A Presence Measure for Virtual Reality and Telepresence Based on Multimodal Conflicts

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Abstract

A measure to rate the quality of individual presence for VR and telepresence systems is introduced based on the perception of bimodal information. Experiments were conducted with a visual-haptic human system interface driven by a virtual reality to validate the new presence measure. The quantitative results were obtained by magnitude estimation of the conflict perceived. It was shown that the new measure could be used as a reliable indicator of how presence is affected by bimodal conflicts.

Keywords--- **Presence definition, presence measurement, visual-haptic telepresence, psychophysics**.

1. Introduction

Presence systems allow humans to operate in target environments in principally two ways. Firstly, virtual reality (VR) systems allow human operators to immerse in an artificially generated environment. Secondly, telepresence systems allow human operators to immerse in a somehow impenetrable, but real environment. See Figure 1 for an illustration.

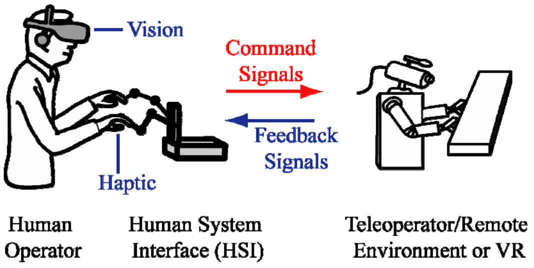

Figure 1. Multimodal presence system: A virtual or remote environment is mediated to a human operator via technological equipment.

In both systems the goal is to generate a high degree of presence. Hence, the assessment of presence within VR and telepresence systems has been an issue since the beginning of presence research. Different theories and descriptions of presence have been developed. Operationalization to measure presence has led to different propositions but only to few implementations. However, effective presence measures are desirable, e.g. for engineers that need mathematical guidelines for designing VR and telepresence applications.

1.1 Presence: Concepts, Factors, and Measurement

Minsky is usually acknowledged as the beginner of conceptual research on presence stating that the operator must be able "to perform normal human functions" and on the same time "receives sufficient quantity and quality of sensory feedback to provide a feeling of actual presence at the work side" (cited in [1]). Subsequently, different concepts of presence based on different philosophies were elaborated. However, no unified theory of presence could be established by now. In the following, the main concepts are introduced.

First refinements of Minsky's concept were conducted by dividing presence into two different forms: Subjective presence can be mentally experienced by the human operator individually and objective presence states the physical effectiveness of an operator in a target environment [2-5]. Criticizing this dualistic Cartesian view several authors developed concepts of presence based on the philosophy of Heidegger and the perceptual theory of Gibson [6-11]. Both linked perception closely to everyday interaction within an environment. Thereupon, Zahoric and Jenison defined presence as "tantamount to successfully supported action in the environment" [6]. Mantovani and Riva extended this ecological definition by a sociocultural dimension emphasizing that "presence is always mediated by both physical and conceptual tools that belong to a given culture" [8]. Also rejecting the Cartesian view Biocca identified presence as a subset of the mind-body problem [11]. To solve the questions 'What is body?" and "What is environment?" matches the key problem of presence research, especially since it is known that the boundaries between body and technology can vary in human's consciousness [12, 13]. Recent conceptual publications try to answer the functional task of presence within the cognitive system. Slater conceived presence as "the selection mechanism that organizes the stream of sensory data into an environmental gestalt or perceptual hypothesis about the current environment" [14]. Additionally, Lee remarked that humans are willingly to accept incoming stimuli in order to react effectively rather than accurately [15]. Floridi calls this concept "Successful Observation" and developed an abstract concept of remote presence to tackle the problems of VR and telepresence to the point avoiding confusion with presence emerging from watching television or reading books [16].

Presence is determined by different factors which vary depending on the theoretical concept. Sheridan assumed the quality and extent of sensory information fed back to the operator as well as exploration and manipulation capabilities as crucial for the subjective feeling of presence [3]. Steuer named vividness (ability to technologically display sensory rich environments) and interactivity (degree to which users can influence the target environment) as the fundamental components of presence [17]. Slater defined external factors (technology related) and internal factors (perception related) to successfully generate presence. Witmer and Singer proposed a four-factor categorization consisting of control-, sensory-, distraction- , and realism factors [18]. Lombard and Ditton additionally named the willingness to suspend disbelief and prior experience of the operator as well as the form of the target reality as influencing factors of presence [19].

Despite the extensive list of factors determining presence, no unified approach to measure presence has been developed. Operationalizations of different presence factors are numerous and range from physiological (e.g. heart rate), performance (e.g. task completion time), ratings (e.g. presence questionnaires) to psychophysical measures and measures based on physical quantities: Lawrence proposed to compare the dynamical characteristics of the displayed environment to the target environment to analyse the quality of presence systems for mechanical environments [20]. Similarly, Yokokohji defined the equality of position and force on both sides as 'ideal response' to quantify haptic telepresence [21]. Sheridan proposed three different measures for multimodal presence. Reflexive responses to external stimuli, rating experiments dealing with several factors, and discrimination between real vs. artificial should quantify the realism of the environmental representation [3]. Presence questionnaires to assess the degree of immersion and involvement in the target environment are proposed by different authors [4, 18]. Measures based on task performance are proposed by Schloerb in [5]. Mantovani and Riva refused to measure presence by comparison between real and artificial environment but proposed to measure the realism of the user interaction with the human system interface instead [8]. IJsselsteijn et al. introduced different objective measures: measures based on postural and physiological responses of the human operator and dual task measures based on a distractive cognitive load [22]. Physiological measures are also proposed in [23].

Experimental studies that quantify the perceived presence predominantly use presence questionnaires and are constraint to one modality. Only few studies analyzed the perception of multimodal feedback with respect to the presence generated. Visual presence is analyzed e.g. in [4, 24, 25, 26, 23]. Visual-haptic presence is analyzed e.g. in [27].

1.2 Hypotheses

The main contribution of this article is a new presence measure based on the assessment of multimodal conflicts. The measure is evaluated in relation to a question of a presence questionnaire taken from [18]. The new measure is set up theoretically and evaluated experimentally. In the experimental part we assessed the perception of conflicting multimodal information. Two hypotheses were tested.

- Hypothesis 1: Conflict is expected to be rated higher the more the conflict increases. On the same time presence ratings are expected to be rated lower by both measures.
- Hypothesis 2: Both measures are influenced by the reference modality.

Deterioration of displayed redundant information is expected to result in an overall decrease of the participants' rating of presence. However, because resolution of human perception is known to be restricted, small conflicts of redundant information remain undetected: It is therefore expected, that conflicting redundant information below the just noticeable difference (JND) will not affect presence rating, but above the JND will result in a decrease (Hypothesis 1). Additionally, an increase of the bimodal conflict should not only be perceivable by the human operator, but also result in an increased sensation of conflict above and should not be altered below the detection threshold. Influence of the modality in which no variation occurs (further referred to as reference modality) was also expected: Differences should be easier perceivable with visual variations, therefore, presence ratings should be lower as well as conflict ratings should be higher when the haptic modality remains unaltered and the visual modality varies (Hypotheses 2). Moreover, conflict rating directly addresses the question of perceived intermodal conflict, whereas presence rating should concentrates on a broader concept of quality of the display.

The article is organized as follows: In Section 2 the presence measure is introduced and its implications for virtual reality and telepresence systems are explained theoretically. In Section 3 a visual-haptic VR is described that is used for the experimental evaluation described in Section 4. In Section 5 presence generated by the VR system is evaluated based on the results of the experiment and the new presence measure. Conclusions are provided in Section 6.

2. Presence by Assessment of Multimodal Conflicts

2.1 Presence and Multimodal Conflicts

The presence definition used throughout this article is taken from [11]. It defines presence in a generally accepted way. Individual presence means "*the phenomenal state by which an individual feels located and active in an environ-*

ment, and, especially in the case of telepresence, the class of experience where the environment is mediated by a technology".

The presence measure introduced in this publication operationalizes the factor 'consistence of multimodal information fed back to the human operator and displayed by the human system interface'. Several authors (e.g. [3, 4, 8]) emphasized the importance of this factor. The measure is based on the assessment of multimodal perceptual conflicts. A *perceptual conflict* is a perceivable difference between realistic information about an environmental state sourcing from two sensors of different modalities (redundant information). Hence, the operators' perceptual system is not able to generate a realistic, coherent estimate about the environmental property by the obtained information [28]. However, a conflict has to be larger than a certain threshold before it can be detected. Below this threshold conflicting information is fused consistently (see [29] for an example).

Hence, the proposed measure takes into account both, the quality of the VR system and the perceptual properties of the human operator.

2.2 Definition of the Presence Measure

Since perception of the conflict depends on its size, we define the ideal display of consistent information as follows:

Def: Ideal Display of Consistent Information
Redundant information about an environmental property is displayed consistently, if and only if the operator can integrate the sensed information to a coherent percept.

According to this definition the operator will perceive a conflict if redundant information is not integrated. The smallest conflict that can be detected is called threshold or just noticeable difference (JND) in psychophysics. As stated in H2 we hypothesize that perception of presence decreases with increasing conflict. Hence, the presence measure can be formulated by

$$P(c) = 1 - f(c), \tag{1}$$

where c is the conflict between the bimodal information. The function f describes the degradation of presence caused by the conflict. It is related to the type of psychophysical measurement used to measure the extent of the perceived bimodal conflict. If a rating method is used to assess the conflict, then f should be the mean rating of the extent of the bimodal conflict. f is zero if the conflict cannot be perceived.
By definition it cannot be larger that one.

$$0 \le f(c) \le 1.$$

The bimodal conflict c induced by the human system interface is described by

$$c = \left| \frac{x_1 - x_2}{x_2} \right|.$$

It represents the normalized difference of the information x_1, x_2 sensed by the two modalities (e.g. distance, stiffness, mass). The term is also called Weber Fraction in psychophysics.

According to the definition we speak of ideal presence if

$$P = 1.$$

No presence is generated if

$$P = 0.$$

2.3 Implications for VR and Telepresence

The proposed measure can be applied to assess presence generated by bimodal VR-systems as well as for telepresence systems. In both cases the measure quantifies the quality of the human machine interaction at the human system interface. According to this an ideal VR-system is defined by a presence system where the generated reality by the human system interface does not generate any perceptual conflicts. In the same way an ideal telepresence system is a presence system where the generated reality by the human system interface does not possess any perceptual conflicts. These definitions raise the question to what extent the measure assures that the generated reality by the HSI equals the target reality (VR or remote environment). Under the assumption that at least one modality involved in the feedback signal carries the information about the environmental property of the target environment the measure also assures the equality between displayed environment and target environment.

3. Human System Interface and VR

3.1 Hardware and Software

The human system interface (HSI) provides visual and proprioceptive (haptic) feedback. Furthermore, it measures finger positions and forces. See Figure 2 for a photo of the device and Figure 3 for a sketch of the haptic subsystem.

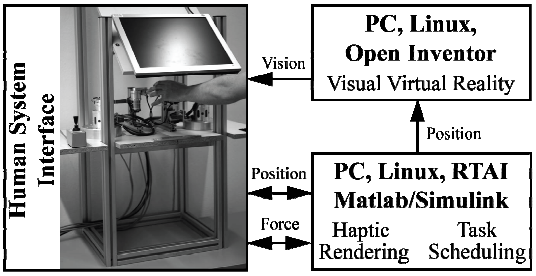

Figure 2. **Human system interface and real-time processing unit: Visual and proprioceptive (haptic) is fed back and positions are sensed**

Proprioceptive information is exchanged via a haptic interface comprised of two SCARA robots providing a single degree of freedom each. The system interacts with the index finger and thumb to enable gripping movements. High fidelity components like Maxon motors and Harmonic Drive Gears enable best possible control. Workspace is about 80mm and maximum force is about 35 N. Position information is measured by angle encoders. Force is sensed by strain gauges attached on both robot links.

Visual information is provided by a TFT screen. Thereby, the compliant environment is represented by a grey cube squeezed by two orange spheres (on opposed cube sides) representing finger positions (see Figure 4). The TFT screen is slanted by 40° and mounted in the line of sight to the hand enabling participants to look at the display as if they were looking at their hand[1].

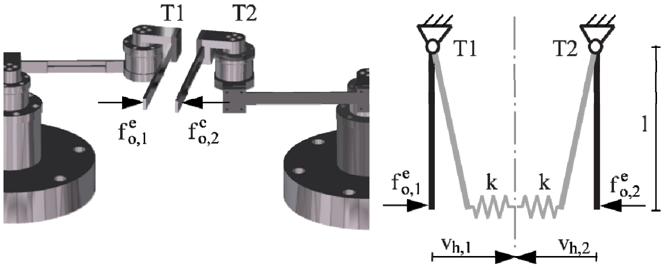

Figure 3. **Kinematical structure of the haptic display: Two scara robots present compliance information for gripping movements**

The system is connected to a PC running RealTime Application Interface for Linux (RTAI). SCARA sensor signals are recorded by a "Sensoray 626" DAQ-Card providing 16 bit sensing resolution. Signal processing algorithms are implemented as Matlab/Simulink models with real-time code generated automatically. The system operates at 1 kHz sampling frequency. Measured positions are transferred to a second PC running the visual virtual reality programmed in Open Inventor.

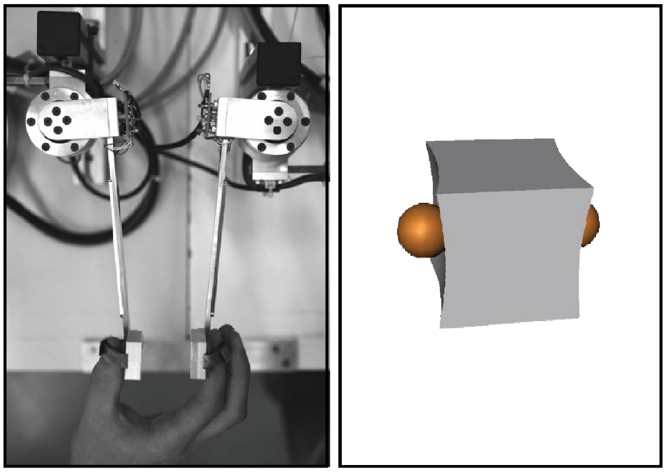

Figure 4. Haptic and visual feedback: The haptic feedback renders a compliant cube to be explored by thumb and index finger. In the visual feedback fingers are replaced by orange spheres

3.2 Dynamics and Control

Rendering of mechanical environments, called "haptic rendering", is a difficult problem in robotics. Performance and stability issues have to be considered. Hence, the dynamics and the control system are explained in the following.

The identical robots of the HSI are controlled independently using the same admittance control scheme (see Figure 3 for kinematical configuration). In the following, the concept is explained using a single robot system without loss of generality. Furthermore, the explanation is restricted to translational movements only (kinematical transformations are ignored) since robot links are only moved little when performing the gripping tasks.

For dynamics consider a mechanical robot with a single translational degree-of-freedom. The dynamical equation is given by

$$M_h \dot{v}_h + n = g_h - f_o^e,$$

where M_h and n_h denote mass and nonlinearities of the robot. Robot force g_h depends on motor torque T and on link length l, respectively (Figure 3). The velocity of the tool tip is denoted by v_h. Input-output linearization is achieved by commanding

$$g_h = f_o^m + n_h.$$

The resulting linear dynamics are

$$M_h \dot{v}_h = f_h^m - f_o^e,$$

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[1] The tool transformation has no influence on the dynamics of the gripping movement, if participants are given a learning phase (e.g. see [34]).

where f_h^m is the new motor force of the linearized HSI. A velocity controller realizes the command signal f_m^h according to

$$f_h^m = G_h(C_v(v_v - v_h)),$$

where G_h represents the dynamics of the actuator, which can be reduced to the dynamics of the current control. The HSI is serially connected to the human operator, whose fingers are described by the dynamics Z_o. The velocity of the HSI and the velocity of the operator's fingers are opposite

$$v_v = -v_o.$$

The dynamics of the robot interacting actively with the human operator are described by

$$f_o = Z_o(v_o) + f_o^m,$$

where f_o^m is the force actively intended by the human operator who is impeded by the force f_o that mediates the virtual reality (VR).

The dynamics of the VR is described by the admittance Y_v which represents pure stiffness yielding

$$v_v = Y_v(f_m^e) = k^{-1}\frac{df_m^e}{dt},$$

where *k* [N/mm] is the stiffness coefficient (compliance being *1/k*). The control concept employing inner velocity control driven by a virtual reality with force reference is called admittance control. It is best suitable for rendering non-rigid environments like compliant environments. Minimal compliance (= maximal stiffness) that can be rendered is *1/k=0.19* mm/N (value obtained experimentally).

A block diagram of the human operator interacting with the haptic HSI is depicted in Figure 5**.** Hollow arrows depict physical interactions, filled arrows are used for signal interactions. All subsystems are considered to be linear and time-invariant.

The fidelity of the VR depends on dynamics and control of the HSI. The robot is light weighted, dynamics of the motor current control are negligible, and velocities are small (i.e. friction effects negligible). Consequently, the transparency of the system can be seen as nearly ideal and the displayed dynamics Y_d can be considered equal to the dynamics of the VR

$$Y_d = Y_v.$$

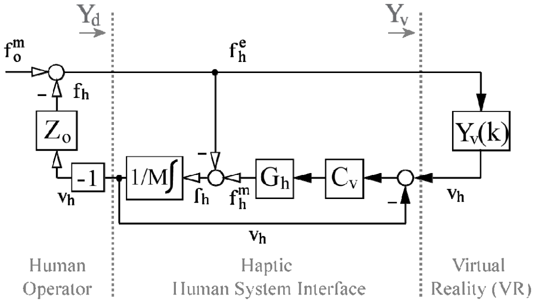

Figure 5. Admittance Control: The haptic virtual reality is generated with different stiffness coefficients. High performance is achieved through light weighted robot and appropriate control

4. Experiment

4.1. Participants

30 participants of the Technische Universität, München as well as the Ludwigs-Maximilians-Universität, München took part in this study and were paid for participation. Half of them received haptic constant and visual variable stimuli (group Hc), the other half visual constant and haptic variable stimuli (group Vc). Average age of group Hc (8 men, 7 women) amounted to 24 years. In Group Vc 9 men and 6 women took part with an average age of 25 years. All participants were right-handed and had normal or corrected-to-normal vision.

4.2. Stimuli

All stimuli were cubes of 80 mm edge length displayed visually and haptically by the HSI (see Section 3.1). Depending on group membership either the visual (group Vc) or the haptic modality (group Hc) amounted to the reference compliance of 0.851 mm/N, while the other modality deviated from the target modality. These intermodal deviations were selected according to the results of [32] and additionally, to cover a relatively broad range above as well as below the perception threshold (amounting 85% see [32]). The exact percent of deviation from the reference compliance were chosen to be 0, 30, 60, 80, 120, 160, 200, 240 or 280%.

4.3. Design

Rating of bimodal conflict as well as rating of feeling presence had to be tested across the set of all nine bimodal stimuli for either the visual or the haptic modality remaining the unaltered reference modality. Reference modality was chosen as a between-participants variable, while deviation from reference compliance was a within-participants variable.

Therefore, within each modality group participants had to rate each of the 9 stimuli according to the perceived bimodal conflict as well as their feeling of presence. To make sure that participants based their ratings only on either perceived discrepancy or their feeling of presence, both measures were assessed in different blocks. Order of blocks was randomized across participants introducing a new group factor (further referred to as “order of blocks”): Group P started with rating their presence feeling, group D with the extent of the perceived bimodal conflict. Each of the nine stimuli was presented 4 times to measure the feeling of measurement block and 8 times to measure the perceived discrepancy.

Additionally, another control variable had been introduced only in group Hc, i.e. whether a congruent stimulus was presented prior to test session or not (further referred to as “experience with a congruent stimulus”).

4.4. Experimental procedure

Participants were seated in front of the HSI (see Section 3.1) and grasped the device with their dominant hand. They nearly looked perpendicular at the screen while testing the compliant cube. Each stimulus presentation followed the same basic scheme: As indicated by auditory signals the compliant stimulus was presented for 4s. Subsequently, participants had to response according to the assessment block. Participants were instructed and performed a test session before the experiment started.

Measurement of perceived conflict

The block for assessing the perceived conflict started with a short baseline response time measurement. After that four blocks had to be conducted. Participants were instructed to enter their answer through a joystick as fast and as accurate as possible by deciding whether they had perceived a conflict between the visual-haptic information (yes, no) between the visual and the haptic compliance presentation (see also [32]). Afterwards, they rated the extent of the bimodal conflict ranging from “0” (no conflict perceived) to “10” (large intermodal conflict perceived).

Measurement of feeling present

After each stimulus presentation participants rated their feeling of presence according to an item of the Witmer & Singer presence questionnaire (see [18]). The item was chosen to be “How natural did your interaction with the environment seem” (translated into German by [33]). The answer had to be given on a 7-point scale with “1” indicating “very naturalistic” and “7” “not very naturalistic”.

Both questions (extent of the bimodal conflict, presence) as well as their rating scale were fixed above the screen. The non-target question was covered. Between both assessment blocks (extent of the bimodal conflict, presence), participants were asked to fill in a questionnaire consisting of the subscale “immersive tendency” depicted from [18] and translated into german by [33].

4.5. Data analysis

First of all, questionnaire data have been descriptively analyzed, and their potential influence on the assessed ratings was determined. Both ratings (presence, bimodal conflict) were averaged across repetitions.

Prior to testing the hypotheses influence of control variables, namely “order of blocks” and “experience” (see Section 4.3), has been tested with separate 9x2x2 ANOVAs with repeated measurements (intermodal conflict) and both between-participant factors separately for group Vc and Hc.

In order to make both samples better comparable, all values have been corrected against the congruent stimulus. Hypotheses were tested with two separate ANOVAs above (120-280% intermodal conflict) and below (30-80% intermodal conflict) detection threshold of 85% (see [32]). A significant main effect of bimodal conflict was further tested by a trend test. All effects were corrected for assumed sphericity by Greenhouse Geisser correction, if necessary. Significance level was set to 5%.

5. Results

Questionnaire data

Influence of participants’ immersive tendency was tested to analyze whether individual ratings are based on personal trait or on the experiment: Results indicated that not the personal trait but the experimental variations accounted for the individual ratings.

The immersive tendency subscale is comprised of two factors, namely emotional involvement and degree of involvement. In group Hc, participants’ emotional involvement (mean m = 28.8, standard deviation sd = 6.1) as well as degree of involvement (mean = 19.3, sd = 5.6) did not statistically significantly differ from the German norm sample (see [33]). Additional, no difference could be found for group Vc (emotional involvement: m = 28.2, sd = 6.4; degree of involvement: m = 21.2, sd = 5.5). None of the both factors comprising immersive tendency correlated with either rating of presence or rating of perceived conflict.

Control variables

Influence of control variables, namely influence of order of blocks (group) and of experiencing a congruent stimulus on both ratings was tested: Results indicated that the order of blocks revealed no influence. Participants with no experience in congruent stimulus ratings had to be excluded further from experiments.

Group Hc. The ANOVA revealed no effect of “order of blocks” on either presence rating ($F(1,11)=0.19$, $p=0.675$) or rating of perceived conflict ($F(1,11)=1.66$, $p=0.237$). Therefore, order of blocks had not to be considered in further analysis. However, an influence of “experience with the congruent stimulus” prior to the test session could be observed in presence ratings ($F(1,11)=11.10$, $p<0.05$; $\eta^2=0.502$) indicating that without presentation presence ratings yields higher scores. Presentation of the congruent stimulus did not generally influence ratings of extent of the bimodal conflict (F(1,11)=2.73, p=0.127). Additionally, the test factor showed a significant interaction with displayed visual-haptic conflict ratings (Greenhouse Geisser corrected: F(2.2,24.6)=5.61, p<0.05; η^2=0.338), but not on presence ratings (Greenhouse Geisser corrected: F(1.9,21.5)=1.99, p=0.162). This interaction indicated a u-shaped relation between conflict rating and displayed conflict, when the congruent test stimulus had not been presented as a reference stimulus. Therefore, participants with no congruent stimulus experience were excluded from further analysis.

Group Vc. The ANOVA revealed no effect of "order of blocks" on either presence rating (F(1,13)=1.30, p=0.276) or rating of perceived conflict (F(1,13)=0.96, p=0.346).

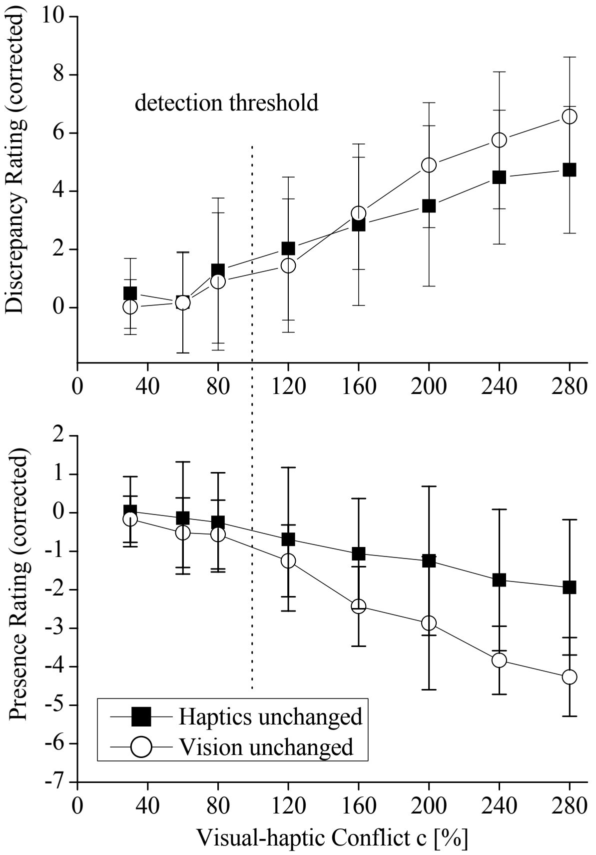

Figure 6. Mean conflict rating (*f(c)*) increases and presence rating (presence question) decreases with increasing visual-haptic conflict. Perception threshold was taken from [32].

Rating of extent of the bimodal conflict (new measure)

Displayed perceived visual-haptic conflict above the perception threshold of 85% [32] influenced the ratings (F(4,84)=67.43, p<0.05; η^2=0.763) and was due to a linear trend (F(1,21)=141.66, p<0.05; η^2=0.871). As can be seen in Figure 6, rating of extent of bimodal conflict increased with increasing displayed visual-haptic conflict. No influence between both groups, Vc and Hc, could be observed (F(1,21)=0.84, p=0.370). The interaction between displayed discrepancy above detection threshold and (unaltered) reference modality was statistically significantly (F(4,84)=6.24, p<0.05, η^2=0.229); however, the effect size (η^2) is rather low.

Below the detection threshold variation of intermodal conflict from 30% to 80% influenced conflict rating (Greenhouse Geisser corrected: F(1.3,27.8)=5.29, p<0.05), but effect size is rather low (η^2=0.201). Additionally, as can be seen in Figure 6 no clear trend could be observed. Neither the interaction (Greenhouse Geisser corrected: F(1.3,27.8)=0.30, p=0.654) nor reference modality (F(1,21)=0.17, p=0.688) reached statistical significance (see Figure 6).

Rating of feeling present (presence question)

The ANOVA showed a statistically significant main effect of conflict above detection threshold of bimodal conflict (Greenhouse Geisser corrected: F(2.5,52.7)=29.06, p<0.05; η^2=0.580) which was due to a linear trend (F(1,21)=105.84, p<0.05; η^2=0.834). There was a significant influence of reference modality alone (F(1,21)=8.603, p<0.05; η^2=0.291) and in interaction with bimodal conflict (Greenhouse Geisser corrected: F(2.5,52.7)=4.77, p<0.05; η^2=0.185). However, effect size is rather low: The main influence is due to variations of bimodal conflict. With the visual modality remaining unaltered, rating of conflict decreased more pronounced than with the haptic reference modality (see Figure 6).

Below the detection threshold neither variation of intermodal conflict from 30% to 80% (F(2,42)=1.73, p=0.190) nor the interaction (F(2,42)=0.12, p=0.888) nor influence of reference modality (F(1,21)=0.67, p=0.423) reached statistical significance.

Presence rating according to the new measure

Ratings of perceived intermodal conflict were transformed according to Section 2.2. Figure 8 shows the result of the introduced presence measure P(c) as introduced in equation (1). Since it is directly related to the perceived conflict, presence is rather high, if the conflict is small. However, due to the method of assessment (individual rating), presence is not ideal with the conflict smaller than the JND (c < 85%). This is because the JND is not an absolute but a statistical value. However, for conflicts c below the JND mean presence is P_{mean}(c<85%)=0.96 in group Hc and 0.94 in group Vc. With increasing conflict above the detection threshold *P(c)* decreases monotonically.

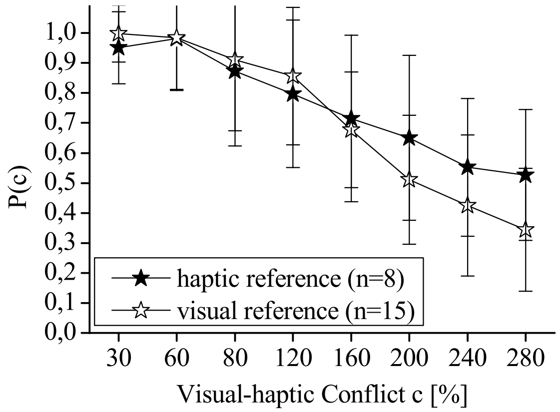

Figure 7. Introduced presence measure: Presence rating of the VR system is rather high when conflicts could not be detected statistically. Presence decreases monotonically if perceivable conflicts increased.

As has been reported in Section 5, both presence measures, the post-test rating and the conflict based rating showed a linear decrease with visual-haptic conflicts increasing above the detection threshold.

6. Discussion

According to the results it could be affirmed for visual-haptic human system interfaces that the feeling of being present in a different environment depends on the congruent display of information. Conflicting information deteriorates the feeling of presence. In this study this was tested in case of visual haptic information but it is assumed that the result is valid principally for all permutations of bimodal/multimodal information. Hence, the measure could be applied to a variety of VR- and telepresence systems. However, the function *P(c)* will change for other modality combinations.

An advantage of the measure is that it can be used as a cost function to be part of control strategies of the involved robots: Control strategies will focus on reducing the conflict rather than on minimizing position or force errors.

A disadvantage of the measure is its limitation to redundant information. Complemental information, like color and form of an object, cannot be evaluated with the measure in its current formulation. This might be achieved by extending the measure to more abstract information and to a more abstract definition of the term ‘conflict’ beyond its psychophysical sense.

8. Conclusions

An experiment was presented assessing presence and perception of conflict within a visual-haptic virtual reality. It was shown that with increasing incongruence between visual and haptic information the perceived conflict increases and the rating of presence decreases.

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