity is not only a medium trait but a *user* trait as well. Heeter states: 'Some media are more interactive than others; some receivers are more active than others (Heeter 1989, as cited in Heeter 2000).'

Moreover, in the context of current research and application of VR, this report will focus on interactivity not only as a user and medium trait, but explicitly as something that is also determined by content and purpose of the VR experience.

The *content* or VE of a VR experience can also have an effect on the level of interaction. Interaction in VR happens between the participants and the content of the VE, and is mediated by the VR technology, the medium. Some content can be more interactive than other content; an avatar, for instance a virtual dog, will generally be more interactive than a virtual rock.

Finally, the *purpose* of a VR experience can also affect the level of interaction. The purpose or goal determines what things the user will hope or expect to find in the VE. If the participant set out for a relaxing stroll through a virtual garden, but gets mixed up in a bloody shoot-em-up game, for instance, then a long and pleasant interaction with the VE seems unlikely.

This view of interactivity determined by the purpose, participant, medium and content of the VR experience seems especially helpful and important for the design and application of VR. For one, VR content is getting more interactive, for example with the use and coming of age of agent technology or avatars. However, maybe the main advantage of this PPMC-Model is that it provides a good framework for investigating and describing the relationship between interactivity and presence, as will be evident in the next chapter.

2.6 SUMMARY

This chapter reviewed the concept of interactivity. First, it defined interaction in terms of action and reaction. Then, the interaction cycle was described, including the review of seven goal forming, execution and evaluation sub-processes of this cycle. Furthermore, the chapter reviewed the use of our mental models to make sense of things. It described how these models of ourselves and our environment are formed through our experience, observation, training and instruction. The chapter also described the concept of affordances of the environment, which tell

us what the possibilities for action are. Then, the chapter presented a new view on interactivity in VR: the PPMC-view. It analyzed the PPMC-Model and its four components – Purpose, Participant, Medium and Content – which determine our interactivity in VR experiences. Finally, this chapter presented arguments why this PPMC-Model seems legitimate, emphasizing that not only the medium, but the purpose, the participant, and the content have a crucial effect on interactivity as well. It argued that the PPMC-view provides a good framework for analyzing the relationship between interactivity and presence.

3 INTERACTION'S EFFECT ON PRESENCE

This final chapter hopes to provide some insight in paragraph 3.1 into the way in which interaction can affect presence, and in paragraph 3.2 what the constraints on interaction are in order to enable this effect. Based on these constraints, this chapter in paragraphs 3.3 through 3.6 will then describe how the four PPMC-components, the purpose, the participant, the medium and the content, can affect the interactivity in a VR experience. In doing this, it will point out the possible importance of accepted methods of task analysis and user study, and theories on usability in general for the design and application of VR experiences. It will also review some empirical studies that seem to support the PPMC-view.

3.1 HOW INTERACTION AFFECTS PRESENCE

Still little explicit and concrete information is available on the relationship between interaction and presence in VE's. However, several researchers have expressed their belief that interaction has an important, or even crucial role in creating a sense of presence in VR (Biocca & Delaney 1992, Flach & Holden 1998, Mantovani & Riva 1999, Lombard & Ditton 1997, Regenbrecht et al. 1998, Schubert et al. 1999a, 1999b, Sheridan 1992, Steuer 1992, Zahorik & Jenison 1998). Some scholars have mostly implicitly made suggestions as to the nature of this relationship between interaction and presence. This view, related to the role of mental models, and another view concerning the role of attention and involvement will be described here.

Interaction shaping the Virtual Mental Model

As was evident from the previous chapters, mental models are thought to have an important role in both the sense of presence and in interaction. Much work in presence research, partly described earlier, either implicitly or explicitly expresses the view that during the experience in VR the participant builds up a mental model related to this experience (see for example Biocca 1997, Schuemie 1999, Schubert et al. 1999a, 1999b, Sheridan 1992, 1999, Slater & Usoh 1994, Thie and Wijk 1998). This mental model is thought to consist of some model of the spatial layout of (part of) the environment, a model of possible actions of the body in the VE, and some model of the self, that is, the body and its dynamics. In this view, this mental model is seen as one of the main constructs, or the prominent one, in experiencing a sense of presence. This sense of being with the entities, objects, and events in the VE actually develops from the mental model because it represents the self as being in the VE.

In the previous chapter the important relationship between people's mental models and the interaction with their environment was described. In short, interaction is driven and understood by use of these models of how things work, but our interaction with the world also forms these models.

From this, the relationship that interaction has with presence is now evident. Our interaction with VE's forms the mental model, which enables the sense of presence; interaction confirms our mental model of being in the VE, which, in this report, will be called the virtual mental model (VMM).[9] That is, it *can* do this. Interaction will have to comply to certain criteria, as will be described later on.

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[9] This virtual mental model in a way overlaps people's normal mental models; that is, both types of mental models share some common knowledge of how things work that is general to the virtual and the real world.

Interaction Strengthening Attention and Involvement

Another way in which interaction is related to presence is by its ability to strengthen people's attention or involvement (see also Lombard & Ditton 1997). To be able to successfully interact with something, people in most cases need to focus their attention (see also Norman 1998b). In this way, interaction with objects or entities in the VE can strengthen attention, and in general this will lead people to become more involved in their interaction with the VE. As described earlier, in the field of presence research attention and involvement are thought to be major components in enabling a sense of presence.[10] Furthermore, focusing attention and possibly getting more involved will usually enable better interaction, which makes this a cyclic reinforcing process. However, for interaction to strengthen attention and involvement, and possibly presence, it again has to comply to some criteria.

3.2 WHEN INTERACTION AFFECTS PRESENCE

The criteria that interaction has to comply to so that it can facilitate or strengthen the sense of presence as described above can be described through two basic constraints: interaction has to be *engaging* and interaction has to be *comprehensible*. In short, interaction has to be engaging because otherwise the interaction would not be engaged in, and it has to be comprehensible because otherwise it would not shape or maintain someone's virtual mental model.

In the following, this report will mainly focus on interaction that is comprehensible.

Engaging Interaction

Both possible effects of interaction on presence given above can of course only occur if interaction does indeed take place. Some interaction can only confirm the virtual mental model and can only strengthen attention and involvement if the participant actually *engages* in this interaction. For this, any potential interaction, at least, has to be engaging; it has to be able, first of all, to catch the interest of the participant, but also to keep that interest.

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[10] See the earlier description of presence by involvement (Witmer & Singer 1998), and the description of the Embodied Presence Model by Schubert et al. (1999a, 1999b) in the Presence chapter.

Exactly what characteristics can make interaction engaging lies beyond the focus of this report. It probably has a place in some other fields of research such as the psychology of perception, human factors, empirical aesthetics, and/or ergonomics; we to refer to literature from these fields, but especially in the context of VR it seems an area that needs more attention. However, some general observations can be made, and these will be described in the paragraphs below on the Purpose, the Participant, the Medium, and the Content of the VR experience. Notably, characteristics of some of these individual PPMC-components in many cases have a similar effect on both the comprehensibility and the engagement of interaction.

Comprehensible Interaction

For people to be able to shape and maintain the so-called virtual mental model, as it was characterized earlier, interaction has to be comprehensible, that is, it has to make sense. The virtual mental model, in this respect, is just like our ordinary mental models of things in the real world. To be able to understand and integrate things from a VE with the mental models people already have, these things have to make sense. In other words, these things have to correspond to knowledge people already have.

For interaction to make sense, it has to correspond with the mental models people have of things and events around them, based on their experience, training, observation and/or instruction. Notably, what exactly makes sense is subject to change, is intersubjective and is also socially and culturally determined.

The correspondence with mental models, as mentioned in this definition, will be explicated below. The other parts of the definition will be dealt with in the paragraph on the Effect of the Participant.

Norman's work (1998b) in fact sets the first part of our definition, stating that things make sense when they correspond to knowledge we already have, knowledge which lies in our mental models.

> 'When things make sense, they correspond to knowledge that we already have, so the new material can be understood, interpreted, and integrated with previously acquired material. Now we can use rules and constraints to help understand what things go together (Norman 1998b p.68).'

However, the view that interaction is comprehensible when it corresponds to people's mental models can be found in work on presence research as well. For example, Loomis (1992) states that externalization, which would be closely related to presence, can happen when afference, the sensory input, is 'lawfully related' to

efference, the commands issued to musculature in the body, and when someone is able to model this relationship.

Another example is Zahorik & Jenison (1998) who argue, as described in the Presence chapter, that action has to be lawful to enable presence, that is it has to be 'commensurate with the response that would be made by the real-world environment in which our perceptual systems have evolved.' This definition seems to support the view that interaction has to match, in a way, our expectations, in other words has to correspond to the mental model.

Arguably, the view on the importance of intersubjectivity for presence by O'Brien et al. (1998) as characterized in the Presence chapter, also makes a point for the importance of interaction corresponding to our mental models. Reiterating, the authors claimed that intersubjectivity, in short the things known in common by people, forms a basis for interactions between people and their environment. But it is also more or less evident from their view on the transposing of real world competencies of orientation, movement and interaction into the VE.

The Relation between Engaging and Comprehensible Interaction

Comprehensible and engaging interaction are not independent of each other. Factors that can make interaction comprehensible can for example have an influence on whether or not interaction is engaging, and vice versa. Something that is very comprehensible or easy to do will generally not require much attention or will not be captivating. In many situations, and arguably for activities in VR in particular, people would want the things they do to provide at least a minimal amount of challenge. However, as argued before, things should not get too complicated; if interaction with something in the VE gets incomprehensible it is likely that the participant walks away from the interaction.

However, for subconscious interactions the opposite seems to be the case: our subconscious interactions with the environment probably should be as comprehensible as possible. In everyday life, we become aware of our subconscious interactions if something goes wrong; in this case we blame ourselves or the things we interacted with (also see Norman 1998b). But in VR experiences we probably blame VR, thus losing our sense of presence.

3.3 EFFECT OF THE PURPOSE

This paragraph will describe the way the purpose can affect the comprehensibility and engagement of interaction, and why modeling of the participant's actions can

therefore be useful. It will also give some empirical support for the effect of the purpose.

How the Purpose affects Interactivity

Based on the purpose of the VR experience, for instance a certain task or activity, the participant will have determined, in many cases, some goals, intentions, expectations and/or needs that she or he wants to reach or satisfy, sometimes through some plan for action. In the VR experience the participant will then look for things that can possibly be helpful in this. In other words, the purpose will determine the affordances that the participant wants to find in the VE. In this way the purpose influences what things in the VE a participant judges to be engaging or not. But probably the purpose of the VR experience will also influence what interactions are found to be comprehensible; affordances or interactions that do not seem helpful for that purpose will probably also make less sense.

The Use of Activity Modeling

To be able to provide participants with engaging and comprehensible affordances and interactions in a VE it therefore is useful to perform a task analysis or to model the participant's activities. This way, it is possible to identify what information, objects, activities or even other people, participants are dependent on. Techniques for task analysis and modeling of participant activities as used in the field of Human-Computer Interaction could be helpful in this (see also Hix & Hartson 1993, Newman & Lamming 1995). Norman's action model as described earlier (Norman 1998b) could also prove to be useful. Kaur et al. (1999) tried to demonstrate this; Normans' model was used to determine 'information and usability needs' by developing more detailed models of interaction for a broader range of behavior in VE's.

Empirical Evidence

An experiment by Welch et al. (1996) seems to provide some empirical support for the combined effect of purpose and content of the VE. The authors reported a significant positive effect for interaction on presence in two almost similar experiments. In these experiments interaction was manipulated by either letting the subject drive a car or be a passenger, i.e. be a passive observer. In a study with 19 subjects and 8 conditions in a within-subject design the method of paired comparison was used, a procedure where the subjects are exposed to two VEs and are required to indicate which generated a higher sense of presence.

3.4 EFFECT OF THE PARTICIPANT

What is considered engaging by, or what is comprehensible to someone, depends in part on that participant's cultural and social background, on the experience and knowledge, on the participant's interests, wishes and mood, and on the participant's perceptual, psychological and physical possibilities and limitations. Smets (1995) describes this from the ecological theory of perception:

> 'An organism will be able to detect only those patterns to which it is attuned physically and perceptually as a result of evolution and its own experience.'

As an example, Heeter (2000) states that orientation to interactivity is a personality characteristic and she cites Screven (1999) who studied museum visitors and found different visitor dispositions, and the visitor's context and history to affect the level of motivation, attention, and effort they exert at particular exhibit elements.

In the context of what kind of effect a certain type of participant has on engagement and comprehensibility, the next paragraphs will deal with human's adaptability, the social and cultural influence and the use of a participant study.

Human's Adaptability

Humans are adaptable. What makes sense and what is engaging is therefore subject to change, since social and cultural influences through new experiences, observations, training or instruction can reshape our mental models. For example, Held & Durlach (1992) suggest that 'operator familiarization' through training and appropriate exposure could result in 'appropriate models of the transformed world, task, self, etc.'

Smets (1995) provides an example of human's adaptability. Baby's born without arms have difficulty developing depth perception. When equipped with simple stick-like prostheses that let them reach and touch, depth perception does develop. Depth becomes comprehensible.

Biocca (1997) also discusses the way in which human and technology (and its interface) evolve by their influence and adaptation to each other, creating cyborgs in a way:

> '*The cyborg's dilemma:* The more natural the interface the more "human" it is, the more it adapts to the human body and mind. The more the interface adapts to the human body and mind, the more the body and mind adapts to the non-human interface. Therefore, the more natural the interface, the more we become "unnatural," the more we become cyborgs (Biocca, 1997).'

An interesting example Biocca provides in this respect, is the possibility of some kind of *hyperpresence*, some higher sense of being with others, by providing people optimized social cues.

Slater & Usoh (1994) hint at another example of how mental models could be changed to enable some sort of natural magical interaction in VE's. For instance, zooming out in a VE could be accomplished by enlarging the virtual body through a hand gesture of the hand moving up from the head. This is an example of how people adapt their mental model of navigation to incorporate such magical interaction.

Social Mediation, Cultural Mediation and Intersubjectivity

In line with views by Heeter (1992), Mantovani & Riva (1999), and O'Brien et al. (1998) on presence and reality as something which is socially negotiated and culturally mediated, our mental models, and therefore the things that make sense, are based on knowledge that is also dependent on the social and cultural context.[11] In other words, our mental models are based on experience, observation, training and instruction that is inevitably influenced by the social and cultural setting in which it takes place.

Participant Study

As is evident from the previous paragraphs, the participant will have an important effect on what and to what extent things in a VE are engaging and comprehensible. From this it is obvious that it is valuable to have knowledge of what type of person will be using the VE. Knowledge like this can support decisions during the design and implementation of the VE.

However, there has not been much work done on this specific field yet, and as Kaur (1999) puts it, there is only fragmentary knowledge of some participant issues. The earlier cited work by Screven (1999) only provides some clues. However, as with task analysis methods, the Human-Computer Interaction field provides a reasonable body of literature on user study methods which seem partly applicable (see for example Newman & Lamming 1995).

Furthermore, concerning the participant's experience, motivation and involvement there is an overlap with the research on the sense of presence. In this respect, Witmer & Singer's (1998) work on the Immersive Tendencies Questionnaire (ITQ) is worth mentioning (see also the accompanying article,

[11] The views by Mantovani & Riva's (1999) and O'Brien et al. (1998) on presence were discussed in the Presence chapter.

Schuemie et al. 2000b, as given in appendix A). The authors performed a cluster analysis of data filled in by 152 subjects. The results revealed three sub-scales:

- *Involvement*, the propensity of subjects to get involved passively in some activity, such as reading a book.
- *Focus*, the ability to concentrate on enjoyable activities and block out distraction.
- *Games*, the frequency with which the subject plays games and the level of involvement in these games.

Another theory from presence research seems relevant as well. Slater & Usoh (1993) use the therapeutic technique known as Neuro-Linguistic Programming (NLP) to characterize the user's psychological perceptual system. The NLP model claims that subjective experience is encoded in terms of three main representation systems: visual (V), auditory (A) and kinesthetic (K) and that people have a tendency to prefer one system over the others. Furthermore, when a person represents a memory they tend to choose one of three perspectives: first person, second person (from another person's view) or third person (from an abstract, non-personal view). Slater and colleagues performed several experiments that suggested a relation between presence on the one hand, and the main representation system and perceptual position on the other. Although the theory has a focus on presence, there seems to be a big overlap with the view on the effect of the participant on interactivity as presented in this paragraph.

Empirical Evidence

One experiment by Schubert et al. (2000) seems to provide a little support for our view of the effect of the participant. The authors performed an experiment, with 26 subjects in a between-subject design, with 2 conditions: either the participants were told that the animations in the VE were independent of their actions or they were told the animations responded to the user's actions (it was not said in which way). This illusory interaction did not have a significant effect on overall presence. It did however have a small but significant effect on Spatial Presence (see the IPQ in the Measurement paragraph in the chapter on Presence). This experiment suggests, in our view, that these participants reported an increase in Spatial Presence because their expectations were influenced, which in turn affected their subsequent experience of the VE.

3.5 EFFECT OF THE MEDIUM

The medium of the VE, that is the mediating technology employed, could limit how engaging or comprehensible interaction can be. This could be the case, for instance, if interaction is limited through technology that introduces a big feedback delay. Other examples are that the medium restricts the intensity or resolution of stimuli, and that the medium limits the number of sensory modalities employed. If the medium does not transmit either the participant's actions or the VE's reactions in a sufficient way, the perception of the VE's affordances could be limited, thereby influencing the comprehensibility and engagement of any (possible) interaction.

At best, the medium is or becomes invisible or participants become unaware of it, just like our natural medium, our body's senses and effectors. However, some work in presence research has suggested that at least to a certain degree and for certain aspects people are flexible to this naturalness of the interface (see for example Towell & Towell 1997). Probably, this again depends on whether or not interaction remains comprehensible and engaging, despite any limitations in the medium. In other words, if the VR medium corresponds to or can be integrated easily enough with the model people have created of their natural medium. Thus, the medium should be comprehensible and the medium should be unobtrusive, that is it should *not* be engaging. This issue of the medium being comprehensible and unobtrusive is related to the usability of the medium, which will be discussed in more general terms in the paragraph Effect of the Content.

Of course, knowledge of which factors of the medium have the biggest impact and to what degree is crucial. Although this aspect of VR has received a fair amount of attention in presence research, more than the other PPMC-components, there still remains a lot to be done. In the following, some empirical studies of these factors will be described. This description will follow a categorization based on Steuer's (1992) categorization of the speed, range and mapping of a medium's interactivity. In contrast to Steuer's categorization, our categorization will *explicitly* include factors that relate not only to the action phase of an interaction, but to the reaction phase as well. In other words it can include not only Steuer's so-called interactivity factors, but his vividness factors as well.[12] Both categorizations will be defined in the subsequent chapters on the speed, range and mapping of the medium.

[12] The difference between this report's and Steuer's (1992) terminology and view was discussed in the paragraph Definition of Interaction and Interactivity of the previous chapter.

Speed of Medium

Steuer (1992) defines the speed of the medium as the rate at which input can be assimilated into the mediated environment. In this report the speed of the medium will be defined more in line with Schuemie's (1999) definition as the speed with which the medium responds to inputs by a participant:

The speed of the medium is the rate at which input by a participant can be assimilated into the virtual environment and the resulting changes can be fed back to the participant.

In respect to the speed of the medium Heeter (2000) cites Nielsen (1999) for minimal response times for a media system:

- A response time of 0.1 second so that participants perceive it as instantaneously.
- One second, so that the participant's flow of thought remains uninterrupted although the participant will notice the delay.
- Ten seconds for keeping the participant's attention focused on the dialogue.

Range of Medium

The range of the medium is defined by Steuer (1992) as the number of possibilities for action at any given time, which is 'determined by the number of attributes of the mediated environment that can be manipulated and by the amount of variation possible within each attribute.' Steuer gives examples as the amount of change of temporal ordering, intensity, frequency, and spatial organization. In this report the range of the medium will be defined as a combination of Steuer's and Biocca & Delaney's (1992) definition as the number of inputs from the participant that the medium accepts and to which it responds:

The range of the medium is defined as the number of possibilities for action at any given time and the amount of feedback or reaction to such actions. This is determined on one side by the number of attributes of the mediated environment that can be manipulated and by the amount of variation possible within each attribute, and on the other side by the number of attributes that feed back the manipulation and by the amount of feedback possible from each attribute.

Mapping of Medium

Mapping of the medium is defined to be the ability of a system to map its controls to changes in the VE in a natural and predictable manner (Steuer 1992). Again, this report will define the mapping of the medium more in line with Schuemie (1999) as the degree of correspondence between the type of participant input and the type of medium response:

The Mapping of the medium is defined on one side to be the ability of a system to map the input by the participant to changes in the virtual environment in a natural and predictable manner, and on the other side to be the ability of a system to map the changes in the virtual environment to the output to the participant in a natural and predictable manner.

Empirical Evidence

Related to the speed of the medium, the earlier cited experiment by Welch et al. (1996) found a negative correlation between feedback delay and presence. Feedback delay, the delay between a user action and the response of the display to that action, was set at either the minimum possible with the equipment (which was 200-220 msec) or at an additional 1.5 seconds.

Related to the range of the medium, Hoffman et al. (1996) reported a strong significant effect for tactile augmentation; 14 subjects participated in a within-subject design with 2 conditions. In one condition the subjects could see a ball, in the second condition they could also touch it because a real ball was placed in exactly the same position as the virtual one. Presence was measured using one question.

Related to the mapping of the medium, both Hendrix & Barfield (1996a) and Schubert et al. (2000) found a significant effect for head tracking. In an experiment with a jigsaw-like puzzle, Smets (1995b) found head tracking to be more important than resolution of the display for spatial task performance. Axelsson et al. (2000) found subjects to have a significant higher sense of presence in a CAVE when compared to desktop VR; 42 subjects were required to solve a three-dimensional puzzle together in VR, half of them using a CAVE-system while the other half used desktop VR. However, Barfield et al. (1998) did not find a significant effect for type of input device when comparing a 3 Degrees-Of-Freedom (DOF) joystick with a 3 DOF space mouse in the study already described in the section on vividness.

3.6 EFFECT OF THE CONTENT

The content of some VE will only facilitate engaging and comprehensible interaction, if it offers affordances that the participant wants or needs and if these affordances can be perceived and interpreted correctly by the participant. As described earlier, what affordances are wanted and needed is determined by the purpose and the participant. The correct pickup of affordances is, as will be argued in the following paragraphs, also dependent on the content's usability and possibly the correct social interaction with content.

Content's Usability

Some of the factors that determine whether or not the content of the VE *correctly* displays its affordances are probably similar to the factors in the real world. Thus, the content of the VE should be usable to enable engaging and comprehensible interaction. Usability of artifacts, devices and computers has been the topic of much research and insights from this research are partly applicable to the design of the VE's content. Earlier cited work by Norman (1998b), Newman & Lamming (1995) and Hix & Hartson (1993), provides a good basis in this field.

Although usability in the context of VR is foremost a characteristic of the content of a VE, the purpose, type of participant and the medium of course also affect this usability. Newman & Lamming (1995) for example, describe two important processes, amongst a few others, to get to usable interactive systems: task analysis and user study.

There have been a number of authors who have made explicit references to the importance of usability specifically in the context of VR or other designed experiences (see also Heeter 2000). For example Mantovani & Riva (1999), and Ellis (1996) suggest that the key questions in VR design are: can the participant accomplish the task and acquire the necessary info, does the participant have enough control authority, and can the participant correctly sequence subtasks. Another example is, as mentioned earlier, Kaur et al. (1999) who used Norman's action model to determine general design properties in respect to usability and information requirements.

But Norman's work (1998b) provides more insight into usability in general. Especially worth mentioning are his views of what he calls the cognitive gulfs and his seven design principles.

Norman states that in people's interaction with systems, problems arise from two gulfs between people's mental representations and the physical components and

states of the environment.[13] One, the gulf of execution, relates to the extent in which the system provides actions that correspond to the intentions of the person. The second, the gulf of evaluation, relates to the extent in which the system 'provides a physical representation that can be directly perceived and that is directly interpretable in terms of the intentions and expectations of the person.'

Norman proposes seven design principles to make tasks as easy as possible:

- *Use knowledge in the world and in the head*, by complying to people's mental models and knowledge, using good conceptual models in the design of systems, and using physical, semantic, cultural and logical constraints.
- *Simplify the structure of tasks*, to minimize planning or problem solving, e.g. by providing mental aids, making things visible thus improving feedback and control, by automation but keeping the task much the same, or by changing the nature of the task.
- *Make things visible*, thus bridging the gulfs of execution and evaluation by making visible what is possible and how actions should be done and what the effect of actions is.
- *Get the mappings right*, by exploiting natural mappings. Make sure the user can determine the relationships between intentions and actions, between actions and effects, between actual system state and what is perceivable, and between perceived state and the needs, intentions, and expectations of the user. Things to think about are, for example, the positioning and movement of controls, and timely and correct feedback possibly by graphics or pictures.
- *Exploit the power of constraints, both natural and artificial*, so that the user feels as if there is only one (correct) thing to do.
- *Design for error*, allowing the user to recover from errors, to know what was done and what happened, and to reverse any unwanted outcome.
- *When all else fails, standardize* actions, outcomes, layout, and displays so that people 'can learn it and use it effectively' and standardize as soon as possible to save people trouble, but late enough to accommodate advanced technologies and procedures.

Content's Social Interaction

In the design and application of VR it becomes increasingly important to have knowledge on the characteristics of good social interaction. Firstly, because many VR applications involve participants communicating with each other, a subject which has had a reasonable amount of attention in the field of communications research. Secondly, because our interactions with some systems seem to have a

[13] The gulfs of execution and evaluation are of course strongly related to the two phases of Norman's action model, execution and evaluation. This action model was described in more detail in the chapter on Interactivity.

social character. The following will shortly go into the second reason, and then some guidelines to good social interaction will be reviewed.

Why Content is Social

Lombard & Ditton (1997) state that from several studies (see for example Nass et al. 1995) it has become clear that humans tend to treat computers as social entities, because these computers use natural language, interact in real-time, and fill traditionally social roles. However, this seems to apply not only specifically to computers, but to other things that exhibit basic social cues in general. Heeter (2000) subscribes to this and cites Nehaniv (1999) to emphasize that humans expect these 'entities' to construct a picture of them during the interaction, and that humans expect these entities to have awareness of the history of this interaction.

Norman (1992) as cited in Smets (1995) goes even further stating that systems should interact as humans would:

> 'Just as people need to communicate acts, intentions, and emotional states, to give continual feedback and evidence of expected actions and outcomes, so too will machines have to interact more fully, more completely, to provide the same kind of information. Will we have to repeat the whole ensemble of human emotional and facial expressions in our artificial devices? Yes, I think so. (Norman 1992, as cited in Smets 1995)'

It seems appropriate that this view on systems being treated as social beings also directly, and maybe especially, applies to VR experiences with their content. Increasingly, VE's are being constructed that consist of other users, avatars and other social beings, such that social interactions become a prominent factor. So much so, that in the research on presence a distinction is made between presence and social presence or co-presence: the sense of being together with another social being in the virtual world. This social presence is thought to be a part of overall presence.

What makes Interaction Social

From what has been described in the previous paragraph it could be argued that it is crucial to take factors for good social interaction into account for the design and application of VR experiences.

Nehaniv suggests, for example, that computers should have narrative intelligence, by recognizing narrative structure, expressing narrative structure (storytelling), and having narrative structure (Nehaniv 1999, as cited in Heeter 2000).

Cooper, as another example, describes desirable characteristics for a polite interface, some of which can be intuitively related to engaging and comprehensible interaction: a polite interface should be interested in me,

deferential to me (respectful, attentive), forthcoming (available), have common sense, should anticipate my needs, should be responsive, taciturn about its personal problems, well informed, perceptive, self-confident, should stay focused, should be fudgable, and give instant gratification (Cooper 1999, as cited in Heeter 2000).

As a final example, Norman has the following advice for new and improved interactive interfaces (Norman 1998a, as cited in Heeter 2000). These interfaces should include:

- Central role of language.
- Richer internal representation of data objects including participant history of interaction.
- More expressive interface.
- Designed for expert participants, optimize for people with decades of computer experience.
- Shared control proactive computers and agents without human commands.

Empirical Evidence

Two experiments by Hoffman et al. (1998) and Slater et al. (1998b) seem to provide support for the presented view on the effect of the content. Hoffman et al.'s experiment seems to specifically support the view on content being comprehensible, but at the same time it supports the view on the effect of the participant. The authors found that when chess-pieces in a VE were positioned in a meaningful way, this contributed to a significantly higher sense of presence for experienced chess-players in an experiment involving 33 subjects of 4 categories: non-chess players, weak players, strong players and tournament-level chess players. The meaningfulness then relates to the effect of the content, and the players' experience to the effect of the participant.

Slater et al. found a positive significant effect for body movement on presence; 20 subjects were used in a between-subject design with 4 conditions. The VE portrayed an area with plants, some of which had leaves with discolored undersides. All subjects were given the task of counting the diseased plants. For half the subjects, the plants were of similar height and could easily be inspected while looking at eye height in standing position, for the other half there was greater variance in the height of the plants and the subjects had to move their bodies in order to see the undersides of the leaves. Half of the subjects were given the extra task of also remembering the location of the diseased trees. However, the results of this latter experiment were inconclusive.

A few experiments on social presence or co-presence also seem to be related to this view on the effect of the content. The argument for this is that if the content provides engaging and comprehensible social interaction, it could enable presence as was described earlier. However, the results are still inconclusive. Slater et al.

(1998a) found a significant positive correlation between presence and co-presence in an experiment with 30 subjects. Similarly, Thie & van Wijk (1998) found a significant relationship between presence and co-presence in an empirical study with 48 subjects using desktop VR. In this experiment, social cues however were found to have no significant effect on either social presence or presence. Social cues in one condition were limited because users could not pick their own avatar or nickname, nor could they make gestures. In the second condition this was made possible. In another study by Axelsson et al. (2000) described in the section on the effect of the medium, presence and social presence were not found to be related. Subjects reported higher presence in the CAVE system, but no higher social presence.

3.7 SUMMARY

This final chapter tried to provide some insight into the way in which interaction can affect presence, the main topic of this report. It argued that interaction firstly can confirm our mental model of being in the VE, which was called the Virtual Mental Model (VMM), similar to the way in which our ordinary mental models are shaped and confirmed in everyday life. And it reviewed the crucial part that such a VMM is thought to have in creating or maintaining a sense of presence. Secondly, the chapter argued that interaction in a VE can strengthen attention and involvement in the VE, similar to way in which we need to focus attention, and probably get involved, to interact successfully with things in everyday life. And it reiterated that these mental states of attention and involvement are thought to be major factors for presence.

Furthermore, the chapter presented the view that interaction can only confirm our VMM and strengthen our attention and involvement if it is engaging and comprehensible. It briefly touched on the concept of engaging interaction, and then examined comprehensible interaction in detail. Interaction was defined as being comprehensible if it corresponded to our mental models. The chapter reviewed the fact that such comprehensibility is subject to change, is intersubjective, and that it is socially and culturally mediated. Also, the chapter reviewed the relationship between comprehensible and engaging interaction.

Finally, this chapter then described in more detail how the four PPMC-components – the purpose, the participant, the medium and the content – can affect the engagement and comprehensibility of interactivity in a VR experience. In regard to the effect of the purpose of the VR experience it suggested the use of activity modeling as it being used in the field of Human-Computer Interaction (HCI). For the effect of the participant it reviewed the adaptability of humans and the role of social and cultural mediation, and it suggested that a user study as

used in the field of HCI could provide a valuable tool for the design of VR experiences. With respect to the medium of a VR experience, the chapter looked into different aspects such as the speed, the range and the mapping of the medium. In doing this, it pointed out the possible importance of accepted methods of task analysis and user study, and theories on usability in general for the design and application of VR experiences. In the review of the effect of the four PPMC-components, moreover, some empirical studies that seem to support the PPMC-view were described.

4 CONCLUSION

This report presented the results of a survey of the literature on the sense of presence and interactivity in virtual reality (VR), and especially the relationship between these two concepts. The survey tried to supply more insight into these subjects with the specific aim to facilitate better treatment of phobias using the so-called Virtual Reality Exposure Therapy (VRET).

The first chapter reviewed theories on the nature of presence that have an important place in immersive virtual reality research. Three important views were presented; the Traditional View, the Ecological View, and the Embodied Presence Model. The Traditional View sees presence mainly as a result of immersion or involvement, emphasizing the quality of the visual or acoustic display of the VR experience. The Ecological View sees presence more as a result of successfully supported action and as a social construction, and emphasizes the importance of a lawful perception/action coupling. It reviewed the Embodied Presence Model which can be seen as a combination of the Traditional and the Ecological View, and which entails the importance of the perception/action coupling, and the view that interaction makes use of mental models.

As such the Ecological View, and especially the Embodied Presence Model, seems to provide a solid basis for the examination of the relationship between presence and interaction. Moreover, because we found the Embodied Presence Model to be one of the more elaborated and complete models, which also has seen a fair

amount of empirical testing, and can accommodate two important subjects in presence, namely involvement and spatial presence.

The first chapter of this report and the article we referred to (Schuemie et al. 2000b) also reviewed the reason why we are interested in the sense of presence: because it is thought to be a major factor in evoking anxiety. Presence therefore seems important for the treatment of phobias in VR, as in the case of Virtual Reality Exposure Therapy (VRET). And, although the relationship between presence and emotional responses such as anxiety remains somewhat disputed, the general belief is that presence does have a positive effect.

Furthermore, it is important for any research on presence to have a good method of measurement of presence. This subject was therefore reviewed as well in the first chapter and the accompanying article (Schuemie 2000b), and it was stated that this subject remains somewhat problematic and needs more research. It described the Igroup Presence Questionnaire in detail, as it appears to be one of the more reliable and valid means of measurement of presence.

The other concept that was reviewed in detail in the second chapter is interactivity. The report tried to give a clear definition of this much used and underdefined term: interactivity was defined as the actions by a human and the reactions by the environment. It reviewed the action cycle model as seven sub-processes for goal forming, execution and evaluation, and it described how we make use of mental models and affordances of the environment for our interaction with the environment. But more importantly, this report proposed a new view on interactivity in VR: the PPMC-View. This view models interactivity in VR experiences as something that is determined by four components: the Purpose, the Participant, the Medium and the Content of a VR experience. The report reviewed why this PPMC-View seems legitimate, emphasizing that not only the medium, but the purpose, the participant, and the content have a crucial effect on interactivity as well. Furthermore it suggested that this view provides a good framework to investigate the relationship between presence and interactivity.

The examination of this relationship in the last chapter proposed a view on the effect of interaction on presence based on two arguments. The first argument was that interaction can shape and maintain our mental model of being in the VE, and as such affects the sense of presence. The second argument was that interaction can strengthen attention and involvement in the VE, two factors which are thought to have a prominent effect on the sense of presence. The chapter then contended that in order to do these things interaction had to be engaging and comprehensible. Based on these two constraints the chapter then described, based on the new PPMC-Model, how the four components, that is the purpose, the participant, the medium and the content of a VR experience, can affect the interactivity in a VR experience. In this description, the chapter pointed out the possible importance for VR of theories on usability as used in the field of HCI, and

especially the methods of activity modeling and user study. The chapter also reviewed some empirical studies that seem to support the PPMC-View.

From all this, it can be concluded that the new PPMC-View appears to provide a good basis for analyzing the relationship between presence and interaction in VR, but possibly also for analyzing interactivity in VR in general. It pointed to the possible usefulness of methods of user study and activity modeling for the design and application of VR. Moreover, the report also presented some empirical studies that seem to provide some support for this PPMC-View. However, it is also clear that presence-interaction research as under consideration in this report is complicated: a lot of concepts and relationships remain open to discussion, and therefore need more research. To begin with: this applies to the proposed PPMC-View. The view on the effect of the medium on interactivity seems to be generally accepted, and also has much empirical evidence to support it. But this actually seems to be the only component for which this is the case. Some authors have made suggestions, more or less explicit, on the effect of the other components, but usually in different terms or contexts, and then more in relation to the participant, than to the purpose or content of a VR experience. Furthermore, there seem to have been only a limited number of studies specifically related to the purpose, the participant, or the content. In regard to the combined effect of the purpose and the content, the one experiment that was reviewed seems to suggest a positive effect. Concerning the participant, two studies suggested that expectations of a participant can have an influence on the sense of presence, although in one study no significant effect was found. The experiments on co-presence that were reviewed in relation to the effect of the content provided inconclusive results, but two other experiments seem to support this issue a little.

More research is certainly needed on the usefulness of methods of user study and activity modeling in the context of interactivity in VR. As it seems, there have been no relevant studies that we know of that have been specifically aimed at these subjects, except for the one by Kaur et al. (1999),.

Concluding, it can be stated that the insight into the relationship between presence and interactivity is growing. More research is needed, however, to determine what exactly the role of interactivity is in this respect.

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