Visual cues and virtual touch: Role of visual stimuli and intersensory integration in cross-modal haptic illusions and the sense of presence.

Frank A Biocca, Yasuhiro Inoue, Andy Lee, Heather Polinsky, and Arthur Tang.
Media Interface and Network Design (M.I.N.D.) Labs
Michigan State University

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Summary

Intermodal integration (sometimes referred to as intersensory integration) may be a key psychological mechanism contributing to a sense of presence in virtual environments. Sensorimotor processes associated with multimodal integration may integrate perceptual cues and motor actions into a coherent experience and relatively consistent model of objects and spaces. When the cues come from virtual environments, intermodal integration may generate a sense of presence in a coherent virtual world. Because stimuli from virtual environments frequently fail to provide coherent and consistent cues, evidence of the role of intermodal integration might be found in intersensory illusions, the results of the user's attempt to integrate an inconsistent environment. Secondly, if intermodal integration plays a role in the generation of presence, then intersensory illusions should be correlated with the illusion of presence in a coherent virtual world.

Extending a study by Biocca *et al.* (2001), a between subjects experiment was conducted in which users picked and moved objects in a vitual environment. Four conditions were created in which visual and audio feedback of a tactile force was either present or absent. The visual feedback, the visual analog of a physical force, is a spring extended and snapped computer graphic cubes and other primitive objects into their hands when they picked them up to move them. Auditory feedback, a "snap" sound, occurred in some conditions when the spring retracted. There was no haptic feedback. Users provided with the visual feedback cue of physical force, the virtual spring, reported significantly higher levels of haptic sensations of “physical resistance,” even though the interface included no haptic displays. Although the audio cues did not appear to contribute to the haptic illusions, they did add to a perception of the naturalness of the environment, a dimension of our presence measure. Visual cues did not have a significant effect on presence. Evidence that cross-modal illusions and presence might emerge from similar mechanisms was found in a significant and robust correlation of .54 between reports of presence and cross-model illusions.

Finally, we suggest that this perceptual illusion might be used to engineer improvements in user experiences with multimodal interfaces, specifically by supporting limited sensory displays (e.g., haptic displays) with appropriate synesthetic stimulation to other sensory modalities (e.g., visual and auditory analogs of haptic forces).

1. Introduction

There are two key questions that underly research on the design of virtual environments. One is: What are the mechanisms that give rise to presence? Another is: How do the senses and motor actions interact to create the stable illusions of virtual environments? We report a study that further demonstrates that these two questions are linked, specifically that the sensory stimuli interact to the point of creating synesthetic illusions, and that these illusions are related to the experience of presence. This connection suggests a role for intermodal or intersensory integration and presence.

1.1 Do the senses talk to each other?

Do the senses talk to each other? This is essentially what William Molyneux asked the philosopher, John Locke, in the seventeenth century. He wondered whether a man born blind who was able to touch a cube and a globe so that he could recognize the difference, would be able to distinquish the difference if, by some miracle, his sight was restored and he were made to see. Would his haptic sense tell his eyes the difference between the cube and the sphere?

In a similar way, research in media psychology and human computer interaction often inquires how stimuli to one sensory channel affect stimulation to another. In a way, we are asking a version of Molyneus' question: Do the senses talk to each other? If so, what information do they exchange? How do these different forms of information merge into an experience of a coherent world, one where the sensing self is present?

The human sensorimotor system is designed to experience the world as a whole, merging and synthesizing input from different sensory modalities in an ongoing and dynamic fashion. Each sensory system appears quite independent. However, research on intermodal integration suggests that this impression of sensory independence is "more illusory than real" (Stein, Wallace, & Meredith, 1995/ p. 683c).

Illusions in virtual environment systems may be greatly assisted by the process of intermodal integration and the "assumption of unity" (Welch & Warren, 1980). Users of virtual environments may have an assumption that multimodal stimuli emanate from a single focal object or event, because in the physical world objects or events have redundant cross-modal cues.

Information from one modality (e.g., visual) can interact with information from other modalities (e.g., aural or haptic) to: (1) enhance the properties of the illusion in an interacting modality, (2) "fill in" information or disambiguate information in another modality, or (3) drive attention to a location, object, or event. (Stein et al., 1995; Stein & Meredith, 1993; Welch & Warren, 1986)

In a previous paper and in an upcoming review (Biocca, Forthcoming; Biocca, Kim, & Choi, 2001), we introduced a classification of different ways the senses are made to interact in visual environments. One type of cross-modal interaction, ***cross-modal enhancement or modification***, involves the perceived enhancement or decrement of cues of one sense by information from another sense. During cross-modal enhancement or modification, the property of a stimulus in one sensory modality alters the experience of stimulus properties presented in another sensory modality influencing the user’s perceptions of an object property such as fidelity or location, or timing of an event. In Molyneus’ sense, we could say that one sense “talks to another,” and like the blind man who is made to see and whose tactile sensory channel “talks” to the visual channel, the object perception of the sensory channel is somehow enchanced by this intrasensory information.

Molyneus’ intellectual descendants have documented these effect in numerous studies on various aspects of human perception confirming in many ways that stimuli in one modality can alter experience in another. (see reviews Cytowic, 1989; Marks, 1978; Stein & Meredith, 1993; Welch, 1978; Welch & Warren, 1986) While intersensory interactions vary, the visual sensory channel is more likely to skew the interpretation of information processed by the other senses, a phenomenon sometimes referred to as “visual capture”. (see review Welch & Warren, 1980) Below we briefly consider how the visual sense sometimes dominates in visual-to-haptic and visual-to-aural intersensory biases and cross-modal interactions.

In virtual environments, it is not uncommon for the felt and visual location of the hand to be misaligned and discrepant. There are numerous studies showing that when visual and proprioceptive cues of the location of the hand are discrepant, the perceived location of the hand or a haptic stimulus to the hand will be strongly influenced by visual cues (see recent. (Pavani, Spence, & Driver, 2000; and review Welch & Warren, 1980) Biocca and Rolland (Biocca & Rolland, 1998) demonstrated that adaptation to flaws in visual and haptic feedback in virtual environments can temporarily discoordinate the normal functioning of the visual and haptic senses of the user. The user’s functioning in the physical environment is impaired temporarily after they have exited the virtual environment.

1.2 What visual and auditory cues might increase intersensory illusions and presence?

Is there such a thing as a visual analog of a haptic force? Do some visual cues provide more information on haptic properties than other visual cues? Can some visual cues be so suggestive that it is easy to mentally model the feel of a surface? Can a visual cue be so informative, that one can “almost touch” the object? It has long been observed that some visual cues provide information that can distort haptic sensations.

Moylneux, who we referred to in a previous section, discovered one form of this cross-modal interaction, the size-weight illusion. A classic example of visual-to-haptic intersensory interaction is the size-weight illusion. (Cross & Rotkin, 1975) Given two objects of equal weight but different volumes, participants perceive the larger volume to be lighter than the smaller volume when lifted. Although both haptic and visual cues contribute to this illusion, (Ellis & Lederman, 1993) visual cues alone are sufficient. So perceived weight, or more generally the perception of inertial forces, may be an interaction of visual and haptic cues.

Lecuyer and his colleagues demonstrated one way in which visual and haptic cues might interact in the perception of a virtual environment. (Lecuyer, Coquillart, & Kheddar, 2000) They found that the perceived resistance of an isotonic haptic force on a space ball was influenced by the visual cue, the degree to which a virtual spring was visually compressed.

Taking this further, an exploratory experiment conducted by Biocca et al. (Biocca et al., 2001) found that people in immersive virtual environments reported not just an interaction of cues, but seemed to experience a visual-to-tactile synesthesia in a setting where there was no haptic feedback, and therefore few, if any haptic cues. They also found that the levels of presence in the virtual environment were correlated with reports of synesthesia; people experiencing higher levels of presence were more likely to report synesthesia in the environment.

In this previous study on visual-to-haptic cross modal transfer, we suspected that a visual cue of a haptic force, a virtual spring that extended and snapped when objects were moved, was a key contributor to the visual-to-haptic illusion. We also suspected that an audio cue, a snapping sound when the spring contracted and the object snapped into the hand, might contribute or interact with the visual cue to contribute to the cross-modal haptic illusion. But these variables were not controlled. A key question is: Can a visual analog of a haptic force provide a strong enough cue to generate significantly higher reports of haptic sensations? If it "looks" like it takes force to move something, does it "feel" as if it takes more force that when the cue is not present? To put it in Moylneus' words: Does the visual sense of a force talk to the haptic sense? And to ask a question that Moylneux never asked: Does this intersensory talking help to create a coherent environment, or more specifically, our sense of presence in a coherent environment?

2. Hypotheses

2.1 The role of visual and auditory cues in creating haptic cross-modal illusions

This experiment extends the research of Biocca *et al.* (2001) by directly testing and confirming that the cross modal haptic illusion is caused by visual and auditory cues of haptic forces. It also asks whether the visual and auditory cues interact.

H1: Visual cues of haptic forces will increase reports of cross-modal haptic illusions.

H2: Audio cues of haptic forces will increase the reports of cross-modal haptic illusions.

2.2 Modal feedback and presence

Guided by Gibsonian action-based theories of sensorimotor interaction in VR (Smets, Overbeeke, & Stappers, 1995a, 1995b; Smets & Overbeeke, 1995; Smets, Stappers, Overbeeke, & van der Mast, 1994), presence researchers have found evidence that virtual environments that link vivid sensory feedback to motor actions will contribute to the sense of presence in the virtual environment. We have called this feature of virtual environments sensorimotor coordination (Biocca, 1997), that is, the degree to which there is a link between motor action and sensory feedback and the degree to which sensory cues are coordinated. Replicating Biocca *et al.* and providing more evidence for the causal role of sensorimotor coordination in illusions of presence, we hypothesized that:

H3: Visual feedback linked to motor actions will increase the sense of presence.

H4: Audio feedback linked to motor actions will increase the sense of presence.

2.3 The interactions of cross-modal illusions and presence in mental models from virtual environments

Biocca et al (2001) also suggested that the illusion of telepresence in virtual environments was, in part, generated by mechanisms of intersensory integration (**Biocca**, Forthcoming). If presence and cross-modal sensory illusions result from the same brain mechanisms for sensorimotor integration, then they should be correlated. Therefore,

H5: Reports of cross-modal illusions and presence will be correlated.

3. Method

The research design involved a 2 X 2 between subjects factorial experiment conducted in an immersive virtual environment. The independent variables were: (1) presence of visual cues of haptic forces and (2) presence of audio cues of haptic forces. Both factors had two levels: (a) cues present or (b) cues absent.

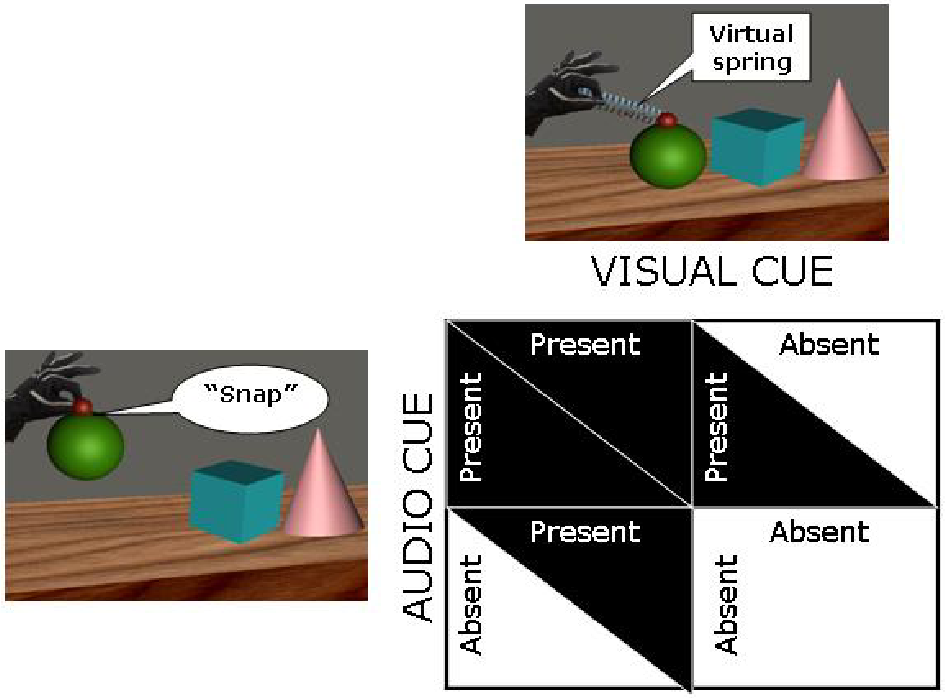


Figure 1. *The two-independent variables were the inclusion of a visual cue of haptic force and/or an audio cue of haptic force. In the visual cue conditions, subjects experienced a virtual spring that extended from the object prior to it snapping into the hand. In the audio cue condition they also experienced a "snap" sound when they lifted the object.*

3.1 Participants

A total of 74 participants, college students at a large Midwestern university, completed the experiment for extra credit.

3.2 Stimulus Materials

Immersive virtual reality system: Participants were exposed to a 3D stimulus environment using an immersive virtual reality system. The hardware platform was the SGI Onyx Reality Engine with two graphics pipes. Multigen Smart Scene software was used to create the 3D virtual environments. The environments were displayed to the participants through a V8 Virtual Research stereoscopic head mounted display. A Polhemus magnetic tracker measured the position and orientation of the participants' head and hands. The position and orientation data was used to move the participants' viewpoints in the virtual environment and to display a 3D cursor (a blue transparent sphere with an embedded tubular cross) for each of their hands. Fakespace® pinch gloves allowed participants to grab and move objects by pinching their fingers together.

Because of the nature of this study, it is important to underline the fact that the virtual reality system ***did not*** include any tactile or force feedback displays.

<u>Virtual environment:</u> The virtual environment that was used for this experiment was a modification of the control environment used for the experiment by Biocca and his colleagues (2001). It was composed of a 3D room that had a table with eight virtual objects made of primitive shapes (i.e., pipes, cubes, cones, spheres) and an empty tray on another table. The objects all differed in terms of their characteristics: shape, size, and color.

Four versions of the environment were operationalized with the presence or absence of visual cues, audio cues, or both. A visual cue of haptic force was used in half the environments. Objects in the virtual environments were "snappable," i.e., they had a virtual spring attached to them when they were picked for movement with the pinch gloves. The spring dynamically visualized the existence of a physical force. The participants pulled on the spring and observed the spring expanding and growing taut before it finally "released" the virtual object, which "snapped" into the hand (see Figure 2).

In half of the conditions there was no visual cue of a haptic force. The objects could simply be picked and moved. There was no spring release mechanism.

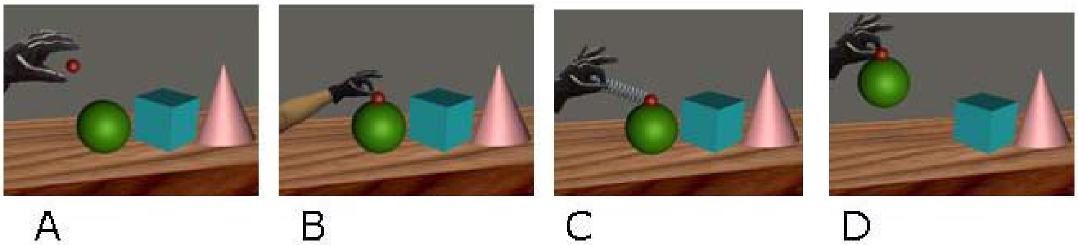


Figure 2. *Illustration of the object grasping and lifting sequence experience in the virtual environment. Subjects wore a sensor glove (added here for illustration), and saw their hand represented by a 3D spherical cursor in the virtual environment (A). In the visual cue conditions the user picked and lifted a virtual object by putting the 3D cursor in contact with the object (B). As they lifted, a virtual spring extended between the 3D cursor and the object for a short distance (C). As they continued to pull a fixed distance, the objects snapped into their hands (D). In conditions with no visual cue included, users simply intersected their 3D cursor with the object and lifted it (sequence A,B,D).*

There were two different sound effects used as cues of haptic force. In conditions where a visual cue was present, both a "stretching" sound and a "popping" sound were used. The stretching sound was played when the virtual spring was stretched and the participants could hear the popping sound when the spring was shrunk and the object was picked up. In the condition where there was an audio cue without a visual cue, only the popping sound was played when particpipants touched and picked up an object. No stretching sound was used. In the conditions without the audio cue but with the visual cue, a virtual spring was present but neither the stretching sound nor the popping sound was used. Finally, in the condition where there were no visual nor audio cues, participants picked up an object without seeing a virtual spring or hearing any sound.

3.3 Measures

Spatial ability. Spatial ability was measured using the mental rotation tasks in the French Kit paper and pencil test of cognitive abilities (French, Ekstrom, & Price, 1963)The French Kit measures of spatial ability include two timed tests (three minutes each) assessing three-dimensional rotation of 44 pairs of cubes. Three sides of each cube are visible and labeled with the objective to mentally rotate each pair and determine if they are the same or different. The total number of correct responses have been found to be a reliable and valid measure of spatial ability (French et al., 1963).

Presence. Presence was measured using the sense of presence inventory (SOPI) created by the Independent Television Commission and Goldsmiths College of University of London. The five point Likert scales measure three dimensions of presence labeled spatial presence, involvement, and naturalism (Lessiter, Freeman, Keogh, & Davidoff, 2001).

Reports of haptic sensations: Five items were developed to measure the degree of reported cross-modal haptic illusion based on ones used in Biocca *et al.* (2000). The items measure the degree to which the participants felt a “physical force” and the degree to which the participants felt a “sense of touch” when manipulating objects in the virtual environment. We also used the four items from the ITC-SOPI instrument that also seem to tap cross-modal illusion experiences. The items are listed in Appendix 1.

Individual differences: Two other measures of computer game experience, past synesthetic experience, and demographic data were also collected, but these are not reported here.

3.4 Procedure

Participants were greeted and given instructions about the experiment. This was followed by the spatial ability measure. Participants viewed video instructions on the use of the head-mounted display, navigation around the virtual environment, and the use of pinch gloves. In a training session participants navigated a virtual environment where they could see and walk around a small open area surrounded by buildings and the sea. When participants felt comfortable with the environment, they were randomly assigned to one of the four conditions and transferred to the experimental virtual environment. The experimenters provided brief instructions about the task. Once inside the virtual environment, all participants completed the task of moving eight objects from the original location on the virtual table to a tray on another table. After the participants completed the task of moving all the objects, they took off the virtual reality equipment. The participants then completed the following self report measures in this order: presence measure, cross-modal haptic illusion measure, past experiences of synesthesia, video game experiences, and demographics.

4. Results

4.1 Scales

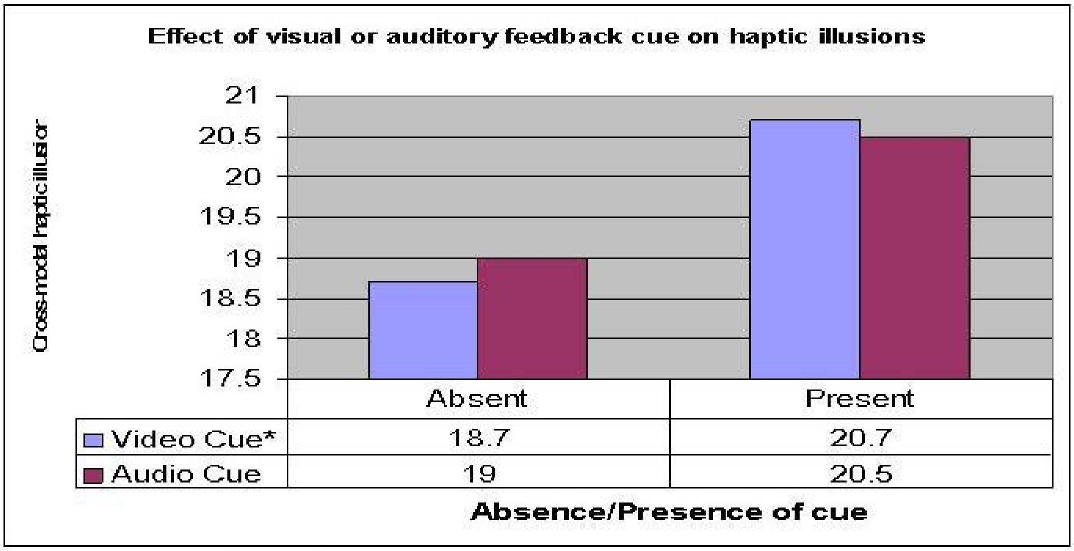
Presence The presence scale was factor analyzed into three factors, spatial presence, naturalness presence, and engagement presence. We tested the internal reliability of the dimensions of the presence scales. The average reliability of the dimensions using Chronbach's apha was $\underline{\alpha} = .73$, $n = 72$.

Reports of the haptic sensations scale: The reports of the haptic sensations scale were tested for reliability, $\alpha = .66$, $\underline{n} = 74$.

4.2 Hypothesis testing

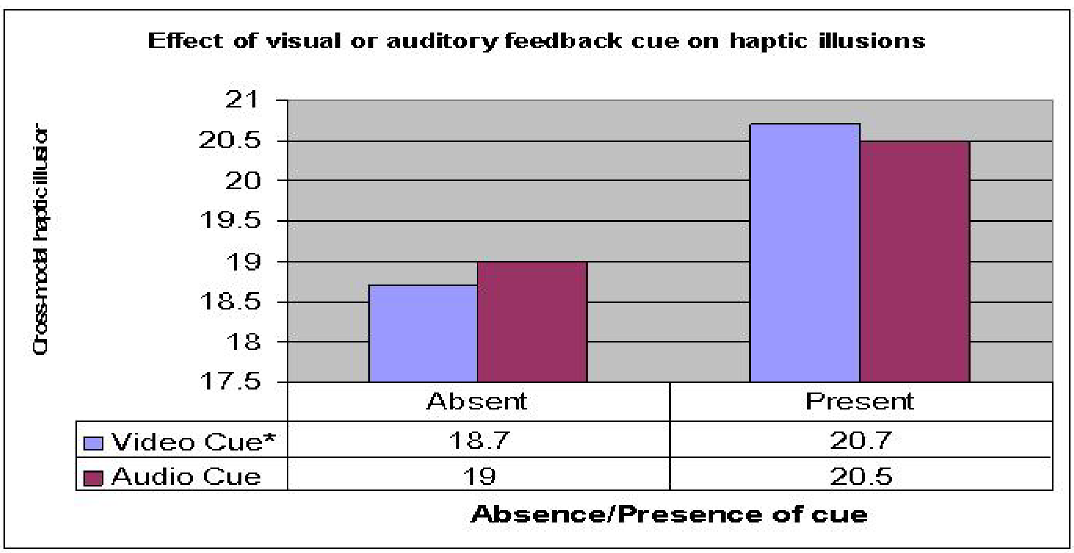
> H1: Visual cues of haptic forces will increase the reports of cross-modal haptic illusions.
>
> H2: Audio cues of haptic forces will increase the reports of cross-modal haptic illusions.

Hypothesis 1 and 2 were tested with a factorial ANOVA. See Figure 3. Hypothesis 1 was supported, $\underline{F}$ (1,72) = 4.03, $\underline{p} = 0.05$. The presence of visual cues of haptic forces led to increased reports of cross-modal haptic sensations. Hypothesis 2 was not supported, although the means were in the predicted direction, $\underline{F}$ (1, 72) = 2.28, $\underline{p} = 0.14$. There was no significant effect of the presence of visual and audio cues on cross-modal reports of haptic illusions, $\underline{F} = 0.26$, $\underline{p} = 0.60$.



* Note: $p < .05$

Figure 3. The presence of a visual and auditory cue appeared to increase reports of haptic sensations, but only the visual cue was statistically significant.



* Note: $p < .05$

Figure 4. The presence of a visual and auditory cue appeared to increase reports of spatial presence, but only the auditory cue was statistically significant.

H3: Visual feedback linked to motor actions will increase the sense of presence.

H4: Audio feedback linked to motor actions will increase the sense of presence.

Hypothesis 3 and 4 were tested with a factorial ANOVA to test the interaction effect of visual and aural cues in the virtual environment on the sensation of presence in the virtual environment. See Figure 4. The hypotheses were tested on each of the three dimensions of presence measured: spatial presence, engagement, and naturalness. Hypotheses 3 was not supported on tests involving all three dimensions: Engagement Presence, F (1, 72) = 1.46, p = 0.23; Naturalness Presence, F (1, 72) = 0.00, p = 0.99; and Spatial Presence, F (1, 72) = 0.83, p = 0.37. The visual feedback cues did not significantly increase presence beyond what was already afforded by the virtual environment.

Hypothesis 4 was partially supported. Audio feedback cues did significantly raise users' reports of spatial presence, F (1,72) = 6.03, p = 0.02, but did not affect reports of engagement presence, F (1,72) = 0.01, p = 0.92, or naturalness presence, F (1,72) = 0.94, p = 0.34. Therefore, it appears that the presence of audio cues heightens the subjects' sense of feeling as if they are in the virtual space but not necessarily their sense of engagement or their evaluation of the naturalness of the environment. No interaction effect was found between the video and audio cues on the presence dimensions: engagement presence, F (1, 72) = 0.19, p = 0.67; naturalness, F (1, 72) = 3.71, p = 0.06; and spatial presence, F (1, 72) = 1.24, p = 0.27.

Hypotheses 5 was supported. See Figure 5. Significant correlations were found between reports of cross-modal haptic illusions and all three dimensions of presence: engagement presence, r = .29, p < .01, naturalness presence, r = .41, p < .01, and spatial presence, r = .54, p < .01.

5. Discussion

There are two key findings in this study: (1) evidence that visualizations of haptic feedback will lead some participants to report haptic illusions in the absence of stimulation of this sensory channel by the interface, and (2) the apparent connection of these cross-modal interactions, specifically cross-modal transfers, and the experience of presence. We discuss these below in order.

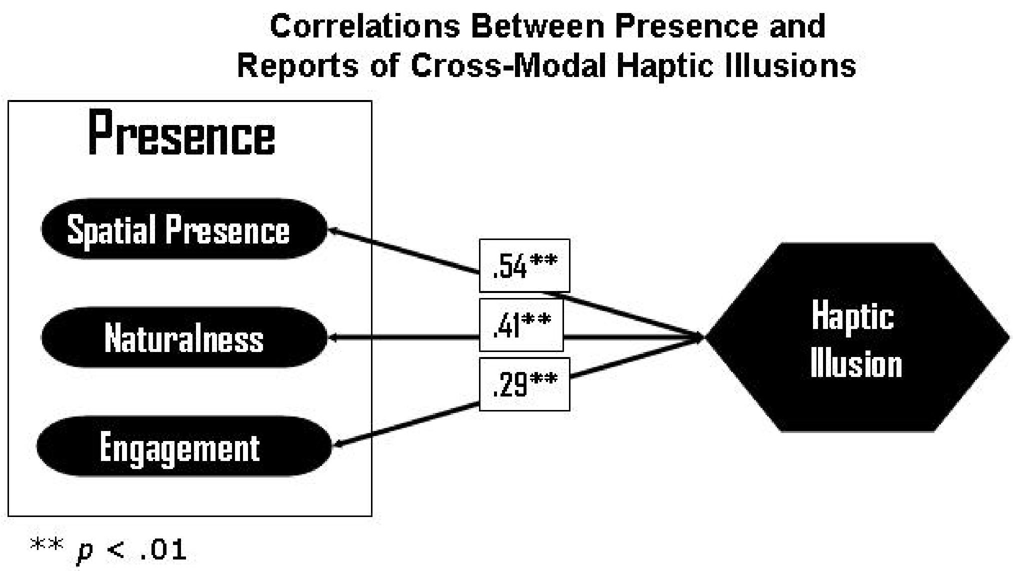


Figure 5. *All three measures of presence were significantly correlated with reports of the illusory visual-to-haptical sensations*

5.1 The role of visual cues of haptic feedback on reports of haptic illusions

The study found evidence of cross-modal visual-to-haptic transfers. Biocca and his colleagues' (Biocca et al., 2001) non-intuitive finding that users of immersive virtual reality systems may sometimes experience haptic illusions when no haptic stimuli are presented was replicated. This study replicates the finding that some participants report haptic illusions in the absence of stimulation of this sensory channel by the interface. But this study extends the finding by identifying that a key cause of the illusory haptic sensations is the visual cue of haptic feedback. The cue, a virtual spring, is a visual analog of a haptic force. It ties the hand to the object, stretches as the user pulls, and then suddenly snaps the object into the hand as a visualization of a haptic force. This visualization was strong enough for subjects to report increases in haptic sensations. Adding audio cues did not appear to significantly contribute to the haptic illusion even though the means are similar to the effects of the visual cues. It could be that the audio cue did not significantly improve the experience, but the finding that it increased the sense of spatial presence suggests that it was salient enough a cue to have psychological effects on the users.

This finding suggests that designers might be able to improve haptic sensations in virtual environments by adding visual cues that visualize haptic forces. These cues need not be realistic.

5.2 Intermodal integration as a route to presence and cross-modal illusions

Individuals who reported cross-modal illusions were also lkely to report experiencing presence in the virtual environments. These correlations may be indirect evidence that a common causal mechanism, such as intermodal integration, might be at the route of both or the correlation might be due to subjects' tendency to report illusions in virtual environments, both illusions of presence and illusory haptic sensations.

The pattern of correlations provide some support for the interpretation of a common mechanism associated with intermodal integration of spatial stimuli. The need to integrate spatial location during object manipulation (see Graziano, 1999) may provide an explanation for the pattern of the findings. As in the study by Biocca and his colleagues, spatial presence, the sense of being there, was primary in the sense of presence. The correlation between spatial presence and the reports of haptic illusions was comparatively quite high, $r = .54$. The process of intermodal integration of generating a coherent mental model of the virtual environment may be the source of these illusions. In some cases, individuals may be using cues from the physical environment to fill a coherent virtual environment with sensory detail that is not actually present, but that users expect would be present if the experience occurred in the physical environment.

6. Conclusion

It appears that, in virtual environments, like the physical environment, the senses do indeed "talk to each other." The information they share may reinforce and interact with each other to create a model of an internally consistent world. If it looks like there is a physical force, then we may consistently feel the force. Virtual environments are one of the few places where sensory cues may be uncoupled, impoverished, and inconsistent. Nonetheless, in the interaction among senses, the user still assembles a consistent environment. One byproduct of assembling this consistent environment from the multimodal cues may be the feeling that one is present inside this construction. This multimodal interaction among the senses and motor systems that so intrigued Moylneux may spin a cocoon for consciousness, the illusion of a consistent world, even when there is no world there, when it is a virtual world.

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Correspondence concerning this article should be addressed to Frank Biocca, Media Interface and Network Design (M.I.N.D.) Labs, College of Communication Arts and Sciences, Michigan State University, East Lansing, Michigan 48824. Electronic mail address: Biocca@msu.edu.

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9. Appendix

<u>Cross-modal Haptic Illusion Measure</u>

Please indicate HOW OFTEN YOU FELT the following sensations while in the virtual environment by circling just ONE of the numbers using the five-point scale below.

	Never				Always
1. I felt physical resistance when trying to move the objects………	1	2	3	4	5
2. I felt the force of gravity when trying to move the objects………	1	2	3	4	5
3. The larger objects weighed more than the smaller objects.………	1	2	3	4	5
4. The smaller objects weighed less than the larger objects.………..	1	2	3	4	5
5. I could feel the objects.……………………………………………	1	2	3	4	5