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Effects of platform (immersive versus non-immersive) on usability and enjoyment of a virtual learning environment for deaf and hearing children

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Abstract

We report a user study focusing on the effects of platform (immersive, non-immersive) on usability and enjoyment of a deaf-accessible game for K-5 math and science education. The study highlighted hearing status and gender differences in using the two systems. Twenty-one children played the SMILE game [AVW07] in a FLEX immersive display with wand interaction and on a desktop computer with mouse and keyboard interaction. They were tasked with traveling to two different locations in the virtual environment, and with constructing an object (e.g., baking a cake). Their speed and accuracy in the tasks were scored, and they completed a survey with rating questions on game fun and ease of use in both platforms. Measured task times (travel and object construction) did not differ consistently with platform. Object construction took longer in the FLEX whereas non-primed search travel took longer on the desktop. Hearing Status was significant for cake baking and approached significance for travel. Deaf children took longer and made more mistakes than hearing children on both platforms. Gender was not significant for the travel but was significant for object construction with girls taking longer than boys on both systems. Increased video game familiarity was correlated with reduced travel times and reduced errors on both platforms. Platform differences were seen in the rating of 'fun', with the FLEX rated significantly more fun than the desktop by all subjects.

Categories and Subject Descriptors (according to ACM CCS): K.3.1 [Computer Uses in Education]: Computer-assisted instruction (CAI); H.5.2 [User Interfaces]: User-centered design

1. Introduction

The display system (or platform) is an integral part of a Virtual Environment (VE). Many VE are categorized based on the platform they use (e.g., Fish Tank-application, CAVE-application, desktop VR-application, etc.) [BDR*02]. Key differences among different VE systems include level of immersion, field of view (FOV), resolution, stereo/non-stereo mode, user interface [RPJ99]. Here we are concerned with the differences between immersive and non-immersive platforms. According to Slater et al. [SLUK96] immersion is a quantifiable characteristic of a technology, defined by the extent to which displays are *extensive*, *surrounding*, *inclusive*, *vivid* and *matching*. VE displays are considered extensive if "they can accommodate many sensory systems"; surrounding if the information arrives at the participant's sensory organs from any (virtual) direction; and inclusive to the extent that all sensory data from reality is excluded. Vividness refers primarily to resolution and quality of the visual display, as well as richness of the information content, and matching refers to the correspondence between the "participant's proprioceptive feedback about body movements and the information generated on the displays".

The concept of immersion can be translated into a set of system characteristics, which the Virtual Reality Laboratory at University of Michigan [Uni] has defined as follows: head-referenced viewing, stereoscopic viewing, direct, natural interactions with virtual objects with 6DOF input devices or data gloves, display of the virtual world in full scale and properly related to human size, auditory, haptic, and other non-visual feedback.

Although several researchers argue that there is a relationship between immersion and user task performance in VE, the benefits of immersive versus non-immersive systems on children's learning are, so far, primarily anecdotal [Gru04].

This paper adds to the relatively small body of literature by reporting a study quantifying the effects of immersive versus non-immersive platforms on children's appeal and task performance in a deaf-accessible virtual learning environment (VLE). In the study we compare a Spatially Immersive Device (SID), e.g, the Fakespace FLEX [Fak06] with wand interaction, to a non-immersive desktop computer with mouse+keyboard interaction for playing a math and science educational game. In addition to measuring the effects of platform on task performance and user enjoyment of the game, we highlight hearing status and gender differences in using the two VE systems.

The paper is organized as follows: in section 2 we discuss related work; in section 3 we describe the user study, in section 4 findings are reported; and in section 5 we discuss results and provide conclusive remarks.

2. Related work

There is evidence that immersive VE provide an improved system for display and interaction with 3D worlds [PPW97]. Ruddle et al. [RPJ99] compared travel in a virtual building walkthrough using a head mounted display (HMD) and a desktop computer. Their results showed that participants who were immersed in the environment using the HMD traveled through the building 12% faster. Pausch et al. [PPW97] compared head-tracked versus non-head tracked modes for a search task to determine if a specific alphabet letter was drawn on one of the walls of a virtual room. Results showed that, when the letter was present, there was no significant performance improvement in the immersive mode. When the letter was not present, detection of target absence was substantially faster in the immersive environment than in the non-immersive display.

Slater et al. [SLUK96] compared playing three dimensional chess in an IVE with data glove touch interaction and on a workstation screen with mouse interaction. Results suggested that increased immersion (egocentric rather than exocentric viewpoint, and greater vividness) improved performance in a task involving comprehension and memory of a complex 3D object. Mizell et al. [MJSS00] investigated IVR technology advantage over more conventional displays for visualizing complex 3D geometry. Subjects were shown an abstract rod sculpture on a Fakespace Boom display, an SGI workstation with 3DOF control of the image orientation, and a CAVE system, and were tasked with assembling a physical replica of the sculpture. Results showed that head-tracked immersive VR had a significant advantage over joystick-controlled display modes, especially when 3D objects were visualized in super-scale, surrounding the user.

2.1. Virtual Environments for Education

Although some studies suggest that VE can facilitate learning (e.g., [Rou04] [You97]), there is little information concerning which virtual reality features play a key role in enhancing understanding, or how to customize them for different learning applications. A few studies suggest that immersive VLE improve user's engagement and, to a certain extent, learning. Bricken and Byrne [BB93] argue that users are intrigued by interactions with well designed immersive worlds and spend more time and concentration on a task. According to Salzman et al. [SDLC08], immersion may make important concepts and relationships more clear and memorable, helping learners to build more accurate mental models. McCormick [Mcc95] suggests that enabling users to experience a phenomenon directly from different points of view (egocentric and exocentric) may improve performance and deepen learning by providing multiple and complementary insights.

Recently, Salzman et al [SDLC08] proposed a general model that describes how VR features, the concept being presented, learner characteristics, and interaction and learning experiences work together to influence the learning process in VLE. They applied this model to Project Science Space (i.e., NewtonWorld, MaxwellWorld and PaulinWorld) to evaluate key VR features that facilitate mastery of complex, abstract concepts. In a user study of NewtonWorld students commented that the ability to view phenomena from multiple viewpoints (egocentric, exocentric) was crucial to understanding. Asked to list features they liked the most, almost all participants listed egocentric reference frame and the multi-sensory cues. Results of a user study that compared MaxwellWorld (MW) to a similar non-immersive learning environment (EM Field-EMF) showed that the MW students were better able to define concepts than EMF students. For learning experience, student ratings indicated that they felt significantly more motivated by MW than EMF, but interaction was more difficult in MW and some students experienced simulator sickness symptoms. Although the learning experience and interaction experience were negatively related, students rated MW significantly more positively than EMF.

3. Description of the study

Our study builds on Salzman's research [SDLC08] as it attempts to identify the interplay between immersion and interaction/learning experiences with the overall future goal of determining whether immersion has a significant, measurable effect on learning outcomes for hearing and deaf children. This study aimed to (1) determine platform (immersive, non-immersive) effects on task performance and appeal of the SMILE game [AVW07], and (2) identify hearing status and gender differences in playing SMILE on the immersive and non-immersive systems. To measure task performance we developed a set of tasks and measured *time to complete each task* and *number of errors* while performing the task; to evaluate game enjoyment we used *rating questions*, *observation*, and *think aloud protocol*.

3.1 Participants

21 children ages 61/2-11years; 7 deaf, 14 hearing; 13 males, 8 females.

3.2 Materials

Game

Participants played the SMILE™ game prototype developed by the authors. SMILE is an immersive learning game that employs a fantasy 3D virtual environment and a bilingual interface to engage K-5 deaf and hearing students in math and science-based educational tasks. It includes an imaginary town populated by fantasy 3D avatars that can communicate in written and spoken English, or in American Sign Language (ASL). The user can explore the town, enter buildings, select and manipulate objects, construct new objects, and interact with characters. The game is designed for display on a variety of platforms including stationary immersive projection systems (FLEX), portable immersive systems (Fish-tank), and desktop computers. A demo of SMILE is available at http://www2.tech.purdue.edu/cgt/i3/smile/

Platforms

FLEX system with wand interaction (immersive)

Each subject stood in the center of the immersive, four screen FLEX display housed at the Purdue University Envision Center for Data Perceptualization and viewed the game through light-weight LCD active stereoscopic glasses. Each user wore an InterSense head tracker, which enabled the application to determine position and orientation of his/her eyes and re-draw the environment to match the user's perspective. Travel and object manipulation were accomplished with an Intersense I-900 wand. Haptic feedback was not provided.

Desktop computer with mouse+ keyboard interaction (non-immersive)

The game was displayed on a Dell Precision Workstation 690 with a 22" Dell E228WFP Wide Flat Panel Monitor with a resolution of 1280x800 pixels. The computer was positioned on a desk and subjects sat at a distance of about 0.5 meters from the monitor. Participants played the game with mouse and keyboard: they used the keyboard to travel through the city of 'SMILE Ville' and to switch between two game modes (i.e., learning and testing), and the mouse to manipulate virtual objects and make the avatar sign.

3.3 Procedure

Participants came to the Envision Center and participated individually. They were presented with a brief overview of the game and given a demonstration on how to use the immersive interaction devices. They were taken on a virtual tour of 'SMILE Ville' on both platforms. Since this study focused on the effects of platform on enjoyment and usability of the game, not on learning and knowledge acquisition, all participants were given a pre-test before the hands-on session to ensure that all subjects had the basic mathematics skills necessary to complete the activities and to determine the participant's familiarity with computer games.

Evaluation of task performance

The experiment included travel and object manipulation tests. The travel test required the subjects to perform one primed search and one search with unknown location of the target; the object manipulation test required them to construct an object. Both tests were administered as cross-over design tests, with 10 subjects using the immersive platform first, and the other 11 using the non-immersive platform first. The sequencing of the 2 tests was randomized among platforms and subjects. The subjects' time to complete the travel tasks and the object construction activity, as well as the number of errors while constructing the object were recorded and analyzed via a general linear model with a repeated measures model.

Evaluation of game enjoyment

After completing the hands-on experiment on each platform, subjects completed a survey focusing on fun of the game, ease of use, and desire to play the game again. All children used a pictorial Likert scale with 4 smiling faces to respond to each question. In addition, all testing sessions were recorded on video, which was scored for positive and negative instantiations.

4. Findings

4.1 Task Performance

Travel time: primed search

Subjects were tasked with traveling from the 'SMILE Ville' sign to the door of the clock-store, visible from the start position (see fig. 2). The participants were not required to stay on the paths, they could move anywhere in the environment. A terrain-following constraint was used to limit the subjects to only a specific plane. In other words, subjects could only 'walk' on the ground instead of being able to freely 'fly' to the target.

Platform Effect: Travel time to the Clock Store did not differ between the FLEX (mean 63.7s) and desktop systems (70.1s).

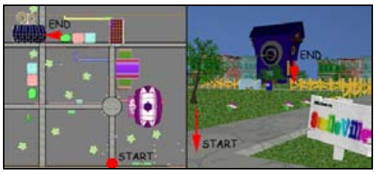

Figure 2: *Location of start and end positions for primed search. Orthographic view, left; perspective view, right.*

Hearing Status and Gender Effects: Travel time differed significantly by hearing status (deaf children took longer (mean 80.4s) than hearing (60.2s), $F(1,15) = 11.8$, $p=.004$). Deaf children took 28.8% longer in the FLEX and 38.1% longer on the desktop. Travel time was nearly significantly correlated with video game familiarity ($p=.06$), and affected slightly by gender ($p=.09$), with girls taking 16.6% longer (mean 69.9s) than boys (59.9s) in the FLEX and 10% longer on the desktop (girls 74.4s, boys 67.6s).

Travel time: non-primed search

Subjects were tasked with traveling from the clock-store to the bakery, not visible from the clock-store (see fig. 3).

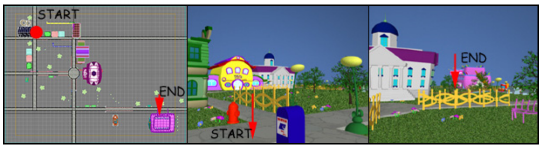

Figure 3: *Location of start and end positions. Orthographic view, left; perspective views, center and right.*

Platform Effect: There was a difference in travel times from the clock store to the bakery between the FLEX (mean 60.6s) and the desktop (67.1s), with the desktop taking 10.6% longer, $F(1,15)=5.65$, $p=.03$. Video game familiarity was significantly correlated with navigation ($p<.05$). The greater the familiarity with video games, the less time it took to travel in both platforms.

Hearing Status and Gender Effects: Hearing status was a significant main effect, with deaf children taking longer than hearing children, $F(1,15)=5.08$, $p<.05$ on both platforms (15.9% longer in the FLEX (deaf 66.7s, hearing 57.6s), 18.2% on the desktop (deaf 76.3s, hearing 62.4s)). Gender by itself was not significant, but the interaction of hearing status and gender neared significance, $F(1,15)=4.3$, $p=.55$. Deaf girls took longer (mean 71s) than boys (63.5s) in the FLEX, and hearing girls took longer (66.6s) than boys (60.1s) on the desktop; at the same time, deaf girls and boys took the same amount of time on the desktop (76s) and hearing girls and boys took as long in the FLEX (57.7s).

Object construction time

Subjects made a virtual cake by following a recipe. The children were asked to: read a recipe, select correct ingredients located on the baking room counter, weigh ingredients using a scale, put the correct amount of ingredients in a cake pan, open the oven door, put the cake pan in the oven, and open the oven door to see the result when the timer beeped.

Platform Effect: Duration of the cake baking activity in the FLEX (mean 344.5s) and on the desktop (mean 286.8s) neared significance ($p=.08$), with activity time in the FLEX 20.1% longer than on the desktop.

Hearing Status and Gender Effects: Hearing status was significant, $F(1,15) = 14.0$, $p=.002$, with deaf children taking 23.4% longer than hearing children on both platforms (FLEX deaf 384.9s, hearing 309.1s; desktop deaf 326.6s, hearing 266.9s). Gender was also significant, $F(1,15)=5.36$, $p<.05$, with girls taking 12.6% longer than boys. Girls took 14.9% longer (374.6s) than boys (326s) in the FLEX and 10.2% longer on the desktop (girls 304.3s, boys 276.1s).

Object construction - number of errors

Platform Effect: There was no significant difference in the number of errors made between the FLEX (mean 1.5) and the desktop (.6) platforms. Number of errors was significantly correlated with video game familiarity, $p<.02$. Those with least video game familiarity made the most mistakes.

Hearing Status and Gender Effects: There was a significant hearing status by gender interaction, $F(1,15)= 5.5$, $p<.05$; deaf girls made more errors (mean 2.7) than everyone else. The difference between deaf and hearing and between boys and girls was more pronounced in the FLEX than on the desktop.

4.2 Game enjoyment

The FLEX was rated significantly more fun than the desktop, $F(1,15) = 9.32$, $p<01$. These ratings were significantly correlated with age, $p<.05$. The younger the subjects, the more they liked the FLEX. Children aged 6.5-8 all gave the FLEX the highest rating, whereas children aged 9 and 10 split their FLEX ratings between 1 (Best) and 2 (Next best). 81% of the children rated the FLEX as 1.

There was a significant gender effect, $F(1, 15) = 6.09$, $p<.05$; girls liked both platforms more than boys. There was no significant difference between the FLEX and the desktop on ratings for ease of play. However there was a significant gender effect, $F(1,15)= 53.94$, $p<.001$, with boys finding both platforms easier to use than girls. When asked about playing the entire game again, for the FLEX, there was no variation– all 21 subjects were most enthusiastic about playing the game again. For the desktop presentation, all of the girls were most enthusiastic about playing the game again. The boys, however, were much less enthusiastic about playing the game again on the desktop, $F(1,15)= 4.94$, $p<.05$.

5. Discussion and conclusion

We have investigated platform effects on task performance and likeability of an educational game for deaf and hearing children. We compared a Spatial Immersive Device (SID) with wand interaction to a desktop PC with mouse/keyboard interaction for performing travel and object manipulation tasks. We identified hearing status and gender differences.

Platform differences were seen in travel speed and in object construction speed and accuracy. Travel times for the non-primed search task were significantly longer on the desktop than in the FLEX. This could be due to the fact that travel on the desktop was accomplished via keyboard and children had to remember the mapping of keys to different directions of travel and rotations of the environment. Travel with the wand seemed more intuitive to them since they used the wand joystick for moving through the environment, with direction of travel specified by wand orientation. Rotation was easier too because it was accomplished by depressing one button only and rotating the wand in the desired direction.

Another explanation for longer travel time on the desktop could be that children gained a better understanding of the spatial layout of ‘SMILE Ville’ in the FLEX compared to the desktop. Hence, they were able to remember the location of the bakery in relation to the clock-store, and get there faster. This hypothesis is supported by our observation of the children spending more time searching for the bakery on the desktop than in the FLEX.

Activity time to bake the cake in the FLEX took longer than on the desktop. Observation and think aloud protocol showed that this was due primarily to difficulty children experienced picking up and weighing objects in the FLEX. We noticed signs of frustration and comments such as ‘some of the ingredients are really hard to pick up’, ‘the scale is hard to read’, and ‘the 3D glasses really bother me’.

Hearing status and gender differences were seen in both travel tasks and the cake baking activity, with deaf children taking longer than hearing children and girls taking longer than. Platform differences were evident in the rating of fun, with the FLEX rated significantly more fun by all subjects. Age was significantly correlated with ratings of fun - the younger the subjects, the more they liked the FLEX.

This study brings us one step closer to answering our main research question: what are the features of VLE that make them effective for, and accessible to, deaf and hearing children, girls as well as boys, and non/pre-readers (K-1) as well as readers (2-3).We plan to continue these studies as development of the program progresses. Future work includes evaluation of learning outcomes with kindergarten and elementary school aged hearing and deaf children. The evaluation will be done in collaboration with two West Lafayette elementary schools and with the Indiana School for the Deaf (ISD) in Indianapolis. Critically, information of this type will provide guidelines for future VLE developments to meet the STEM educational needs of all students.

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