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Adaptive Generation of Emotional Impact Using Enhanced Virtual Environments

Abstract

In this paper we introduce novel methods of intensifying and varying the user experience in virtual environments (VE). VEs technically have numerous means for crafting the user experience. Little has yet been done to evaluate those means of expression (MoEs) for their emotional impact on people and to use their capability to create different experiences and subtly guide the user. One of the reasons is that this requires a system which is capable of easily and dynamically providing those MoEs in such a way that they can easily be composed, evaluated, and compared between applications and users. In the following, we first introduce our model of both informational and emotional impact of VEs on users, introduce our dynamic, expressive VR-system, and present our novel evaluation and rating method for MoEs. MoEs can be used to guide attention to specific objects or build up an emotion or mood over time. We then present a study in which users experience 30 selected MoEs and rate their qualitative emotional impact using this rating method. We found that different MoEs can be used to elicit many diverse emotions which were surprisingly consistent among the test persons. With these results, our work enables new ways to make VEs more interesting and emotionally engaging, especially over a longer period of time, opening new possibilities, for example, to increase the motivation for long, stressful, and tiresome training as in neurorehabilitation.

1 Introduction

Dynamical multifaceted virtual environments are known to enhance the interest, the presence, and the quality of the user's experience. For example, neurorehabilitation and virtual environments (VEs) are used together for motivating patients, displaying a feedback of their biophysiological signals or their training results, and guide the motion speed and the frequency of exercises (Holden, 2005; Cikajlo & Matjaĉić, 2009).

We propose to additionally look into methods that subtly and emotionally support the user in a training process: Emotion enhances the presence of the user (Alcañiz, Baños, Botella, & Rey, 2003) and presence enhances the user's motivation (IJsselsteijn, Kort, Westerink, Jager, & Bonants, 2006). Emotion and motivation are further known to be very closely related. Emotion

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Table 1. *Currently Implemented Means of Expression (MoEs)*

MoE type	Modality	MoEs
Post-processing	Visual	Color balance, brightness, contrast, saturation, bloom, blur, color grading, depth of field, edge detection, edge enhance, rain
Shader	Visual	Grass, water, sky, marble, wood, glass, granite
Geometry states	Visual	Fog, highlight, texture, material
View	Visual	Zoom, fisheye, stereoscopic depth
Navigation	Interaction	Walk motion, motion metaphor, jitter, sensitivity, nonlinear mapping, collision effect
External	Multimodal	Ambient light, stage devices (fog, snow, rain, and wind)
Feedback	Multimodal	Audible, haptic heartbeat
Composite	Multimodal	Night, bright sun, overcast sky, winter, thunderstorm, nonphotorealistic MoEs
Sound/music	Auditive	Volume, frequency filter, pitch, muffle, dropoff function
Sound floor	Audiotactile	Volume, floor section, sound sample
Olfactoric	Olfactory	Concentration multiplier, dropoff function

leads, for example, to motivation and to action tendencies (Frijda, 1986). Also, motivation has been shown to lead to better performance for neurorehabilitation with games (Perry et al., 2011) and virtual environments (Cikajlo & Matjaĉić, 2009). Therefore, we think that emotional VEs could greatly benefit neurorehabilitation and virtual reality (VR) applications in general.

To give an example: Imagine that a user of a particular VE for physical training becomes frustrated with a repetitive task to be conducted. The system knows this, either through physiological or facial expression analysis or by way of an attending person, who enters that information into the system's graphical user interface (GUI). Through some internal decision process or story engine, the system decides to try to guide the user into a more relaxed state. As a result, it changes the environment to soft colors and a sunset scenario or to other cues which have been rated relaxing.[1] Bored users could experience a short thunderstorm, snow fall, stimulating music, faster VE navigation speed, or sound floor feedback. A user who works too fast or too slow can receive subtle rhythmic cues, like varying overall brightness or varying the color of a specific object in the desired speed.

To enable scenarios like this, we want to open up the field of emotionally enhanced VEs or *emotional VEs.* Emotional VEs are VEs that in addition to working in the common way by conveying specific information to the user, accentuating parts of the scene, or displaying informative data values, here also change the scene subtly or try to maximize the emotional touch of the VE to create more interesting and diverse experiences.

As a first step in this paper, we present a model of how emotions and VEs are linked together and how emotions can be elicited by subtle cues. In the following, we call the subtle cues used to influence the experience of a VE on a user *means of expression* (MoEs) or in short: MoEs. MoEs are visual, aural, navigational variations and other cues, to potentially excite, calm or emotionally touch the user just by modification of an existing virtual world (see Table 1 for examples). Then, we briefly describe our dynamic and adaptive VR System capable of presenting MoEs in an application-independent way. After that, we present a carefully designed evaluation

1. The state of relaxing has high valence, low arousal, and high dominance in Russell's emotion model (Russell, 1980). Russell defines a three-dimensional emotional space using the dimensions of valence, arousal, and dominance. Valence is the range between positive and negative emotions. Arousal is the range of calm or boring emotions to exciting or stressful emotions. Dominance is the range between feeling small due to the current experience to feeling in control of the scene.

method and user study to rate the emotional impact of MoEs in VEs. We finally discuss the results and implications of our findings and their relevance to designing emotionally enhanced neurorehabilitation applications in VEs.

2 Emotional VEs—Creating Emotional Impact

Little has yet been done to formally explore the capabilities of VR as a *medium* to elicit emotion, a prerequisite to creating adaptive emotional VEs. Therefore, we started to investigate how to utilize potential cues in immersive VR to elicit emotions. We start with a review of the related work, present our thoughts on the diverse components and contributing factors to model the final message that is received by a user, and then present our emotional impact model.

2.1 Related Work

El-Nasr (2006) investigated how dynamically controlled lighting of virtual environments relates to the tension of the user. Strategies such as increasing warm/cold color contrast, increasing saturation, decreasing lightness, and increasing contrast, that are known methods to create tension in films, have been applied to VR and games. In a first-person shooter game environment, the tension was modelled through the number of current enemies and the health of the player character. The lighting reflected the development of these measures over time. They found in an installation study with interviews that the experience and the presence improved with their lighting compared to static lighting. Players stated that the information presented through the lighting made the game easier. Our interpretation of this is that players used the lighting only as a source of information (through the rather obvious mapping to game parameters) and nonplayers saw this lighting as an addition to the experience. This implies that it is important whether a feature is designed for information or emotional experience and this design has to be different, depending on the user group.

Morie (2002) introduces an approach to influence the users' decisions with attracting and repelling elements. Those elements are described as time, sound, smell, motion, events, information, objects, design, characters, and corroberative details. Corroberative details are details in the virtual environment which support the goal, the task, or the setting. On top of that, Morie and Williams (2003) use this approach to model the experience space in virtual environments and apply predictable patterns of emotional response as a hypothetical user reaction. The focus for Morie et al. is to urge the user into a specific direction or decision. We instead want to intensify and vary the experience of the user as an additional emotional supplement, potentially adaptively amplifying the original target of the application.

Another related area of research is the link of emotion and presence. Baños et al. (2004) state that both immersion and emotion have an influence on presence. For emotional environments, they find immersion to be less important for presence. They use the VE scene as an emotion elicitation method. Their scene has two predefined emotional target impacts: sad and neutral. The weather, lighting, music, and narrative elements are different in both versions. But also, emotion elicitation methods like the Velten technique (vocalizing emotional messages; Velten, 1968), emotional images (IAPS; Lang, Bradley, & Cuthbert, 2008), and an emotion elicitation movie are integrated in the scene. These elicitation methods are integrated as mini-game and, in the case of the movie, as theater visit. The influence of immersion is measured with monitor and immersive display versions. Riva et al. (2007) broaden this study with a relaxing version of the scene. The results confirm the elicitation of the intended mood states and the emotionally toned scenes showed a significantly higher presence than the neutral scene ($p < .05$). This setup is fixed to the three emotional settings. In our work we can also create such precrafted environments. The flexibility of our system allows a greater range of emotional settings and the possibility for a moderator or therapist to influence the emotional impact during the session. This therapist can take the ratings of the MoEs as a guide of his or her application. In Baños' and Riva's work it is not possible to see which techniques add to the emotional impact to which degree. That makes the predictable reuse for new scenes more difficult. Further, the Velten technique, the

IAPS images, and the emotional movies are rarely seamlessly integratable in a scene. We think that VEs need their own reference content and techniques. Our work is a step in this direction.

Alcañiz et al. (2007) introduce a virtual world for the purpose of healing phobia, which is dynamically modifiable by the therapist. They use different landscape settings, dynamic weather effects, and time of the day. Participants see the landscape from an open hall which is the constant in the scene. The therapist can control these features in real time. Alcañiz et al. apply this system for the therapy of a child with nyctophobia (fear of darkness). During the therapy, the time of the day and the lighting of the hall are made darker step by step. The landscape is changed from a beach to a thick black forest as a final step. The real-time usage of the effects is close to our work, but we want to give the user a more believable environment with soft transitions. Alcañiz et al. use their configurable system as building blocks for a therapy. We want to subtly change and enrich the emotional impact of a given environment.

Robillard, Bouchard, Fournier, and Renaud (2003) examine the fear and presence of phobic and nonphobic participants with VEs that directly depict the phobic elements. They found a significantly higher fear factor in the phobic participants, which verifies the application for phobia therapy ($p < .05$). Further, they found a relation between fear and presence. The phobic participants felt more anxious before and after the tests and they also felt a higher presence.

Bouchard tries to elicit emotion independently of the VE. In Bouchard (2008), a mood is induced with classic techniques before the immersion, and in Bouchard (2011), the mood is induced during the immersion using the Velten technique (vocalization of emotional messages). This is useful for phobic patients, while for our work, the inherent impact of the VE and its relation to presence is more important.

2.2 Generating Qualitative Emotional Virtual Experiences

We see a great potential of VEs to create truly engaging experiences—if, finally, we understand the fabrics of such experiences. Even though emotional applications exist, VE systems are often only used to provide specific, targeted information. Emotional, aesthetic appeal is added, if at all, by a designer, artist, or storyteller at the time of designing the application. Examples of emotionally well-designed VE applications are, for example, some Walt Disney VR installations (Mine, 2003) and VR installations such as Osmose und Ephémère (Davies, 2003). Those are predefined and very well-crafted experiences, much like a film. We instead want to better understand the theory of building such experiences and make their creation easier for nonartists. We further want to be able to create emotional virtual experiences more dynamically and we want to analyze which components and cues have which impact on the users. As a starting point, we introduce a more holistic view of creating experiences which takes into account the emotional impact. These ideas can then be applied for efficient training in VEs.

In the following section, we introduce how we see the relationship between author, system, and user and how the communication between these persons and the system can be characterized. After that, we give a definition of MoEs and describe how they fit into our concept.

2.3 An Extended Communication Concept

In our model, the impact of a VE experience on an user has an *informational* part and an *emotional* part. Both parts can lead to an action. On the informational side, the new information can lead to an action through the new knowledge. On the emotional side, the emotion causes an action tendency (Frijda, 1986), such as move toward or move away. Our general model is illustrated in Figure 1.[2] Additional to the *information* and the *emotional setting*, there are also the components *appeal* and information about the *author* that form the four components of communication, as described in the model of von Thun (1981). This model describes the communication from the author over the system to the user.

2. Please find high-resolution color plates of the figures in the supplementary material accompanying the online version of this article, and at http://imve.informatik.uni-hamburg.de/projects/QIE.

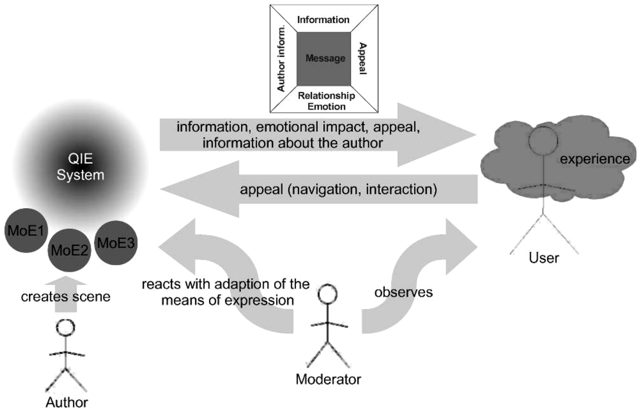


Figure 1. *Qualitative interactive experience model.*

There are several roles involved in the model: First, there is the author of a virtual environment, who envisions a specific informational and (often subconsciously) emotional impact. The author uses objects and MoEs to create a virtual world. Second, there is the system (our system is called the Qualitative Interactive Experience [QIE] system; see Figure 1) which consists of the multimodal input and display hardware, the software, the authored scene contents, and (in our system) the dynamically applicable MoEs (smaller circles in Figure 1). Third, there is optionally a moderator or therapist who can adjust the cues that are used. Fourth and most important, there is the user who experiences the content created from the author through the VE. The impact to the user is partly that envisioned by the author and partly not (Beckhaus, 2010). That impact adds to the user's experience.

The informational and the emotional part have atomic building blocks which are often referred to as cues. We call them information bits in the informational case and MoEs in the emotional case. As our work focuses on the emotional part, we further define and discuss MoEs in the next section.

2.3.1 Means of Expression. In our model MoEs are used to create emotion and mood. What are valid MoEs and how are they found for VE? In communication theory, Schulz von Thun (1981) identifies informational content, appeal to the receiver, information about the sender (author), and relationship of the sender to the receiver, including emotional content, as the parts of any communication. Communication and all media (being a form of communication) use supportive methods to underline information and transport relational and emotional contents. Examples for interpersonal communication are intonation, facial expression, gestures, body posture, word selection, talking speed, and breaks. These almost subliminal submessages can change the meaning of a message completely, and can, for example, make an otherwise neutral message very interesting. Additionally, the communication is mediated through a medium, which adds even more possibilities.

We define supportive emotional information as *MoEs.* An extended definition of MoEs is their ability to change the user experience in some way: Any parameter that is able to change the emotional experience of the user can be defined as an MoE.

We used several approaches to identify MoEs in VE.

1. We looked at other established and better-researched media, and explored whether their MoEs could be applied to VE as well (literature review).
2. We examined the involved hardware and software where possible changes can take place. Artificial content has many possibilities where changes can take place (bottom-up approach).
3. We collected which MoEs are special to VE, which can be envisioned, which would help changing VEs dynamically, and which could be emotionally relevant (top-down approach).

In our *literature review*, we investigated, for example, the medium of film. In film, we can differentiate character-based MoEs and noncharacter-based MoEs. Character-based examples are facial expression, actor movement, dialogue, vocal expression, costume, character qualities, character history, and the narrative situation. Noncharacter-based MoEs in the film medium are, for example, image composition, sounds, music, lighting, set design, cut, camera (angle, distance, zoom, motion), depth of field, cut rhythm, coloring, postprocessing, and special effects (see also Mikunda, 2002; Smith, 2003).

When we look at the technical possibilities that exist to change the multimodally displayed content of VE (*bottom-up approach*), there is a multitude of possible MoEs. This is because almost anything is created artificially in VE and many properties of the rendering, navigation, interaction, and geometry can be manipulated in real time.

Hardware-based possibilities are, for example, as follows:

- **Visual.** Resolution, brightness, contrast, field of view, stereoscopy, tracking.
- **Auditive.** Sample rate, frequency response, volume.
- **Navigation.** Device, degrees of freedom, buttons.
- **Interaction.** Device, selection, manipulation.

Software-based possibilities are as follows.

- **Visual.** OpenGL/scenegraph/VR-System: materials, shaders, shader uniform variables, view on the scene, light sources, geometry.
- **Auditive.** Spacial rendering, sound propagation model, filters.
- **Haptic.** Collision response, motion response, touch.
- **Interaction.** Metaphor, selection difficulty, manipulation possibilities, and modes of manipulation.
- **Navigation.** Metaphor, additional movements, ground structure, combination with sound/haptics, collision, physics, fall, swim, jump, run, and levitate.

The *top-down* approach examines which MoEs could be, with regard to their emotional impact, important for VE. Nature as a constant to most people's lives has an emotional impact on us which is beyond like and dislike. This impact is relatively uniform for all people. It is reflected in the impact of colors, shapes, composition of shapes, nature sounds, and many more. Because of that, natural phenomena such as time of day, seasons, and weather conditions have a rather predictable influence on our mood. Therefore, they are good MoEs which are already used in computer games. Lighting and coloring are known to be very important for emotional impact (Ou, Luo, Woodcock, & Wright, 2004). Music and sound are important emotional factors as well (Juslin & Sloboda, 2001).

Combining the introduced approaches to systematically investigate MoEs in VE, we identified the following groups of interesting MoEs by grouping similar MoEs by their impact, their application, or their addressed senses: visual appearance, weather, time of day, view manipulation, sounds, music, navigation, interaction, olfaction, haptics, and ambient conditions. For our evaluation study, we selected 30 MoEs which were widely spread over these groups.

2.4 Emotional Impact Model

Building on our general model of impact of VEs on users described earlier, we introduce our emotional impact model. This model aims at integrating different aspects of the VE impact cycle. By VE impact cycle we refer to the potential capability of our design to allow for a closed-loop user-feedback system that, in short, integrates assessing and modeling the user state, generating guiding emotions based on knowledge of the impact of specific MoEs and combinations of those plus the intentions of author and application, and then again measuring the impact that those emotions have on the user.

Figure 2 shows those different modeling needs in boxes: at various stages of an overall impact model, the submodels need to integrate existing user models, system models, or theory models with the specific need of this stage of the cycle. Those stages are: the description of the inherent emotional impact of the MoEs, the off-line evaluation which allows developers to fill these descriptions, the description of the emotional impact we want to have, the predicted emotional impact from the timing and the experienced context and used MoEs, and the (not yet realized) real-time evaluation of the emotional state of the user. The upper part of Figure 2 shows model requirements for the evaluation of MoEs; the lower part of Figure 2 shows model requirements for use in an application.

After a review of psychological models of emotion, computational emotion models, emotional theories, and analysis methods for different media, we propose the following composite model: The emotional user state

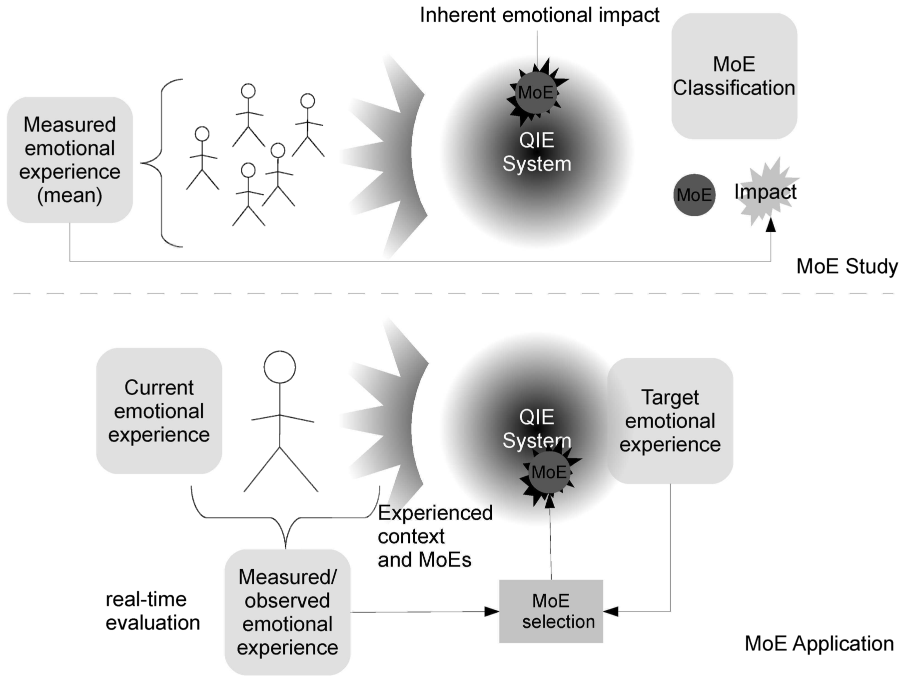


Figure 2. *Stations of emotional data.*

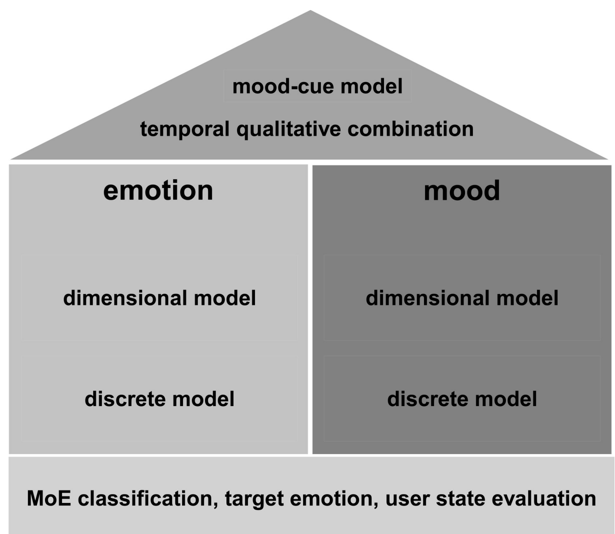


Figure 3. *Emotional impact model.*

consists of a mood section and an emotion section. This model is adapted from the psychologist Frijda (2000) and the theory on the emotional structure of film by Smith (2003). Emotions are seen by Frijda and by Smith as shorter and moods as longer lasting emotional phenomena which are both important for the emotional impact. The two constructs are, therefore, integrated in our model. The mood and the emotion component themselves are described with one or more models for evaluating emotions: We use a discrete model, a dimensional model, an appraisal model, and an action tendency model to have high flexibility in the description of emotional content. A similar composite approach is used in the emotionML markup language (Schröder, 2008).

A discrete emotion model is a model which builds upon specific emotions. In some theories, those emotions are seen as the basic emotions which can form all remaining emotions (comparable to basic colors). A dimensional emotion model tries to define the axis of the emotional space. Appraisal models are cognitive emotion models which take the situation, the importance, and other factors into account. Action tendencies, finally, are reaction patterns to given situations. To reduce the complexity of this model, we use only a combination of dimensional and discrete models at the moment.

Our emotional impact model is illustrated in Figure 3. The different parts in our system which contain emotional information all use different parts of this emotional impact model. The inherent emotional impact of the MoEs is modelled with an emotion that is described using a combination of the discrete and dimensional models. This combination is also the most important part for all other locations of emotional information, such as rating of MoEs, defining an emotional target impact, and evaluation of the emotional impact.

The relation between emotions and mood is made through Smith's mood-cue theory (roof in Figure 3). A structured application of emotional cues leads to the buildup and sustaining of a mood. The mood on the right side shifts the emotional focus to specific emotional cues. Smith uses this theory to explain the emotional structure and the emotional experience of films. We want to apply this theory to VE as a tool of analyzing the emotional impact and we propose its usage for timed interactive buildup of specific moods using our MoEs.

This model (further detailed in Haringer & Beckhaus, 2011) is important as the basis of our concept of emotional impact and how MoEs can help to build up emotions and moods in VE. Rating the MoEs according to their emotional impact is a first step to support an application, not only with applying these cues somehow, but also to use their composition and timing for an enhanced emotional and overall experience. In the next section, we introduce our adaptive system which can dynamically add, remove, and blend many multimodal MoEs on a per object, per area, or per whole scene basis.

3 Adaptive VE System

In this section, we give a short overview of our system which is used to create the MoEs and which is used to perform our studies on VE and emotional impact. Technically, our system uses the following main principles.

- Uniform access to many context-independent multi-modal MoEs.
- Application of these means to any object or area in the virtual world.
- Full use of the power and the flexibility of VR systems.
- Easy addition of new MoEs.
- Easy control interface for adding, grouping, and blending different MoEs.
- Application of flexible emotional impact mappings to the MoEs.

To provide uniform access to the scene and to the MoEs, two interfaces have to be provided: one for the scene content, and one for the MoEs. This allows designers to assign MoEs to objects in real time. The scene is structured in many semantically important objects and areas. Only these objects are visible at the interface level. The interface for the MoEs is very simplistic: Each object and area can hold multiple MoEs. The MoEs can be added and deleted from each object/area, can be turned on and off, and they can be customized by one or more parameters. The intensity parameter is mandatory for all MoEs and describes to what percentage a MoE is currently applied. This parameter is important for being able to softly blend the MoEs in and out.

Above this interface level, our system provides fading and grouping functionalities to make soft transitions when introducing or removing MoEs. It is also possible to build complex combinations of MoEs and scene objects which can then be controlled as one entity. Additionally, our system allows designers to attach any MoEs with an emotional impact which has been rated using a discrete and/or dimensional emotion model. This assignment can be made globally, for a specific context, or for a specific user.

The system is controlled via a GUI which allows designers to manipulate all objects with all available MoEs in real time. The interface can be also operated by real-time control messages which can be generated as a reaction to real-time user evaluation in the future. For a more detailed description of the system see Haringer and Beckhaus (2010a, 2010b).

We presented this system in a demo over three days of the IEEE Virtual Reality Conference 2010. There, we demonstrated its capability to flexibly assign MoEs at real time and, at the same time, did a first small study on the potential of our system and MoEs to generate interest, higher presence, and motivation in participants. Ninety-four percent of the informally interviewed people (about 100 persons participated, 53 of whom were interviewed) reported the scene to be more interesting, 77% felt a higher motivation to perform tasks in the virtual environment, and 66% felt a higher presence. These positive results encouraged us to proceed with formal evaluations of MoEs and impact on people in VEs. We present this study in the following.

4 User Study: Rating of the Emotional Impact

4.1 Introduction

With the previously described system to create and assign MoEs dynamically and the model for emotional impact, we can now rate the MoEs and, therewith, build a basis for creating dynamic emotional experiences. With these ratings, it is possible to define a target emotional impact. Matching MoEs can then be automatically selected and applied.

We rated a large set of MoEs in a user study. For this evaluation, we built an island scenario landscape scene including beach, water, grass, forest, and mountains. The requirements of a scene and its presentation for evaluating the MoEs were: the scene had to be of high quality and the frame rate should never drop below 20 fps. The MoEs to be evaluated should fit into the scene context and the scene should have a size and a content which is able to keep users interested beyond 20 min (without MoEs). The scene itself had to be emotionally neutral, in order to not interfere too much with the MoEs that are to be rated.

4.2 Background

Thirty MoEs were selected and applied on a locational basis: The users had to walk on a pathway through the environment. Along this pathway were several waystones which were each connected to one or more MoEs. When the user was approaching a waystone, the intensity of the cue increased; at the waystone, it reached its maximum, and, when moving away, the intensity decreased. At the maximum, that is, at each waystone, the user had to stop and complete two self-report evaluations, one for assessing discrete emotions, and one for assessing dimensional emotions.

The self-reports are done via a touch screen, which was black during the navigation through the world. The dimensional self-report used the self-assessment manikin of Bradley and Lang (1994) with nine points per dimension. The discrete emotion self-report used the Plutchik emotion circle (Plutchik, 1962) with eight discrete emotions (joy, fear, surprise, sadness, disgust, anger, anticipation, and trust). The user can select one or more of the eight emotions. The strength of each emotion can be selected by the distance to the center of the circle.

We also used continuous measures which can supply information about the user's experience not only at discrete measurement points, like most self-report assessment methods do. Biophysiological signals are such continuous measurements as have been used in biofeedback applications (Bersak et al., 2001), the measurement of presence (Meehan, Insko, Whitton, & Brooks, 2002), neurorehabilitation (Novak et al., 2010), and emotion recognition (Nasoz, Lisetti, Alvarez, & Finkelstein, 2003; K. H. Kim, Bang, & S. R. Kim, 2004). Further biophysiological measure-taking does not introduce potential breaks of presence (beyond the eventual discomfort of wearing the sensors) like interviews or questionnaires do. Further, biophysiologic signals are not subject to conscious thought and, therefore, cannot be easily feigned. We selected the widely used signals blood volume pulse (BVP), respiration (RSP), and galvanic skin response (GSR), which were recorded during the whole session. From the BVP signal, that is similar to a low-quality ECG signal (only the R-peak can be computed precisely), heart rate (HR), vasodilation, and heart rate variablility (HRV) can be extracted (Malik, 1996). The GSR signal provides the skin conductance level and the respiration signal, the respiration rate and the respiration amplitude as a derived signal (Curtin, Lozano, & Allen, 2007). As HR, HRV, GSR, and respiration rate are known to be mapable to Russell's arousal axis (Bradley & Lang, 2007), we relied on those signals.

The goal of the presented study is to investigate which emotional impact different MoEs have. In addition to rating these MoEs, this evaluation is made to examine whether the different effects have a similar impact on all users and, if not, whether there are groups of users who rate the effects similarly, or whether the impact is strongly individual for most users.

4.3 Methods

4.3.1 Comparison to IAPS. For being comparable with well-examined emotional content, we selected the International Affective Picture System (IAPS, Lang et al., 2008) and its assessment method, the self-assessment manikin (SAM; Bradley & Lang, 1994) as a reference study. To guarantee whether IAPS and the SAM evaluation are valid for our lab setting, we performed an IAPS prestudy. The following alterations to the original study were introduced: We used a larger screen space, we added biophysiological measurement to the test, and we added a second self-assessment method. We performed our IAPS study with 26 IAPS images and 22 participants.

The same IAPS study was performed with 26 screen shots of our VE scene with MoEs. We wanted to examine how screen shots of scenes with an enabled MoE relate to the immersive experience of this MoE. Our hypothesis was that the emotional impact would be the same, but with a lower intensity for the screen shots.

4.3.2 Participants. In our main study, we had 30 participants with a mean age of 28.9 ($\sigma = 8.5$) ranging from 17 to 52. There were 12 female and 18 male participants. Seventeen were students, of whom eight were studying computer science and seven were studying human–computer interaction. Six participants were computer scientists and seven were computer science related professionals. Thirteen played computer games regularly, 12 seldom or never. Fifteen had experienced stereoscopic images in films, games, or VE. Fourteen had experienced a VE environment, but only two of them for over 1 hr in total. The participants were recruited from the computer science campus and received no payment.

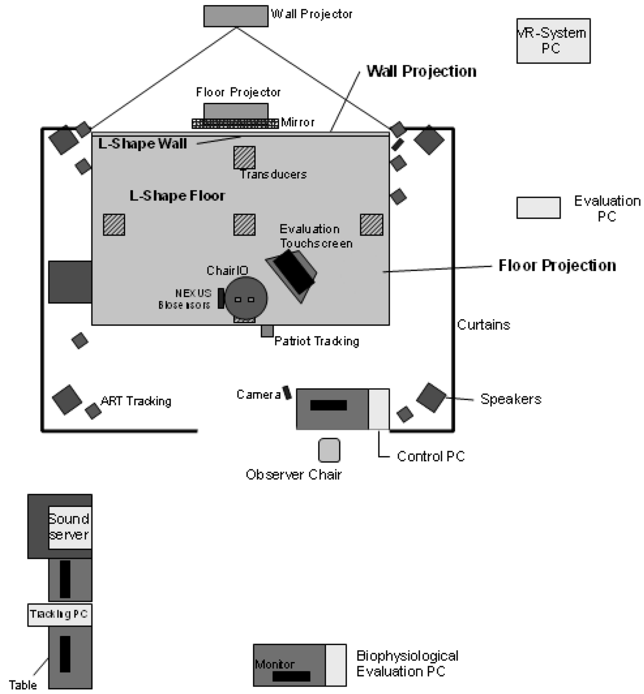


Figure 4. *Lab setting for the study (top-down view).*

4.3.3 Materials. The study was performed in an L-Shape active stereo VE display, with a 148-in (diagonal) floor and a 143-in (diagonal) wall, each with a resolution of 1440 × 1050 pixels. The system is supported by a 4.1 multichannel audio system and five transducers below the floor for audiotactile stimulation. For navigation, the chair-based ChairIO device (Beckhaus, Blom, & Haringer, 2005) was used. ChairIO was shown to be a very intuitive 3D navigation interface, which can be used almost instantly without needing much attention. It uses hip motion to navigate on the ground of a virtual world. Figure 4 shows the setting for the study.

The physiological data were acquired with a Mind Media Nexus10 biofeedback device using original Mind Media sensors. The participants wore a BVP sensor on the middle finger and a GSR sensor on the index and ring finger of the left hand, which rested on the left thigh. Respiration was measured using a chest belt. The user wore 3D shutterglasses which held a head-tracking target. The evaluation touch screen was placed on the front left side of the user and it was comfortably usable with the shutter glasses on.

4.3.4 Stimuli. Thirty MoEs were used in the study. They were from the groups coloring (hue: yellow, red, green, purple, magenta, orange, blue), weather (sunny, cloudy, fog, thunderstorm, winter, sunset, night), nonphotorealistic visual effects (drawing style, reduced colors, glowing landscape), implicit MoEs (going uphill, downhill, lookout point), sound cues (birds, ocean waves, wind, thunder), sound floor (trembling ground, fast heartbeat), music (spiritual, tense film music, accelerating rock ballad), navigation jitter, and widening field of view. Some of the visual MoEs which have been used in the study can be seen in Table 2. The stimuli were not randomized for reasons which will be covered in the discussion section.

4.3.5 Procedure. The study lasted about 1 hr and 30 min. First, an anonymous personal data questionnaire (gender, age, profession, media usage), the Interactive Tendencies Questionnaire (ITQ, Witmer & Singer, 1998), a self-constructed emotional tendencies (emotion in films, emotional range), and a current mood questionnaire (today's emotional baseline) had to be answered (15 min). After the questionnaires, some slides introduced the study and the evaluation methods (5 min). Then, the navigation was trained (1–3 min) and, finally, the main study took place (50 min). After the main study, a short version of the Presence Questionnaire (PQ; Witmer & Singer), a self-constructed experience questionnaire, and the Simulator Sickness Questionnaire (SSQ; Kennedy, Lane, Berbaum, & Lilienthal, 1993) had to be filled out (10–15 min).

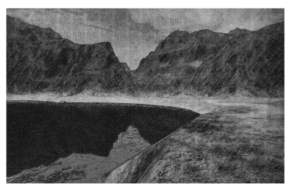
In the main study, the participant had to navigate from waystone to waystone on a clearly visible path in the virtual environment. When a waystone was reached, the participant stopped. The conductor of the study then stopped the navigation and head-tracking completely to avoid motion sickness problems during the evaluation. The environment was still visible, and all dynamics such as water, rain, and the like were still moving, to avoid a break of presence. The user evaluated the emotional impact of the currently applied cues on the touch screen in front of him or her. After that, the user answered three short questions as to his or her subjective liking of the MoE(s), the influence on the virtual environment, and the influence on their presence. After the questions, the navigation was released and the user moved along the path toward the next waystone.

To help the participants with directions and to make sure each participant approached each waystone from a similar direction, the instructor gave advice, if necessary. To make a fitting story for the study experience and to avoid major experienced breaks of presence due to the evaluation, participants were told that they had to rate the emotional impact of a landscape scene and changes within this scene while travelling through this scene. They should evaluate the impact on their personal evaluation screen which they carried with them in the virtual environment and they had radio contact with the instructor which helped them during their evaluation. This followed the idea that a story is ultimately formed in the head of the user and that a carefully designed story might reframe a potential distraction into something in support of the story, thus not causing a break in presence (Beckhaus & Lindeman, 2011). The participants were told not to turn to the instructor and after the first three evaluation periods, most of the participants answered the questions automatically. We only occasionally found indications of breaks in presence in the biophysiological data during this phase. Those effects were small compared to the effects we recorded during unplanned interruptions. To minimize any influence on our physiological evaluation results, we only used the data outside the evaluation phases.

4.4 Data Processing

BVP was recorded at 128 samples per second, and GSR and RSP signals were recorded at 32 samples per second. We computed heart rate, respiration rate and heart rate variability from the raw signals and recorded them at 32 samples per second. The heart rate signal was continuously averaged from three consecutive R peaks. The respiration rate was averaged from three

Table 2. *Description and Illustration of Some Selected Visual MoEs. (See supplemental material for color images.)*

MoE	Description	Parameters	Screenshot
Hue/lightness/ saturation adaption	Changes the hue/ lightness/ saturation of an object or the whole scene	HSL, intensity	
Color reduction	Reduction of colors to 2–64; nonphotorealistic	Color count, mixing factor with original image, intensity	
Bloom	Very bright appearance of objects or the whole scene	Threshold, blur, intensity	
Color grading	Application of complex color conversions	Schema, intensity	
Winter	Season and weather effect: white landscape, winter sun, snow	Snowing speed, wind turbulence, whiteness, intensity	
Thunderstorm	Weather effect: dark clouds rain, dark landscape, rain, lightning and thunder	Brightness, rain intensity, lightning frequency, intensity	
Sketch	Nonphotorealistic sketch effect	Color of the landsape, intensity	

consecutive respiration maxima. The GSR signal was used without alteration. HRV was determined as a percentage of power for the bandpass in the range 0.04 to 0.16 Hz (Malik, 1996). The HRV time window was 16 seconds.

Further processing was performed for heart rate, respiration rate, GSR, and HRV. As the evaluation requires the test persons to move, we used the time from the point where an MoE first appeared to the point where the navigation stopped and the evaluation phase began. At this point, the MoE was fully faded in. After the start of the evaluation, the participants move slightly to perform the SAM and PEC evaluations, which introduce movement artifacts to the biophysiological signals. Marks for MoE start and evaluation start were manually added, based on the synchronized video showing the whole setup from behind. As this time period is different for every user and every MoE, we divided this time span into five zones. For each zone we normalized the signals based on the user's signal value range and then computed the average value. In this form, the same MoE for different users and different MoEs could be compared. Based on those values, we could build a mean per MoE with all participants. For the t-tests, we compared zone one (before an MoE is in effect) with zone five (MoE in full effect and fully experienced).

4.5 Results

First we look at our IAPS prestudy. The results of our IAPS study show that there was no overall significant difference, $p < .05$, compared to the original IAPS results (multivariate ANOVA). The two studies were further found to be correlated in a highly significant way, $p < .05$. In the examination with MoE scenes compared to the MoE scene screen shots presented in an IAPS manner, we stated the hypothesis that the emotional impact would be the same, but with a lower intensity for the screen shots. We found both to be true for a large majority of MoEs (81%).

The self-report results of the main study are the evaluation of SAM, PEC, and the subjective questions. Figure 5 shows the valence arousal and dominance means and error bars for all 30 evaluated MoEs which were evaluated with the SAM. The standard deviations were comparable to the IAPS image study. This is a good result, as the highly emotional IAPS images had been expected to give more congruent answers than the rather neutral landscapes, which are enriched by MoEs.

Figure 6 shows the discrete rating quantities for the four positive and the four negative Plutchik emotions. Almost no MoEs were rated with anger and disgust, which is reasonable because of the rather neutral landscape context. Anger was even hard to elicit with the IAPS images (Bradley & Lang, 2007) and strong disgust ratings were only achieved with images of spiders, snakes, and mutilation victims. The discrete ratings were more user-dependent than the dimensional ratings: on average, less than 50% rated an item with the same emotion. Further, the means of the rated values had a high standard deviation and the measured values did not follow the Gaussian normal distribution. Because of this, only the quantities of how many participants rated a specific emotion have been further evaluated.

We also set up t-tests between all pairs of MoEs to judge how discriminable the MoEs were, based on their evaluation. For the SAM evaluation, 69% of the pairs were significantly discriminable, $p < .05$. For the PEC evaluation, 74% were significantly different, and with SAM and PEC together, 77%, $p < 0.05$. This means that the evaluated MoEs can be distinguished by their emotional impact, and, therefore, can be used to create different and targeted experiences.

We further examined possible differences in rating between specific user groups using clustering methods. Over all images, no user groups with a specific pattern were found. However, for individual MoEs, as well as for certain types of MoEs, for example, the change in the hue, individual groups were identified using valence arousal dominance clustering (hierarchical clustering, depth 4).

The questionnaire results show that 86% of the users find the virtual world more interesting and rich with the MoEs. The question of whether a particular MoE lets users feel more a part of the world on a unipolar scale from 1 to 5 was answered in an overall mean of 3.2 ($\sigma = 0.8$) which indicates a rise in presence. Other questionnaire results (age, gaming experience, emotional

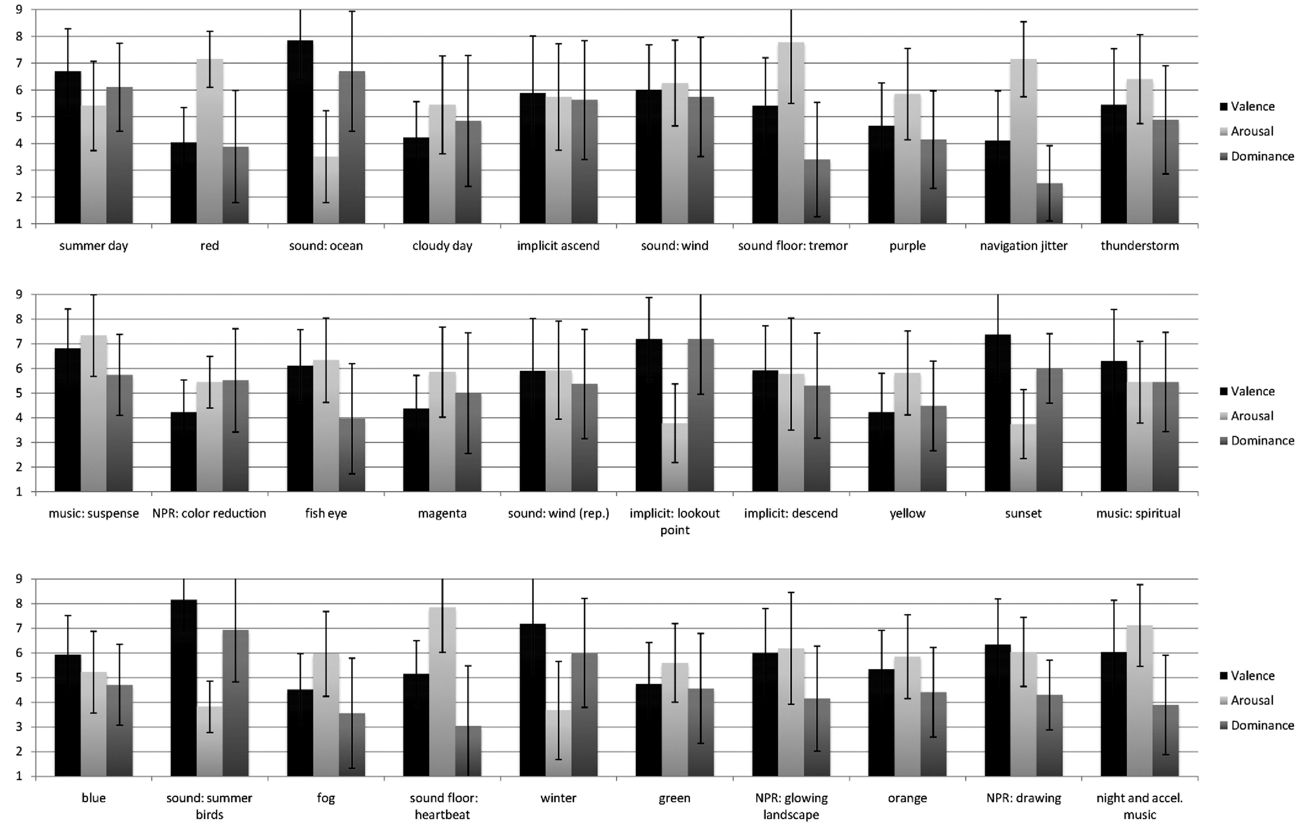


Figure 5. *Self-assessment manikin results.*

range) were compared with the SAM and PEC ratings (ANOVA) but did not produce any significant results, $p < 0.05$.

The evaluation of the SSQ resulted in two of 30 participants having strong symptoms, five medium symptoms, and five minor symptoms of simulator sickness. This is a common distribution of symptoms (Kennedy et al., 1993). It is also an indicator that the study, in spite of the 45 min of immersion (without introduction and questionnaires), proved to be not too strenuous for the users. Kennedy et al. suggest 20 min as a typical duration for immersive studies.

The evaluation of the biophysiological data was made using the correlation with the arousal axis, because HR, GSR, and respiration rate mainly have an impact on this dimension (see Bradley & Lang, 2007). The analysis of HRV could not be used, because of the rather short intervals of MoEs exposure. The signals HR, GSR, and respiration rate were further processed as described in Section 4.3.

The results show a rise of HR and GSR mean values for all but two MoEs for HR and all but six MoEs for GSR. Only a few MoEs show a statistically significant difference, $p < .05$, of HR (five MoEs) and GSR (seven MOEs). Only two MoEs can reduce the HR and GSR. We found that the MoEs with a stronger increase of HR and GSR are those with the highest arousal ratings and those with decreasing HR and GSR are among the MoEs with the lowest arousal. This indicates a correlation between arousal and the HR and GSR signals. A significant correlation, $p < .05$ (Pearson), of HR with arousal was only found for the MoE (shaking ground) which shows very high arousal in the SAM evaluation. For the summer birds and the branding sound MoEs, the heart rate decreases and also significantly correlates with the arousal, $p < 0.05$ (Pearson).

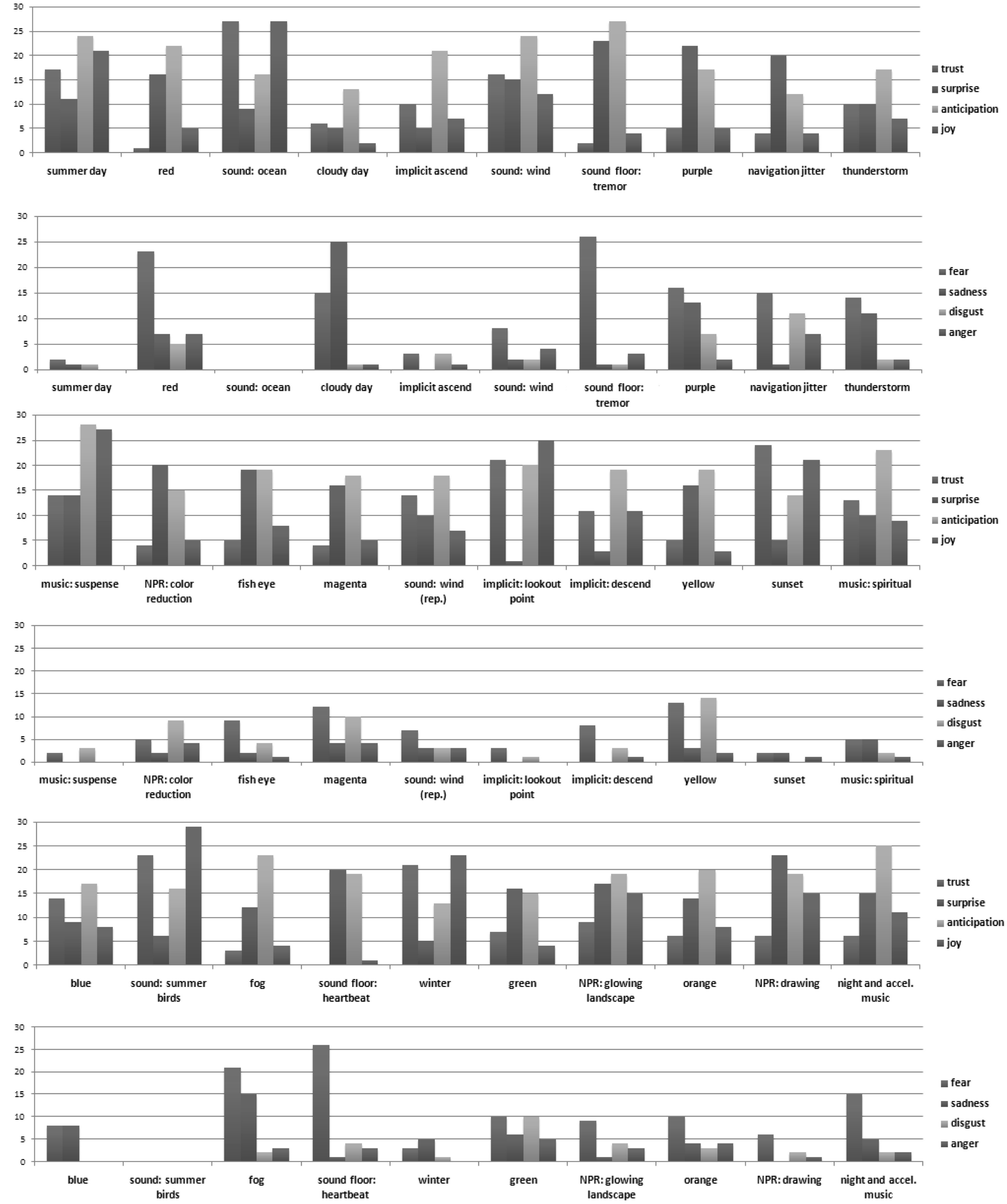


Figure 6. *Discrete Plutchik evaluation results (quantities).*

5 Discussion

The results of the user study confirm that a differentiation of a user-independent emotional impact of MoEs by rating their presentation in a VE is possible. This means that a majority of users will experience a specific MoE or a combination in a similar way and with the rated tendency. The collected evaluation values should not be used as strict rules like "red-colored objects always induce fear." The context as well as the individual users play a substantial part for the emotional impact experienced, as discussed previously.

Using different MoEs with similar rated emotional impact during the experience will most probably be able to induce a specific mood in an even larger group of users, as Smith found for filmic emotion and mood elicitation (Smith, 2003). According to Smith, MoEs fitting the mood have a higher emotional impact than MoEs which do not fit. This means that if one MoE does not emotionally fit for a specific user, it will not influence the overall mood that much, as long as other MoEs fit properly. Therefore, it is sufficient that the majority of the applied MoEs match. This applies to our MoEs which have been evaluated consistently for 70% of all persons. Statistically, three of four MoEs would stimulate the intended emotion. The application of this theory to VE has to be further verified in a future study.

An individual calibration on a per-user basis allows designers to select the best-fitting MoEs for a specific user. The rather important and individual discrete emotional ratings can be used here. Our suggestion for an individual calibration is a short IAPS-like session where several MoEs are shown as screen shots. The user rates them with the dimensional and the discrete emotion model (biophysiological measures could also be included). These results are then used for an individual rating of the MoEs. As not all MoEs can be tested in single file (i.e., sequentially), a selection of them (identified with an independent component analysis of the described general study) can be used.

Another important result is the distinctness of the MoEs' impact. The evaluations differ from each other to a very high percentage. Seventy-seven percent of the MoEs are significantly discriminable ($p = 0.95$), and 13% show a strong tendency for being different (pair-wise t-tests). This proves the individual emotional impact of the examined MoEs. Further, the covered emotion space is surprisingly similar to the IAPS study. This means that MoEs are indeed capable of changing the impact of a scene in different directions.

The extent of the disgust, fear, and grief experienced does not match the situations depicted in IAPS. This was rather predictable, as the MoE study showed a neutral landscape while the IAPS also showed explicit strong emotional content. The relatively small difference for the dimensional evaluation is rather surprising. Possibly the fact of being in a virtual environment, compared to seeing pictures, strengthens the impact of MoEs.

5.1 Nonrandomization

As mentioned in Section 4.3, the stimuli of our study were not randomized. The results are dependent on the context (location) where the user experiences the MoE. The MoE and its location are seen as one experience that is being rated. The examination of the influence of the context is planned in a further study. As for this study, MoE and context are evaluated together, and so randomization would result in randomizing the locations and pathways in the scene and, therefore, in totally different scenes. As generating different scenes was too elaborate, we used nonrandomized MoEs. To somewhat compensate for the nonrandomization, we tried to stick to a valence arousal baseline similar to the IAPS study (Lang et al., 2008). This means that after a strongly positive image/MoE, a neutral and then a negative combination are used. After the role of the context has been examined, randomized studies will be possible.

5.2 Physiological Data

The general rise of GSR and heart rate could be explained with the experience of something new and unknown, which also shows in the Plutchik emotion of surprise. The biophysiological data only supported the MoEs with a very strong or a very weak arousal. For being able to distinguish more MoEs with biophysiological data only, the measurements held too scant information. The main problem, in our opinion, was the short MoE exposure and the unusable data through motion artifacts after the self-report evaluation started. In future studies, longer exposure times and a period of no action before the evaluation starts are planned. Additionally, to add the valence dimension, electromyogram measures of the face (Bradley & Lang, 2007) and a camera-based facial emotion recognition are useful for further evaluations.

6 Application to Training and Neurorehabilitation

The user study showed that it is possible to alter the emotional impact of a VE scene using MoEs. The impact of the single MoEs is, across users, similar enough to assume a comparable overall impact for multiple MoEs. MoEs can, therefore, be used to enhance presence, motivation, interest, and dwell time.

This potentially also benefits training and rehabilitation. In neurological rehabilitation, patients need to perform specific movements numerous times, which can be boring, tiresome, and potentially also painful. The main task of a training support system is to show patients how to move, how well a movement has been performed, and how to improve the movement the next time. Above that, this laborious therapy should be as convenient, diverting (in a sense of the felt passage of time), and motivating as possible. Emotionally designed applications maintain attention like few other resources. This is known for general design (Norman, 2004) as well as for VEs (El-Nasr, 2006; Morie & Williams, 2003; Riva et al., 2007). We propose to introduce emotion not only with suitable content, story, and avatars, which are well known for their emotional impact (Slater, Pertaub, & Steed, 1999), but also with the vast possibilities that the environment itself offers (e.g., see Table 1).

A first possibility to use our model, system, and evaluation for neurorehabilitation is the accentuation of objects or regions with rated MoEs. This can be used to catch the attention of the patient. Through the large amount of available MoEs, the accentuation can be more or less frequently updated to stay interesting to the user. Rated MoEs can be used to keep the patient in a specific mood by using roughly similar-rated MoEs for accentuation. Another possibility is to use MoEs with rather different ratings to generate interest and motivation with a large emotional range. Especially for color changing and nonphotorealistic rendering on specific objects, users reported that the MoE-enhanced objects caught their attention immediately. This indicates the principal ability for using MoEs for accentuation. The effectiveness of the accentuation capability for all MoEs compared to each other should be further investigated in the future.

A second possibility is to use rated MoEs to support neurorehabilitation by eliciting emotions to enhance the presence and motivation of the patient. The study presented in this paper showed that the tested MoEs are able to elicit a range of different emotions. Elicited emotions are further found to be comparable for a high percentage of users. This allows generating moods and emotions in a variety of ways. The MoEs can be attached to locations in the VE, they can be timed, they can be used to sustain a mood using Smith's theory, they can be applied by a moderator, they can be used by a story engine, or they can be used as a reaction to real-time user assessment. For neurorehabilitation, we suggest a mixture of locationally bound, timed, and moderated cues.

The third possibility is to use the MoEs as a reaction to biophysiological input signals, forming an emotional informed feedback loop, either for biofeedback or for changing MoEs. Our system is capable of real-time transformation and dynamically assigning the signal to the intensity or any other parameter of any MoE. We have, for example, mapped a heartbeat sound (on speakers or sound floor) to every heartbeat of the user and mapped the skin conductance value to the overall brightness, hue, or saturation of the scene. For neurorehabilitation, a feedback of the motion quality and/or biophysiological values can be mapped to a large range of MoEs. We have not yet conducted a formal study on how well the various MoEs work for targeted biofeedback purposes, though. The more elaborate closed-loop version is to adjust the VE by selecting MoEs according to user states or story. Koenig et al. (2011) manipulated the feelings bored, excited, and overstressed using the difficulty level of a VR task during robot-assisted treadmill training. They adjusted the difficulty level due to the psychological state of the subjects, which was extracted from biophysiological signals. Novak et al. (2010) introduce a VR pick-and-place task with two difficulty levels and an additional cognitive task. They introduce a method to extract a rough psychological state in a closed-loop setup. They also use a simple valence-arousal emotion model which is sufficient for basic rehabilitation control. Our model can support these by mapping the MoEs to the coarse standard emotion model (mainly arousal). Nevertheless, our approach has a more elaborate emotion model and tries to distinguish between the three Russell dimensions and the eight Plutchik emotions (mood is not an issue here, as it can be estimated over time from the emotion signals). This means our requirements for a MoE emotion recognition closed-loop approach are much higher. As it is still impossible to extract these data from physiological signals alone, we suggest a combined facial, voice, and biophysiological neural network solution (Kim et al., 2004; Haringer & Beckhaus, 2008). Still, it is hard to achieve a mapping to the complete model in the near future, but any fraction of the current emotional state like valence, arousal, disgust, sadness, anger, and joy is helpful for the selection of MoEs. If an observer or moderator is present, the current state of the user can be rated by him or her in the mixed dimensional and discrete model.

The application of our setup for such neurorehabilitation tasks not only allows designers to adjust the difficulty level, it can be used to generate VEs with different emotional target states. The existence of the many easily accessible MoEs increases the flexibility of a VE scene and creates more exciting, interesting, and motivating experiences. Due to the knowledge of how different MoEs emotionally affect the subjects, a very powerful and subtle method of moving the impact in a specific direction has been created. On a very simple level, it is possible to present different versions of the application each time, without changing the original (e.g., training) application. For a closed-loop approach, as detailed emotional states such as those used in our emotional impact model are not yet automatically measurable, a rough state as used by Novak et al. (2010) and Koenig et al. (2011) could be utilized to estimate the reaction to the MoEs and change the type, target emotion, or frequency of the MoEs based on the simplified emotional model.

The emotional flexibility on the elicitation side of the VE is a major improvement over merely adjusting difficulty levels and adds another dimension. Emotions are known to be more fundamental functions than cognitive tasks (Plutchik, 1980; Frijda, 1986). Emotional VEs and emotion-enhanced tasks might aid cognitively impaired stroke victims more than purely cognitive tasks. On the other hand, negative emotions could possibly be problematic for some subjects. These ideas have to be verified in studies with the specific target groups.

As motivation helps neurorehabilitation (Maclean, Pound, Wolfe, & Rudd, 2002) and emotion creates motivation (Alcañiz et al., 2003; IJsselsteijn et al., 2006; Frijda, 1986), we strongly encourage the introduction of diverse and emotionally enhanced experiences for learning and neurorehabilitation. Our approach can further help to make robot-based neurorehabilitation VEs more versatile and emotionally controllable. The challenge in the application to neurorehabilitation, as in any application, is to find the right pattern of the MoEs and the target emotions. We support this with the emotional impact model for VE, a method to apply MoEs over time, adequate evaluation methods, a pool of emotionally rated MoEs, and a method to modify the emotional target impact.

7 Conclusion

In this paper, we presented a way to rate MoEs for their emotional value or impact and rated 30 MoEs with 30 participants. We showed that with the presented MoEs, it is possible to elicit various emotions. The rated MoEs can be used for the indication of information and the emphasis of specific objects, as well as for building an emotional experience. The rating can help to identify which MoEs are used best in the moment according to the potentially known user state, the quality of the rehabilitation process, and the time until the end of the training.

Our analysis of VE cues and our introduced MoEs emphasize the multitude of possible MoEs. Simply changing the used MoEs after a time can make the training more versatile and interesting, and enhance user motivation. We also introduced an emotional impact model which describes all occurrences of emotional data potentially used in a closed-loop emotional system. We briefly described our system, which allows runtime changeability of MoEs and their parameters. It provides a unified interface for objects, MoEs, and the control parameters of these MoEs, and it is able to apply any MoE to any object, section, or the whole scene.

We explored VE as a medium more formally and showed how different MoEs used in VEs affect people. To this end, we proposed an emotional model suitable for VEs, and we also rated different MoEs for their emotional impact on people. With this we showed that it is not only possible to convey specific targeted information to users of VEs (i.e., speech info, training commands, or avatars that mimic the user or guide the user to improve), but that it is also possible to have an effect on people using more subtle and potentially emotional cues. This provides a new enriched approach for training environments, as the emotional state of a trainee contributes greatly to the final outcome of training (and, of course, the experience). With the system presented here, which is capable of dynamically adapting to new situations, it is now possible to add emotional cues in real time, depending on the current state of the user. This could automatically be done by a system that knows about the training schedule, or that knows about the current user state (e.g., through evaluating physiological responses or facial expressions).

The evaluated MoEs are only a small selection of the over 100 MoEs that are already implemented in our system and the multitude of MoEs that are possible with VE. Future work has to show which MoEs are best for accentuation and which for biofeedback, such as in the context of neurorehabilitation. Also, the effect of controlling the emotional impact in neurorehabilitation training VEs has to be proven directly in a study with real patients. A further long-term goal is to create a complete closed-loop system which can assess the detailed emotional state of a user in real time, for example, from physiological data and facial expressions. This requires technical and predictive advancements in automatic emotion recognition.

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References

Alcañiz, M., Baños, R., Botella, C., & Rey, B. (2003). The EMMA project: Emotions as a determinant of presence. *PsychNology Journal*, *1*(2), 141–150.

Alcañiz, M., Botella, C., Rey, B., Baños, R., Lozano, J., de la Vega, N., et al. (2007). EMMA: An adaptive display for virtual therapy. In D. Schmorrow & L. Reeves (Eds.), *Foundations of augmented cognition* (pp. 258–265). Berlin: Springer.

Baños, R., Botella, C., Alcañiz, M., Liaño, V., Guerrero, B., & Rey, B. (2004). Immersion and emotion: Their impact on the sense of presence. *CyberPsychology & Behavior*, *7*(6), 734–741.

Beckhaus, S. (2010). [Virtual + 1] * Reality, blending "virtual" and "normal" reality to enrich our experience. In S. Coquillart, G. Brunnet, & G. Welch (Eds.), *Virtual Realities, Dagstuhl Seminar 2008* (pp. 77–96). Berlin: Springer.

Beckhaus, S., Blom, K., & Haringer, M. (2005). Intuitive, hands-free travel interfaces for virtual environments. In *IEEE VR2005 Workshop: New Directions in 3D User Interfaces* (pp. 57–60). Aachen: Shaker Verlag.

Beckhaus, S., & Lindeman, R. W. (2011). Experiental fidelity: Leveraging the mind to improve the VR experience. In S. Coquillart, G. Brunnet, & G. Welch (Eds.), *Virtual Realities, Dagstuhl Seminar 2008* (pp. 39–50). Berlin: Springer.

Bersak, D., McDarby, G., Augenblick, N., McDarby, P., Donnell, D. M., McDonald, B., et al. (2001). Intelligent biofeedback using an immersive competitive environment. Paper presented at the Designing Ubiquitous Computing Games Workshop, Atlanta, GA.

Bouchard, S. (2008). Anxiety increases the feeling of presence in virtual reality. *Presence: Teleoperators and Virtual Environments*, *17*(4), 376–391.

Bouchard, S. (2011). Emotions and the emotional valence afforded by the virtual environment. In J.-J. Kim (Ed.), *Virtual reality* (pp. 501–514). Rijeka, Croatia: InTech.

Bradley, M. M., & Lang, P. J. (1994). Measuring emotion: The self-assessment manikin and the semantic differential. *Journal of Behavioral Therapy and Experimental Psychiatry*, *25*(1), 49–59.

Bradley, M. M., & Lang, P. J. (2007). The International Affective Picture System (IAPS) in the study of emotion and attention. In J. A. Coan & J. J. B. Allen (Eds.), *The handbook of emotion elicitation and assessment. Series in affective science*. Oxford, UK: Oxford University Press.

Cikajlo, I., & Matjaĉić, Z. (2009). Advantages of virtual reality technology in rehabilitation of people with neuromuscular disorders. In G. R. Naik (Ed.), *Recent advances in biomedical engineering* (pp. 301–320). Rijeka, Croatia: InTech.

Curtin, J. J., Lozano, D. L., & Allen, J. J. B. (2007). The psychophysiological laboratory. In J. A. Coan & J. J. B. Allen (Eds.), *The handbook of emotion elicitation and assessment. Series in affective science*. Oxford, UK: Oxford University Press.

Davies, C. (2003). Landscape, earth, body, being, space, and time in the immersive virtual environments Osmose and Ephémère. In J. Malloy (Ed.), *In women, art, and technology* (pp. 322–337). Cambridge, MA: MIT Press.

El-Nasr, M. S. (2006). Projecting tension in virtual environments through lighting. In *Proceedings of the 2006 ACM SIGCHI International Conference on Advances in Computer Entertainment Technology.*

Frijda, N. H. (1986). *The emotions.* Cambridge, UK: Cambridge University Press.

Frijda, N. H. (2000). The psychologists' point of view. In M. Lewis & J. M. Haviland-Jones (Eds.), *Handbook of emotions* (2nd ed., pp. 59–74). New York: Guilford Press.

Haringer, M., & Beckhaus, S. (2008). Framework for the measurement of affect in interactive experiences and games. In *Proceedings of CHI'08 Workshop, Evaluating UX in Games.*

Haringer, M., & Beckhaus, S. (2010a). Dynamic visual effects for virtual environments. In *Proceedings of the Winter School of Computer Graphics 2010.* Plzen, Czech Republic.

Haringer, M., & Beckhaus, S. (2010b). Effect based scene manipulation for multimodal VR systems. In *Proceedings of the IEEE Virtual Reality Conference 2010.*

Haringer, M., & Beckhaus, S. (2011). Modell und Bewertung der emotionalen Wirkung von interaktiven virtuellen Umgebungen. In *Proceedings der Mensch und Computer 2011, entertainment interfaces track*. Chemnitz.

Holden, M. (2005). Virtual environments for motor rehabilitation: Review. *CyberPsychology & Behavior*, *8*(3), 187–211.

IJsselsteijn, W. A., Kort, Y. A. W. de, Westerink, J., Jager, M. de, & Bonants, R. (2006). Virtual fitness: Stimulating exercise behavior through media technology. *Presence: Teleoperators and Virtual Environments*, *15*(6), 688–698.

Juslin, P. N., & Sloboda, J. A. (2001). Music and emotion, theory and research. In P. N. Juslin & J. A. Sloboda (Eds.), *Handbook of music and emotion* (pp. 3–20). Oxford, UK: Oxford University Press.

Kennedy, R. S., Lane, N. E., Berbaum, K. S., & Lilienthal, M. G. (1993). Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness. *The International Journal of Aviation Psychology*, *3*(3), 203–220.

Kim, K. H., Bang, S. W., & Kim, S. R. (2004). Emotion recognition system using short-term monitoring of physiological signals. *Medical & Biological Engineering & Computing*, *42*(3), 419–427.

Koenig, A., Omlin, X., Zimmerli, L., Sapa, M., Krewer, C., Bolliger, M., et al. (2011). Psychological state estimation from physiological recordings during robot-assisted gait rehabilitation. *Journal of Rehabilitation Research & Development*, *48*(4), 367–386.

Lang, P., Bradley, M., & Cuthbert, B. (2008). *International Affective Picture System (IAPS): Affective ratings of pictures and instruction manual.* (Tech. Rep. No. A-8). Gainesville, FL: University of Florida.

Maclean, N., Pound, P., Wolfe, C., & Rudd, A. (2002). The concept of patient motivation: A qualitative analysis of stroke professionals' attitudes. *Stroke*, *33*(2), 444–448.

Malik, M. (1996). Heart rate variability: Standards of measurement, physiological interpretation and clinical use. *Circulation*, *93*, 1043–1065.

Meehan, M., Insko, B., Whitton, M., & Brooks, F. P., Jr. (2002). Physiological measures of presence in stressful virtual environments. In *Proceedings of the 29th Annual Conference on Computer Graphics and Interactive Techniques* (pp. 645–652).

Mikunda, C. (2002). *Kino spüren: Strategien emotionaler Filmgestaltung*. Wien: WUV-Universitätsverlag.

Mine, M. (2003). Towards virtual reality for the masses: 10 years of research at Disney's VR Studio. In *Proceedings of the Workshop on Virtual Environments 2003* (pp. 11–17).

Morie, J. F. (2002). Coercive narrative, motivation and role playing in virtual worlds. In *Proceedings of the 6th World Multiconference on Systemics, Cybernetics and Informatics, Vol. XII, Industrial Systems and Engineering II* (pp. 473–479).

Morie, J. F., & Williams, J. (2003). The Gestalt of virtual environments. In *Proceedings of the 6th Annual International Workshop on Presence*.

Nasoz, F., Lisetti, C. L., Alvarez, K., & Finkelstein, N. (2003). Emotion recognition from physiological signals for user modeling of affect. In *International Journal of Cognition, Technology, and Work*, *6*(1), 1–32.

Norman, D. A. (2004). *Emotional design*. New York: Basic Books.

Novak, D., Ziherl, J., Olenšek, A., Milavec, M., Podobnik, J., Mihelj, M., et al. (2010). Psychophysiological responses to robotic rehabilitation tasks in stroke. *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, *18*(4), 351–361.

Ou, L.-C., Luo, M. R., Woodcock, A., & Wright, A. (2004). A study of colour emotion and colour preference. Part I: Colour emotions for single colours. *Jounal of Color Research and Application*, *29*(3), 232–240.

Perry, J. C., Andureu, J., Cavallaro, F. I., Veneman, J., Carmien, S., & Keller, T. (2011). Effective game use in neurorehabilitation: User-centered perspectives. In P. Felicia (Ed.), *Handbook of research on improving learning and motivation through educational games: Multidisciplinary approaches* (pp. 683–725). IGI Global.

Plutchik, R. (1962). *The emotions: Facts, theories and a new model*. New York: Random House.

Plutchik, R. (1980). A general psychoevolutionary theory of emotion. In R. Plutchik & H. Kellerman (Eds.), *Emotion: Theory, research, and experience* (Vol. 1, p. 3–33). New York: Academic Press.

Riva, G., Mantovani, F., Capideville, C. S., Preziosa, A., Morganti, F., Villani, D., et al. (2007). Affective interactions using virtual reality: The link between presence and emotions. *CyberPsychology & Behavior*, *10*(1), 45–56.

Robillard, G., Bouchard, S., Fournier, T., & Renaud, P. (2003). Anxiety and presence during VR immersion: A comparative study of the reactions of phobic and non-phobic participants in therapeutic virtual environments derived from computer games. *CyberPsychology & Behavior*, *6*(5), 467–476.

Russell, J. A. (1980). A circumplex model of affect. *Journal of Personality and Social Psychology*, *39*(6), 1161–1178.

Schröder, M. (2008). *Elements of an EmotionML 1.0 W3C incubator group report 20 November 2008*. Retrieved from http://www.w3.org/2005/Incubator/emotion/XGR-emotionml/

Slater, M., Pertaub, D., & Steed, A. (1999). Public speaking in virtual reality: Facing an audience of avatars. *IEEE Computer Graphics and Applications*, *19*(2), 6–9.

Smith, G. M. (2003). *Film structure and the emotion system*. Cambridge, UK: Cambridge University Press.

Velten, E. (1968). A laboratory task for induction of mood states. *Behaviour Research and Therapy*, *6*(4), 473–482.

von Thun, F. S. (1981). *Miteinander reden 1 - Störungen und Klärungen*. Reinbek: Rowohlt Tb.

Witmer, B. G., & Singer, M. J. (1998). Measuring presence in virtual environments: A presence questionnaire. *Presence: Teleoperators and Virtual Environments*, *7*(3), 225–240.