The Effects of Multisensory Cues on the Sense of Presence and Task Performance in a Virtual Reality Environment.

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Abstract

The aim of this study was to evaluate the effect of visual, haptic and audio sensory cues on participant's sense of presence and task performance in a highly immersive virtual environment. Participants were required to change a wheel of a (virtual) racing car in the 3D environment. Subjective ratings of presence and comfort were recorded using the Immersive Tendencies Questionnaire (ITQ), [WS98], the Presence Questionnaire (PQ) [WS98] and Simulator Sickness Questionnaire (SSQ), [KLB*_93]. The time taken to complete the task was used as an objective performance measure. Auditory, haptic and visual cues signalling critical events in the simulation were manipulated in a factorial design. Participants wore 3D glasses for visual cues, headphones for audio feedback and vibration gloves for tactile feedback. Participants held a physical pneumatic tool. Events, such as the full extraction of a bolt were signalled by haptic (vibration frequency change), acoustic (change in tool sound) and visual (colour change of bolt) cues or combinations of cues. Data was collected in two blocks containing all eight sensory cue combinations: the task was once performed in a normal VR environment (control) and once (motion) in an environment where the position of the virtual environment was sinusoidally modulated by 2 cm in the depth plane at 0.5 Hz to simulate inaccurate participant tracking. All participants completed all 16 conditions in a pseudorandom sequence to control for order and learning effects. Subjective ratings for presence, discomfort and perceived cues effectiveness were recorded after each condition. Participants performed best when all cues were present. Significant main effects of audio and tactile cue presentation on task performance and also on participants' presence ratings were found. We also found a significant negative effect of environment motion on task performance and participants' discomfort ratings.

Categories and subject descriptors (according to ACM CCS): performance measures, auditory feedback, haptic I/O, virtual reality.

1. Introduction

Virtual reality (VR) environments are useful as tools for training, perceptual motor research, interpersonal communication, data visualisation and many other purposes that depend on accurate presentation of visual stimuli and recording on user interaction with VR. Users evaluation of these systems often includes all qualitative experience a user has whilst engaging and interacting with a given system [PR14]. It is generally believed that high levels of immersion can cause an increased sense of presence that can make some applications more effective [BM07; LSS*_12]. Here, immersion refers to the objective description of what any particular system does provide, whilst presence is associated to the state of consciousness of the user and the sense of 'being' in the virtual world [SLU*_96]. Many presence-evoking media technologies were designed so that people can accomplish a task with greater efficiency and previous studies show that greater immersion in VR cause subjects to perform better. This was confirmed in studies of target localisation and acquisition [Oak09; BM07; AMH95] spatial attention [SS09] as well as interaction with a VR system [BIL*_02]. It has been suggested that illusion of self-motion can also make a positive contribution to the overall experience and effectiveness of VR systems [RSA*_06] however, undesirable side effects of self-motion have been identified mainly in the large scale collaborative VR environments where one user controls the (shared) view of a number of users in the simulation. The presentation of anchors in VR and avoidance of non-informative signals has been suggested to minimise these undesired side effects of self-motion [MSW*_13]. Future research into multisensory cuing and self-motion coordination should further investigate which factors contribute the most to the desirable effects of VR systems.

1.1. Multimodal cues

In order to support training and performance in VR it is essential to provide necessary sensory cues that are required for the task [PR14]. It has been generally believed that the greater number of human senses stimulated, greater the capability of the stimulus to produce a sense of presence. In studies where uni-modal, bimodal or multisensory stimuli are provided it has been found that the subject reported a greater sense of presence when more sensory cues were provided [LS08; BM07; LSS*_12] and especially when they were presented 'matching' location and direction [MWR*_05]. However, it has been pointed out that the importance of all sensory cues may not be equal. Typically, simulation in the VR environment relied mostly on visual cues as these were found to be most important. Previous research has shown that addition of auditory cues can enhance human performance as well as the perceived sense of presence at minimal increase in cost [JDN*_09; JEE*_04; MWT*_12]. Some studies have suggested that there is a lack of haptic cuing in VR environments mostly dues to expensive devices, associated with technology and difficulties in achieving a realistic haptic interaction [Edw00]. Studies that address haptic cuing in VR have found that tactile feedback can potentially be a promising type of additional feedback as it can contribute to effective interaction when the visual or auditory modalities are compromised, engaged or overwhelmed [AMH95; HSC*_05; JEE*_04; VJE03]. However, others have found the opposite when they reported that tactile and audio feedback can also be perceived as distracting and annoying, decreased overall performance as well as having negative effects on accuracy [Oak09; Bre03; VJE03].

Overall, previous studies have argued that additional multisensory information can enhance the interaction with a system through providing more salient stimuli [BIL*_02], however it has been also identified that some of the cues, mostly tactile cues, are much more difficult to present due to technological constrains and cost. The main aim of this study was to investigate whether the presentation of the relevant information in the different domains will have any subjective or objective difference to task performance. Our research focuses on influences of unimodal, bimodal and multimodal sensory information and its resulting effects on perceived sense of presence and individual task performance.

2. Methods

2.1. Participants

For this study we recruited 16 participants via opportunity sampling. There were 11 males and 5 females, with the age ranging from 18-48. All participants reported normal to corrected to normal vision and normal hearing.

2.2. Virtual reality set up

The experiment was conducted at the Virtual engineering centre (VEC) facility located in Science and Technologies Facilities Council (STFC) in Daresbury. VEC is part of the School of Engineering at the University of Liverpool. It contains virtual laboratories with High Performance Computing (HPC) and provides facilities for advanced modelling, simulation and immersive visualisation.

2.3. Apparatus

The laboratory consists of a planar display screen of length 6.0 m and height 2.1 m behind which are two active stereo projectors that create 3390 x 1200 resolution images at a rate of 120 Hz. 3D stereo images are produced by an NVIDIA Quadro K6000 GPU. Observers wear wireless LCD shutter glasses that are synchronized with the projectors to provide stereoscopic images. Object position is tracked using 16 high-spec infrared cameras (VICON Bonita B10, 250 fps capture speed, motion resolution of 0.5mm of translation and 0.5 degrees of rotation in a 4m x 4m volume using 9mm markers). Position data, computed using VICON Tracker software, is broadcast in real-time across the internal network using a VRPN protocol at a rate of 200 Hz and used to update the virtual environment.

The following objects are tracked in order to provide the required interaction within the virtual immersive environment: glasses (for head tracking and POV adjustment), subject hands (to drive subject's virtual hands) and the impact wrench, the tool used to remove wheel bolts. A faithful digital mock-up of the impact wrench is used to interact with the bolts. Through accurate calibration both hands and impact wrench overlap with their virtual counterparts from the subject's perspective. In this way the subject has the perception that (s)he interacts with virtual objects (wheels and bolts) using his/her real hands and the real power tool. The wheel change simulations runs at a constant speed of 15 fps across all possible combinations of cues to ensure an accurate time recording in all experiment conditions (i.e. times are not affected by enabled/disabled cues).

Tactile stimulus is provided by two "tactile gloves" realised by adding to the VICON hand tracking kit a vibration motor attached to the palm (Fig. xx). The motor is actuated by PWM drives receiving information on collision detection, level of vibration, etc. by a device wirelessly connected to the CPU running the immersive scenario. The vibration occurs with variable intensity, based on the specific task. For example, the subject can feel an intermediate level of vibration when screwing a bolt out or back in place, which steps up to the maximum level as soon as the bolt is completely screwed in or reduced to zero when is completely removed. In this way we mimic the intensity of vibrations generated by the impact wrench when performing the real task

Figure 1. Apparatus used in the experiment

2.4. Performance measures:

In this study we used overall task performance as an objective measure and the sets of questionnaires as a subjective measure. The questionnaire used in this experiment were Immersive Tendencies Questionnaire

(ITQ)[WS98], Presence Questionnaire (PQ) [WS98] and Simulation Sickness Questionnaire (SSQ) [KLB*_93].

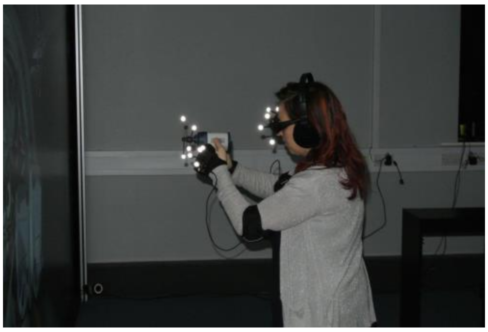

Figure 2. Participant wear headphones, vibration gloves and holding impact wrench whilst performing the task.

2.5. Procedure

Before participants started the experiment they were required to fill in the Immersive Tendencies Questionnaire and Simulation Sickness Questionnaire to provide a baseline measure. The room was darkened during all experiments. Participants wore 3D shutter glasses, vibration gloves and headphones that played continues white noise to mask vibration noise from the gloves (see figure 2). The task was to change the wheel on the virtual racing car in the 3D environment as fast as possible. During the task participants were provided with additional visual, tactile and audio cues. The cues were presented as unimodal, bimodal and multimodal feedback in randomized order (A, V, T, AV, AT, TV, AVT, NONE). The virtual environment was manipulated in two experimental blocks containing either static or lateral motion (0.2Hz) of the whole visual scene. Within each block participants performed the task 8 times in randomized order of conditions. Each block lasted approximately 15 minutes and participants had at least 15 minutes break between the two successive blocks.

2.6. Task

Each participant started with two practice trials. This was followed by experimental conditions in each block in counterbalanced order. The time started when the participants got in contact with the physical tool. First, they had to unscrew 5 bolts from the wheel on the virtual racing car (see figure 1.). After this they had to pick the wheel up and put it on the stand located next to the racing car. Then they had to go and grab another wheel from the stand on the other side, attach it on the racing car and screw the bolts back in. The overall recording stopped when the participants placed the tool back on the table.

2.7. Multisensory cues

During the task participant were presented with different sensory cues. The visual cues presented during the task included the bolts turning yellow when in contact with the tool and red when the bolts were completely out; the wheel turned yellow when in contact and red when in the right position; the virtual hands of the participant turn yellow when in contact with virtual parts. The tactile cues presented during the task included a vibration sensation when the tool was in contact with the bolt following a more intense vibration when the bolt was completely out; and when the virtual hands were in contact with the wheel. The audio cues presented during the task included a drilling noise when in contact with the bolt and a ‘snap’ sound when the wheel was placed on the stand and on the racing car. After each condition participants were asked to rate their sense of presence on a short questionnaire (7 questions). After each experimental block participants had a short break and were asked to rate their sense of presence on PQ, their feeling of discomfort on SSQ and two sensory questions asking them which cue or a combination of cues they found most useful in the bolt screwing task and in the wheel position task. After this, participants performed the task in a second experimental block (8 times) whilst filling the short questionnaire between conditions. Then participants were asked to fill in a second set of the same questionnaires as before.

3. Results

Descriptive statistics for each condition are presented in Table 1. Overall, participants rated the multisensory feedback most favourably, which is confirmed in their overall task performance.

Condition	**Objective data**	**Subjective data**
A	49744.91 (9266.17)	5.7 (1.4)
V	52395.53 (13474.73)	5.3 (1.5)
T	49927.91 (8765.34)	5.6 (1.2)
AV	49184.60 (6390.88)	5.9 (1.4)
AT	49501.02 (12552.18)	6 (1.5)
TV	50274.69 (10051.76)	5.8 (1.4)
ATV	46916.04 (8109.92)	6.4 (1.2)
NONE	55168.88 (14464.42)	4.2 (1.3)

Table1. Descriptive statistics Mean (SD) for each condition

We analysed our experimental results with 2x8 repeated measures ANOVA on overall task performance. We found a marginally significant main effect of condition ($F(7,112) = 1.977, p=0.06$). To investigate this further we grouped together conditions where each of the sensory cues was on and off. Overall mean times when cues were on and off can be seen in Figure 3. After performing a paired sample t-test we found a significant effect of audio ($p < 0.05$) and tactile cues ($p < 0.05$). This suggests that participants performed significantly better when audio and tactile cues were on as oppose to off.

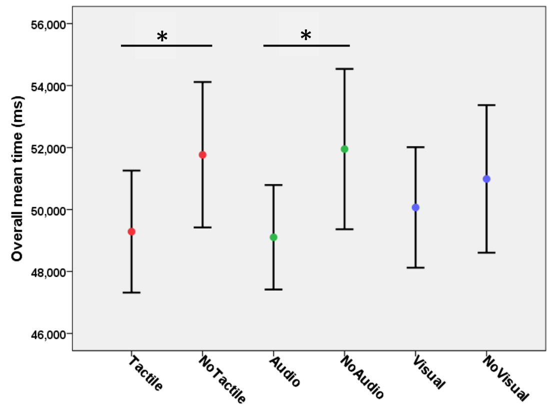

Figure 3. Significant main effects of three factors used in the factorial design: Tactile, Audio and Visual. Error bars represent standard error of the mean

Furthermore, we found a significant correlation between objective and subjective data (r = -0.979, p< 0.001). This suggests that when participants reported an increased sense of presence they completed the task faster (see figure 4.).

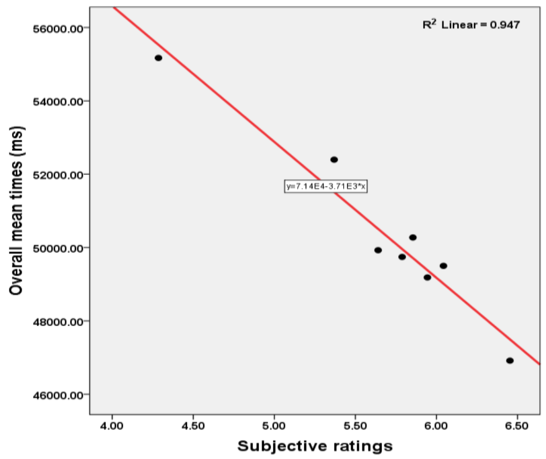

Figure 4. Correlation between subjective and objective measures

3.1. Modulation of the environment

To investigate the effect of the modulation of the environment we compared objective and subjective ratings and we found a significant negative correlation between the feelings of discomfort and perceived sense of presence (r = -613, $p < 0.05$) (see figure 5). This suggests that when participants reported increased feelings of discomfort their perceive feeling of immersion and presence decreased.

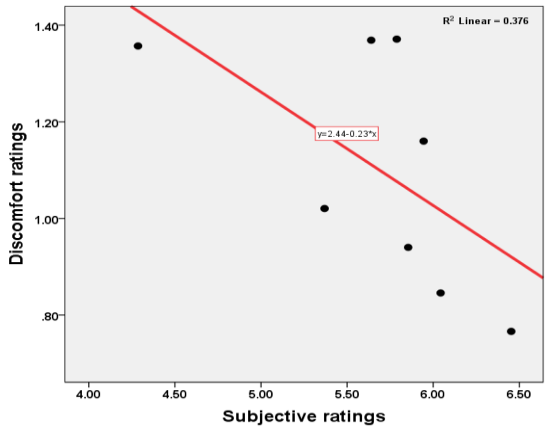

Figure 5. Correlation between discomfort and sense of presence

4. Discussion

The presented study was designed to investigate the potential beneficial effects of multisensory feedback on human performance in association with unimodal, bimodal and trimodal sensory cues. Our results show that trimodal feedback (AVT) was the most preferred type of feedback followed by bimodal (AV, AT, TV) and then unimodal feedback, which is in line with previous research [LS08; BM07; KHJ*_12; JEE_04; AMH95] We also investigated favourable effects of multisensory feedback on perceived sense of presence in virtual reality environments. Our results clearly show that objective and subjective measures were enhanced by presentation of multimodal feedback. As previous studies have suggested these results may reflect the fact that multimodal feedback can maximise human physical abilities as well as enhance users sense of presence and immersion in the VR environment [LS08; BM07; LSS*_12] The main findings of our study is to suggests that we need to include user experience when investigating the usability of feedback signals [KHJ*_12]. We argue that the auditory, tactile and visual cues are important additional cues that add to the objective performance as well as subjective evaluation of VR environments.

5. Conclusion

In order to support training and performance in VR it is essential to provide necessary sensory cues that are required for the task. These cues can be presented in uni-modal, bimodal or multimodal modalities, including different viewing perspective and stereoscopic presentation. The results from our study show that multimodal feedback can have the most favourable effects on users' perceived sense of presence and task performance. Future implications of our research suggest that even though the additional multisensory cues are pseudo-realistic i.e. they provide relevant information in an unrealistic fashion; they are still enhancing the user's sense of presence and helping in task performance. For our future research we propose to investigate whether the multisensory cuing will support the transfer-of-learning between real and virtual settings. An understanding of conditions and multisensory cuing under which VR users experience a enhance sense of presence and performance give us a valuable insights into human cognition and psychology [KHJ*_12; BH95; PR14]. Furthermore, it can help designers to allocate proportionally computational resources when building future designs of the virtual systems with multimodal feedback.

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