# Increasing the effectiveness of human-computer interfaces for mental health interventions

Thesis submitted for the degree of
Doctor rerum naturalium (Dr. rer. nat.)
at the University of Würzburg in Germany
Faculty of Mathematics and Computer Science

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Würzburg, 2020

Thank you, Marc Erich Latoschik, for your guidance and support.

**Abstract**

Human-computer interfaces have the potential to support mental health practitioners in alleviating mental distress. Adaption of this technology in practice is, however, slow. We provide means to extend the design space of human-computer interfaces for mitigating mental distress. To this end, we suggest three complementary approaches: using presentation technology, using virtual environments, and using communication technology to facilitate social interaction. We provide new evidence that elementary aspects of presentation technology affect the emotional processing of virtual stimuli, that perception of our environment affects the way we assess our environment, and that communication technologies affect social bonding between users. By showing how interfaces modify emotional reactions and facilitate social interaction, we provide converging evidence that human-computer interfaces can help alleviate mental distress. These findings may advance the goal of adapting technological means to the requirements of mental health practitioners.

# Contents

# Chapter 1

# Summary

## 1.1 Research question

Technology has a long history as a catalyst for innovations in somatic medicine. Technicians created machines that drove pharmacological discoveries. For example, microscopes enabled the detection of bacteria in 1676, later recognized as causing many illnesses.[176] Technicians also built tools that health practitioners use to help people in need. Hemodialysis machines support kidney functions in dialysis and are one example out of many such innovations. Furthermore, technicians built human-machine interfaces that enable health practitioners to improve their diagnostic techniques, allowing them to choose the most effective treatments: Wilhelm Conrad Röntgen, for example, invented a device to examine bone structures through unimpaired skin in Würzburg in 1895.[187] Other technical devices help patients during their daily live: for example, brain-computer interfaces enable paralyzed people to interact with their environment;[62] or mechanical prostheses interpret muscle signals to compensate for physical disabilities.[15]

This story of success in somatic medicine, however, does not generalize to mental health. No matter how large the benefit of technology for patients with somatic conditions advanced, we mostly rely on direct human engagement to alleviate mental conditions: until today, technology plays a limited role in treating mental distress. To the contrary: humanity looks back on a long history of adverse outcomes in their quest to help people in mental distress with technological means. Inducing artificial fevers (awarded with the Nobel Prize in Physiology or Medicine in 1927) or severing parts of the brain (lobotomy, awarded with the Nobel Prize in Physiology or Medicine in 1949) are two prominent examples of technological procedures that injured patients. Even current technical mediated treatments like electroconvulsive therapy are highly controversial,[180] and patients and researchers are increasingly questioning psychopharmacological interventions due to side effects and questionable effectiveness.[56,162] Hence, despite remarkable technological advances over the last decades, mental health seems still far beyond the sphere of technological influence.

Nevertheless, some specific technological developments impact mental distress: the immersive presentation of fear-related stimuli, known as virtual reality exposure therapy, mitigates specific phobias.[160,177,207,208] Furthermore, the ubiquitous accessibility of the world wide web allows people to connect to their loved ones and peers and communicate with minimal costs across vast distances, for example, utilized to provide remote psychotherapy via video conferencing tools. However, the impact of technological means on patients' actual treatments fastly remains in the research realm. Technological uptake by practitioners is slow.[55,204] This reservation might indicate that current research findings match practitioners' requirements only to a limited degree.[67] Research on the direct effect of technological means on crucial constructs for psychotherapy is scarce. To target mental distress with technological devices, we need to focus on the experiences that alter our emotional states, ideally positively in the long run. Emotions are direct information about the relevance and attainment of our current personal goals. To increase the practical relevance of research for practitioners, we need to extend the technological design space to induce emotions. Such knowledge allows for developing human-computer interfaces that contribute to mental distress relief. In this thesis, we work towards extending the design space of human-computer interfaces by evaluating the effect of technological means on emotions with three complementary approaches: using presentation technology, using virtual environments, and using communication technology to facilitate social interaction. We advance the current state of knowledge on these approaches to influence emotions by addressing the following research questions: How do the elementary aspects of presentation technology affect the emotional processing of these stimuli? Knowledge about such processes allows adapting technological means to the required impact of interventions. How can we modify the perception of our environment with the use of presentation technologies? Knowledge about this technology allows us to design virtual environments in ways that meet patients' needs. Finally, how can we use communication technologies to affect social bonding between users? Such knowledge helps to leverage the most critical factor in psychotherapy, the building of supporting relationships.

## 1.2 Method

We approach the question of how human-computer interfaces can facilitate emotional experiences from three directions: First, we ask how the manipulation of perception qualities themselves affect emotional reactions to the content of the human-computer interface: Therefore, we first analyzed visual human-computer interfaces' most fundamental parameter: the visual angle they comprise chapter 2. We manipulated the visual angle of a percept and measured differences in emotional reactions to the displayed content. We furthermore tested how these reactions interact with auditory cues. The design-space of Human-computer interfaces, however, goes beyond visual and auditory modalities. Therefore, we analyzed how haptic information interacts with other modalities in its capacity to influence the emotional perception of users: in chapter 3 we manipulated the quality of haptic information and measured its effect on presence, the sensation of users to be in a virtual environment while knowing they are using a human-computer interface. Introducing haptic information to human-computer interfaces allows us to induce the sensation to own a virtual body.[23] In chapter 4, we hypothesize that owning a virtual body provides means to intensify the emotional perception of the virtual surrounding. We manipulated the sense of virtual body ownership and analyzed the emotional reactions to virtual stimuli.

Presence and virtual body ownership are the most common measures for users' subjective reactions to immersive human-computer interfaces. Even though both constructs are different, they have a theoretical overlap. In chapter 5, we, therefore, tested the hypothesis that both measures share a common factor and hence, to some degree, measure a similar sensation.

Virtual body ownership is an example of how profoundly the influence of human-computer interfaces on users' perception can be. We assessed the boundaries of how multi-modal stimuli might alter the emotional experience of the virtual environment. Therefore, in chapter 6, we tested if sensory information manipulation can even induce the sensation that body parts swap.

Social interactions play a crucial role in mitigating mental distress. Hence, we extended our analysis of the influence of human-computer interfaces on emotions beyond single users to their influence in interacting groups. We ask how human-computer interfaces facilitate emotional bonding in relationships. Therefore we studied how information transfer can facilitate interpersonal relationships: In an exploratory study, we observed how knowledge management affects person-centered dementia care.

In the context of this thesis, we furthermore conducted studies on the manipulation of emotions with human-computer interfaces, that we report in-depth in the following references: We analyzed the effect of avatar realism on emotions.[245] We found that personalized avatars significantly increase body ownership, presence, and dominance compared to generic avatars. Furthermore, the degree of immersion significantly increases virtual body ownership, agency, and presence. We investigated the effect of personalized avatars on simulated social interactions.[126] We found that realistic avatars were rated more human-like and increased acceptance. We prototyped tangible items to induce emotional memories in people with dementia.[139] We analyzed the effects of gaze directions on avatar-mediated interactions.[190] Computer-mediated natural-gaze behavior provided positives effects on the perception of social interaction. We analyzed the effects of social relatedness on the robot-assisted gait training.[104] Our findings support the hypothesis that social relatedness and autonomy provide critical content features in computer-mediated gait rehabilitation. Furthermore, we developed a recommender system for personal photos to facilitate relationship building with people with dementia.[72]

## 1.3 Related work

Each study in this thesis builds on literature that we discuss in the respective chapters. The following provides an overview of these discussions.

### Visual angle modulates affective responses to audiovisual stimuli

Previous studies on the interaction of emotional reactions and visual perspective, which focus on the content level, have mostly relied on photorealistic images.[36,49,181] They also induce mechanisms of object and scene recognition. These mechanisms cause variations in the size of the stimuli that confound the observer's perceived distance and his ability to discriminate the content of the stimuli. In these studies, the variation of the distance and the ability to discriminate may influence emotional responses to stimuli. However, such high-level processes influence the emotional perception of stimuli. At the same time, early perceptual information may trigger emotional responses. Such information may consist of elementary presentation characteristics of the stimuli, such as the visual angle of a percept. This visual angle is already available in the early stages of processing, independent of high-level object recognition.[167,231] We analyze how this essential feature of visual interfaces affects emotional perceptions independent of high-level content processing. Moreover, we integrate the finding that visual and auditory perception are also mainly interdependent.[33,154,229,241,242] In chapter 2, we analyze how the visual angle of a percept interacts with the perception of auditory content in organizing emotional perception.

### Congruent visual and haptic feedback increases presence

Current human-computer interfaces mainly transmit visual and acoustic information. In everyday settings, however, haptic information provides an additional modality that can profoundly impact emotions. Haptic information, however, is hard to manipulate dynamically and hence is rarely used to induce content specific emotions. We analyze the potential power of haptic interfaces to induce emotions. Therefore, we conducted a study to analyze the effect of haptic information and the congruence to visual perceptual qualities on the sense of presence.

Presence provides an essential subjective measure for the effectiveness of virtual reality systems.[214] There are several theoretical approaches to define presence, which was introduced by Akin et al.[2] (see Skarbez et al.[214] for an overview). However, the different approaches to presence share the common understanding that presence describes the feeling of being physically present in the virtual environment. Several approaches propose that presence directly relates to the congruence of sensory feedback to the user's expectations.[168,169,172,205,217] For example, heat and congruent wind sensations increase presence,[54], and congruent haptic feedback increases fear responses to virtual threats.[156]

Congruent visual and haptic feedback can even induce the illusion that a virtual object is part of one's body, the illusion of virtual body ownership.[23,107] We assume that the perceived sensation of having a virtual body confounds the impact of haptic information on presence. In previous studies, where participants saw a virtual body, congruent haptic feedback increased their sense of presence.[87,121] To exclude the potential confounder of owning a virtual body, in chapter 3, we studied the effect of haptic feedback on presence when people did not experience a virtual body.

### Virtual body ownership intensifies the emotional response to virtual stimuli

The induction of virtual body ownership is a powerful means to alter the user's perception. We hypothesize that this illusion alters not only the perception of one's body but also the emotional evaluation of the virtual surroundings. Previous studies showed the effects of virtual body ownership on a wide range of cognitive processes. It alters the perceived position of the real body part when the virtual body appears displaced.[23,130,195] It changes the perceived size and distance of virtual objects.[7,99,132,236–238] It changes the attributes towards the social group of the virtual body.[7,60,61,64,141,174] It increases the awareness of the virtual body.[239] It influences spatial orientation,[178] tactile perception,[137] and modulates pain.[75,145–147,150,165,171] However, we know little about the effect of virtual body ownership on the emotional responses to virtual stimuli. We know that virtual body ownership modulates fear and arousal for specific stimuli that threaten the virtual body.[3,34,82,186] However, the question remains how the ownership of a virtual body affects general emotional responses that are not directly related to the virtual body. Therefore, in chapter 4, we evaluated responses to virtual stimuli in a virtual world while manipulating the sense of virtual body ownership.

## Presence and virtual body ownership constitute a common factor

Presence and virtual body ownership are the most prominent constructs to measure the effect of virtual reality interfaces. Both constructs differ in their ability to capture critical outcome measures.[200] Some studies found correlations between presence and anxiety responses, but only when the arousal was sufficiently high (see Diemer et al.[53] for an overview). However, presence does not predict the outcomes of virtual exposure therapy.[53] Some studies suggest a causal influence of emotions on presence.[24,76,79] Virtual body ownership proved a higher degree of external validity compared to presence. Previous studies reported only weak associations between presence and critical outcome measures,[24,53,76,79,200] whereas virtual body ownership proved to have a broader influence on the perception of users.[7,60,61,64,99,130,132,174,195,237,238] On the one hand, they seem to capture different experiences, while both constructs provide indicators for how users accept virtual stimuli as real while knowing they are not. Presence provides this indicator for the virtual surrounding and virtual body ownership for the virtual body within this surrounding. Even though the virtual surrounding and the virtual body are different things, they are closely related: Our body is part of the environment, and we perceive our environment by using our bodies. Hence, it is not surprising that presence and virtual body ownership correlate.[98,99,245] However, no research examines both constructs' causal interdependence to understand the nature of this correlation. In chapter 4, we support the hypothesis that both constructs, while weighing different aspects of an experience, mutually induce each other and, hence, essentially describe a common underlying construct.

## Virtual body ownership can arise for anatomically implausible body configurations

The illusion to own a virtual body not only can arise for bodies that resemble one's own body, but also for modified bodies. People demonstrated high flexibility in what they accept as virtual bodies. For example, people accept displaced,[130] translated,[23] or scaled bodies.[106,132] Furthermore, people can accept additional body parts as parts of their bodies[80,91,197,221] or partially removed body parts.[201] However, in previous studies, modified body parts are anatomically plausible: they only expand or reduce to the existing body. Previous studies have suggested that virtual body ownership requires anatomical plausibility of the virtual body.[107,186] Laterally incongruent or anatomically misaligned virtual bodies reduced virtual body ownership. People rejected a virtual right hand, which was stimulated synchronously with the left hand.[233] People also rejected a virtual foot, which was stimulated synchronously to the hand.[80] However, the integration of visual and tactile information does not necessarily depend on anatomical plausibility: lateral confusion of sensory information occurs, for example, if people see one of their hands being touched while feeling the touch on their other hand.[173] In chapter 6, we, therefore, analyze if virtual body ownership can arise for lateral body swaps.

## Self-organizing knowledge management might improve the quality of person-centered dementia care

Interpersonal bonding remains the central means to alter emotions. Hence we assess how we can use human-computer interfaces to leverage the power of communication. Therefore, we focus on the example of person-centered dementia care. Person-centered care is a humanistic care approach that emphasizes relationship building and interpersonal communication in dementia care. Person-centered faces economic challenges: Profit maximization in care facilities reduces administrative support.[129] Limited salaries and training limit the ability of staff to provide person-centered care.[254] A low-cost policy leads to a reduction in staffing levels, high annual turnover, and burnout rates among nursing staff.[248] Such policies hinder the development of attitudes, stable relationships between staff and residents, and working methods essential for person-centered care. The economization of care also promotes fragmentation of care professions[35] and institutions.[38] This fragmentation limits the responsibility for person-centered care to a small group.[59] However, person-centered care includes the entire social environment of the residents. Cost reductions restrict communication between staff and residents, which often consists of nothing more than instructions.[133] Such economic constraints translate to communication barriers, which are the main factors hindering person-centered care.[115] The fragmentation of the nursing professions hinders the transfer of information. Empathetically addressing residents' needs requires knowledge of their history, preferences, routines, and behavioral patterns.[115] The institution-wide communication of this knowledge is crucial for person-centered care.[115] However, this exchange of information often does not take place.[115] The transfer of knowledge lacks openness, accuracy, punctuality, and systematics.[115,203] Existing documentation systems lack the information that is necessary for person-centered care.[31,94] Accessible information is often outdated and too time-consuming to read.[115] Word-of-mouth techniques often lack consistency, accuracy, and they do not spread across different professions.[115] Hence in chapter 7, we assess how human-computer interfaces can organize and transfer knowledge to facilitate person-centered care.

## 1.4 Results

In chapter 2, we report how the visual angle of a percept influences emotional responses to audiovisual stimuli. We conducted a $2 \times 2 \times 3$ factorial repeated-measures experiment with 143 undergraduate students. We showed that visual angle weights affective relevance of perception modalities independent of object representations. Visual angle serves as an early-stage perceptual feature for organizing emotional responses. Control of this presentation layer allows for provoking or avoiding emotional responses where intended.

In chapter 3, we investigate how haptic feedback influences the sense of being present in a virtual environment. We conducted a single-factor repeated-measures experiment with 56 undergraduate students. We showed that congruent visual and haptic feedback increased presence compared to incongruent feedback and visual feedback alone. This effect does not require a virtual body. Furthermore, we provided evidence for the convergent validity and sensitivity of a one-item mid-immersion presence measure. Congruent visual and haptic feedback increases the effectiveness of virtual environments.

In chapter 4, we investigate how virtual body ownership organizes the emotional perception of a virtual environment. We conducted a single-factor repeated-measures experiment with 21 undergraduate female students. We showed that virtual body ownership intensifies emotional responses to virtual stimuli. The virtual stimuli can be unrelated to the virtual body, apart from sharing an environment. Hence, virtual bodies can increase the effectiveness of human-computer interaction.

In chapter 5, we investigate how presence and virtual body ownership relate to each other. We conducted two experiments with 42 undergraduate students. We show that presence induces virtual body ownership and that virtual body ownership induces presence. We conclude that presence and virtual body ownership constitute a common factor. A common factor allows applying knowledge about one construct to the other.

In chapter 6, we investigate how changeable the perception of one's own body is. We conducted a two-factorial repeated-measures experiment with 56 undergraduate students. We showed that virtual body ownership can arise for a virtual body with laterally swapped hands. Hence, virtual body ownership does not require anatomical plausibility. This flexibility in self-perception can serve clinical applications that target body-environment relations.

In chapter 7, we investigate how information technology can improve person-centered dementia care quality. We show that self-organizing knowledge management provides a promising tool to improve the quality of person-centered care. It can reduce communication barriers that impede person-centered care. Transferring content-maintaining tasks from caregivers to relatives is beneficial for both parties. Shared knowledge about situational features facilitates person-centered interventions. We provide evidence that computer-supported communication flow can increase the effectiveness of clinical interventions.

## 1.5 Conclusions and outlook

We investigated how human-computer interfaces can increase the effectiveness of mental health interventions. Such knowledge informs the development of new technologies that support people with mental burdens. We used two different research approaches to find answers to this question: experimental research and field studies.

We conducted experiments to investigate how the presentation of information influences emotions. Emotions are central to mental health interventions. We investigated emotional responses to human-computer interfaces. We showed that an increased visual angle intensifies emotional responses (chapter 2). Human-computer interfaces enable remote social interaction when real interaction is not possible. We assume that accepting a virtual environment or a virtual body as real facilitates remote social interaction. We investigated the felt realness of a virtual environment or body. We showed that congruent visual and haptic feedback increases presence in a virtual environment (chapter 3). We showed that virtual body ownership increases emotional responses to the virtual environment (chapter 4). We showed that presence and virtual body ownership constitute a common factor (chapter 5). We showed that virtual body ownership can arise for anatomically implausible body configurations (chapter 6). So the presentation of visual and haptic stimuli modulates the perception of reality. The perceived realness of stimuli affects emotional responses.

We conducted a field study to investigate how current interface technology can increase mental health interventions' effectiveness. We showed that self-organizing knowledge management provides a promising tool to improve person-centered care quality (chapter 7). Computer-supported communication flow can increase the effectiveness of clinical interventions.

Our results support the hypothesis that human-computer interfaces can increase the effectiveness of mental health interventions by providing the means to induce emotions.

## Next steps

### Visual angle modulates affective responses to audiovisual stimuli

In chapter 2, we showed that visual angle affects the presentation of stimuli independent of object recognition processes. However, what other qualities of human-computer interfaces affect emotional responses, independent of the presented content? We assume that multisensory stimulus presentation also intensifies emotional responses, independent of the content.

### Congruent visual and haptic feedback increases presence

In chapter 3, we showed that people accept being in a static environment if they can touch it. However, how do people respond to a dynamic environment if they transform their shape by applying force? We can study this question by keeping visual and haptic feedback constant while participants either feel or cause a transformation. We hypothesize that causing a transformation increases emotional responses to the virtual environment (see Braun et al.[28] for a related discussion on agency and body ownership).

Presence increases if people get congruent haptic feedback in addition to visual feedback. So how do expectations influence the perception of a virtual environment? We hypothesize that knowledge about the realness of a virtual environment modulates emotional responses to it.

### Virtual body ownership intensifies the emotional response to virtual stimuli

In chapter 4, we showed that virtual body ownership intensifies emotional responses to virtual stimuli. However, how do different virtual bodies modulate this effect? Different bodies induce different emotional reactions. We hypothesize that the perception of a virtual body modulates the perception of the environment. Faces represent a body part that links to one's identity. We expect that experiencing ownership of different faces[140] modulates the perception of a virtual environment.

### Presence and virtual body ownership constitute a common factor

In chapter 4, we showed that presence and virtual body ownership share a common factor. However, to what extent do the effects of virtual body ownership translate to presence and vice versa? We assume that presence moderates emotional responses to virtual stimuli. To test this hypothesis we propose presenting images from chapter 4 in the virtual environments of chapter 3 and assess emotional responses. If presence and virtual body ownership share a common factor, how can we define independent measures for virtual environments' effectiveness? Such measures need to predict outcomes that are of interest beyond theoretical considerations: for example, treatment effects or effects on behavior, attitudes, or memory.

### Virtual body ownership can arise for anatomically implausible body configurations

In chapter 6, we showed that people do not require anatomical plausibility to experience virtual body ownership. However, how does the implausibility of a virtual body affect the perception of the virtual environment? We hypothesize that anatomical implausibility modulates the affective responses to the environment.

**Self-organizing knowledge management might improve the quality of person-centered dementia care**

In chapter 7, we used qualitative research to investigate the effectiveness of human-computer interfaces in dementia care. However, how can we validate these findings if larger data sets are available? We propose using predictive modeling to optimize individualized computer-supported interventions in mental health. Statistical interference successfully guides traditional hypothesis testing. It guides how we formulate hypotheses, and it defines what knowledge we generate. Statistical interference indicates if an effect is present in a population. It uses samples to estimates how populations differ in specific variables. This approach is efficient when theoretical considerations guide the collection of data. However, statistical interference often does not meet the requirements of clinical practice. Knowledge about differences between populations often is insufficient to guide clinical decisions. Such decisions include diagnosis, prognosis, and optimal treatment selection. These decisions often depend on a combination of patient characteristics. Predictive modeling provides statistical methods to support such decision-making processes. Predictive modeling, however, challenges assumptions about mental health research. First, the performance of predictive models depends on large amounts of data. In general, the more diverse the variables, the better the performance. Second, predictive models obscure the rules of how to make a decision. In general, they do not contribute to generalizable theories. Nevertheless, the results of predictive models apply to individual clinical decisions. The successful implementation of predictive modeling in clinical practice consists of four research stages. First, we need to generate hypotheses about variables with a predictive value for a given outcome. Second, we need to assess the feasibility of data collection. Third, we need to find models with high prediction performance for the data collected. Performance evaluation involves validating the models with independent test cases. Fourth, we need to demonstrate the clinical efficacy of the model. The clinical efficacy of a predictive model depends on the practical demands of practitioners. It is not equivalent to high performance in controlled test scenarios.[230] We assume that predictive modeling augments statistical interference about the effectiveness of human-computer interfaces for mental health applications.

## Conclusion

This thesis provides a means to extend the design space of human-computer interfaces for mitigating mental distress. To this end, we suggest three complementary approaches: using presentation technology, using virtual environments, and using communication technology to facilitate social interaction. We provide new evidence that elementary aspects of presentation technology affect the emotional processing of virtual stimuli, that perception of our environment affects the way we assess our environment, and that communication technologies affect social bonding between users. These findings may advance the goal of adapting technological means to the requirements of mental health practitioners. We provide converging evidence that human-computer interfaces can help alleviate mental distress: interfaces modify emotional reactions; interfaces facilitate social interaction. Both effects can facilitate the work of mental health practitioners.

# Chapter 2

# Visual angle modulates affective responses to audiovisual stimuli


**Abstract**

What we see influences our emotions. Technology often mediates the visual content we perceive. Visual angle is an essential parameter of how we see such content. It operationalizes visible properties of human-computer interfaces. However, we know little about the content-independent effect of visual angle on emotional responses to audiovisual stimuli. We show that visual angle alone affects emotional responses to audiovisual features, independent of object perception. We conducted a $2 \times 2 \times 3$ factorial repeated-measures experiment with 143 undergraduate students. We simultaneously presented monochrome rectangles with pure tones and assessed valence, arousal, and dominance. In the high visual angle condition, arousal increased, valence and dominance decreased, and lightness modulated arousal. In the low visual angle condition, pitch modulated arousal, and lightness affected valence. Visual angle weights the affective relevance of perception modalities independent of spatial representations. Visual angle serves as an early-stage perceptual feature for organizing emotional responses. Control of this presentation layer allows for provoking or avoiding emotional response where intended.

## 2.1 Introduction

What we see influences and evokes emotions. This content-based evocation works with single pictures, e.g., displaying a crying person or a tortured animal, as well as by stories told as, e.g., in movies. Notably, this effect does not only occur in response to iconic or tangible objects or events. For example, color-to-emotion associations elicit affective responses even to very simple stimuli.[103]

Today, what we see is often mediated or even determined by technology. Visual information is central for graphical displays prominent in current Human-Computer Interaction paradigms, from 2D Graphical User Interfaces to Virtual and Augmented Reality. Inevitably, the graphical information presented in such displays impacts the affective response of users. For the design of graphical user interfaces, it is, therefore, crucial to understand the effect of visual displays on emotions. Such knowledge allows for preventing unintended or eliciting intended emotions. The content layer surely has affective power (e.g., Lang et al.[125]); however, we know little about the affective power of the presentation layer.

The presentation layer of graphical displays has several properties, including display size, resolution, maximum brightness, color resolution, contrast, and dynamic range, and field of view. The combination of size, resolution, and field of view determines the overall maximum quantity of visual information displayed simultaneously. The user-to-display distance then determines the perceivable information. The most general measure to operationalize the resulting quantity of visual information is the visual angle.

The goal of this study is to identify how the visual angle modulates the emotional responses to audiovisual content. Previous studies on emotional responses to visual angle focus on the content layer. Larger naturalistic stimuli induced increased arousal and dominance ratings compared to smaller stimuli[49]; they also induced lower heart rates and higher skin conductance[181]; as well as increased arousal ratings and skin conductance.[36] Naturalistic stimuli are more engaging compared to simple stimuli and hence provide suitable means to study emotional responses (see De Cesarei et al.[47] for a review). Natural scenes, however, induce mechanisms of object and scene recognition. They induce effects that might confound the analyses of visual angle: notably, object size variations and spatial information destiny. Moreover, general attentional processes differ for naturalistic and simple stimuli: Observers, for example, categorized natural scenes in the near absence of spatial attention while they failed to distinguish simple stimuli.[63,131] In this study, we address the emotional effect of visual angle without using photo-realistic images.

Size variations of naturalistic stimuli confound the perceived distance of the observer to the stimulus. Size variations also confound the ability of the observer to differentiate the content of the stimuli. Both perceived distance and content discrimination, in turn, affect emotional responses to stimuli. Apart from these high-level processes, low-level perceptual information already starts to initiate emotional responses. This low-level information is independent of presentation properties like color, brightness, spatial information density, or complexity.[100] Early stages of natural scene recognition are independent of high-level object recognition.[167,231] Regularities in the appearance of scenes, however, modulate object recognition even in early processing stages (see De Cesarei et al.[47] for a review). The use of such regularities limits the impact of visual noise, information density, or object size. The processing of regularities in scenes correlates to neural activities that associate with categorization tasks.[45,46] The visual angle is independent of scene characteristics. We, hence, assume that the visual angle of a percept constitutes a visual feature that is available independent of object recognition processes. In this study, we investigate the impact of visual angle while minimizing the impact of object recognition effect, which might confound emotional responses.

Visual and auditory perception is interdependent.[154] This interdependence affects the processing of emotional stimuli. Visual information influences the perception of emotional auditory content: Videos of musical performance, for example, affect emotional response to musical stimuli.[33,229,241,242] Furthermore, visual information intensfies emotional ratings of congruent auditory content.[39] Vice-versa, auditory-induced emotions affect the emotional perception of visual content.[135,144] Hence we hypothesize that visual angle not only affects the emotional responses to visual but also to auditory information. In the current study, we address how the visual angle interacts with auditory content perception to organize emotional responses.

This article reports novel findings on the effect of visual angle on affective responses to audiovisual content features. We investigated the impact of visual angle on affective responses to visual and auditory stimulus features independent of object recognition processes. Visual content features modulated affective perception only when the visual angle was high. Auditory content features modulated affective perception only when the visual angle was low. Our results indicate that visual information availability modulates emotional responses on early processing steps. We suggest that this processing step is independent of object recognition processes.

### 2.1.1 Theoretical background

The importance of a percept for the intentions of the perceiver shapes her emotional responses.[244] The visual angle is one of the first perceived properties of such a percept. Previous studies confound the emotional effect of visual angle with variations in perceived proximity and information density.

The visual angle is a function of the physical size of the percept and its distance to the observer. Both parameters affect the evaluation of the importance of the percept.[227] The cognitive representation of a percept is size-invariant.[16,95,116] Hence the size of a percept relates to the physical distance of the observer to the object.[134] Perceivers link changes in percept size to approaching and receding movements. Approaching movements intensify affective responses compared to receding movements.[161] This effect even holds if participants just imagined changes in stimulus size.[42] Participants also represented distal events in a more abstract, schematic way.[69,84,232] Increasing the perceived physical distance to aversive stimuli reduces their perceived threat.[18,158,249] In line with this reasoning, increasing the size of photorealistic images intensifies subjective arousal and dominance ratings.[36,181] Hence this effect of size variation might be due to perceived proximity instead of visual angle. In this study, we analyze the effect of visual angle independent of perceived proximity.

Furthermore, spatial information density may confound the emotional effects of stimulus size variation. Previous studies about the effect of stimulus sizes use naturalistic stimuli (e.g., the International Affective Picture System[125]). Size reduction of such naturalistic stimuli increases spatial information density: less space displays the same information. This densification increases the difficulty of discriminating content.[134] Discrimination of content, in turn, is necessary for a content-specific emotional response. The variation of spatial information density might explain the variation of emotional responses to varying stimulus sizes: De Cesarei and Codispoti[43] reports that reducing fine-grained details in constant-sized images modulates emotional response in the same way as size variation does. Moreover, a temporal variation of spatial information density might affect emotional responses, though the empirical results are incoherent (see De Cesarei and Codispoti[44] for a review). Hence we assume that information density confounds emotional responses to the size variation of naturalistic stimuli.

A fixed visual angle defines two states: inside and outside the percept. These separated areas inevitably define a boundary. To operationalize visual angle, we used monochrome rectangles comprising the minimal set of perceptual features: a spatial boundary defined by contrasting colors. We assume that the perception of monochrome rectangles of varying size dissociates the effects of spatial information density from the visual angle. Monochrome rectangles reduce the perceptual features that facilitate object recognition to a minimum (object shape, surface details, three-dimensional shading, texture, and object coloring).[188,226] We assumed that monochrome rectangles aggravate a three-dimensional object representation and consequently, their positioning in space. Color information seems independent of object perception. The recognition of the emotional scenery information is not affected by color information.[26,27,37,193]

### 2.1.2 Contribution

We tested the effect of visual angle on the emotional perception of audiovisual features. Monochrome color rectangles operationalized visual angle. We varied visual content features among different lightness values of the stimulus color. We operationalized auditory content features as different pitches of pure tones. Participants perceived these tones simultaneously with the visual stimuli. Participants then rated their subjective valence, arousal, and dominance response. We assumed that the visual angle determines emotional responses, independent of object recognition processes. Furthermore, we assumed that the visual angle moderates the emotional effect of visual and auditory content features. For the high visual angle condition, we observed that increased arousal decreased valence and dominance perception, and that visual content features modulated arousal. For the low visual angle condition, we found that pitch modulated arousal and that lightness affected valence. These results indicate that visual angle weights the emotional relevance of per-

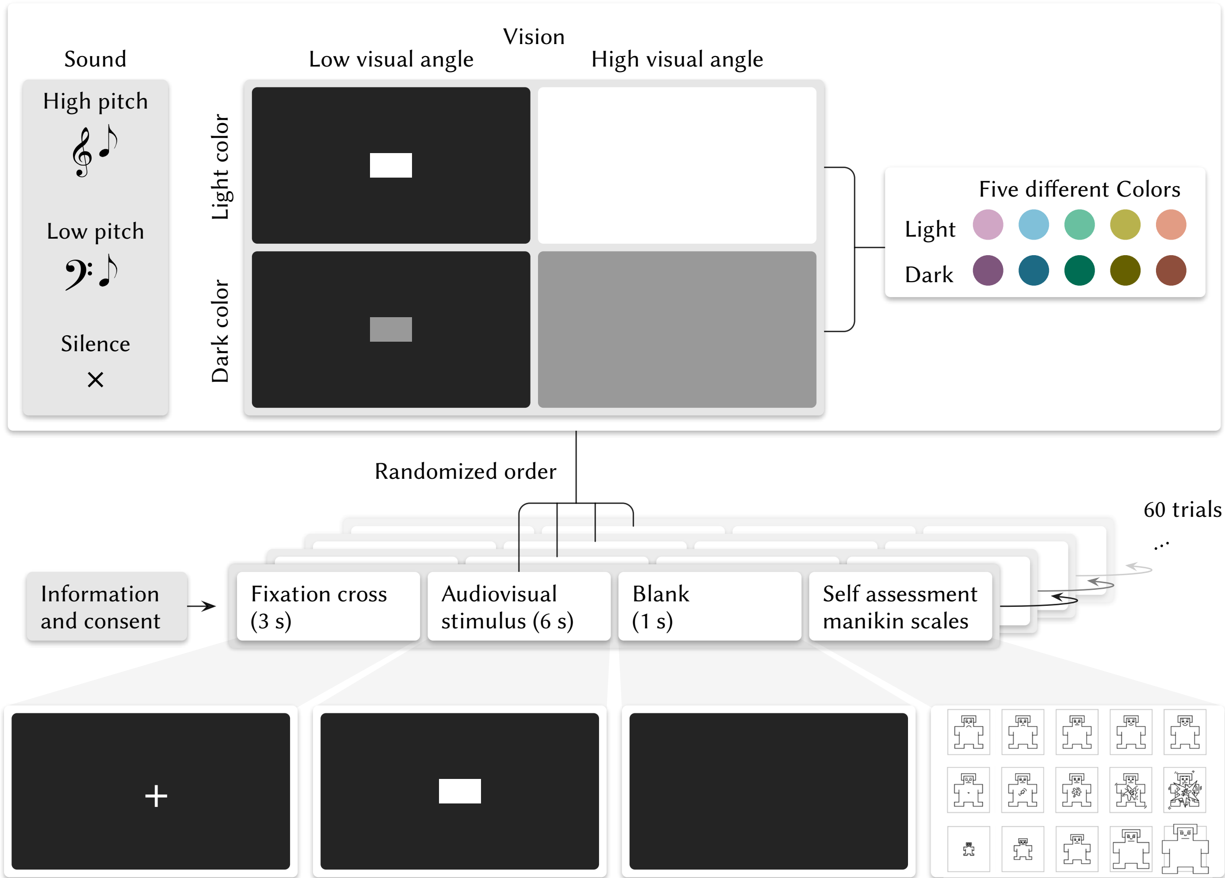


**Figure 2.1: Procedure and stimuli.** Participants completed 60 trials in a repeated measures $2 \times 2 \times 3$ factorial design. Each trial began with the presentation of a fixation cross. Then participants saw a monochrome rectangle and heard a sound. The rectangle was either small or filled the whole screen. The rectangle had one of five colors, either light or dark. Participants heard either a pure tone in a high or low pitch or no tone at all. We corrected pitches for equal-loudness. Afterward, participants reported valence, arousal, and dominance on self-assessment manikin scales.

ception modalities. A higher visual angle increases responsiveness to visual features and decreases responsiveness to non-visual features. These findings inform the design of new human-machine interaction techniques that incorporate visual information transfer and emotional processing.

## 2.2 Method

### 2.2.1 Participants

Undergraduate students (143, 118 women) from an anonymized university volunteered to participate in the experiment. All participants provided written informed consent before participation. They received course credit for participation. All participants reported normal or corrected to normal vision and normal hearing. We excluded 7 participants from the analysis for whom technical problems prevented a correct stimulus presentation. The final sample size consisted of $N = 136$ participants (113 women), with age ranging from 18 to 28 years ($M = 20.85$, $SD = 1.86$). Participants were naive regarding the hypotheses of the experiment. This study received ethical approval from the institutional ethics committee.

### 2.2.2 Design and procedure

The experiment followed a repeated-measures $2 \times 2 \times 3$ factorial design with the factors visual angle (low vs high), lightness (low vs high), and pitch (none vs low vs high). We repeated each of these 12 conditions with five hues. Each participant completed 60 trials in a balanced, randomized order. Trials began with the presentation of a fixation cross (3 s). Participants then simultaneously saw a monochrome rectangle and heard no or a pure tone for 6 s. The rectangle varied in lightness, visual angle, and hue. The pure tone varied in pitch. After a black display (1 s), participants self-assessed valence, arousal, and dominance on self-assessment manikin scales. Participants selected responses with a mouse and proceeded to the next trial by clicking a button. We instructed participants to report their emotional responses to the audio-visual stimulus. Figure 2.1 illustrates the experimental design.

### 2.2.3 Experimental manipulation

Stimuli consisted of the simultaneous presentation of a visual and an auditory cue for 6 s. Visual cues consisted of monochrome rectangles that varied in size, lightness, and hue. We used an RGB approximation of the Munsell color space to specify the presented colors. The Munsell color space aims to represent color in a psychophysically plausible way[119], consisting of three dimensions: value (light to dark), chroma (gray to colored) and hue (circular scale). We used the five principal hues red (10R), yellow (10Y), green (10G), blue (10B), and purple (10P). For the factor lightness, we used the Munsell value 7 for the high lightness and 4 for low lightness. Chroma was constant at 6. We approximated the resulting Munsell colors (hue value/chroma) with the following RGB values (in brackets): 10R 7/6: (225,156,134), 10Y 7/6: (184,177,84), 10G 7/6: (108,191,161), 10B 7/6: (130,192,216), 10P 7/6: (207,167,196), 10R 4/6: (141,78,62), 10Y 4/6: (102,95,6), 10G 4/6: (4,108,83), 10B 4/6: (34,106,131), and 10P 4/6: (125,86,123). In the low visual angle condition, the rectangle was 139 mm long and 78 mm high. For the focal viewing distance of 550 mm, this corresponds to 15° horizontal and 8° vertical visual angle. In the high visual angle condition, the rectangle comprised 930 mm $\times$ 523 mm (80° $\times$ 51°). In the high pitch condition, we presented a pure tone at 523.251 Hz (musical note C5) and 48 dB. In the low pitch condition, we presented a pure tone at 130.813 Hz (musical note C3) and 65 dB. We corrected the loudness of the high pitch tone for equal-loudness[224] to the low pitch tone by -17 dB. We obtained the correction value from a small prestudy ($N = 3$). It lies within the expected range.[224] We assume that the perceived loudness of the two tones was approximately equal. We sampled both tones with 48 kHz.

### 2.2.4 Measures

We used the self-assessment manikin scales[25] as primary outcome measures. **??** depicts the self-assessment manikin scales. Self-assessment manikin scales allow non-verbal pictorial assessment of self-reported affective experience immediately after stimulus presentation. We used self-assessment manikin scales with five pictures, labeled with a 9-point Likert scale from 1 (*low/negative*) to 9 (*high/positive*). This measure assumes the conceptualization of emotion as three independent dimensional bipolar factors: valence, arousal, and dominance.[170,192] Valence conceptualizes approach or avoidance tendencies. Arousal conceptualizes the perceived level of physiological activity. Dominance conceptualizes the perceived level of control. Before the experiment, we described the self-assessment manikin scales to the participants, as proposed by Lang et al.[125] Dimensional self-reports about affective experiences that are made directly after an emotion-eliciting event have reasonable validity.[151] The validity and reliability of the self-assessment manikin scales are reasonable.[25] In general, dominance is considered the least sensitive scale among the three and seems to correlate positively with valence.[25,191,246] We collected additional questionnaire measures after the experiment, which we did not include in this report.

### 2.2.5 Apparatus

We used a standard PC for stimulus presentation and response registration. A 42 in (106.68 cm) LCD screen (NEC MultiSync V422) displayed visual stimuli against a black background in a darkened room. Before the experiment, we color-calibrated the screen with a colorimeter (Datacolor Spyder 5 ELITE). We presented auditory stimuli with headphones (Sennheiser HD 201). During the experiment, a chin rest supported the head of the participants. The distance between the eyes of the participants and the monitor was 55 cm. Participants used a mouse to select responses. **??** illustrates the apparatus.

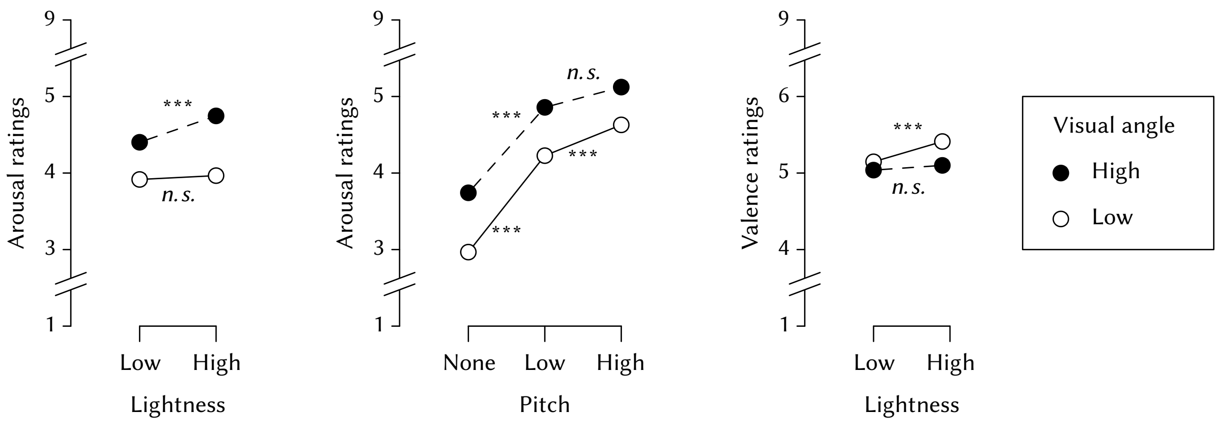


**Figure 2.4: Interaction plots for significant first-order interaction effects.** Dots indicate estimated marginal means of arousal and valence ratings for low (white) and high visual angle (black) as a function of lightness or pitch levels. Arousal and valence ratings range from 1 (*low/negative*) to 9 (*high/positive*). Along lines, $p$-values indicate results of pairwise mean comparisons. Abbreviations: *n. s.*: not significant (Bonferroni-Holm adjusted), ***: $p < .001$.

### 2.2.6 Statistical analysis

Valence, arousal, and dominance ratings consist of Likert scale data, that approximate interval measurement.[22] We aggregated ratings over five hue categories. For each dependent variable, we then applied a repeated-measures analysis of variance (ANOVA) to analyze for main and first-order interaction effects of visual angle, lightness, and pitch. When necessary, we Greenhouse-Geisser corrected degrees of freedom. To achieve a global alpha level of 5%, we Bonferroni–Holm adjusted the significance thresholds of the 18 ANOVA tests for multiple comparisons. We report generalized $\eta^2$ ($\eta_g^2$) as a measure of effect size. Post hoc, we pairwise contrasted the levels for significant interaction effects. We Bonferroni–Holm adjusted the significance thresholds of the comparisons to the 18 a priori tests and the 27 post hoc tests. We used R[179] and the afex package[213] to analyze the data. Data and code for all analyses are available at [anonymized OSF link].

## 2.3 Results

We conducted a repeated-measures experiment with three factors. In each trial, we presented a monochrome light- or dark-colored rectangle either covering a low or high visual angle. Simultaneously, we presented none, a low, or a high pitch tone (corrected for equal-loudness). Afterward, participants reported subjective valence, dominance, and arousal ratings. We excluded 7 participants from analysis due to technical problems during the experiment. We included all remaining $N = 136$ participants (113 women) into the analysis. Each participant conducted 60 trials. We applied univariate repeated measures ANOVAs. We Bonferroni–Holm adjusted the alpha levels of the 18 tests for main and first-order interaction effects to a global alpha level of 5%. We report generalized $\eta^2$ ($\eta_g^2$) as a measure of effect size.

Visual angle had a significant main effect on valence ($F(1,\ 135) = 12.55$, $p < .001$, $\eta_g^2 < .01$), arousal ($F(1, 135) = 112.93$, $p < .001$, $\eta_g^2 = .05$), and dominance ($F(1, 135) = 43.19$, $p < .001$, $\eta_g^2 = .05$). Lightness had a significant main effect on valence ($F(1, 135) = 8.66$, $p = .004$, $\eta_g^2 < .01$) and arousal ($F(1, 135) = 18.60$, $p < .001$, $\eta_g^2 < .01$). Pitch had a significant main effect on valence ($F(2, 270) = 80.22$, $p < .001$, $\eta_g^2 = .12$), arousal ($F(2, 270) = 167.21$, $p < .001$, $\eta_g^2 = .19$), and dominance ($F(1.74, 235.10) = 54.41$, $p < .001$, $\eta_g^2 = .07$). Table 2.2 summarizes the estimated marginal means of significant main effects.

Visual angle and lightness showed a significant interaction effect on valence ($F(1, 135) = 11.67$, $p < .001$, $\eta_g^2 < .01$) and arousal ($F(1, 135) = 19.77$, $p < .001$, $\eta_g^2 < .01$). Visual angle and pitch also showed a significant interaction effect on arousal ($F(2, 270) = 6.73$, $p = .001$, $\eta_g^2 < .01$). Table 2.1 summarizes the $p$ and $\eta_g^2$-values of the main and interaction effects. Figure 2.4 shows two-way interaction plots of the significant interactions.

Post hoc, we used pairwise contrasts to compare

**Table 2.1: Main and interaction effects**. Summary of $p$ and $\eta_g^2$-values for main and first order interaction effects on valence, arousal, and dominance ratings. Abbreviations: *n. s.*: not significant (Bonferroni-Holm adjusted), ***: $p < .001$.

| | Valence | | Arousal | | Dominance | |
|---|---|---|---|---|---|---|
| | $p$ | $\eta_g^2$ | $p$ | $\eta_g^2$ | $p$ | $\eta_g^2$ |
| Visual angle | *** | $< .01$ | *** | .05 | *** | .05 |
| Lightness | .004 | $< .01$ | *** | $< .01$ | .039 | *n. s.* |
| Pitch | *** | .12 | *** | .19 | *** | .07 |
| Visual angle × lightness | *** | $< .01$ | *** | $< .01$ | .253 | *n. s.* |
| Visual angle × pitch | .489 | *n. s.* | .001 | $< .01$ | .235 | *n. s.* |
| Lightness × pitch | .458 | *n. s.* | .682 | *n. s.* | .519 | *n. s.* |

**Table 2.2: Marginal means**. Estimated marginal means and standard errors (SE) of significant main effects. All main effects were significant, except the main effect of lightness on dominance.

| | | Valence | | Arousal | | Dominance | |
|---|---|---|---|---|---|---|---|
| Factor | Level | Mean | SE | Mean | SE | Mean | SE |
| Visual angle | Low | 5.28 | 0.08 | 3.94 | 0.09 | 5.56 | 0.10 |
| | High | 5.07 | 0.08 | 4.57 | 0.10 | 4.90 | 0.10 |
| Lightness | Low | 5.09 | 0.07 | 4.16 | 0.09 | | |
| | High | 5.26 | 0.08 | 4.36 | 0.09 | | |
| Pitch | None | 5.78 | 0.08 | 3.35 | 0.09 | 5.77 | 0.11 |
| | Low | 4.92 | 0.08 | 4.54 | 0.11 | 4.98 | 0.10 |
| | High | 4.83 | 0.09 | 4.88 | 0.11 | 4.94 | 0.10 |

estimated marginal means for combinations of visual angle with lightness and pitch levels. We Bonferroni-Holm adjusted alpha levels of comparisons to a total number of 45 tests (27 post hoc and 18 ANOVA tests). Estimated marginal means averaged over pitch significantly differed pairwise ($p < .001$) for arousal; except for the pairing low visual angle and high lightness compared to low visual angle and lightness ($p = .027$). Estimated marginal means averaged over pitch significantly differed pairwise ($p < .001$) for valence; except for the following pairings: high visual angle and lightness compared to low lightness with high ($p = .415$) as well as low visual angle ($p = .640$); high visual angle and low lightness compared to low visual angle and lightness ($p = .044$). Estimated marginal means averaged over lightness significantly differed pairwise ($p < .001$) for arousal; except for the following pairings: high visual angle and pitch compared to high visual angle and low pitch ($p = .006$); low visual angle and high pitch compared to high visual angle and low pitch ($p = .023$).

## 2.4 Discussion

We tested the effects of visual angle on emotional responses to audiovisual stimuli. Stimuli consisted of minimal spatial features to not induce three-dimensional object representations. Higher visual angle increased arousal and decreased valence and dominance during stimulus exposure. Only in the high visual angle conditions did visual content features (lightness) modulate arousal. Only in the low visual angle conditions did auditory features (pitch) modulate arousal, and did lightness affect valence responses. Arousal indicates the strength of emotions in terms of felt physiological activation.[9] These results indicate that the visual angle weights the emotional relevance of perception modalities: Visual features have higher emotional relevance when the visual angle is high, whereas auditory features have higher emotional relevance when the visual angle is low. This processing step does not require spatial object representations. We conclude that visual angle serves as an early-stage perceptual feature for organizing emotional responses to audiovisual stimuli.

This model extends previous findings that investigate the impact of visual angle in the perception of motivational-relevant spatial objects. Previous studies used photorealistic stimuli. Photorealistic stimuli induce higher emotional response when presented in a large visual angle.[36,181] The visual angle of photorealistic stimuli modulates arousal and valence responses to stimuli content (e.g., erotic couples, mutilated bodies).[36,181] Photorealistic stimuli induce motivational response patterns (e.g., sexual arousal or threat). Two factors moderate these responses: the perceived distance to the stimulus; and the ability to distinguish the stimuli content. Variation of visual angle of photorealistic stimuli confounds both. Visual angle determines object size and spatial information density. Our design minimized the effect of these confounders. Hence we attribute the observed gate-keeper effect to the visual angle independent of object recognition processes.

In our study, participants saw the edges of a smaller or larger rectangle. By definition, a visual angle separates two different areas: the area that lies inside the visual angle and the area that lies outside the visual angle. Edges, in turn, constitute at least a two-dimensional object. Hence by definition, it is not possible to fully dissociate visual angle from object recognition. However, the present study decreases the impact of object recognition to a minimum. Two-dimensional geometric forms have little association with characteristics of functionality. The less realistic, three-dimensional, and graspable an object appears to be, the less strong its physical affordance is.[225] Hence we assume a limited impact of object recognition on our results.

Dominance ratings in our study differ from studies that used photorealistic stimuli. Perceiving the counterpart as dominant in general decreases the own felt dominance. In line with this assumption, increased visual angle decreased dominance ratings in our study. In a previous study, however, participants reported increased dominance for an increased visual angle, when they saw photorealistic stimuli.[49] Hence we hypothesize that the presence of objects in the visual percept can invert the effect of visual angle on dominance. This observation supports the assumption that object recognition played a minor role in the presented study. Moreover, it supports the hypothesis that dominance is a cognitive construal of affect states.[9]

The stimuli in our study, in general, elicited low engagement and neutral feelings (moderate mean ratings for valence, arousal, and dominance). This result reflects the use of minimalistic stimuli (monochrome squares with constant, pure tones) that have minimal motivational relevance. Naturalistic scenes are more engaging[47], but also induce more complex responses that could contain confounders. However, the observed effects were present even when contrasting low engaging stimuli. We hypothesize that amplified effect sizes occur in controlled settings with higher engaging stimuli.

### 2.4.1 Design implications for human-computer interfaces

In this study, we show that the visual angle modulates the emotional responses to audiovisual information. Future experiments need to assess how this effect generalizes to naturalistic applications. We assume that the observed modulation effect informs the design of human-computer interfaces as follows.

#### Sensory Quantity Affects Emotional Response

Our results support the assumption that the degree of immersion modulates arousal responses to stimuli. Immersion here refers to the amount of sensory information an interface delivers.[216] We increased immersion in two ways: first, we increased the visual angle, second we augmented visual with auditive stimuli. Both modifications increased arousal responses. Thus we assume that visual angle and multisensory augmentation provide means to modulate emotional responses to media. This result is in line with previous findings from naturalistic scenarios. For example, users reported higher enjoyment, excitement, and more physical arousal watching movies on large compared to small screens[110,136] Users engage in more heuristic, affective processing when watching stimuli on larger screens compared to more systematic, cognitive processing when watching stimuli on small screens.[108,109] Video games[228] and movies[183] are more engaging on large screens. Movies and pictures with music increase emotional processing compared to stimuli without music.[11,12] Our results support the assumption that human-computer interfaces can make use of visual angle and multisensory augmentation to control arousal responses. Emotional responses are, for example, relevant if the interface demands fast decisions or high situational awareness from the users. Decision support systems for medical treatments or the surveillance of critical security systems as in autonomous driving provide such applications. In such use cases, adaptive control of visual angle and augmented audio would provide means to increase arousal responses if appropriate. Controlling arousal, in turn, allows modulating further attention processes, such as short-term memory performance.[142] Innovations in augmented and virtual reality, for example, as in-car displays, increasingly provide means to timely adapt visual angle during security-critical scenarios.

While the visual angle modulates engagement, the visual angle also affects performance on visual tasks. If users can turn their heads towards a target stimuli, an increased visual angle increases navigation and search performance.[4] If, however, users have a fixed center of view, their ability to perform tasks on their peripheral visual fields is limited (see Strasburger et al.[222] for a review): For example, users react slower to peripheral compared to central stimuli. They also have more difficulties in detecting patterns and changes in peripherical compared to central stimuli. Future studies, therefore, need to investigate how altering the visual angle can help balance emotional engagement with task performance.

**The visual angle modulates the affective processing of visual features**

The arousal response to visual content features (here lightness) only changed significantly if the visual angle was high. This interaction suggests that the emotional processing of visual features requires a sufficiently high visual angle. This finding is consistent with naturalistic studies in which an increase in screen size intensified responses to arousing[36] or pleasant images.[181] Human-computer interfaces can use this interaction to reduce or amplify emotional responses to visual content features. For example, a low visual angel might reduce the adverse emotional effects of violent content.

**The visual angle modulates the affective processing of auditory features**

The arousal response to auditory content features (here pitch) only changed significantly if the visual angle was low. This interaction suggests that a low visual angle facilitates the emotional processing of auditory content features. This finding is in line with findings, that suggest that auditory attention is inversely related to visual engagement: For example, Cate et al.[32] suggests that auditory cues direct attention to the far peripheral view, away from central visual cues. Furthermore, auditory cues increase performance for interfaces with small buttons.[30] Human-computer interfaces can use this interaction to reduce or amplify emotional responses to auditory content features by modulating the visual angle. For example, medical monitoring tasks can benefit from an efficient balancing of auditory and visual information processing (e.g., Klueber et al.[112]).

### 2.4.2 Conclusion

The visual angle defines the total amount of available visual information. Our results indicate that visual information availability modulates emotional responses on early processing steps. High visual information availability increases emotional response and increases the relevance of visual content information. Low visual information availability increases the relevance of other modalities. We suggest that this effect is predominantly independent of object recognition processes. These findings inform developments of new human-machine interaction techniques that incorporate visual information transfer and emotional processing. It seems critical to be aware of this causal relation for building better interfaces. Control of the presentation layer, i.e., the quantity of perceivable information by visual angle, will help avoid unintended emotional responses and provide a means to provoke emotional effects when desired.

**Publication**

This chapter is published in *Computers in Human Behavior*.[71]

**Data and code availability**

Data and code for all analyses are available at https://osf.io/ctu4g/.

**Summary**

*What was the research question?*
How does the visual angle of a percept influence emotional responses to audionvisual stimuli?

*What was already known about this topic?*
The perceived size of objects modulates the emotional responses to these objects.

*What did this study add to our knowledge?*
Visual angle weights affective relevance of perception modalities independent of object representations. Visual angle serves as an early-stage perceptual feature for organizing emotional responses.

*Why are these findings important?*
Control of the visual angle allows for provoking or avoiding emotional response in human-computer interaction.

# Chapter 3

# Congruent visual and haptic feedback increases presence

**Abstract**

Interacting with a virtual environment means touching it. Virtual reality systems, however, do not provide haptic feedback. We investigate the effect of haptic feedback on the sensation to feel present in a virtual environment. We conducted a single-factor repeated-measures experiment with 56 undergraduate students. We manipulated the congruency of haptic to visual feedback and assessed presence. We assessed presence with a single question during the time participants saw the virtual environment and with two questionnaires after they left the environment. We show that congruent visual and haptic feedback increases presence compared to incongruent feedback and compared to visual feedback alone. This effect does not require a virtual body. Furthermore, we provide evidence for the convergent validity and sensitivity of a one-item mid-immersion presence measure. We conclude that congruent visual and haptic feeback increases the effectiveness of virtual environments.

## 3.1 Introduction

Virtual reality systems create the illusion of being in a virtual world. Presence describes the sensation of being in a virtual environment despite the knowledge one is not. Being somewhere, however, induces the urge to interact with the environment. People control movements by anticipating the sensory effects of their actions.[120] Hence, interacting with a physical environment means touching it.[194] But including haptic feedback in a virtual environment is challenging. Displays create visual feedback. Speakers create auditory feedback. But there are few devices that create haptic feedback. So what do we lose if we leave haptics out of virtual reality? We investigate how haptic feedback influences presence. We assume that haptic feedback increases the effectiveness of virtual reality systems.

Presence aims to measure the effectiveness of virtual reality systems.[214] Since its introduction by Akin et al.[2] researchers proposed different theories and operationalizations of presence (see Skarbez et al.[214] for a review). The different operationalizations of presence have one common denominator: the feeling of being physically present in the virtual environment.

Some theories assume that people experience presence if the sensory feedback is congruent with their expectations.[168,169,172,205,217] Heat and wind sensations that are congruent to virtual environemt increase presence.[54] Congruent haptic feedback increases fear responses to virtual threats.[156]

People can even experience the illusion of owning a virtual body if the sensory feedback is congruent with their expectations. People experience ownership of an artificial hand if they see a pencil stroking the artificial hand and simultaneously feel strokes on their hand.[23,107] We assume that the perceived sensation of owning a virtual body affects presence (chapter 5). If people had a virtual body congruent haptic feedback increased presence.[87,121] We investigate the effect of haptic feedback on presence where people did not experience ownership of a virtual body.

The goal of this study is to understand how haptic feedback modulates presence. We conducted a single-factor repeated-measures experiment with 56 undergraduate students. We manipulated the congruency of haptic to visual feedback and assessed presence. We assessed presence with a single question while participants viewed the virtual environment, and with two questionnaires after they left the environment. We show that congruent haptic feedback increases presence compared to incongruent haptic feedback and compared to visual feedback alone. This effect does not require a virtual body. In Gall and Latoschik[70] we reported the between-group results of this study. Furthermore, we provide evidence for the convergent validity and sensitivity of the one-item mid-immersion presence measure. We conclude that congruent visual and haptic feedback increases the effectiveness of virtual environments.

## 3.2 Method

### 3.2.1 Participants

Undergraduate students ($N = 56$; 35 women) from the University of Würzburg volunteered to participate in the experiment. The age of the participants ranged from 18 to 27 years ($M = 20.32$, $SD = 1.71$). All participants provided written informed consent before participation. They received course credit for participation. All reported normal or corrected-to-normal vision and the absence of motor impairments. Participants were naive regarding the hypotheses of the experiment. The institutional ethics committee approved this study.

### 3.2.2 Design and procedure

The experiment followed a single-factor repeated-measures design with two levels. We manipulated the factor congruency of visual and haptic feedback (congruent vs incongruent). Participants completed the two conditions in a balanced, randomized order.

Participants sat in front of a table. They wore a head-mounted display. In each condition, participants saw a virtual representation of the table in front of them. Between the two conditions, we varied the position of the virtual table. In the congruent condition, the virtual table appeared in the same position as the real table. In the incongruent condition, the virtual table appeared shifted from the real table. We instructed the participants to look at the table for 30 s. Then we asked participants how present they felt in the virtual environment. Afterward, we instructed participants to touch the table with both hands while looking at it for 30 s. Then we again asked participants how present they felt in the virtual environment. Participants pointed at a virtual object, as described in Gall and Latoschik[70].

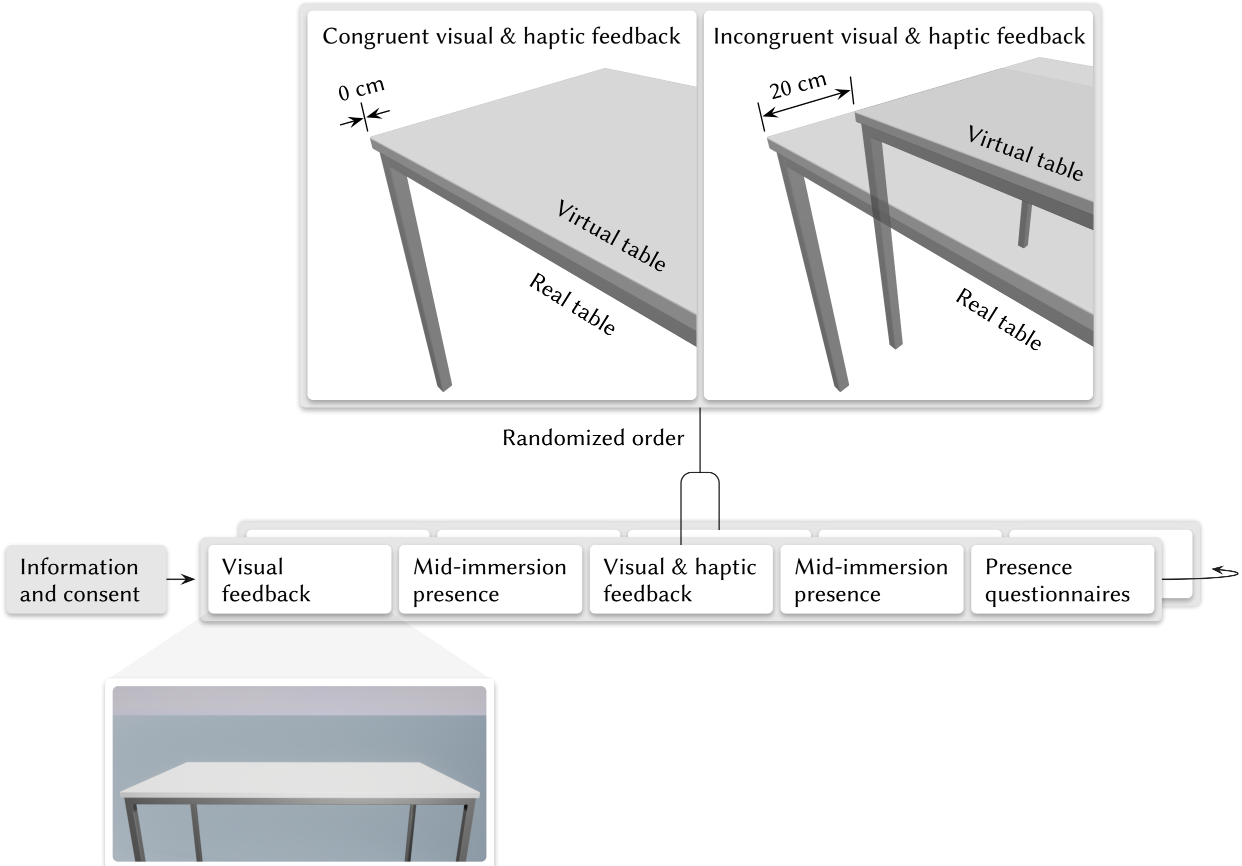


**Figure 3.1: Procedure and stimuli.** The experiment followed a single-factor repeated-measures design with two levels. Participants saw a virtual representation of the table in front of them for 30 s. We asked participants how present they felt in the virtual environment. Afterward, they touched the table while looking at it for 30 s. Haptic feedback was either congruent or incongruent to visual information. In the congruent condition, the virtual table appeared in the same position as the real table. In the incongruent condition, the virtual table appeared shifted from the real table. We then asked participants again how present they felt in the virtual environment. Afterward, participants completed two presence questionnaires.

We, however, do not discuss this task here. Participants then removed the head-mounted display and answered presence questionnaires. Between the two conditions, participants rested for 5 min. Figure 3.1 illustrates the procedure.

### 3.2.3 Apparatus

Participants wore a head-mounted display (HTC Vive Headset) during Experiment 1 (Superlux HD330). They sat in front of a table. A sensor (HTC Vive controller) tracked the position of the table. An Intel Xeon E3 3.40 GHz, 16 GB RAM computer with an NVIDIA GeForce GTX 980 Ti graphics card rendered the stereoscopic images at 90 Hz. We implemented the sensor data integration and visualization of the virtual environment in the Epic Games Unreal Engine 4.14. Figure 3.2 illustrates the apparatus.

### 3.2.4 Stimuli

Participants saw a virtual representation of the table. The virtual table stood on an infinite, empty floor. In the congruent condition, the virtual table appeared in the same position as the real table. In the incongruent condition, the virtual table appeared shifted by 20 cm in the posterior-anterior axis. In this case, the virtual table was more distant to the viewer than the real table. A calibration measurement of the system showed that the motion-to-photon latency was below 40 ms. The threshold for detecting visuomotor delays is above 100 ms.[66,209,210] Figure 3.1 depicts the virtual stimuli.

**Figure 3.2: Apparatus.** Participants sat in front of a table. They wore a head-mounted display. Participants looked at a virtual representation of the table. Meanwhile, they touched the real table. A sensor tracked the position of the table.

### 3.2.5 Measures

While participants still saw the virtual environment, we asked a single question to assess presence twice. Participants answered two presence questionnaires, after they removed the head-mounted display: the MEC spatial presence questionnaire[243] and the Igroup presence questionnaire.[198]

#### Mid-immersion presence question

We assessed presence by asking "To what extent do you feel present in the virtual environment?" (adapted from Bouchard et al.[24]). Participants answered each question aloud on a scale from 0 (*not at all*) to 10 (*totally*). Before the experiment, we explained to the participants that "presence is the subjective impression of really being there in the virtual environment." There is evidence that brief one-item presence measurements during immersion are more sensitive to the subjective feeling of presence than post-immersive questionnaires.[24,68,215] Hendrix and Barfield[85] confirmed the reliability of a similar presence assessment. Others showed the ability of similar measures to detect treatment effects.[24,88,113] These results give preliminary evidence of the validity of one-item mid-immersion measures.

#### MEC spatial presence questionnaire

The MEC spatial presence questionnaire assumes that spatial presence depends on a variety of sensations.[19,251] We assessed only the sensations that contribute to spatial presence: attention allocation, spatial situation model, and self-location, possible actions.[243] Each scale consists of eight items with five-point Lickert scales from 1 (*I do not agree at all*) to 5 (*I fully agree*). Some studies support the reliability and sensitivity of the measure.[19,163] Correlations with other presence measures support the validity of the MEC spatial presence questionnaire.[13,19,163]

#### Igroup presence questionnaire

Schubert et al.[198] used an exploratory factor analysis on existing presence items to construct the Igroup presence questionnaire. They argue that three sensations contribute to presence: spatial presence, involvement, and realness.[199] Spatial presence describes how much participants felt surrounded by the virtual environment. Involvement describes how much participants focus on the virtual instead of their real environment. Realness describes how much participants judged the virtual environment as real. One additional item correlates with all three subscales: general presence. General presence consists of the item "In the computer-generated world I had a sense of 'being there'." Participants answered on a Lickert scale from -3 (*not at all*) to 3 (*very much*). The other scales consist of four items with seven-point Lickert scales from -3 (*fully disagree* or similar) to 3 (*fully agree* or similar). A confirmatory factor analysis supports the validity of the measure.[198]

### 3.2.6 Statistical analysis

We used two-tailed paired $t$-tests to compare presence ratings between the congruent and incongruent condition. We used the same tests to compare mid-immersion presence ratings before and after participants perceived haptic feedback. We report Cohen's $d$ as a measure of effect size. We calculated Pearson correlations between one-item mid-immersion and multi-item post-immersion presence ratings. We calculated the correlation separately for the environments with congruent and incongruent visual and

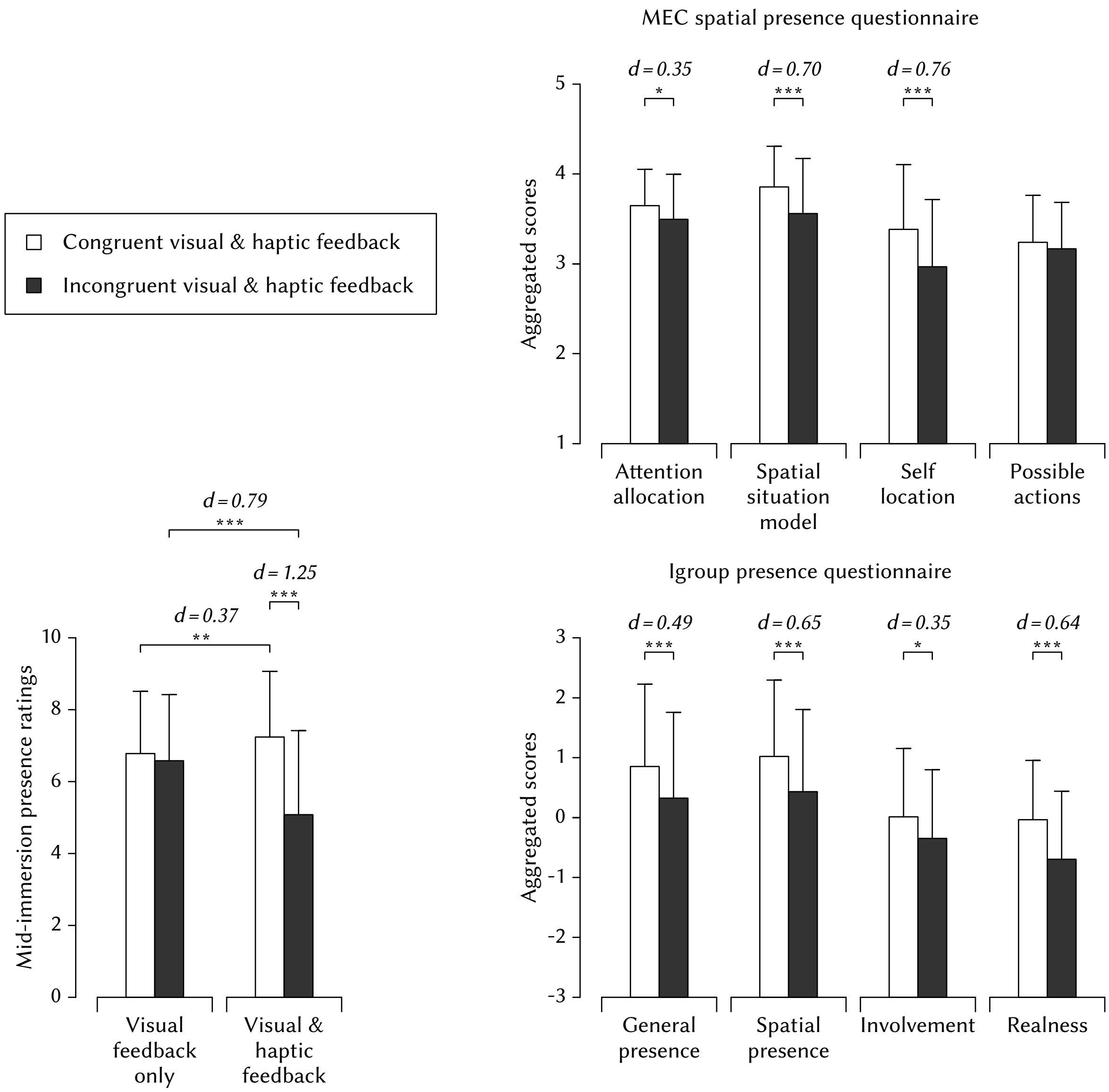


**Figure 3.3: Results.** Mean (+ SD) of mid-immersion and questionnaire ratings. The $p$-values indicate significant results of Bonferroni-Holm adjusted mean comparisons. Cohen's $d$ values indicate effect sizes. The mid-immersion presence rating ranges from 0 (*not at all*) to 10 (*totally*). High MEC spatial presence questionnaire and high Igroup presence questionnaire ratings represent high presence and vice versa. Abbreviations: ***: $p < .001$, **: $p < .01$, *: $p < .05$.

haptic feedback. To achieve a global alpha level of 5%, we Bonferroni-Holm adjusted the significance thresholds of the 28 tests. We used R 3.5.1[179] to analyze the data.

## 3.3 Results

Participants looked around in a virtual environment. After 30 s they also touched a virtual object. The haptic feedback was either congruent or incongruent to the visual feedback. Participants reported a significant increase in presence after they perceived congruent haptic feedback ($t(55) = -2.77$, $p = .008$, $d = 0.37$). Participants also reported a significant decrease in presence after they perceived incongruent haptic feedback ($t(55) = 5.94$, $p < .001$, $d = 0.79$). Figure 3.3 illustrates the mean comparisons and Table 3.1 presents detailed results.

**Table 3.1: Mean comparisons between conditions.** Comparison between presence ratings conducted in two different virtual environments: one with congruent and one with incongruent visual and haptic feedback. Participants answered the mid-immersion question while they saw the virtual environment. They answered the MEC spatial presence questionnaire (MEC-SPQ) and the Igroup presence questionnaire (IPQ) after they removed the head-mounted display. Paired $t$-tests assessed if means significantly differ. We Bonferroni-Holm adjusted significant thresholds for a total of 28 tests. Cohen's $d$ values indicate effect sizes for significant mean differences. Abbreviations: *n. s.*: not significant, ***: $p < .001$.

| | | Congruent | | Incongruent | | Paired $t$-test | | |
|---|---|---|---|---|---|---|---|---|
| Measure | | Mean | SD | Mean | SD | $t(55)$ | $p$ | Cohen's $d$ |
| Mid-immersion presence | Visual feedback only | 6.79 | 1.71 | 6.57 | 1.85 | 1.45 | .153 | *n. s.* |
| | Visual & haptic feedback | 7.23 | 1.82 | 5.09 | 2.33 | 9.38 | *** | 1.25 |
| MEC-SPQ | Attention allocation | 3.65 | 0.40 | 3.50 | 0.49 | 2.59 | .012 | 0.35 |
| | Spatial situation model | 3.86 | 0.53 | 3.56 | 0.61 | 5.24 | *** | 0.70 |
| | Self location | 3.38 | 0.72 | 2.97 | 0.75 | 5.65 | *** | 0.76 |
| | Possible actions | 3.24 | 0.52 | 3.17 | 0.51 | 1.57 | .123 | *n. s.* |
| IPQ | General presence | 0.86 | 1.37 | 0.32 | 1.43 | 3.66 | *** | 0.49 |
| | Spatial presence | 1.02 | 1.27 | 0.43 | 1.37 | 4.86 | *** | 0.65 |
| | Involvement | 0.01 | 1.15 | -0.35 | 1.14 | 2.60 | .012 | 0.35 |
| | Realness | -0.03 | 0.98 | -0.70 | 1.13 | 4.83 | *** | 0.64 |

We conducted mid-immersion and post-immersion presence ratings in both environments. When participants perceived congruent visual and haptic feedback, they reported higher presence during exposure in several questionnaire scales; compared to when they perceived incongruent feedback: for spatial situation model, and self-location in the MEC spatial presence questionnaire; and for general presence, spatial presence, and realness in the Igroup presence questionnaire. Figure 3.3 illustrates the mean comparisons and Table 3.1 presents detailed results.

We assessed the convergent validity of the one-item mid-immersion presence measure. Therefore, we conducted Pearson correlations between the one-item mid-immersion and the multi-item post-immersion presence ratings. Participants reported these mid-immersion ratings after they perceived visual and haptic feedback. We assessed correlations separately for both environments: the one with congruent visual and haptic feedback; and the one with incongruent visual and haptic feedback. The mid-immersion presence rating significantly correlated with all questionnaire scales in both environments. Table 3.2 presents the detailed results.

## 3.4 Discussion

Presence describes the sensation of being in a virtual environment, despite the knowledge that one is not. The goal of this study was to prove that presence depends on the congruency of visual and haptic feedback. The sensation to own a virtual body also depends on the congruency of visual and haptic feedback. We hypothesize that virtual body ownership influences presence (chapter 5). To ensure that visual and haptic congruency influences presence without the need for a virtual body, participants only saw the virtual environment. Congruent haptic feedback significantly increased presence compared to visual feedback alone. Incongruent haptic feedback significantly decreased presence compared to visual feedback alone. Participants also reported significantly higher presence ratings for the environment with congruent compared to the environment with incongruent visual and haptic feedback. We conclude that congruent visual and haptic feedback increases presence.

We provide evidence for the convergent validity of a one-item mid-immersion presence measure. The one-item mid-immersion rating correlated significantly with multi-item post-immersion presence ratings. The one-item measure detected changes in time and between conditions. This result supports the sensitivity of the measure. Memory biases threaten the validity of reports that participants give after leaving the virtual environment.[68,93,235] Mid-immersion measures monitor presence in time.

Our findings extend previous findings of the effect of sensory feedback on presence. Dinh et al.[54] showed that congruent sensations of heat and wind increase presence. Others showed that congruent haptic feedback increase presence if participants

**Table 3.2: Correlations with the mid-immersion presence item.** We provide evidence for the convergent validity of the one-item mid-immersion presence measure. The table shows Pearson correlations between one-item mid-immersion and multi-item post-immersion presence ratings (Pearson's $r$ with $p$-values, $N = 56$). Participants answered the mid-immersion question during exposure to the virtual environment and after they perceived visual and haptic feedback. Participants answered the questionnaires after exposure to the virtual environment. We correlated the ratings separately for different virtual environments: one environment with congruent visual and haptic feedback; and one environment with incongruent visual and haptic. After the Bonferroni-Holm adjustment of significant thresholds, all correlation coefficients differed significantly from zero. Abbreviations: ***: $p < .001$, **: $p < .01$.

| Questionnaire scales | | Visual & haptic feedback | |
|---|---|---|---|
| | | Congruent | Incongruent |
| MEC-SPQ | Attention allocation | .54 *** | .47 *** |
| | Spatial situation model | .61 *** | .71 *** |
| | Self location | .62 *** | .70 *** |
| | Possible actions | .65 *** | .57 *** |
| IPQ | General presence | .59 *** | .62 *** |
| | Spatial presence | .64 *** | .69 *** |
| | Involvement | .42 ** | .36 ** |
| | Realness | .68 *** | .73 *** |

have a virtual body.[86,87,156,220,252] Our findings support the hypothesis that the comparison of actual and predicted sensations modulates presence.[172,205,219] Visual feedback generated predictions about haptic feedback. If haptic feedback matched predictions presence increased. It, however, decreases if haptic feedback did not match predictions.

When people feel detached from the world and feel that the world is unreal, they experience derealization. The intensity of this sensation can vary.[90] derealization often serves as a coping strategy for severe distress.[92,240] Presence and derealization describe the same constructs, but for virtual environments and the real world. Presence allows investigating derealization. Seth[205] argues that derealization arises from failed integration of sensory signals. Our findings support this hypothesis. Distress might induce a disintegration of sensory input signals that causes derealization.

We provide evidence for the convergent validity and sensitivity of a one-item mid-immersion presence rating. We show that congruent visual and haptic feedback increases presence compared to incongruent feedback and visual feedback alone. Our results extend previous findings that demonstrate the impact of multi-sensory information on presence. People require congruent haptic information to accept a virtual environment as their real environment. Hence, visual information alone is not enough to construct effective virtual environments.

### Data and code availability

Data and code for all analyses are available at https://osf.io/yudzc/.

**Summary**

*What was the research question?*
How does haptic feedback influence the sense of being present in a virtual environment?

*What was already known about this topic?*
Heat and wind sensations that are congruent to the visual environment increase presence. Congruent visual and haptic feedback increase presence if participants have a virtual body.

*What did this study add to our knowledge?*
We show that congruent visual and haptic feedback increases presence compared to incongruent feedback and visual feedback alone. This effect does not require a virtual body. We also provide evidence for the convergent validity of a one-item mid-immersion presence rating.

*Why are these findings important?*
Congruent haptic feedback increases the effectiveness of virtual environments. We assume that congruent multisensory information modulates derealization symptoms.

# Chapter 4

# Virtual body ownership intensifies the emotional response to virtual stimuli


**Abstract**

Controlling emotional responses is a crucial part of human-computer interaction. We show that virtual body ownership intensifies the emotional response to virtual stimuli. Owning a virtual body hence helps organize the perception of the environment. In a single-factor repeated-measures experiment, we manipulated the degree of virtual body ownership and assessed the emotional responses to virtual stimuli. We presented emotional stimuli in the same environment as the virtual body. In the high virtual body ownership condition, participants experienced higher arousal, dominance, and more intense valence compared to the low virtual body ownership condition. Virtual body ownership thus intensifies the emotional processing of the virtual environment. This effect does not require any interaction of the stimuli with the virtual body. This result shows that artificial bodies can increase the effectiveness of human-computer interaction. The finding informs the development of applications in psychotherapy, training, and entertainment.

## 4.1 Introduction

Human-computer interfaces can provide people with virtual bodies. People use these virtual bodies to interact with the virtual environment. Moreover, some presentation techniques induce the sensation that the virtual body is one's own body. We call this sensation virtual body ownership. People experience virtual body ownership if felt sensations seem to originate from the virtual body. For instance, ownership arises if people see a pencil stroking an artificial hand and simultaneously feel the strokes on their hand.[23] Virtual body ownership arises from the combination of multiple senses. Virtual reality interfaces can provide visual information that contributes to virtual body ownership. The following factors contribute to the induction of virtual body ownership (see Kilteni et al.[107] for a review): First, the shape, texture, and position of the virtual body seem sufficiently plausible. Second, the virtual body appears in the same place as their real body. Third, the virtual body gets touched in the same place and time as the real body. Fourth, the virtual body moves synchronously to the real body. The latter induces agency: the sensation to control an object. We consider agency a dimension of virtual body ownership (see Braun et al.[28] for a discussion). So if virtual body ownership occurs, the question is, what effect does it have on the perceiver?

Previous studies demonstrated effects of virtual body ownership on cognitive processes. Virtual body ownership alters the perceived location of the real body part if the virtual body appears displaced.[23,130,195] Virtual body ownership alters the perceived size and distance of objects.[7,99,132,236–238] It alters the attributes towards the social group of the virtual body.[7,60,61,64,141,174] It increases the awareness of the virtual body.[239] It affects the spatial orientation[178] and tactile perception.[137] It modulates pain.[75,145–147,150,165,171] We, however, know little about how virtual body ownership influences emotions. Emotions play a central role in human-computer interaction (e.g. Brave and Nass[29]). They organize motivation, attention, memory, performance, and decision making.

Virtual body ownership modulates anxiety and arousal for stimuli that threaten the virtual body.[3,34,82,186] The question, however, remains how virtual body ownership affects general emotional responses to the virtual environment. Hence, we evaluated responses to stimuli not related to the virtual body. Furthermore, we evaluate responses to positive and negative valent stimuli to see if responses generalize across emotional qualities.

The goal of this study is to understand how virtual body ownership modulates emotional responses to the virtual environment. We show that virtual body ownership increases the emotional response to unrelated stimuli in the virtual environment. This result contributes to the question of how virtual body ownership organizes the perception of the environment. We conducted a single-factor repeated-measures experiment with 21 undergraduate female students. We manipulated the degree of virtual body ownership and assessed the emotional responses to virtual stimuli. We presented emotional stimuli in the same environment as the virtual body. Stimuli did not interact with the virtual body. In the high virtual body ownership condition, participants experienced higher arousal, dominance and more intense valence compared to the low virtual body ownership condition. Virtual body ownership causes a more intense emotional processing of the virtual environment. This effect does not require the interaction of the stimuli with the virtual body apart from sharing the same environment. We conclude that artificial bodies increase the effectiveness of human-computer interaction.

## 4.2 Method

### 4.2.1 Participants

Undergraduate female students from the University of Würzburg volunteered to participate in the experiment. The sample consisted of $N = 21$ women, with age ranging from 19 to 30 years ($M = 21.62$, $SD = 2.80$). All participants provided written informed consent before participation. They received course credit for participation. All reported normal or corrected-to-normal vision and the absence of motor impairments. Participants were naive regarding the hypotheses of the experiment. The institutional ethics committee approved this study.

### 4.2.2 Design and procedure

The experiment followed a single-factor repeated-measures design with two factor levels. We manipulated the factor temporal synchrony of visuotactile and passive visuomotor stimulation (synchronous vs asynchronous). Participants completed the two

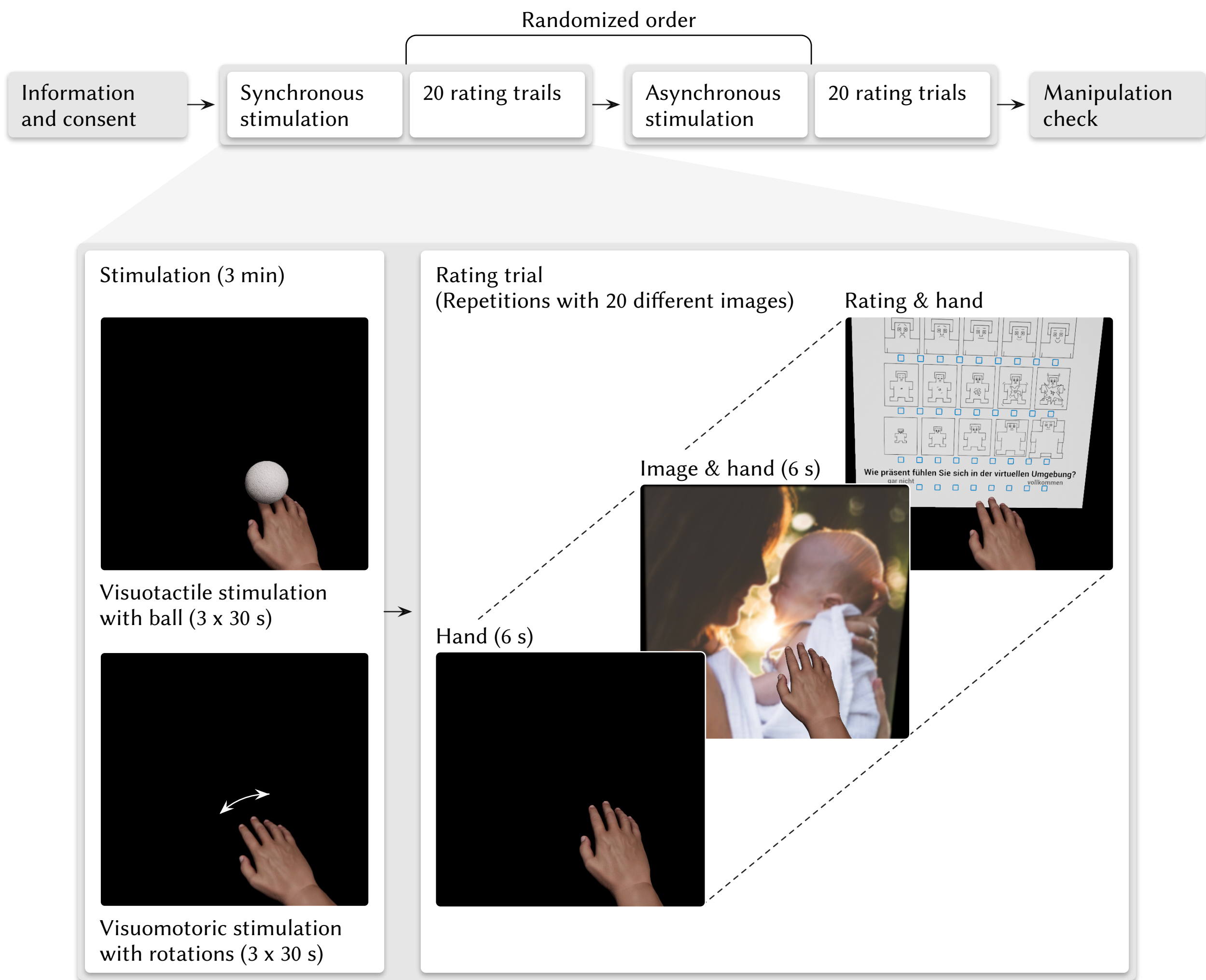


**Figure 4.1: Procedure and stimuli.** Participants completed the synchronous and the asynchronous condition in a balanced randomized order. In each condition, participants received visuomotor and visuotactile stimulation for 3 min. We stroked the hands of participants with a ball and rotated their hands. In the synchronous condition, the hand and the virtual ball moved synchronously to the real hand and real ball. In the asynchronous condition, the virtual objects moved 5 s delayed. Afterward, participants completed 20 trials in each condition. In each trial, participants saw the virtual hand for 6 s, then an image with the virtual hand for 6 s. Afterward, they completed self-assessment manikin and presence ratings. After completing both conditions, participants answered a questionnaire to assess if the manipulation worked. Placeholder image stimulus by Julie Johnson on Unsplash.

conditions in balanced, randomized order.

Participants sat in front of a table. They placed their right hand on a hand rest and wore a immovable head-mounted display with headphones. In the synchronous and the asynchronous condition participants continuously saw a virtual representation of their right hand.

At the beginning of each condition, the experimenter delivered visual-tactile and passive visuomotor stimulation. We alternated between visual-tactile and passive visuomotor stimulation every 30 s for a total of 4 min. The experimenter manually delivered visual-tactile stimulation by stroking the index and middle finger from the fingertips to the back of the hand with the styrofoam ball. In the synchronous condition, the virtual styrofoam ball synchronously strokes the virtual hand. In the asynchronous condition, the virtual styrofoam ball moved 5 s delayed. The experimenter manually delivered passive visuomotor stimulation by rotating the hand rest around

13 degrees. In the synchronous condition, the virtual hand rotated synchronously. In the asynchronous condition, the virtual hand rotated 5 s delayed.

After the stimulation period, participants completed 20 rating trials. In each trial, participants saw the virtual representation of their right hand for 6 s. Then, participants saw an image from the international affective picture system on a frontal plane behind the virtual hand for 6 s. Afterward, participants self-assessed valence, arousal, and dominance on self-assessment manikin scales and a one-item presence scale. The scales appeared behind the virtual hand. Participants used a mouse in their left hand to select answers and to continue to the next trial.

Afterward, we conducted mid-immersion one-item virtual body ownership and agency ratings with the headphones. Between the two conditions, participants rested for 5 min. Figure 4.1 illustrates the procedure.

**Figure 4.2: Apparatus.** We presented visual stimuli in a immovable head-mounted display. Participants placed their right hands on a hand rest. The experimenter delivered visuotactile stimulation with a styrofoam ball attached to a position sensor. The experimenter delivered visuomotor stimulation by rotating the hand rest. A sensor tracked the position of the hand rest. We presented Brownian noise in headphones.

### 4.2.3 Apparatus

During the experiment, the right hand of participants rested on a hand rest. The hand rest defined static positions for each finger. The examiner could rotate the hand rest around the wrist by 13 degrees without touching the participant. A position sensor (HTC Vive Controller) tracked the rotation angle. The examiner could stroke the hand of the participant with a styrofoam ball. The styrofoam ball had a diameter of 5 cm. A position sensor (HTC Vive Controller) tracked the position of the styrofoam ball. Participants looked through an immovable head-mounted display (HTC Vive Headset). The static field of view comprised the right hand at a distance of 35 cm. An Intel i7 4.00 GHz, 16 GB RAM computer with an NVIDIA GeForce GTX 1080 Ti graphics card rendered stereoscopic images at 90 Hz. We implemented sensor data integration, visualization of the virtual environment, and response registration in the Epic Games Unreal Engine 4.17. We presented auditive stimuli with a headphone (Superlux HD330). Figure 4.2 illustrates the apparatus.

### 4.2.4 Stimuli

Participants saw a virtual representation of their right hand. The virtual hand appeared in the same position as the real hand. During visuotactile stimulation participants also saw a virtual representation of the styrofoam ball. In the synchronous stimulation condition, the virtual styrofoam ball appeared in the same position as the real styrofoam ball. In the synchronous stimulation condition, the virtual hand rotated analogous to the real hand. In the asynchronous stimulation condition, we delayed the movements of the virtual styrofoam ball and the virtual hand by 5 s. To neutralize noises of the tactile or motoric stimulation, we presented Brownian auditive noise through the headphones at 50 dB during the visuotactile and visuomotor stimulation. A calibration measurement of the system showed that the delay in the synchronous conditions was below 40 ms. The threshold for detecting visuomotor delays is above 100 ms.[66,209,210]

In each condition, we presented 20 pictures from the international affective picture system.[124] The pictures appeared on a frontal plane behind the virtual hand. The virtual index finger pointed to the center of the image. The virtual hand covered a lower right fraction of the image. So participants still saw the virtual hand when they looked at the image. The 20 images consisted of ten images with low and ten images with high valence female norm values. On average the female norm arousal values of both groups were approximately equal. For the positive image group, female norm values on a Likert scale from 1 (*negative/low*) to 9 (*positive/high*) were[124]: valence $M = 7.00$, $SD = 0.62$; arousal $M = 6.79$, $SD = 0.28$; dominance 5.38, $SD = 0.34$. For the negative image group, female norm values on a Likert scale from 1 (*negative/low*) to 9 (*positive/high*) were: valence $M = 2.47$, $SD = 0.43$; arousal $M = 6.63$, $SD = 0.43$; dominance 3.10, $SD = 0.71$.[124] The postive valent image group consisted of the following images (international affective picture system number with description in brackets): 4525 (attractive male), 4668 (erotic couple), 4698 (erotic couple), 5621 (skydivers), 5629 (hiker), 8001 (basketball player), 8158 (hiker), 8179 (bungee jumper), 8180 (cliff divers), and 8185 (skydivers). The negative valent image group consisted of the following images (international affective picture system number and description in brackets): 9623 (fire), 9600 (ship), 7380 (roach on pizza), 6250,1 (aimed gun), 6220 (boys with guns), 2811 (gun), 1932 (shark), 1271 (roaches), 1201 (spider), and 1052 (snake). Figure 4.1 depicts the virtual stimuli.

### 4.2.5 Measures

After each trial participants completed a questionnaire that consisted of self-assessment manikin scales and a one-item presence scale. The questionnaire appeared on a frontal plane behind the virtual hand. The virtual hand did not cover parts of the questionnaire. We used the self-assessment manikin scales[25] to assess emotional responses in each trial. Self-assessment manikin scales allow non-verbal pictorial assessment of self-reported affective experience immediately after stimulus presentation. Self-assessment manikin scales assessed norm values for international affective picture system images.[124] We used self-assessment manikin scales with five pictures, labeled with a 9-point Likert scale from 1 (*low/negative*) to 9 (*high/positive*). This measure assumes the conceptualization of emotion as three independent dimensional bipolar factors: valence, arousal, and dominance.[170,192] Valence conceptualizes approach or avoidance tendencies. Arousal conceptualizes the perceived level of physiological activity. Dominance conceptualizes the perceived level of control. Before the experiment, we described the self-assessment manikin scales to the participants, as proposed by Lang et al.[125] Dimensional self-reports about affective experiences made directly after an emotion eliciting event have reasonable validity.[151] Validity and reliability of the self-assessment manikin scales are reasonable.[25] Dominance is the least sensitive scale among the three and correlates positively with valence.[25,191,246]

Furthermore, we used a visual one-item mid-immersion presence scale to assess self-reported presence in each trial, as proposed in Bouchard et al.[24]. Participants answered the following question on a scale of 1 (*not at all*) to 9 (*totally*): "To what extent do you feel present in the virtual environment?" There is evidence that brief one-item presence measures during immersion are more sensitive to the subjective feeling of presence than post-immersive questionnaires.[24,68,215] Hendrix and Barfield[85] confirmed the reliability of a similar presence rating. Others showed the ability of this and similar measures to detect treatment effects[24,88,113] gives preliminary evidence of its validity.

At the end of each condition, we assessed virtual body ownership and agency while participants still saw the virtual hand. We presented auditive one-item mid-immersion questions through the headphones. Participants answered the following questions out loud on a scale of 0 (*not at all*) to 10 (*totally*): "To what extent do you have the feeling as if the virtual body is your body?" (virtual body ownership, adapted from[101]) and "To what extent do you have the feeling that the virtual body moves just like you want it to as if it is obeying your will?" (agency, adapted from[101]).

### 4.2.6 Statistical analysis

We used linear mixed models to compare valence, arousal, dominance, and presence ratings between the synchronous and the asynchronous stimulation condition. We modeled participants and stimuli as additive random effects to account for their interdependence in the repeated measurements. We used lme4[10] in R 3.5.1.[179] to calculate the model and lmerTest[122] to calculate the p-values. We compared valence ratings separately for stimuli with high (i.e., positive) and low (i.e., negative) norm valence. Positive and negative valent stimuli modulate the intensity of valence ratings in inverted directions. To assert if our manipulation worked, we used two-tailed paired $t$-tests to compare virtual body ownership and agency ratings between the synchronous and asynchronous stimulation condition. We calcu-

**Table 4.1: Mean comparisons.** Summary of mean comparisons of valence (seprated by positive and negative stimuli), arousal, and dominance ratings. Abbreviations: CI: confidence interval, SE: standard error, SD: standard deviation, ***: $p < .001$.

| Variable | Difference (95 % CI) | SE | $t$ | $p$ | Synchronous Mean (SD) | Asynchronous Mean (SD) | $d$ |
|---|---|---|---|---|---|---|---|
| Valence (positive stimuli) | 0.33 [0.14, 0.51] | 0.09 | 3.50 | *** | 5.99 (1.31) | 5.66 (1.49) | 0.27 |
| Valence (negative stimuli) | -0.01 [-0.22, 0.19] | 0.10 | -0.14 | .891 | 3.98 (1.75) | 3.99 (1.57) | |
| Arousal | 0.29 [0.10, 0.47] | 0.09 | 3.05 | .002 | 4.83 (1.72) | 4.54 (1.73) | 0.18 |
| Dominance | 0.28 [0.10, 0.47] | 0.09 | 3.02 | .003 | 4.99 (1.74) | 4.70 (1.83) | 0.19 |

lated Pearson correlations between presence and the variables arousal, dominance, positive valence, and negative valence. To achieve a global alpha level of 5%, we Bonferroni-Holm adjusted the significance thresholds of the eleven tests for multiple comparisons. We report Cohen's $d$ as a measure of effect size.

## 4.3 Results

We examined whether virtual body ownership increases emotional responses to virtual stimuli. Therefore we manipulated the degree of virtual body ownership and assessed responses to emotional stimuli. Participants completed both conditions, each with 20 independent stimuli. We used self-assessment manikin scales to assess the emotional response to stimuli. Furthermore, we assessed presence after each stimuli. To check if the experimental manipulation works we assessed virtual body ownership and agency at the end of each condition. As no irregularities arose, we included the subjective ratings of all 21 participants in the repeated measures analysis.

We presented stimuli with high norm arousal and dominance. In the synchronous stimulation condition participants reported significantly higher arousal ($p = .002$, $d = 0.18$), and dominance ($p = .003$, $d = 0.19$) compared to the asynchronous stimulation condition. We presented stimuli with positive and negative valence. Positive valence translates to high ratings. Negative valence translates to low ratings. Positive and negative valence ratings nullify if analyzed together. Hence, we analyzed valence ratings separately for stimuli with high (i.e., positive) and low (i.e., negative) norm valence. For positive valent stimuli, participants reported significantly higher valence ratings ($p < .001$, $d = 0.27$) in the synchronous compared to the asynchronous stimulation condition. For negative valent stimuli, participants did not report significant difference in the synchronous compared to the asynchronous stimulation condition ($p = .877$). Table 4.1 lists the detailed results of these mean comparisons.

We checked if the intended manipulation of virtual body ownership worked. To this end, we assessed virtual body ownership and agency in each condition after participants completed the trials. In the synchronous stimulation condition participants reported significantly higher virtual body ownership ($t(20) = 6.15$, $p < .001$, $d = 1.34$) and agency ($t(20) = 8.99$, $p < .001$, $d = 1.96$) compared to the asynchronous stimulation condition. Figure 4.3 depicts the mean comparisons.

Paricipants reported higher presence ratings in the synchronous ($M = 4.30$, $SD = 1.99$) compared to the asynchronous condition ($M = 3.30$, $SD = 1.81$, $p < .001$, $d = 0.64$). Furthermore, we correlated trailwise presence and self-assessment manikin ratings. There was a significant correlation between presence and arousal ($r = .59$, $n = 840$, $p < .001$) and between presence and valence ratings for positive stimuli ($r = .41$, $n = 420$, $p < .001$) and for negative stimuli ($r = -.19$, $n = 420$, $p < .001$). There was no significant correlation between presence and dominance ratings ($r = .02$, $n = 840$, $p = .597$).

## 4.4 Discussion

Virtual body ownership measures the degree participants accept a virtual body as their own. Virtual body ownership affects the way people think about the environment and themselves. The effect of human-computer interfaces, however, mainly relies on emotional processes.[29] Nevertheless, the effect of virtual body ownership on emotions is poorly understood. The goal of this study was to prove that virtual body ownership intensifies the emotional per-

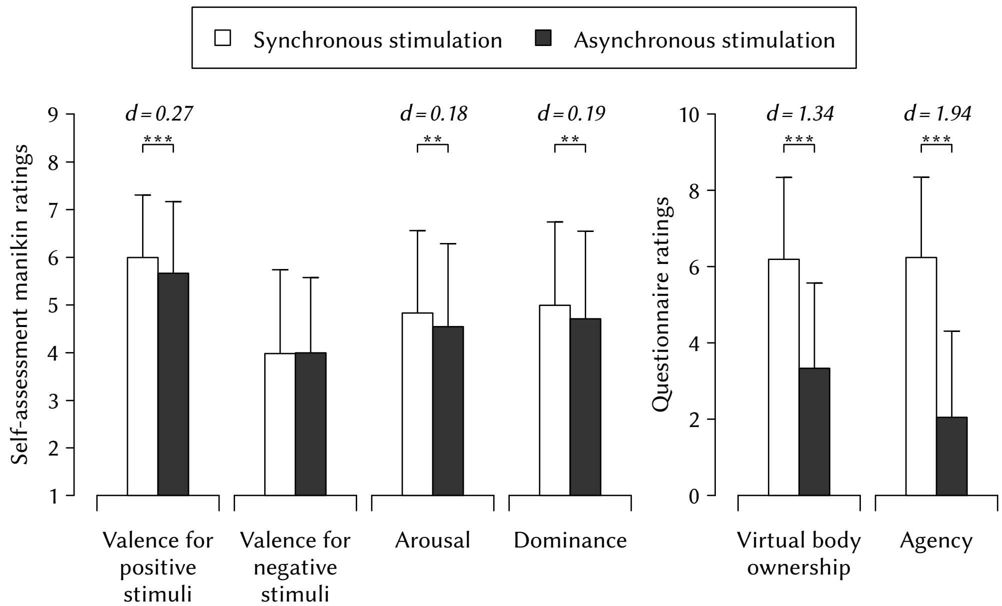


**Figure 4.3: Results.** Mean (+ SD) of self-assessment manikin and questionnaire ratings. Participants reported significantly higher valence for positive stimuli, arousal, and dominance when they receive synchronous compared to asynchronous stimulation. The manipulation check revealed significantly higher virtual body ownership and agency after synchronous compared to asynchronous stimulation. The $p$-values indicate significant results of Bonferroni-Holm adjusted mean comparisons. Cohen's $d$ values indicate effect sizes. Self-assessment manikin ratings range from 1 (*low/negative*) to 9 (*high/positive*). Questionnaire ratings range from 0 (*not at all*) to 10 (*totally*). Abbreviations: **: $p < .01$, ***: $p < .001$.

ception of the virtual environment. We manipulated virtual body ownership and assessed the emotional responses to virtual stimuli. Participants reported higher arousal, higher dominance, and more intense valence if virtual body ownership is high. A manipulation check confirmed that the experimental setup induced virtual body ownership as intended. We conclude that virtual body ownership modulates the emotional responses to the virtual environment.

Participants did not report significantly lower valence ratings for negative valent stimuli. Due to ethical reasons, we presented stimuli with moderate low valence values. We hypothesize that an effect of virtual body ownership emerges if stimuli depict sufficiently adverse content.

Our findings support theories that assume that emotions express the relevance of stimuli to personal goals (see Nelissen et al.[164] for a review). Personal goals relate to one's own body. Therefore, the presence of a body in a particular environment increases the relevance of that environment to one's goals. Furthermore, our findings support theories about the functionality of depersonalization. Depersonalization describes a sense of detachment of one's own body. This detachment reduces the intensity of emotions.[50,51,211,212] They assume that depersonalization serves as a coping strategy in situations of severe distress.

### 4.4.1 Limitations

We used a three-dimensional model to operationalize emotions. Other operationalizations might diversify the effect of virtual body ownership on emotions. We did not present stimuli with low arousal, low dominance, or with neutral arousal, neutral dominance, or neutral valence. Our results, however, support the existence of a causal effect of virtual body ownership on emotional responses. Further studies might qualify and differentiate this effect.

We make no assumptions about cognitive processes that moderate the effect of virtual body ownership on emotions. Our findings suggest that emotional responses correlate with presence. Presence describes the sensation of being at the presented virtual environment.[214] Similar to virtual body ownership, the coherent multisensory information induces presence. We hypothesize that presence and virtual body ownership operationalize a common factor. We confirm this hypothesis in chapter 5.

Furthermore, we make no assumptions about cognitive processes that might confound the effect of virtual body ownership on emotions. The mismatch of sensory information in the asynchronous condition might have distracted participants from the visual stimuli. This distraction might attenuate emotional responses. Future studies might test the potential role of confounding variables. Our results, however, indicate that matching multisensory information increases the emotional response to virtual stimuli.

In our design, we did not separate the theoretical concepts of virtual body ownership and agency. There is an ongoing theoretical discussion about the interplay of both constructs.[28] In virtual reality applications with virtual bodies, however, both concepts co-occur.

### 4.4.2 Implications

Many studies investigate virtual reality for the treatment of psychopathologies. Particularly, virtual reality exposure therapy reduces anxiety in phobic disorders.[67] In psychotherapy, higher activation of emotions is associated with a positive treatment outcome (e. g.[40,78]). Previous clinical studies, however, omitted a virtual body.[67] One reason for this omission might be that virtual body ownership is sensitive to mismatches of perceived and expected behavior of the virtual body. In line with Braun et al.[28], we propose to induce virtual body ownership to intensify the emotional response to therapeutic stimuli. Virtual body ownership might enhance treatment outcomes of virtual reality interventions.

### 4.4.3 Conclusion

We provide experimental evidence that virtual body ownership causes an intensified emotional response to virtual stimuli. The increase in emotional responses is essential for many applications in human-computer interaction. We propose the necessity of inducing virtual body ownership to increase the effectiveness of a virtual reality system. Especially in virtual reality psychotherapy, we assume that a virtual body enhances treatment outcomes.

#### Acknowledgments

Julian Zarges collected the data and contributed to the creation of the apparatus and stimuli. Gotoxy AV-Media GbR, Nuremberg, Germany, provided the virtual hand stimulus.

#### Data and code availability

Data and code for all analyses are available at https://osf.io/quysv/.

**Summary**

*What was the research question?*
How does virtual body ownership organize the emotional perception of a virtual environment?

*What was already known about this topic?*
Virtual body ownership intensifies fear responses to stimuli that threaten the virtual body.

*What did this study add to our knowledge?*
Virtual body ownership intensifies emotional responses to virtual stimuli. The virtual stimuli can be unrelated to the virtual body, apart from sharing a common environment.

*Why are these findings important?*
Emotional responses are essential for many human-computer interaction use-cases, including virtual reality psychotherapy. Virtual bodies can increase the effectiveness of human-computer interaction.

# Chapter 5

# Presence and virtual body ownership constitute a common factor

**Abstract**

Presence and virtual body ownership are important factors characterizing virtual environments. Understanding their relationship contributes to the question of how to evaluate and measure the effectiveness and user experience of virtual reality systems and to predict critical outcomes. Presence describes to what extent people accept a virtual environment as their real environment. In contrast, virtual body ownership describes to what extent people accept a virtual body as their real body. This paper shows that presence and virtual body ownership constitute a common factor, and their measures operationalize this common factor. We conducted two confirmatory experiments with 42 undergraduate students. In Experiment 1, we show that presence induces virtual body ownership. In Experiment 2, we show, in turn, that virtual body ownership induces presence. To accept a virtual environment as real means to accept a virtual body representation in that environment as one's own body and vice versa. Without having a (potentially invisible) body, one does not accept being in a virtual place. Presence and virtual body ownership measure, hence, to some degree measure the same experience.

## 5.1 Introduction

Presence and virtual body ownership are important factors in virtual reality research, and they are often used to characterize prominent qualities of virtual environments. Presence describes to what extent people accept a virtual environment as their real environment. In contrast, virtual body ownership describes to what extent people accept a virtual body as their real body. There are theoretical considerations about the relationship between presence and virtual body ownership. Several measures have been developed and used to qualify and quantify both constructs. No experimental studies, however, have investigated possible interdependencies. We present two confirmative experiments that prove the mutual dependence of presence and virtual body ownership. We conclude that both constructs constitute a common factor and that according measures operationalize this common factor. Hence, presence and virtual body ownership cannot be treated as independent factors.

### 5.1.1 Presence

The motivation to introduce presence in virtual reality research was to measure the effectiveness of immersive systems.[214] The desired outcome of immersive systems is to induce the illusion of physically being in a place despite understanding that one is not. Since its introduction by Akin et al.[2] researchers proposed different theories and operationalizations of presence (see Skarbez et al.[214] for a review). The different operationalizations of presence have one common denominator: the feeling of physically being at the presented virtual environment. There is, however, no consensus on a unified theory or on a tool for measurement. In general, researchers measure presence with subjective rating scales. In this study, we use the most minimalistic operationalizations of presence: Bouchard et al.[24] introduced a one-item subjective rating scale that is assessed during exposure to the virtual environment. This item assesses the feeling of being present in a virtual environment. One-item presence measures during immersion are more sensitive than post-immersive questionnaires.[24,68,215] Hendrix and Barfield[85] found sufficient reliability of a similar presence rating. Schwind et al.[202] found no difference in the comparison of presence ratings during or after exposure. The sensitivity of presence to experimental manipulations strengthen its validity.[24,70,88,113,245] Previous presence research, however, focused mainly on theoretical considerations. The experimental evidence that presence relates to critical outcome measures is weak and controversial.[200] Some studies found correlations between presence and fear reactions, but only if arousal was sufficiently high (see Diemer et al.[53] for a review). Presence, however, does not relate to outcomes of virtual exposure therapy.[53] Some studies indicate a causal influence of emotions on presence.[24,76,79] They showed that emotions influence presence. They, however, did not show that presence influences emotions. There is little support for the claim that presence quantifies the effectiveness of virtual reality systems.

Similar to virtual body ownership, presence depends on the coherence of multisensory information.[70] Virtual body ownership is a more successful measure of the effectiveness of virtual reality systems. In this study, we experimentally investigate the hypothesis that presence is associated with virtual body ownership.

### 5.1.2 Virtual body ownership

The sense of ownership of a body part relies on the integration of different sensations. The manipulation of such sensations can induce the illusion of owning a virtual body part. People tend to accept an artificial hand as their own, if the artificial hand is stroked synchronously with their hand.[23] Virtual reality systems allow for manipulating the visual perception of the environment. We use two visual manipulations that induce virtual body ownership (see Kilteni et al.[107] for a review): First, people see an artificial body part with plausible shape, texture, and anatomical position. Second, people see an artificial body part in the same place where the real body part is. A behavioral measure for virtual body ownership is the proprioceptive drift. Proprioceptive drift occurs if people experience ownership of an artificial body that is in a different position as the real body. In this case, people misjudge the position of their real body.[23,130] Proprioceptive drift only occurs if the virtual and the real body parts are in different places. Moreover, proprioceptive drift is not a sufficient indicator for virtual body ownership.[1,185] Even though both measures correlate, they measure a different effect. Hence, many studies use custom subjective rating scales to assess virtual body ownership. There is, however, no commonly used questionnaire for virtual body ownership. In this study, we use a minimalistic operationalization of virtual body ownership, adapted from Kalckert and Ehrsson [101]: We use a one-item subjective rating scale during exposure to the virtual environment.

In contrast to presence, there are several studies that support the external validity of virtual body ownership. Virtual body ownership has perceptual and behavioral correlates. Virtual body ownership alters the perceived location of the real body part if the virtual body appears displaced. [23,130,195] It alters the perceived size and distance of objects. [7,99,132,236–238] It alters the attributes towards the social group of the virtual body. [7,60,61,64,141,174] It increases the awareness of the virtual body. [239] It affects the spatial orientation [178] and tactile perception. [137] It affects the effectivness of brain-computer interfaces. [97] It modulates pain. [75,145–147,150,165,171] It modulates anxiety and arousal for stimuli that threaten the virtual body. [3,34,82,186]

### 5.1.3 Problem statement

Presence and virtual body ownership aim both to measure the effectiveness of virtual reality stimuli. They conceptualize the degree to which we accept visual stimuli as real. In theory, both concepts are related: Our body is part of the environment that we perceive. We perceive our environment because it interacts with our bodies. Presence and virtual body ownership correlate (chapter 4). [98,99,245] There is, however, no empirical model that describes the origin of this correlation. There is also no research that assesses the causal interdependence of both constructs. We assume that both constructs, to some degree, describe the same experience.

### 5.1.4 Contribution

We show that presence and virtual body ownership constitute a common factor. We show a reciprocal effect of presence and virtual body ownership: one construct induces the other. We conducted two confirmatory experiments with 42 undergraduate students. In Experiment 1, we manipulated presence and induced virtual body ownership. Participants reported significantly higher virtual body ownership in the high presence condition, compared to the low presence condition. In Experiment 2, we manipulated virtual body ownership and induced presence. Participants reported significantly higher presence in the high virtual body ownership condition, compared to the low virtual body ownership condition.

## 5.2 Common materials and methods of Experiments 1 and 2

### 5.2.1 Participants

Undergraduate students ($N = 42$, 33 women) of an anonymized University voluntarily participated in Experiment 1 and 2. All participants participated in both experiments. We conducted Experiment 2 directly after Experiment 1. The participants rested 15 min between the two experiments. The age of the participants was between 19 and 29 years ($M = 21.57$, $SD = 2.13$). All participants provided written informed consent before participating. They received course credit for participation. All reported normal or corrected-to-normal vision and the absence of motor impairments. Participants were naive regarding the hypotheses of the experiments. The institutional ethics committee approved Experiment 1 and 2.

### 5.2.2 Display and sound

In both experiments, participants wore a head-mounted display (HTC Vive Headset) and headphones (Superlux HD330). An Intel i7 4.00 GHz, 16 GB RAM computer with an NVIDIA GeForce GTX 1080 Ti graphics card rendered the stereoscopic images at 90 Hz. We implemented the sensor data integration and visualization of the virtual environment in the Epic Games Unreal Engine 4.17.

To neutralize noises, we presented Brownian auditive noise through the headphones at 50 dB. A calibration measurement of the system showed that the motion-to-photon latency was below 40 ms. The threshold for detecting visuomotor delays is above 100 ms. [66,209,210]

### 5.2.3 Statistical analysis

We used two-tailed paired $t$-tests to compare presence and virtual body ownership ratings between the conditions. To achieve a global alpha level of 5%, we Bonferroni-Holm adjusted the significance thresholds of the three tests in Experiment 1 and 2. We report Cohen's $d$ as a measure of effect size. We used R 3.5.1 [179] to analyze the data. Data and code for all analyses are available at [anonymized OSF link].

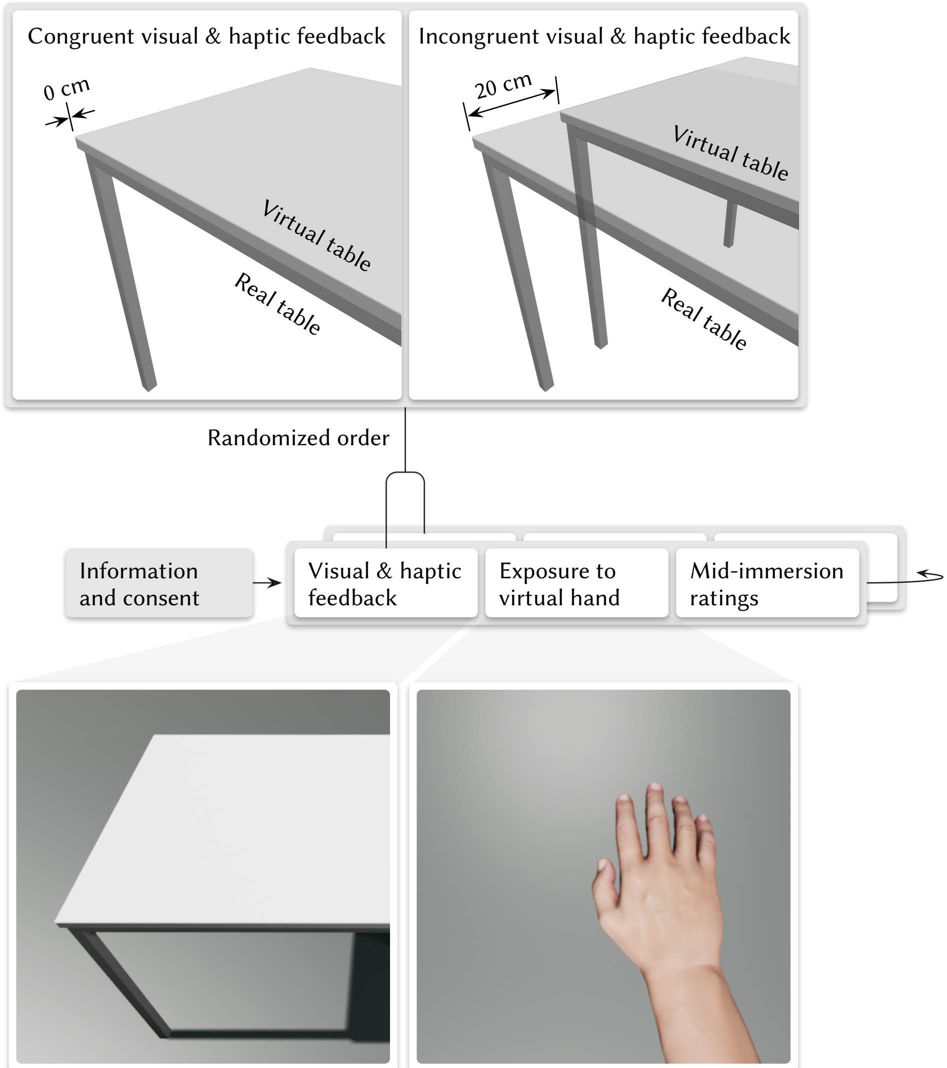


**Figure 5.1: Experiment 1 Procedure and Stimuli.** Experiment 1 followed a single-factor repeated-measures design with two levels. Participants saw the virtual representation of the table in front of them. They touched the table with their left hands for 30 s. To modulate presence, participants experienced either congruent or incongruent to visual and haptic information. In the congruent condition, the virtual table appeared in the same position as the real table. In the incongruent condition, the virtual table appeared displaced to the real table. Afterward, participants saw a virtual representation of their right hand for 20 s. Then, we assessed virtual body ownership and presence.

## 5.3 Experiment 1: The effect of presence on virtual body ownership

In Experiment 1, we show that presence induces virtual body ownership. We manipulated the degree of presence and assessed how participants accept a virtual body as their own. First, participants perceive visual and haptic feedback from a virtual environment. To manipulate presence, we provided haptic information that was either congruent or incongruent to visual information. As intended, participants experienced high presence if visual and haptic information was congruent and low presence if the information was incongruent. In both conditions, participants then perceived a virtual body. Participants reported higher virtual body ownership in the congruent compared to the incongruent condition.

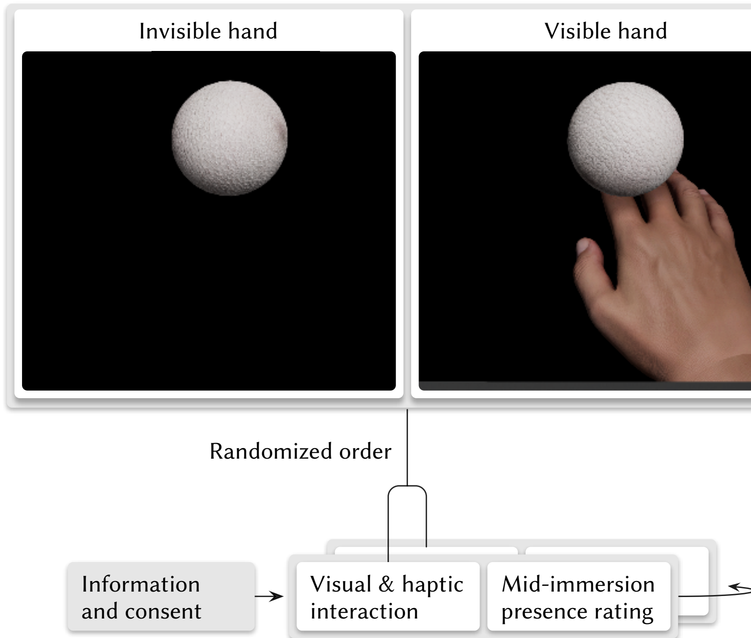


**Figure 5.3: Experiment 2 Procedure and Stimuli.** Experiment 2 followed a single-factor repeated-measures design with two levels. Participants focused on a virtual representation of a styrofoam ball. To modulate virtual body ownership, participants either saw a virtual hand in the place of their real hand or saw an empty space. The experimenter induced a visuotactile interaction with the environment by touching the hand with a real styrofoam ball. The virtual ball moved synchronously with the real ball. Then, we assessed presence.

### 5.3.1 Method

#### Design and procedure

Experiment 1 followed a single-factor repeated-measures design with two levels. We manipulated the factor congruency of visual and haptic feedback (congruent vs incongruent). Participants completed the two conditions in a balanced, randomized order.

Participants sat in a swivel chair between two adjacent tables. They placed their right hand on a hand rest. Then they rotated to the table on their left. Participants wore a head-mounted display and headphones. The left hand was invisible, and the right hand was out of view.

In each condition, participants first only saw a virtual representation of the table in front of them. Between the two conditions, we varied the position of the virtual table. In the congruent condition, the virtual table appeared in the same position as the real table. In the incongruent condition, the virtual table appeared displaced to the real table. We instructed the participants to explore the left half of the table by looking and touching for 30 s with only their free left hand it. During this first phase, participants did not see any virtual body: their left hand was invisible, and the right hand was on the hand rest, out of view. They only saw the virtual table. The congruency of visual and haptic information modulates presence.[70]

Afterward, we instructed the participants to place their left hand on their lap and to look at their static right hand. Now participants saw a virtual representation of their static right hand for the first time. The virtual hand was in the same position as their real hand The examiner manually locked the head-mounted display to an immovable holder. We instructed participants to look at the virtual hand for 20 s. Then we conducted mid-immersion one-item presence and virtual body ownership ratings. We presented the instructions and questions through the headphones. Between the two conditions (congruent vs incongruent virtual table position), participants rested for 5 min. Figure 5.1 illustrates the procedure.

#### Apparatus

Participants wore a head-mounted display and headphones during Experiment 1. They sat in a swivel chair between two adjacent tables. The right hand of participants rested on a hand rest. The hand rest defined static positions for each finger of the right hand. Participants could move their left hand freely. During the procedure, the experimenter locked the head-mounted display to a holder. In this position, the participants looked towards their right hand at a distance of 35 cm. A sensor (HTC Vive controller) tracked the position of the hand rest and the tables. **??** illustrates the apparatus.

#### Stimuli

The virtual table stood on an infinite, empty floor. In the congruent condition, the virtual table appeared in the same position as the real table. In the incongruent condition, the virtual table appeared shifted away by 20 cm in the posterior-anterior axis. The virtual right hand appeared in the same position as the real right hand; the left hand was invisible. Visual exposure to a realistic spatially coincident virtual body induces virtual body ownership.[149] Figure 5.1 depicts the virtual stimuli.

#### Measures

We assessed virtual body ownership by asking, “To what extent do you have the feeling that the virtual body is your body?” (adapted from Kalckert and Ehrsson[101]). To check if the manipulation worked, we assessed presence by asking “To what extent do you feel present in the virtual environment?” (adapted from Bouchard et al.[24]). Participants answered each question aloud on a scale from 0 (*not at all*) to 10 (*totally*). Before Experiment 1, we explained to the participants that “presence is the subjective impression of really being there in the virtual environment.” There is evidence that brief one-item presence measurements during immersion are more sensitive to the subjective feeling of presence than post-immersive questionnaires.[24,68,215] Hendrix and Barfield[85] confirmed the reliability of a similar presence assessment. Others showed the ability of similar measures to detect treatment effects.[24,88,113] These results give preliminary support for the validity of one-item mid-immersion measures.

### 5.3.2 Results

To examine whether presence induces virtual body ownership, we manipulated the degree of presence and presented a stimulus to induce virtual body ownership. We manipulated presence by presenting congruent or incongruent visual and haptic feedback. We used a one-item mid-immersion question to assess virtual body ownership. To check if the manipulation worked, we used a one-item mid-immersion question to assess presence. As no irregularities arose, we included the subjective ratings of all 42 participants in the repeated measures analysis.

Participants reported significantly higher presence in the congruent ($M = 5.98$, $SD = 2.02$), compared to the incongruent condition ($M = 4.52$, $SD = 2.00$; $t(41) = 5.84$, $p < .001$, $d = 0.90$). Hence, the manipulation worked. As expected, participants also reported significantly higher virtual body ownership in the congruent ($M = 5.62$, $SD = 2.08$), compared to the incongruent condition ($M = 4.52$, $SD = 1.95$; $t(41) = 5.61$, $p < .001$, $d = 0.87$). Both comparisons revealed large effect sizes. Figure 5.5 depicts the mean comparisons.

### 5.3.3 Discussion

We investigated the effect of presence on virtual body ownership. We manipulated presence. In the high presence condition, participants perceived congruent visual and haptic information. In the low presence condition, they received incongruent information. Subsequently, participants saw a virtual representation of one hand colocated to their real hand. In the high presence condition, participants experienced higher virtual body ownership. We conclude that presence induces virtual body ownership. In Experiment 2, we prove the inverse.

## 5.4 Experiment 2: The effect of virtual body ownership on presence

In Experiment 2, we show that virtual body ownership induces presence. We manipulated the visibility of a virtual hand. In one condition, participants saw a virtual hand in the place of their real hand. In the other condition, participants saw an empty space in the place of their real hand. People can experience ownership of a volume of empty space.[81,82] An invisible virtual body, however, induces less ownership compared to a visible body.[147] We applied multisensory interaction with the environment to generate a situation in which people experience high levels of presence.[70]

We applied the same visuotactile interaction with the virtual environment in both conditions: participants saw and felt the touches of a moving ball. We finally assessed presence. Presence was higher if participants saw a virtual compared to no hand. We conclude that virtual body ownership induces presence.

### 5.4.1 Methods

#### Design and procedure

Experiment 2 followed a single-factor repeated-measures design with two levels. We manipulated the visibility of a virtual hand (visible hand vs invisible hand). In the visible hand condition, the participants saw a virtual representation of their right hand. In the invisible hand condition, the participants saw an empty space in place of their right hand. The participants completed both conditions in a balanced, randomized order.

Participants sat in front of the table. They placed their right hand on a hand rest and wore an immovable head-mounted display with headphones. Only in the visible hand condition, participants saw the virtual representation of their right hand. All participants saw a virtual representation of a styrofoam ball. We instructed the participants to focus on the virtual styrofoam ball. The participants perceived visuotactile stimulation for 60 s. The experimenter used a styrofoam ball to stroke the index and middle finger form the fingertips to the back of the hand. The virtual styrofoam ball moved synchronously to the real styrofoam ball. Afterward, we conducted a mid-immersion one-item presence rating. Figure 5.3 illustrates the procedure.

#### Apparatus

The right hand of participants rested on a hand rest. The hand rest defined fixed positions for each finger. Participants looked through an immovable head-mounted display and wore headphones. The static field of view comprised the right hand at a distance of 35 cm. The examiner stroked the hand of the participant with a styrofoam ball. The styrofoam ball had a diameter of 5 cm. A position sensor (HTC Vive handheld controller) tracked the position of the styrofoam ball. **??** illustrates the apparatus.

#### Stimuli

Participants saw a virtual representation of the styrofoam ball in front of a black background. The virtual styrofoam ball appeared in the same position as the real styrofoam ball. Only in the visible hand condition, participants saw a virtual representation of their right hand. The virtual right hand appeared in the same position as the real right hand. Figure 5.3 depicts the virtual stimuli.

#### Measures

We assessed the same one-item mid-immersion presence rating as in Experiment 1 with headphones. Participants answered the following question out loud on a scale of 0 (*not at all*) to 10 (*totally*): "To what extent do you feel present in the virtual environment?" (adapted from Bouchard et al. [24])

### 5.4.2 Results

To examine whether virtual body ownership induces presence, we manipulated the degree of virtual body ownership and presented visuotactile stimuli to generate sufficiently high degrees of presence. We manipulated virtual body ownership by altering the visibility of a virtual hand. We used a one-item mid-immersion question to assess presence. As no irregularities arose, we included the subjective ratings of all 42 participants in the repeated measures analysis. As expected, participants reported significantly higher presence ($t(41) = 9.63$, $p < .001$, $d = 1.49$) in the visible hand condition ($M = 6.81$, $SD = 1.85$) compared to the invisible hand condition ($M = 4.00$, $SD = 2.14$). The effect size was large. Figure 5.5 depicts the mean comparison.

### 5.4.3 Discussion

We investigated the effect of virtual body ownership on presence. We manipulated virtual body ownership. In the high virtual body ownership condition, participants saw a virtual hand colocated to their real hand. In the low virtual body ownership condition, participants saw empty space in place of their real hand. In both conditions, participants interacted with the same virtual environment. Participants perceived visual and tactile information of the environment. Subsequently, participants reported higher presence if they saw a virtual representation of their hand compared to no hand. Seeing a colocated virtual hand is sufficient to induce virtual body ownership. We conclude that virtual body ownership induces presence.

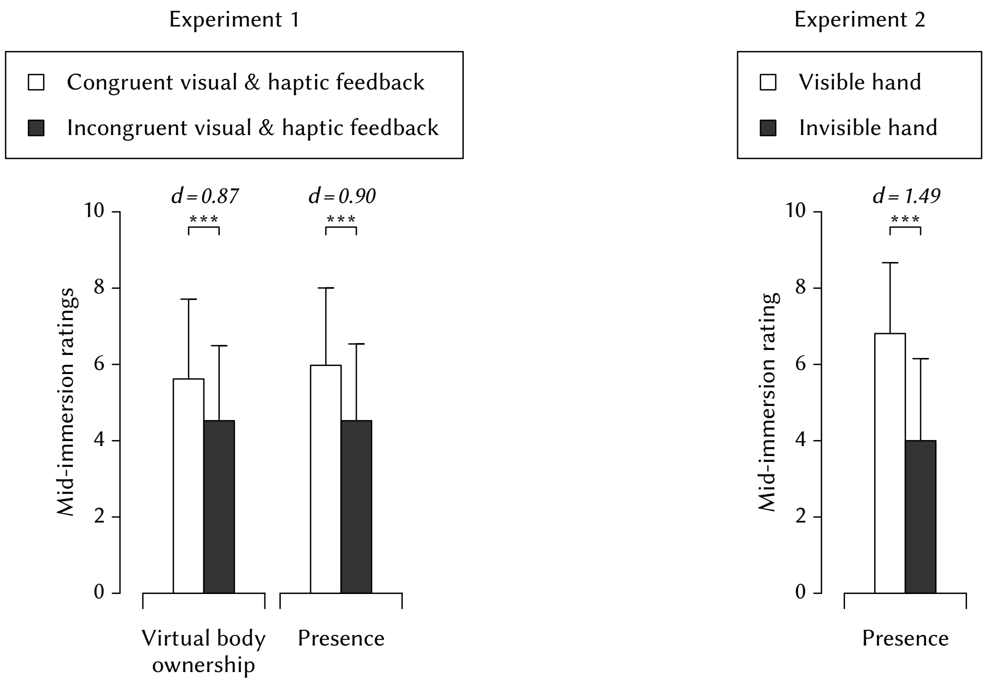


**Figure 5.5: Results of Experiment 1 and 2.** Mean (+ SD) of mid-immersion ratings for Experiment 1 (left) and Experiment 2 (right). In Experiment 1, participants reported significantly higher virtual body ownership if they received congruent visual and haptic feedback, compared to incongruent feedback. In this case, participants also reported significantly higher presence. The manipulation of presence, hence, worked. We conclude that presence induces virtual body ownership. In Experiment 2, we assessed presence visuotactile interaction with the environment. Participants reported significantly higher presence if they saw a visible hand, compared to when they just saw an empty space. We conclude that virtual body ownership induces presence. The $p$-values indicate significant results of Bonferroni-Holm adjusted mean comparisons. Cohen's $d$ values indicate effect sizes. Mid-immersion ratings range from 0 (*not at all*) to 10 (*totally*). Abbreviation: ***: $p < .001$.

These results are consistent with Schwind et al..[201] They showed that the anatomical plausibility of a virtual body modulates presence. Anatomical plausibility, in turn, modulates virtual body ownership.

Presence measures how people perceive a virtual environment. Our results are consistent with studies that show the influence of virtual body ownership on the perception of the environment: Virtual body ownership alters the perceived size of virtual objects[7,99,132,238], even if the virtual body is outside the field of view[236] or invisible.[237] Virtual body ownership, furthermore, increases the fear of stimuli that threaten the virtual body.[3,34,82,186]

#### Limitations

Virtual body ownership might only cause presence if tactile information is available. Presence and virtual body ownership, however, correlate even if people only see the virtual environment.[245] We, therefore, assume that virtual body ownership also induces presence if people only see a virtual environment.

Visual richness might confound our results. There are mixed results on whether visual richness does[79,123,219,247] or does not[54,128,138,143,255] modulate presence. In our study, participants received more visual information when they saw a virtual hand compared to no hand. The environment outside the boundaries of the body, however, was constant in both conditions. Future studies might exclude the potential confounding effects of visual information. Therefore, future studies might use purely cognitive interventions to manipulate virtual body ownership.

## 5.5 General discussion

We tested the mutual dependence of presence and virtual body ownership. Presence describes to what extent people accept a virtual environment as real. Virtual body ownership describes to what extent people accept a virtual body as their own. In Experiment 1, we show that presence induces virtual body ownership. In Experiment 2, we show, in turn, that virtual body ownership induces presence. We conclude that presence and virtual body ownership constitute a common factor and that according measures operationalize this common factor. A common factor allows applying knowledge about one construct to the other.

This finding supports theories that suggest an interdependence of presence and virtual body ownership. Riva et al. [184] assume a direct connection of presence and body ownership: using a body locates people in the place where they act; being somewhere includes possible actions in one's perception of a body. Biocca [17] suggests that whenever people use head movements to alter what they see, they not only experience presence but also become aware of their bodies.

The interdependence of presence and virtual body ownership is consistent with their definitions. To "feel present in the virtual environment" implies to be a person in this place. To be a person implies having a body. To feel, in turn, that a "virtual body is your body" implies that the own body is the virtual body. The body defines one's location. Hence, presence and virtual body ownership by definition imply each other.

Presence induces virtual body ownership. So, if people feel present and see an empty space instead of a body, then they do not assume to be bodiless. They, however, assume to have an invisible body. An invisible body that continuously generates a user-centered first-person perspective congruent with ones' head movements.

People in the same way experience ownership of an invisible body if they receive visuotactile stimulation without a virtual body.[81,82] The absence of a virtual body, hence, limits the experience of presence to the degree to which people feel present inside an invisible body.

Expectations predict sensations.[168,169] The matching of expectations and sensations influences both, virtual body ownership[23] and presence.[70,194,206,217] Expectations about the sensory consequences of motor actions, moreover, guide body movements.[120] People, hence, require a joint representation of the body and the environment. If sensory consequences, however, do not match expectations, this joint representation needs recalibration. Our common factor model suggests that recalibration affects the representation of both: body and environment.

The usefulness of presence in predicting critical outcomes is controversial. Only limited evidence indicates a relationship between presence and critical outcome measures, like emotional responses to virtual stimuli.[200] In this study, we, moreover, show that presence shares a common factor with virtual body ownership. Hence, the assertion that presence uniquely captures the desired outcomes of a virtual reality system, therefore, seems debatable. We stress the need to develop virtual reality measures that predict critical characteristics and qualities of virtual reality systems.

If virtual body ownership and presence constitute a common factor, the question arises, what this factor is, and how it is defined. Our experiments did not directly target to identify the nature of this factor. Hence any answer given is speculative with respect to our results. However, our outcomes stimulate a general direction to discuss. Potential candidates for a common factor could be believability or plausibility or – more concrete – the subjective experience of an alternative reality with all its implications caused by the suspension of disbelieve.[?] Suspension of disbelieve, in turn, is fostered by the immersive properties of virtual reality to be inclusive, extensive, surrounding, and vivid.[218] This would be in line with the understanding of an overall sense of embodiment[105] that anchors our experience in the sensory and actuatory connection to our real or virtual environment.

This hypothesis does not try to differentiate between virtual body ownership and presence but assumes the body ownership illusion and the place illusion to be facets of plausibility and hence believability; metaphorically speaking two sides of a coin. After all, it seems odd and partly random to place the demarcation line between the mental and the physical/virtual world at the skin of one's body. It seems more congruent with the dichotomy of physical/virtual to see the body as the direct and closest extension of the mental self into the physical or virtual environment. Here, the characteristic of embodiment, if it is taking shape as a virtual or a physical body, sets us into the spatial context of the physical or virtual place this body is located at, finally contributing to the same experience of believability and plausibility. These hypotheses are not empirically backed-up by our results but inspired by its general finding. They provide a potential explanation, a basis for further discussion, and to also motivate future work.

### 5.5.1 Limitations

We did not induce agency in both experiments besides the dynamic calculation o the first-person view. The movements of participants did not affect the virtual environment, except the head movements in Experiment 1. Agency might reveal new aspects of the interdependence of presence and virtual body ownership.

We used one-item mid-immersion questions to assess presence and virtual body ownership. There are also other measurements. So far, however, there is no consensus on how to define and measure both constructs.[214] One-item mid-immersion measures, however, are a robust and straightforward approach to operationalize the common denominator of most definitions. One-item mid-immersion questions have reasonable quality metrics.

### 5.5.2 Conclusion

We provide evidence that presence and virtual body ownership constitute a common factor. To accept a virtual environment as real means to accept a virtual body representation in that environment as one's own body and vice versa. Without having a body, one does not accept being in a virtual place. Hence, existing measures of presence and virtual body ownership to a high degree measure the same experience. To facilitate the use of virtual reality, we need to define concise measures that precisely, accurately, and unambiguously measure and predict critical qualities of VR systems, reducing any potential ambiguity, fuzziness, or vagueness as much as possible.

**Acknowledgments**

Maria Ternes collected the data and contributed to the creation of the apparatuses and stimuli. Jan-Philipp Staufert and Daniel Roth provided technical and conceptual support. Gotoxy AV-Media GbR, Nuremberg, Germany, provided the virtual hand stimulus.

**Data and code availability**

Data and code for all analyses are available at https://osf.io/3hsmz/.

**Summary**

*What was the research question?*
Presence and virtual body ownership are established measures in virtual reality research. How do they relate to each other?

*What was already known about this topic?*
Theoretical considerations suggest a relationship between both measures. Presence and virtual body ownership, moreover, often correlate.

*What did this study add to our knowledge?*
Presence and virtual body ownership induce each other. Hence they constitute a common factor.

*Why are these findings important?*
A common factor allows for applying knowledge about one construct to the other. Understanding the relationship of presence and virtual body ownership also contributes to the question of how to evaluate the effectiveness of virtual reality systems. Measures of the effectiveness of virtual reality systems are required to predict critical outcomes.

# Chapter 6

# Virtual body ownership can arise for anatomically implausible body configurations


**Abstract**

Virtual and augmented reality interfaces can induce the illusion of virtual body ownership. Previous work showed that users adapt different body forms, even those with non-human anatomies. So far, research suggested that anatomical positioning should be plausible in order to evoke virtual body ownership. We show that the illusion of owning a virtual body can arise for anatomically implausible bodies In a two-factorial repeated-measures experiment, we manipulated the anatomic plausibility of a virtual body as well as the synchronicity of a visuotactile and visuomotor stimulation. Participants reported higher virtual body ownership after synchronous stimulation compared to asynchronous for both: the natural and the anatomically implausible body configuration. We conclude that virtual body ownership can arise for anatomical implausible body parts. Semantic constraints hence play a minor role in body ownership illusions. This finding extends the design space for future user-embodying interfaces.

## 6.1 Introduction

The feeling of owning one's body helps distinguish body parts from external objects.[48,239] This sensation determines the way how humans interact with their environment. The feeling of owning a body, however, is not static but arises from the integration of multisensory information.[106] Humans integrate visual and sensory information to determine what is part of their own body. The manipulation of such sensory information can alter the perception of the body and induce the illusion that an inanimate object is part of one's body.[23] Immersive interfaces provide such multisensory information. Hence human-computer interfaces can modify the perception of one's body.

### 6.1.1 Virtual body ownership

Virtual reality provides a means to modify visual perception and thus, the perception of the own body. Virtual reality allows displaying a visual replacement of one's own body through avatars. Virtual body ownership describes the impression that such a virtual object is part of the perceiver's body.[220] This impression arises from coherent multisensory information. Synchronous visuotactile and visuomotor stimulation induce virtual body ownership: visual and tactile sensations that seemingly have the same origin; and visual movements that correlate to body movements.[28] Applications that allow users to own a virtual body provide novel means for psychotherapy, training, and entertainment. Therefore, applications aim to utilize body ownership to the full extent. But to what extent can human-computer interfaces modify the perceived body?

### 6.1.2 Related work

Humans show remarkable flexibility in what they accept as their body. For instance, people accept bodies that appear in a different location.[130] Virtual body ownership can also arise for translated[23] or scaled body parts.[106,132] Furthermore, virtual body ownership can arise for additional body parts (e.g.,[80,91,197,221]) or partly removed body parts.[201] These body parts, however, have anatomic plausibility: modified bodies only extend or reduce to the existing body. We define anatomic implausible body configurations, as configurations where body perceptions contradict visual information. This definition does not include deviations that are caused by a spatial inaccuracy (transformation, scaling) or by added or removed body parts.

Previous studies suggested that virtual body ownership requires anatomic plausibility of the virtual body.[107,186] People rejected additional body parts that were laterally incongruent or anatomically unaligned.[80] Furthermore, people rejected a right hand which experimenters stimulated synchronously to the left hand.[233] People also rejected a virtual foot which experimenters stimulated synchronously to the hand.[80]

The integration of visual and tactile stimulation, however, does not rely on anatomic plausibility: seeing a touch on one hand but feeling it on the other hand induces the feeling that the first hand is touched.[173] This finding suggests that sensory integration is flexible to lateral body swapping. Sensory integration, in turn, is responsible for virtual body ownership. So we hypothesize that virtual body ownership can arise in laterally displaced body configurations. This configuration is not anatomically plausible.

### 6.1.3 Agency

Agency is a concept, that is tightly related to virtual body ownership.[28] It describes the sensation to be the single cause of a movement.[41] In this study, we use visuotactile and passive visuomotor stimulation to induce virtual body ownership. During passive visuomotor stimulation, experimenters moved the body of participants while participants see a similar moving object. This procedure can induce a sense of agency over this object. Agency promotes virtual body ownership (see Braun et al.[28] for a review). It generalizes local sensations of virtual body ownership.[234] Therefore, we understand agency as a dimension of virtual body ownership, even though it can arise independently.

### 6.1.4 Contribution

In this study, we show that virtual body ownership can arise for anatomically implausible body configurations. We conducted a two-factor repeated-measures experiment with 56 undergraduate students. We manipulated the anatomic plausibility of a virtual body: participants saw a left and a right hand in laterally swapped and in a natural position. With the natural positions, we checked whether the setup could induce the illusion. Furthermore, we manipulated the temporal synchrony of visuotactile and visuomotor stimulation of both hands. In both anatomical configurations, participants reported significantly higher virtual body ownership if stimulation happened synchronously compared to asynchronous stimulation. We conclude that virtual body ownership can arise for anatomically implausible bodies. Hence, the flexibility of humans to accept inanimate objects as their own bodies exceeds previous assumptions. People can accept virtual bodies beyond anatomical plausibility. This finding extends the design space of user-embodied interfaces for psychotherapy, training, and entertainment.

## 6.2 Method

### 6.2.1 Participants

Undergraduate students ($N = 56$; 39 women) from the University of Würzburg volunteered to participate in the experiment. The age of the participants ranged from 18 to 34 years ($M = 20.93$, $SD = 3.07$). All participants provided written informed consent before participation. They received course credit for participation. All reported normal or corrected-to-normal vision and the absence of motor impairments. Participants were naive regarding the hypotheses of the experiment. The institutional ethics committee approved this study.

### 6.2.2 Design and procedure

The experiment followed a counterbalanced repeated-measures $2 \times 2$ design. We manipulated the factors anatomical body configuration (swapped vs natural) and temporal synchrony of visuotactile and visuomotor stimulation (synchronous vs asynchronous). Participants completed each condition once in a balanced, randomized order.

Participants sat in front of a table. They placed their hands on hand rests and wore an immovable head-mounted display with headphones. In each condition, participants saw virtual representations of their left and right hand and a virtual styrofoam ball. The experimenter manually delivered visual-tactile stimulation by stroking the index and middle finger from the fingertips to the back of one hand with the styrofoam ball. One stroke lasted approximately 500 to 1000 ms. The experimenter manually delivered passive visuomotor stimulation by rotating one hand. One rotation lasted approximately 1500 to 2000 ms We stimulated both hands for 3 min each. We alternated between visual-tactile and passive visuomotor stimulation every 30 s. In the synchronous condition, the virtual styrofoam ball and the virtual hand moved synchronously to their real counterparts. In the asynchronous condition, the virtual styrofoam ball and the virtual hand moved 5 s delayed. In the swapped condition the virtual hands and the virtual styrofoam ball appeared laterally swapped. In this condition, the left hand appeared in place of the right hand and vice versa. Afterward, we conducted mid-immersion one-item virtual body ownership and agency ratings with the headphones. Participants removed the head-mounted display and completed a questionnaire assessment of virtual-body ownership and agency. Between the conditions, participants rested for 5 min. Figure 6.1 illustrates the procedure.

**Figure 6.2: Apparatus.** We presented visual stimuli in a immovable head-mounted display. Participants placed their hands on two hand rests. The experimenter delivered visuotactile stimulation with a styrofoam ball attached to a position sensor. The experimenter delivered visuomotor stimulation by rotating the hand rests. Sensors tracked the position of the hand rests. We presented Brownian noise in headphones.

### 6.2.3 Apparatus

During the experiment, both hands of participants rested on hand rests. The hand rests defined static positions for each finger. The examiner could rotate the hand rests around the wrist by 13 degrees without touching the participant. Two position sensors (HTC Vive Tracker) tracked the rotation angle of the hand rests. The examiner could stroke the

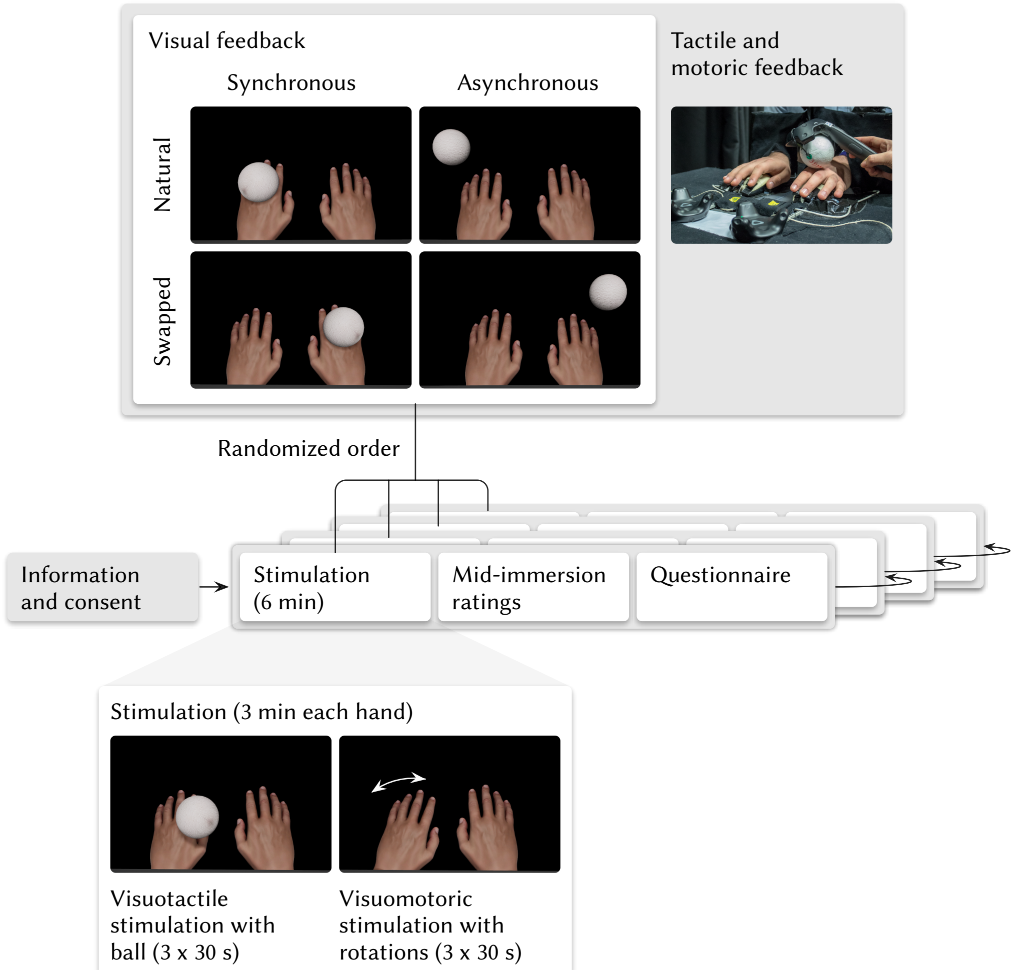


**Figure 6.1: Procedure and stimuli.** The experiment followed a repeated-measures $2 \times 2$ design. In each condition, participants received visuotactile and visuomotor stimulation. We stroked the hands of participants with a ball and rotated their hands. Participants saw a virtual representation of their hands and the ball. The virtual objects moved either synchronous or asynchronous to their real counterparts. Participants saw the virtual objects either in natural or in laterally swapped position. After the stimulation, we assessed virtual body ownership and agency.

hand of the participant with a styrofoam ball. The styrofoam ball had a diameter of 5 cm. A position sensor (HTC Vive Controller) tracked the position of the styrofoam ball. Participants looked through an immovable head-mounted display (HTC Vive Headset). The static field of view comprised both hands at a distance of 35 cm. An Intel i7 4.00 GHz, 16 GB RAM computer with an NVIDIA GeForce GTX 1080 Ti graphics card rendered stereoscopic images at 90 Hz. We implemented sensor data integration, visualization of the virtual environment, and response registration in the Epic Games Unreal Engine 4.17. We presented auditive stimuli with a headphone (Superlux HD330). Figure 6.2 illustrates the apparatus.

### 6.2.4 Stimuli

Participants saw virtual representations of their left and right hand. In the natural conditions, the virtual hands appeared in the same position as the real hands. In the swapped conditions, the virtual hands appeared mirrored in the mid-sagittal plane, which divides the left and right sides of the body. The virtual left hand appeared in the place of the real right hand and vice versa.

During visuotactile stimulation participants also saw a virtual representation of the styrofoam ball. In the natural conditions, the virtual styrofoam ball appeared in the same position as the real styrofoam ball. In the swapped conditions the virtual styrofoam ball appeared mirrored in the mid-sagittal plane.

In the synchronous conditions, the virtual styrofoam ball and hands moved synchronously to their real counterparts. In the asynchronous stimulation conditions, we delayed the movements of the virtual styrofoam ball and the virtual hand by 5 s. To neutralize noises of the tactile or motoric stimulation we presented Brownian auditive noise through the headphones at 50 dB during the visuotactile and visuomotor stimulation. A calibration measurement of the system showed that the delay in the synchronous conditions was below 40 ms. The threshold for detecting visuomotor delays is above 100 ms.[66,209,210] Figure 6.1 depicts the virtual stimuli.

### 6.2.5 Measures

In each condition, we assessed virtual body ownership and agency while participants still saw the virtual hands. We presented auditive one-item mid-immersion questions through the headphones. Participants answered the following questions out loud on a scale of 0 (*not at all*) to 10 (*totally*): "To what extent do you have the feeling as if the virtual body is your body?" (virtual body ownership, adapted from Kalckert and Ehrsson[101]) and "To what extent do you have the feeling that the virtual body moves just like you want it to as if it is obeying your will?" (agency, adapted from Kalckert and Ehrsson[101]).

In each condition, participants completed the questionnaire for virtual body ownership by Roth[189] after exposure to the virtual environment. This questionnaire accesses three subscales of embodiement: acceptance (covering the aspect of ownership perception), control (covering the aspect of agency perception), and change (covering the aspect of a perceived change in the own body scheme).[189] Items ranged on a Lickert-scale from 0 (*strongly disagree*) to 6 (*strongly agree*).

### 6.2.6 Statistical analysis

We used two-tailed paired $t$-tests to compare mid-immersion and questionnaire ratings. We compared ratings between the synchronous and asynchronous condition separately for both anatomical configurations. Furthermore, we compared ratings between both anatomical conditions for synchronous and asynchronous stimulation. To achieve a global alpha level of 5%, we Bonferroni-Holm adjusted the significance thresholds of the 20 tests for multiple comparisons. We report Cohen's $d$ as a measure of effect size. We used R 3.5.1[179] to analyze the data.

## 6.3 Results

We examined whether virtual body ownership can arise for anatomically implausibility body parts. Therefore we applied visuotactile and visuomotor stimulation on swapped hands. We manipulated the temporal synchrony of the stimulation. To check if the setup can induce virtual body ownership, we applied the same procedure on unswapped hands. Participants completed each condition in a balanced randomized order. We assessed virtual body ownership and agency at the end of each condition with mid-immersion items and a questionnaire. As no irregularities arose, we included the subjective ratings of all 56 participants in the repeated measures analysis. We applied Bonferroni-Holm adjustment to control for multiple comparisons.

In the swapped conditions participants reported significantly higher ratings if they received synchronous compared to asynchronous stimulation, except for change: they reported significant higher mid-immersion virtual body ownership ($t(55) = 3.88$, $p < .001$, $d = 0.52$), mid-immersion agency ($t(55) = 6.08$, $p < .001$, $d = 0.81$), acceptance ($t(55) = 4.79$, $p < .001$, $d = 0.64$), control ($t(55) = 5.99$, $p < .001$, $d = 0.80$), but they did not report significant differences for change ($t(55) = 2.00$, $p = .050$). In the natural conditions participants reported significantly higher ratings if they received synchronous compared to asynchronous stimulation, except for change: participants reported significant higher mid-immersion virtual body ownership ($t(55) = 12.42$, $p < .001$, $d = 1.66$), mid-immersion agency ($t(55) = 11.11$, $p < .001$, $d = 1.49$), acceptance ($t(55) = 10.79$, $p < .001$, $d = 1.44$), control ($t(55) = 14.03$, $p < .001$, $d = 1.87$), but they did not report significant differences for change ($t(55) = 2.31$, $p = .025$). Participants reported higher ratings in the natural compared to the swapped condition if they received synchronous stimulation, except for change: mid-immersion virtual body ownership ($t(55) = -10.03$, $p < .001$, $d = 1.34$), mid-immersion agency ($t(55) = -8.78$, $p < .001$, $d = 1.17$), acceptance ($t(55) = -8.82$, $p < .001$, $d = 1.18$), control ($t(55) = -10.29$, $p < .001$, $d = 1.38$), but they did not report significant differences for change ($t(55) = -1.25$, $p = .216$). If participants received asynchronous stimulation, they

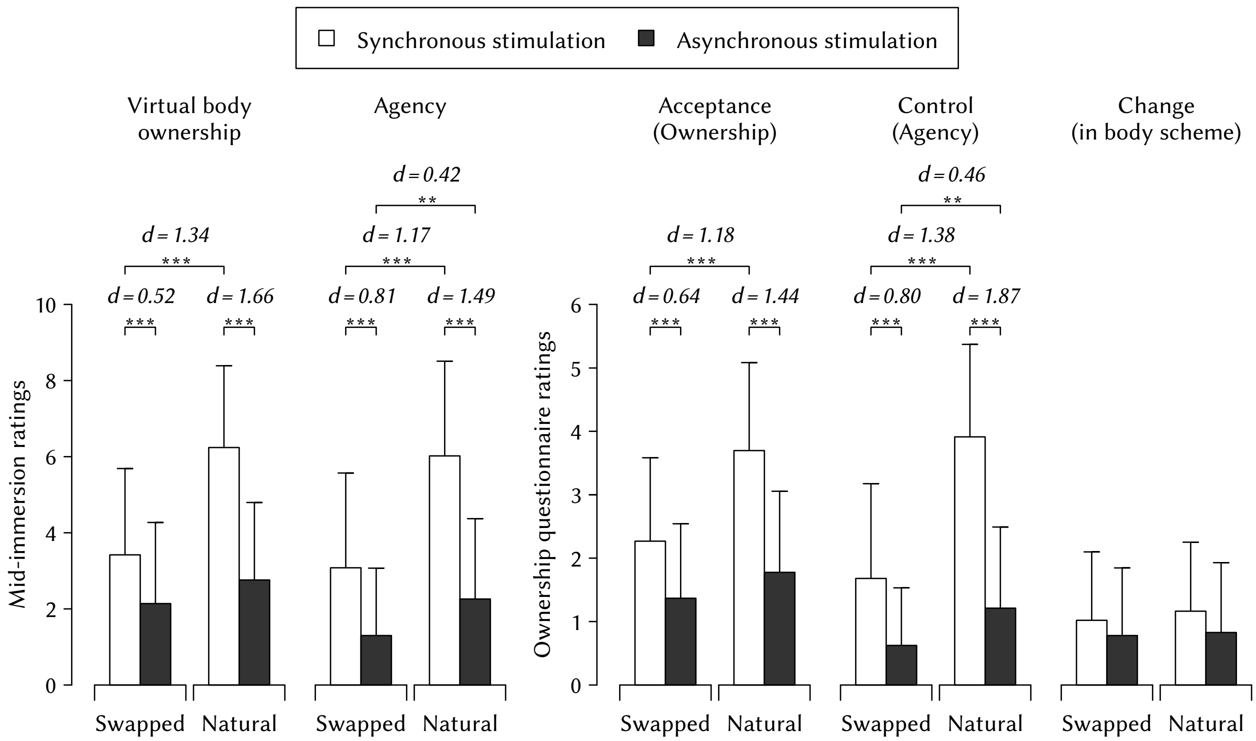


**Figure 6.3: Results.** Mean (+ SD) of mid-immersion and questionnaire ratings. The $p$-values indicate significant results of Bonferroni-Holm adjusted mean comparisons. Cohen's $d$ values indicate effect sizes. Mid-immersion ratings range from 0 (*not at all*) to 10 (*totally*). Questionnaire ratings range from 0 (*strongly disagree*) to 6 (*strongly agree*). Abbreviations: ***: $p < .001$, **: $p < .01$.

reported significant differences between the natural and the swapped conditions for mid-immersion agency ($t(55) = -3.15$, $p = .003$, $d = 0.42$) and control ($t(55) = -3.41$, $p = .001$, $d = 0.46$). If participants received asynchronous stimulation, they reported no significant differences between the natural and the swapped conditions for mid-immersion virtual body ownership ($t(55) = -2.35$, $p = .022$), acceptance ($t(55) = -2.35$, $p = 0.022$), and change ($t(55) = -0.34$, $p = .734$). Figure 6.3 depicts the mean comparisons.

## 6.4 Discussion

Previous studies suggest that virtual body ownership requires a virtual body with a plausible anatomy.[80,107,186,233] Virtual body ownership relies on the perceptual binding of conflicting sensations. Perceptual binding, however, can arise for implausible body configurations.[173] They induced a feeling of touch on one hand that happened on the other hand. Referred sensation describes a tactile sensation that was induced somewhere other than where it is felt.[196] Hence, we examined if referred sensations provide means to induce virtual body ownership of anatomically implausible body configurations.

We examined whether virtual body ownership can arise for swapped hands. Therefore, we conducted a repeated-measures $2 \times 2$ design with 56 undergraduate students. We manipulated the factors anatomical body configuration (swapped vs natural) and temporal synchrony of visuotactile and visuomotor stimulation (synchronous vs asynchronous). We compared the means of the different conditions. If participants saw swapped hands, they reported significantly higher virtual body ownership, agency, acceptance, and control in the synchronous compared to the asynchronous condition. Hence, we induced virtual body ownership of laterally swapped hands. Sensory misinformation can exchange the representation of a body part with another. We conclude that virtual body ownership can arise for anatomical implausible body configurations.

In the natural condition synchronous stimulation induced higher virtual body ownership, agency, acceptance, and control compared to asynchronous stimulation. Hence, the experimental setup provided the intended manipulation. If participants received synchronous stimulation, they reported significantly higher ratings in these scales in the natural condition compared to the swapped condition. Thus, anatomical plausibility serves as a factor that moderates virtual body ownership on a continuous scale. Nonetheless, virtual body ownership arose also for the anatomically implausible body configuration.

Riemer et al. [182] suggest that virtual body ownership requires a congruent mapping between virtual and real body parts. We applied congruent stimulation for laterally mirrored visual stimuli. Our results show that congruence comprises the stimulation in a laterally mirrored body.

For all conditions, participants reported no differences in change. Change measures the perceived shape transformation of the body. Hence participants perceived the form and appearance of their body as stable. This result reflects the design of the experiment. The virtual hands appeared colocated to the real hands with the same size.

### 6.4.1 Limitations

The definition of anatomic implausibilty in our study is informal. Scaling[106,132] and translation[23] of a body also provide some degree of anatomic implausibility. In line with previous studies,[80,233] we, however, assume that laterally mirroring provides a transformation with a high degree of anatomic implausibility. Replacing hand representations requires neglecting anatomic reasoning. Virtual body ownership can arise for additional body parts.[80,91,197] Such configurations also provide a high degree of anatomic implausibility. They, however, do not require altering existing representations of the own body. Virtual body ownership can arise for a hand that is connected to a twisted arm.[171] The hand, however, has an anatomically plausible position. Future studies need to define a taxonomy for body modifications to explore the boundaries of body ownership.

Perceptual adaption provides an alternative explanation of our results. People adapt motoric actions if the world appears left-right inverted.[83,223] The adaption process, however, requires a few days until people can move around and two weeks until the new visual world appears normal to them (see O'Regan and Noë[168] for a review). In our study, participants experienced the inversed environment twice for 7 min. Hence, we assume that such an adaption process plays a minor role here. Future studies might control for perceptual adaption by swapping only specific parts of the body or environment.

### 6.4.2 Conclusion

We show that virtual body ownership can arise for swapped body parts. Our results extend previous findings that demonstrate the flexibility of body representations. This finding suggests that the credibility of visual information largely depends on its synchronicity to movement and touch. Semantic constraints might play a minor role for Body Ownership. We showed that within minutes people question assumptions about the anatomy of their body. They experienced virtual body ownership of swapped hands, an anatomically impossible configuration. Thus, multisensory manipulations can change the basic assumptions about one's own body. This finding extends the design space for future user-embodying interfaces in psychotherapy, training, and entertainment.

#### Acknowledgments

Daniel Roth contributed to the design of the experiment. Julian Zarges contributed to the creation of the apparatus and stimuli. Julian Zarges and Maria Ternes collected the data. Jan-Philipp Staufert provided technical support. Gotoxy AV-Media GbR, Nuremberg, Germany, provided the virtual hand stimulus.

#### Data and code availability

Data and code for all analyses are available at https://osf.io/qe3j9/.

**Summary**

*What was the research question?*
How changeable is the perception of one's own body?

*What was already known about this topic?*
Virtual body ownership can arise for translated or scaled virtual bodies. Virtual body ownership, however, requires anatomical plausibility.

*What did this study add to our knowledge?*
Virtual body ownership can arise for a virtual body with laterally swapped hands. Hence, anatomical plausibility is not required for virtual body ownership. Semantic constraints might play a minor role for virtual body ownership.

*Why are these findings important?*
Interactive systems induce multisensory manipulations that can change the perception of one's body beyond anatomical plausibility. This flexibility in self-perception can serve clinical applications that modify body-environment interactions.

# Chapter 7

# Self-organizing knowledge management might improve the quality of person-centered dementia care

**Abstract**

In institutional dementia care, person-centered care improves care processes and the quality of life of residents. However, communication gaps impede the implementation of person-centered care in favor of routinized care. We evaluated whether self-organizing knowledge management reduces communication gaps and improves the quality of person-centered dementia care. We implemented a self-organizing knowledge management system. Eight significant others of residents with severe dementia and six professional caregivers used a mobile application for six months. We conducted qualitative interviews and focus groups afterward. Participants reported that the system increased the quality of person-centered care, reduced communication gaps, increased the task satisfaction of caregivers and the wellbeing of significant others. Based on our findings, we develop the following hypotheses: Self-organizing knowledge management might provide a promising tool to improve the quality of person-centered care. It might reduce communication barriers that impede person-centered care. It might allow transferring content-maintaining tasks from caregivers to significant others. Such distribution of tasks, in turn, might be beneficial for both parties. Furthermore, shared knowledge about situational features might guide person-centered interventions.

## 7.1 Introduction

People with dementia have a lower quality of life if they live in care homes, compared to living at home.[133] Residents of care homes have a substantial need for psychosocial support.[250] The standard of delivering this support shifted from standardized health care to person-centered care.[118,254] Person-centered care prioritizes the quality of life of residents.[118,254] However, the implementation of person-centered care is stagnant.[58] Communication gaps inhibit person-centered care.[115] We propose to use self-organizing knowledge management to fill these gaps.

### 7.1.1 Person-centered care

Person-centered care emphasizes individual needs of residents to maximize self-determination and well-being.[118,152] Person-centered care improves the care processes and the quality of life of residents.[155,157,253] Health-care professionals understand person-centered care as the most desirable approach to provide psychosocial support.[114,250] Person-centered care realizes commonly accepted humanitarian and ethical values.[57] Despite its broad theoretical acceptance, the implementation of person-centered care is often impeded, in favor of routinized care.[133] Such non-individualized processes impede relationships between residents and caregivers.[77,153]

### 7.1.2 Hurdles of person-centered care

Profit maximization in care institutions reduces administrative support for person-centered care.[129] Limited salary and training constrain the ability of staff to provide person-centered care.[254] Low-cost policies lead to a decrease in staff numbers, high annual turnover, and burnout rates in care staff.[248] They impede the development of attitudes, stable relationships among staff and residents, and work methods that are vital for person-centered care.[166] Economization of care furthermore fosters a fragmentation of care professions[35] and institutions.[38] This fragmentation limits the responsibility for person-centered care to a small group.[59] However, person-centered care includes the entire social environment of the residents. Cost cuts restrict communication between staff and residents, which often consists only of instructions.[133]

Communication barriers are the main factors impeding person-centered care.[115] Fragmentation of care professions obstructs information transfer. Empathically answering to needs of residents requires knowledge about their history, preferences, routines, and behavioral patterns.[115] Facility-wide communication of this knowledge is critical for person-centered care.[115] However, this information exchange often does not take place.[115] Knowledge transfer lacks openness, accuracy, timeliness, and systematics.[115,203] Existing documentation systems lack information required for person-centered care.[31,94] Accessible information is often out-dated and too time-consuming to read.[115] Word of mouth techniques often lack consistency, accuracy, and do not propagate across different professions.[115]

### 7.1.3 Distributed cognition

The theory of distributed cognition[89] can provide a model for reducing the communication gap in person-centered care. Knowledge of the preferences, needs, and personality of the person with dementia can facilitate person-centered care. Due to the fragmentation of care, this knowledge, however, is often distributed in small pieces among different caregivers.[115] Therefore, it is often difficult for caregivers to obtain personal information about the resident in time. Also, knowledge of supportive ways to communicate with the person with dementia can change rapidly over time as their condition evolves. A task that relies on information that is distributed in small pieces among individuals and that changes dynamically over time can be formulated as a distributed cognition task.[89] Thus, strategies for solving a distributed cognitive task might provide help to reduce communication gaps in person-centered care. In other domains, computer-mediated communication proved to be a successful means of supporting distributed cognitive tasks (e.g.,[102]). Notably, self-organizing knowledge management systems can support such distributed cognition tasks.[96] Self-organizing knowledge management systems foster the emergence of shared knowledge and the exchange of knowledge between users. All users cooperate and participate by adding and modifying information. In this way, the system collects distributed information and enables all users to use this information. In our case, users could use shared knowledge to engage in personal and supportive interactions with the person with dementia. In this study, we evaluate how self-organizing knowledge management systems can facilitate person-centered dementia care.

### 7.1.4 Information technology in person-centered care

Information technology can support different aspects of dementia care.[117,127] Martins et al.[148], for example, used Facebook to exchange information among caregivers and significant others. Foong et al.[65] used information technology to facilitate communication between volunteer caregivers. However, existing technologies are not primarily designed to promote meaningful personal relationships between residents and caregivers. Also, systems to date do not address the identified hurdles of person-centered care.

### 7.1.5 Research question

We explored how self-organizing knowledge management affects the quality of person-centered care. We analyzed the potential and limitations of a collaborative communication system in a 6-month field study. After the test period, we conducted in-depth and focus-group interviews. We used the results to develop hypotheses and perspectives for interventions that might improve the quality of person-centered dementia care.

## 7.2 Method

### 7.2.1 Terminology

The study took place in institutional dementia care homes. We, therefore, use the term *caregiver* for formal, professional caregivers who are employees of the care homes and provide care services to the persons with dementia. We use the term *significant other* for people who are close to the respective person with dementia (children or grandchildren, spouse, and other relatives or friends).

### 7.2.2 Participants

We conducted the study in two german institutions for people with severe dementia. We recruited significant others of residents with severe dementia on facility-wide information events. Eight residents, eight significant others, and six caregivers participated in the study. All residents had severe dementia. We combined proxy and process consent. We obtained proxy informed consent from legal representatives of all participating residents. To maximize the ability of residents to participate in the decision of research participation, however, we additionally followed the model of process consent[52]: Before participation, significant others decided if participation reflected the values and preferences of the resident and if he/she would enjoy participating in the study. Caregivers and significant others then informed residents of their potential participation in the study in a manner appropriate to their abilities and looked for signs of assent or non-objection. Caregivers and significant others assessed and verified ongoing consent throughout the study: they continuously looked for signs of refusal to participate in the study and, if identifiable, ended participation. Caregivers and significant others shared information relevant to the well-being of the residents with each other. The institutional ethics committee approved the study.

### 7.2.3 Intervention

CareShare is a collaborative communication system. The cloud-based application provides browser interfaces for mobile devices. CareShare aims to facilitate positive interactions between residents and caregivers. It dynamically provides personal information in a systematic and timely manner. It fosters self-organization among professional caregivers and significant others. The code is available as supplementary material.

#### Fictional usage scenario

In the evening, the resident John wanders around anxiously and restlessly. The caregiver Susi knows the family of the resident well. She tries to reassure John by talking to him about his beloved son. In the conversation, Susi tells John that the son is doing fine with the family business and that he already paid off all debts, there is no need to worry about that. This information brightens John up, and he calms down. In order to communicate John's reaction with her colleagues, Susi opens CareShare on her mobile device and creates a situation card for John (Figure 7.1). She describes the initial situation: "John wanders around in the evening. He seems anxious and restless." Susi then adds heart openers to the situation card. The heart openers communicate the topics that helped John to connect to Susi: "I love my son." and "I need to know I paid off my debts." She uses the messaging function to ask John's family to add

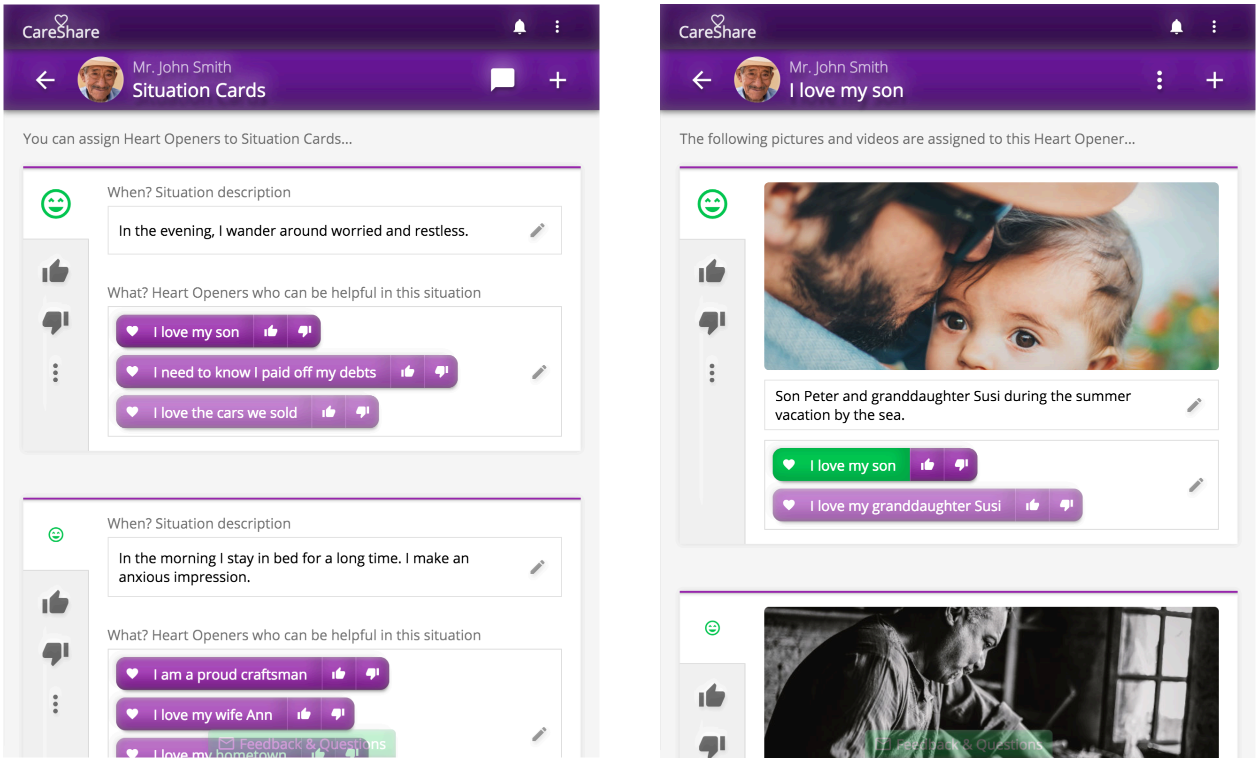


**Figure 7.1: Screenshots of CareShare.** A resident profile contains ordered situation cards (left). Situation cards link to heart openers. Heart openers contain ordered and annotated media files (right). Media files link to associated heart openers. Users can swap the position of situation cards, heart openers, and media files with their neighbors by touching the thumb up or down buttons. Users can edit content by touching the adjacent pencil button. Sample photos by Stephen Lustig, Ferenc Horvath, and Bobby Rodriguezz on Unsplash.

pictures to these heart openers. The next day, family members add pictures to the new heart openers: pictures of John's son and grandchildren, and pictures from the well-working family business. They use the annotation function to describe what the pictures show and add relevant information from John's past. The other evening John again seems anxious and restless. Sam, a new caregiver, who does not know John, opens Susi's situation card in CareShare. He succeeds in engaging John in a warm conversation about John's family business. The proud and happy John tells stories about his business while they both discover the pictures and annotations in CareShare.

### Knowledge retrieval

Person-centered care emerges from situation-specific individualized micro interventions.[14] The impact of such supportive interventions depends on their fit to the situation.[8] The data structure of CareShare aims to link situations to matching conversational topics that can guide supportive interventions. CareShare organizes information in an ordered tree structure (see Figure 7.2). When opening CareShare, authorized users access an individualized list of residents. Each resident profile comprises a list of situation cards and a group chat for associated caregivers and significant others (see Figure 7.1). The order of situation cards encodes their relevance for previous users. Situation cards have a textual description that summarizes observable cues of situations that benefit from person-centered micro-interventions.

Situation cards link to so-called heart openers. Heart openers provide conversational topics for individualized micro-interventions. Supportive micro-interventions increase the well-being of residents and decrease time pressure and job dissatisfaction among staff members.[14] Heart openers label emotional topics that are significant to the resident. These topics guide and enrich communication with residents. In this way, heart openers aim to foster personalized, meaningful interaction. The phrasing of

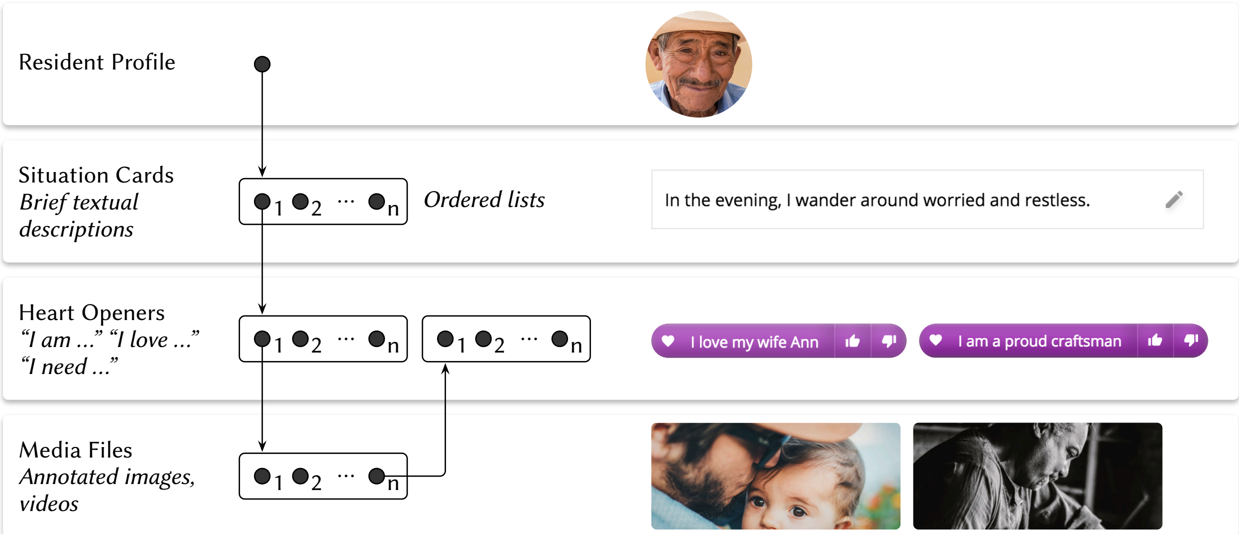


**Figure 7.2: Data structure of CareShare.** Resident profiles link to an ordered list of situation cards. Each situation card links to an ordered list of heart openers. Each heart opener links to an ordered list of annotated media files. Each media file links to an ordered list of heart openers. Users edit content and modify the ordering in each list. Sample photos by Stephen Lustig, Ferenc Horvath, and Bobby Rodriguezz on Unsplash.

heart openers is restricted to three predefined beginnings: "I am . . . " for themes that stabilize a positive sense of the person's own identity; "I love . . . " to indicate relationships and preference; "I need . . . " to express needs and motives. This restriction ensures that heart openers reflect topics of identity, relationships, and needs: central values of humanistic therapies. The order of heart openers within a situation card encodes their prior effectiveness in the situation.

Each heart opener links to media files: images, videos, music, or texts. These media files facilitate communication about the heart opener and inspire engaging interactions. Annotations provide context information for the files. The order of media files within a heart opener encodes their prior effectiveness. Additionally, each file links to heart openers that are relevant to the file. This listing allows the user to access further heart openers that are associated with the corresponding media file. The order of this list of heart openers encodes their significance to the file.

### Knowledge creation

The system aims to foster the emergence of knowledge through collaboration. Users can freely edit, create, and enrich content entities. Self-organizing systems require interpretations not to be comprehensive, complete, or precise to allow dynamic emergence over time.[21] The system distributes tasks to specialized individuals. Staff members integrate outcome information of interventions. Significant others enrich this information with personal material. Such collaboration improves the quality of the content.[74]

Sharing outcome information about interventions improves the quality of person-centered care.[14] Users incorporate feedback about the effectiveness of content. Self-organization is highly feedback-driven.[74] Users linearly sort the content of situation cards, heart openers, and files by relevance. Users perform sorting by swapping adjacent items. This bubble-sort approach requires a low cognitive load. Users can anticipate the effect of each sorting action.

### Knowledge transfer

The system facilitates the flow of information and mutual awareness. These processes foster self-organization.[21] The system displays information in a compressed and concise form. Previous effectiveness determines the order of content. The system informs users about actions with an email notification system. For each resident profile, authorized users manage the access of other users of the resident information. The system allows for instant messaging between users.

### 7.2.4 Procedure

Professional caregivers and significant others used CareShare for six months. They freely chose how and when to use the system. Caregivers received tablet computers to access CareShare. We provided technical support.

### 7.2.5 Data collection

We conducted semi-structured in-depth telephone interviews after the six-month intervention period. The telephone interviews took between 30 and 60 min. Subsequently, we conducted semistructured focus groups[159] in each facility. The focus groups included all participating significant others and professional caregivers. Group interviews encourage participation from people who are reluctant to be interviewed or feel they have nothing to say.[111] We aimed at identifying the effectiveness and costs of the intervention.

### 7.2.6 Analysis

We audio-recorded and transcribed all interviews and focus groups. We anonymized transcripts and checked them for accuracy. We used thematic analysis[175] to identify themes inductively.

## 7.3 Results

### 7.3.1 Person centeredness

Caregivers and significant others reported that CareShare increased personal communication with residents. Caregivers perceived an increase in the well-being of the residents after using CareShare.

> "I heard your mother talking a lot more after I used CareShare with her. That was really amazing. There is a chain reaction [...] she became very eloquent again, which she usually is not."

Caregivers and significant others reported that interaction often became more emotionally engaging.

> "My mother comes out from behind her curtain. You don't notice anything of the dementia anymore; she comes out completely."

Caregivers reported that CareShare promoted relationship building. The information model facilitated personal communication. Heart openers helped elicit positive emotions.

> "With heart openers we are very close to the people. Since the relatives are directly giving us the information, the patients react a lot more to what we say."

Caregivers expressed that the individualized information proved helpful.

> "CareShare helps me relate to a significant part of the resident's life that we would not know and have not experienced."

They indicated the importance of situated personal information for connecting to residents. Caregivers reported that CareShare helped provide a more comprehensive picture of the resident's personality.

> "[One part of the personality] is not accessible. And with the heart opener, we get access to this hidden part. And that is person centering that I do not reduce people to their shortcomings and illness, but that I see them as wholes."

Caregivers and significant others reported that residents responded positively to the system.

> "She said 'I want one [tablet] like this, then I can always look at it.' Because it reflects her memory [...] that she otherwise finds hard to get hold of."

### 7.3.2 Bridging the communication gap

Caregivers and significant others indicated that CareShare helped them foster cooperation. They pursued a common goal that directly affected the well-being of residents.

> "CareShare enables a role change of relatives and employees: doing things together makes an incredible difference for the quality of the relationship."

Caregivers indicated that the quality of accessible information increased. Significant others put deliberate effort into creating high-quality content.

> "I think distance creates closeness: with a little distance, completely different associations are awakened at home, different ideas are developed."

Significant others developed more trust in caregivers.

> "There is a great deal of turnover. Employees come and go. They don't really know my mother. On admission, we were also asked about my mother's biography. But that was just done once and never updated again. That's why I find CareShare's ability to update or add new information very important."

### 7.3.3 Task satisfaction

Caregivers reported that CareShare increased self-efficacy and reduced helplessness.

> "From the information, we could derive very clear instructions to act, which was quite easy to implement. It was also very nice to see that relatives had quite concrete ideas. That was really good for the residents."

> "It compensates the experienced helplessness. [...] You are on the same level because you look at things together and open up to them."

Caregivers reported that CareShare helped them in building a relationship with the residents.

> "CareShare helped gain the trust of the patients; I was very close to them. [...] I got to know some people a lot better because of CareShare."

Caretakers expressed that CareShare reduces perceived task pressure. A larger group shared the responsibility for the content.

> "Someone else is responsible for the content. That makes it easier for me as an employee. It takes away a lot of pressure."

CareShare helped new employees get acquainted with residents.

> "With CareShare, we have a tool in our hands that helps us train new employees."

### 7.3.4 Well-being of significant others

Significant others indicated that with CareShare they were an active part of the care process.

> "CareShare enables me to actively take part in the treatment. [...] This is a lot different from what I could do during a normal meeting with the caretaking staff."

Significant others reported that CareShare strengthened their subjective feeling of connection with the residents. The significant others expressed that they integrate the care process into their everyday life, even if they live far away.

> "Care Share is like a treasure chest for me. This makes it easier for me to interact with my mother. [...] That was the first time that I really thought about her [...] that was really cool, that I could help her like that."

Significant others expressed more confidence that the residents are treated well.

> "It is very positive to know that there are nurses who can deal with my mother's topics. Because they have an excellent tool in hand which stores personal information."

### 7.3.5 Criticism

Participants stress that access to information is not sufficient to guide interaction. A Caregiver reported that knowledge can lead to mistrust in the residents:

> "The other side, however, is that we communicate behind the back of the resident. [...] The patient then asks 'How do they know that?' In the beginning, there is a certain mistrust. [...] At the moment I get all the information at my disposal, but how can I use it concretely and let it flow in?"

Participants expressed the concern that emotional activation could also induce restlessness:

> "Talking to my father about these times almost caused nervousness because of his still existing curiosity, liveliness and restlessness. He wanted to go and play tennis, for example, as he had seen in the photos."

Caregivers and significant others underlined the need for a notification system. They suggested a notification system that communicates with the software they use in their daily routine.

> "I see the problem in the fact that the system must be operated actively in everyday life."

System uptake required training and information.

> "And at first it was too stupid for me because I didn't know what to do. But then I understood it and was able to incorporate what I wanted to say."

Significant others and Caregivers were concerned about data privacy and access management. Participants asked for a compromise between restricted access and flexibility.

> "For me it is very important that I know exactly who gets the information and who has access."

## 7.4 Discussion

The goal of this field study was to develop hypotheses on how to facilitate person-centered care in dementia care homes. We observed the use of a self-organizing knowledge-management system intended to fill communication gaps that might impede person-centered care.[115] We designed the system to enhance positive interactions between residents and professional caregivers and to facilitate cooperation between professional caregivers and significant others.

### 7.4.1 Main findings

Caregivers and significant others reported that CareShare facilitated personal communication and helped to engage in conversation with residents emotionally. Such communication, in turn, promoted relationship building. Caregivers reported that the application helped to provide a more comprehensive picture of the resident's personality. These reports are in line with the assumption that empathically responding to the needs of residents requires knowledge about their personal lives.[115] Our reports strengthen the hypothesis that such knowledge facilitates person-centered care. Scaffolding describes the provision structure, guidance, and encouragement in person-centered care.[5] A requirement for scaffolding is joint attention between the communication partners and a joint decision-making process.[5] Our results support the hypothesis that self-organizing knowledge-management can provide means to facilitate scaffolding during communication.

Caregivers and significant others also reported that CareShare helped to foster cooperation and increased mutual trust among themselves. These reports support the hypothesis that the quality of facility-wide communication and the openness and accuracy of available information is a critical requirement for institutional person-centered care.[115,203] The reports are in line with the assumption that person-centered care is a distributed cognition task that benefits from dynamic systems to facilitate coordination among group members.[89]

Caregivers reported that CareShare increased staff self-efficacy and reduced helplessness when interacting with residents. Significant others reported that CareShare increased their felt connectedness with the residents and their confidence that the residents are treated well.

Participants, however, also reported challenges in the usage of information technology in person-centered care. Emotion activation, in some cases, could lead to restlessness in residents, and knowledge about their personal lives lead to mistrust. System uptake furthermore required training and information. Participants also underlined the importance of data security when handling the data of residents.

### 7.4.2 Possible implications for practice

**The distributed cognition perspective might provide a means of reducing hurdles in person-centered care**

Critical knowledge for person-centered care is often not available for caregivers.[115] It is distributed over different significant others and caregivers. Hence person-centered care poses a distributed cognition problem.[89] Traditional documentation techniques do not solve this distributed cognition problem.[115] Based on our results, we hypothesis that self-organizing knowledge management is effective when applied in person-centered care. We propose to further investigate in decentralizing information organization in dementia care homes. Caregivers and significant others can contribute in their specific domain of expertise. We propose encouraging contributions in small increments. We assume that the knowledge base needs to allow permanent modifications to reflect changing conditions. To date, traditional centralized means mainly remain static or costly to change.

**Transfering content-maintaining tasks from caregivers to significant others might be beneficial for both**

Self-organizing systems can transfer tasks from caregivers to significant others. These tasks include creating, updating, and ordering information. This transition decreases the workload of caregivers. It integrates significant others in the care process. Our results support the hypothesis that this integration increases the well-being of significant others and their sense of connectedness to the resident. Mutual trust and reciprocity seem to constitute critical requirements for collaboration among significant others and caregivers.[6] Based on our results, we hypothesis that collaborative efforts of caregivers and significant others can improve the quality of a shared knowledge base. We assume that a high-quality knowledge base, in turn, facilitates person-centered care. This assumption is in line with the observation that communication between significant others and staff facilitates care that honors the unique perspectives, values, and needs of each resident.[20] We observed that providing tools for collaboration can be beneficial for caregivers, significant others, and residents.

**Situational features might guide person-centered interventions**

Caregivers require information on a timely basis. During an interaction, caregivers have limited time to search and filter information. Hence, information has to match the current needs of the residents. These needs relate to objective situational factors as well as to the emotional state of the resident. Based on our results, we hypothesis that proving information about current needs is feasible with a minimalistic data structure: situational features link to emotional themes. Such data can encode collective, previous experiences and can dynamically accumulate experiences of caregivers and significant others. To date, traditional documentation systems do not provide such information.

### 7.4.3 Limitations

Participants volunteered to share their experiences. Opinions of the self-selected sample do not necessarily generalize to other significant others or caregivers. The sample may overrepresent a population for which collaboration among significant others and caregivers is a priority. Nevertheless, the acceptance of our approach in this limited sample motivates the study of the broader transferability of the hypotheses generated.

We conducted interviews after the 6-month intervention period. We did not collect immediate feedback during the intervention. Feedback thus could be subject to positivity bias: participants may have favored positive over negatives memories. Participants also might have attributed events to the intervention by coincidence. However, long-term commitment is crucial for the success of an intervention. We assume that our results reflect critical long-term effects.

We did not compare outcomes between different approaches. However, our results strengthen the hypothesis that self-organizing knowledge management qualifies to improve the quality of person-centered care. Comparative designs need to test this hypothesis.

### 7.4.4 Conclusion

Based on our findings, we hypothesis that self-organizing knowledge management presents an opportunity for reducing communication gaps in dementia care homes. Ekman et al.[58] propose routines that initiate, integrate, and safeguard person-centered care in daily clinical practice. “The registration of residents’ preferences, beliefs, and values must be considered equally mandatory as clinical and lab findings.”[58] We hypothesis that self-organizing knowledge management systems such as CareShare can assist in facilitating person-centered care. Such systems might assist in reducing the communication gaps in care settings, to increase the task satisfaction of staff, and the wellbeing of significant others. Based on our results, we hypothesis that such knowledge organization improves the quality of person-centered care. We hypothesis that self-organizing knowledge management systems provide the means to individualize dementia care in a context of increasing fragmentation and economization of care.

**Acknowledgments**

Andrea Jandt along with employees of St. Marienhaus Freiburg and Birgit Amelung along with employees of Seniorendienste Bad Wimpfen integrated the application into their workflows. They supported the field study. Birgit Amelung provided conceptual advice. She invented the heart openers. Beate Radzey from Dementia Support Stuttgart provided conceptual and coordinative support. Jan Preßler helped conduct the interviews and evaluate the data. Jan Preßler and Jörn Hurtienne reviewed the manuscript.

### Publication

This chapter is published in the *International Journal of Medical Informatics*.[73]

**Summary**

*What was the research question?*
How can information technology improve the quality of person-centered dementia care?

*What was already known about this topic?*
Communication gaps impede the implementation of person-centered care in favor of routinized care. Self-organizing knowledge management can facilitate information flow.

*What did this study add to our knowledge?*
Self-organizing knowledge management provides a promising tool to improve the quality of person-centered care. It can reduce communication barriers that impede person-centered care. Transferring content-maintaining tasks from caregivers to relatives is beneficial for both parties. Shared knowledge about situational features facilitates person-centered interventions.

*Why are these findings important?*
Computer-supported communication flow can increase the effectiveness of clinical interventions.

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