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TRAVEL IN IMMERSIVE VIRTUAL LEARNING ENVIRONMENTS: A USER STUDY WITH CHILDREN

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ABSTRACT

This paper describes the development and evaluation of three (3) first-person travel interfaces for immersive environments. The three interfaces presented in the paper have been developed for the SMILE™ project (**S**cience and **M**ath in an **I**mmersive **L**earning **E**nvironment), an immersive learning game that employs a fantasy 3D virtual world to engage deaf and hearing children in math and science-based educational tasks. Two interfaces are hand-based, while the third one allows for hands-free motion control. The evaluation aims to: (1) determine which interface is the most effective for the hearing users of SMILE™ in terms of accuracy, speed, appeal, and ease of learning, and (2) identify any gender differences in using the three travel methods. To accomplish this objective we have designed an experiment which compares the three techniques for moving directly to a target object; we varied the distance of the object from the user's starting position and the complexity of the path (number of turns) to reach the destination. Ten (10) hearing children ages 6-11 participated in the study; results show that although all travel techniques are easy to comprehend and use, the wand is the most effective interface. To our knowledge, this is the first paper that reports a study of immersive travel techniques with children. In a future publication we will report the results of the same experiment with non-hearing children.

KEYWORDS

Virtual Environments, Virtual travel, Children, VR Evaluation

1. INTRODUCTION

This paper presents the comparative study of three (3) immersive motion control techniques implemented in the recently developed SMILE™ application (Adamo-Villani, Carpenter & Arns 2006) (Adamo-Villani & Wright 2007). SMILE is an immersive game in which deaf and hearing children (ages 5-11) interact with fantasy 3D characters and objects and learn standards-based math and science concepts and associated ASL signs. SMILE™ includes an imaginary town populated by fantasy 3D avatars that communicate with the participant in written and spoken English, and American Sign Language (ASL). The user can explore the town, enter buildings, select and manipulate objects, construct new objects, and interact with the characters. In each building the participant learns specific math/science concepts by performing hands-on activities developed in collaboration with elementary school educators and in alignment with standard math/science curriculum. Each activity is in the form of a “good deed” whose objective is to make one of the “Smileville” characters smile again. In order to complete the activities, the user is required to navigate to different areas of the town and enter different buildings. Therefore, navigation (i.e., travel and way-finding) is an essential task in the game.

The object of this paper is the description and evaluation of three (3) travel interfaces developed for SMILE™. The first interface presented makes use of a 6DOF wand; the second one is a gesture-based interface comprised of a pair of light-weight 18-sensor data gloves coupled with a 6DOF wrist tracker; the third one is a body-centered interface which utilizes a dance platform. The evaluation study aims to identify strengths and weaknesses of each motion control technique with the goal of determining the most effective one for the hearing users and usage scenario.

In section 2 we discuss travel in Virtual Environments (VE) and we give an overview of current research in design and evaluation of immersive travel techniques. In section 3 we describe the three (3) travel interfaces used in the experiment and in section 4 we present the user study and report the results. Conclusive remarks and future work are included in section 5.

2. BACKGROUND

Navigation is a fundamental task in VE; it includes two separate components: travel and way-finding. Travel refers to how a user moves through space (or time), while way-finding refers to the user’s awareness of where he/she is located and where he/she is going in the virtual world (Sherman & Craig 2003). In this paper we are concerned with travel only and, specifically, with first-person travel methods.

A large number of travel techniques have been suggested and/or implemented by researchers and application developers. According to Bowman et al. (Bowman, Koller & Hodges 1997) most of these techniques fall into four categories: natural travel metaphors, that is techniques that use physical locomotion or some real/pseudo world metaphor for travel; steering metaphors that involve continuous specification of direction of motion (i.e., gaze-directed, pointing, and physical device techniques); target-based metaphors which require a discrete specification of goal; and manipulation metaphors which involve manual manipulation of viewpoint (i.e., for instance, ‘camera in hand’).

In regard to evaluation of immersive travel methods, until recently, research in Virtual Reality (VR) has focused primarily on improving the technology, without much attention to usability and to the specific needs and preferences of the target users. As a result, many VEs are difficult to use and navigate and, therefore, non-effective for their users (Hix et al. 1999). However, in the past few years, user-centered design and usability engineering have become a growing interest in the VR field and a few researchers have started to recognize the importance of VE design and evaluation. For example, Hix et al. (Gabbard, Hix & Swan 1999) have proposed an iterative methodology for user-centered design and evaluation of VE user interaction. Sutcliffe et al. (Sutcliffe & Kaur 2000) have suggested methods for evaluating the usability of virtual reality user interfaces, and Slater (Slater 1999) has focused on evaluation and measure of presence, including the effect of a physical walking technique on the sense of presence. A few user studies concerning immersive travel techniques have been reported in the literature. Bowman et al. (Bowman, Koller & Hodges 1997) have proposed a methodology for evaluating the quality of different motion control techniques for specific VE tasks. Kopper et al. (Kopper et al. 2006) have presented the design and evaluation of two travel methods for multiscale VE (MSVE), and Beckhaus et al. (Beckhaus, Blom & Haringer 2005) have reported an informal user study of two hands-free immersive travel interfaces.

As far as children's use of travel interfaces, Strommen's study (Strommen 1994) is the only one to describe a comparative evaluation of three non-immersive travel techniques for children to control point of view navigation. To our knowledge, no study of immersive travel methods with children can be found in the literature.

Considering the relatively small number of studies of VR travel techniques reported so far and the fluid nature of VE systems and applications, there is still a need of empirically evaluating the usability of immersive travel interfaces. User studies like the one presented in this paper could help to significantly improve the usability of VLEs for children, and VR applications in general.

3. THE TRAVEL INTERFACES

The three interfaces were built using commercially available hardware components and are primarily intended for travel in stationary, multi-screen projection based VR devices (i.e., the Fakespace FLEX), however, they could be adapted for use in Fish tank VR and single screen projection systems.

3.1 The Wand Interface

This interface is an example of the 'flying vehicle control' travel metaphor (Ware and Osborne, 1990) which relies on hand-based gestures and orientation of hand-held pointing devices for control of direction and velocity. It makes use of an Intersense I-900 wand (shown in figure 1) which is essentially a 3D mouse with a 6DOF tracker. The wand contains six buttons and a pressure sensitive joystick that can be programmed to serve a number of uses. The joystick is used for navigation, while the buttons are used to set modes and select options; direction of travel is specified by wand orientation as opposed to user gaze. Rotation is accomplished by depressing one of the buttons and rotating the wand in the desired direction. The main advantage of this interface is that no physical locomotion is required to move through the environment. The main disadvantage is that one hand is used for travel and, therefore, is not available for other concurrent tasks.

Figure 1. Child in The FLEX using the wand

3.2 The Glove Interface

This interface makes use of a pair of light-weight 18-sensor Immersion cybergloves coupled with an InterSense IS-900 6DOF wrist tracker. Each glove has two (2) bend sensors per finger, four (4) abduction sensors, and sensors for measuring thumb cross-over, palm arch, wrist flexion, and wrist abduction; the wrist tracker uses ultrasonic and inertial tracking to determine the position and orientation of the user's hand within the 3D environment.

In addition to travel, in the SMILE application this interface is also used to input the ASL (American Sign Language) 0-20 number handshapes and to grasp and release objects; in this paper we consider travel tasks only. In order to travel through the environment, the user makes one of five (5) hand gestures. The "L" handshape of the manual alphabet is input to move left, the "R, B, F" handshapes to move right, backward, and forward respectively, and rotation is accomplished by making the "T" handshape and moving the hand in the desired direction.

A problem inherent with implementing gesturing as a means of interaction is 'the fact that natural gesturing involves a series of transitions from gesture to gesture essentially creating a continuum of gesturing' (Mapes & Moshell 1995). This makes distinguishing successive gestures very difficult, as the hands and fingers may be constantly moving. In order to ensure recognition accuracy, our interface requires users to form the "neutral" hand pose between different successive gestures. Figure 2 shows the 5 navigation gestures along with the "neutral" handshape, on the left; and a student traveling in SMILE with the glove, on the right.

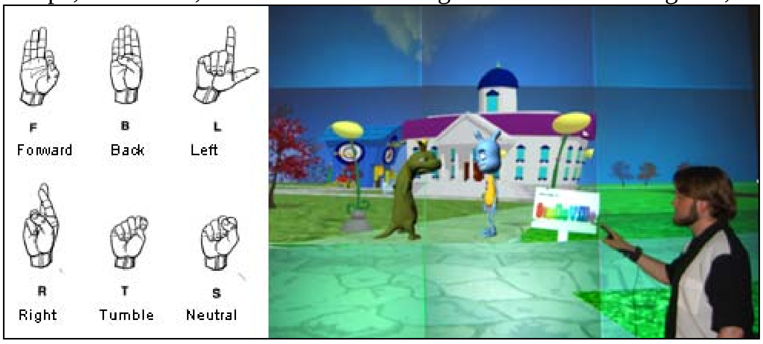

Figure 2. The six (6) travel hand gestures, left; user traveling with the glove, right

Recognition. To recognize the hand gestures input via the gloves we have used a neural networks approach based on the Fast Artificial Neural Network Library, (FANN) (Nissen 2000). This library supports various configurations of neural networks. For SMILE we have used the standard complete backward propagation neural network configuration with symmetrical sigmoid activation function. This configuration includes a set of twenty-eight (28) networks, one per hand gesture, with eighteen (18) input neurons that corresponds to the eighteen (18) angles provided by each data glove. To date, the hand gestures recognized by the system include: twenty-one (21) ASL number handshapes + five (5) navigation gestures + one (1) grasp gesture + one (1) "neutral" gesture. A more detailed description of the gesture recognition system can be found in (Adamo-Villani, Heisler & Arns 2007).

Communication with SMILE™. The handshape recognition software runs on a Windows-based laptop. However, the SMILE application, when running in immersive environments, such as a tiled wall or a CAVE-like device, runs on a cluster of several workstations. These workstations may run either Linux or Windows. Thus it is necessary for the recognition software to communicate with the SMILE™ application through some external mechanism. The VRJuggler software that SMILE™ is built on provides a C++ library for external communications via a TCP/IP network, called VPR (VRJuggler Portable Runtime). SMILE™ uses these external interfaces by first opening a TCP/IP connection to the computer running the handshape recognition application, during the initialization of the SMILE application. When recognition of a handshape occurs, the application sends the recognized gesture over the network via theTCP/IP socket.

3.3 The Dance Mat Interface

The dance mat is an example of body-centered travel technique which uses *stepping* as a locomotion metaphor (to control direction and velocity of travel). The interface makes use of the Cobalt Flux dance platform; communication between the mat and the FLEX system is implemented using the Linux joystick drivers through Gadgeteer, VRJuggler device handler. The dance mat is connected to the USB port of the computer using a wireless device which allows PlayStation 2 game pads to connect to a PC. It is treated by the drivers as an 11-button mouse, with each button having a digital on and off state. A configuration file assigns a digital proxy to each button and the proxies can be programmed for different functions.

Currently, the user steps on the front arrow of the platform to translate forward, on the back arrow to translate backward, and on the side arrows to move left or right. Stepping on two arrows at once allows the user to move diagonally. The user can rotate clockwise or counter clockwise by stepping on the diagonal arrows. Stepping on the button in the center of the mat disables all the other buttons temporarily, this prevents the user from moving accidentally. The buttons are programmable, so other methods of navigation can be implemented. The main advantage of the dance mat interface is that it allows for hands-free navigation; one disadvantage is that the user is required to continuously step on the buttons and this can lead to fatigue and loss of balance. Figure 3 shows the dance mat used for the experiment.

Figure 3. User in the FLEX traveling with the dance mat

4. USER STUDY

The goal of the user study was to determine which motion control technique is the most effective for the hearing users of the application (children ages 6-11). In the context of SMILE™, the following quality factors were selected as key attributes of effectiveness of virtual travel techniques: *accuracy*, *speed*, *ease of learning*, and *appeal*.

4.1 Experiment design

Subjects. Ten (10) hearing children age 6-11 years; four (4) females and six (6) males. The minimum number of participants was estimated using the Nielsen and Landauer formula (Nielsen & Landauer 1993) based on the probabilistic Poisson model. Results of the study show that the number of subjects was sufficient.

Stimuli. Nine (9) different travel layouts, each one consisting of a path and a target object (a spaceship) placed at the end of the path, the width of the path (6 ft) is equal to the width of the path in SMILE™. The paths differed only in length (50, 100 and 150 ft) and in number of turns included (1, 2, and 3 90 degrees turns). The nine paths used for the experiment are represented in figure 4.

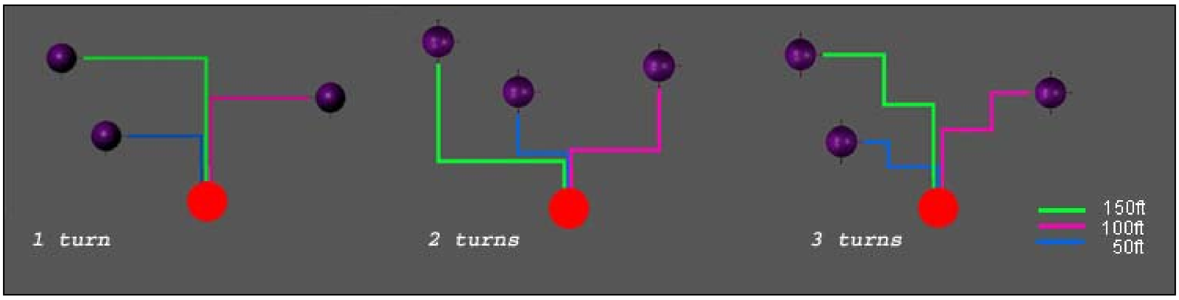

Figure 4. The 9 paths used for the experiment

Procedure. The experiment took place in the 4-wall FLEX VR theater housed at the Envision Center for Data Perceptualization, at Purdue University. Subjects were assigned the task of traveling directly to an explicit target object (a spaceship) placed at the end of each of the nine (9) paths; upon reaching the target, the spaceship would take off into the sky. Subjects were tasked with reaching the nine (9) targets with the dance mat, the wand, and the data glove (for a total of twenty-seven (27) trials). The tests were administered as a cross-over design experiment, with four (4) subjects using the dance mat first, three (3) subjects using the wand interface first, and three (3) subjects using the data glove first. The sequencing of the paths, in regard to their length and number of turns, was randomized among travel interfaces and subjects. A terrain following constraint was used to limit the subjects to only a specific plane. In other words, subjects could only “walk” on the path instead of being able to freely “fly” to the spaceship.

The subjects’ time to reach the target, the number of errors (i.e., the number of times the subjects hit the edge of the path), and the time required to learn how to use the travel technique were recorded. In addition, subjects were asked to identify the travel interface that they perceived as “most fun”. Results related to time and number of errors were calculated via a general linear model with a repeated measures model.

4.2 Results

Time. To meet the assumption of normality of the error terms in our model, a log transformation was employed on our time response variable. Results show that the trial effect is significant at the 1% level ($p = 0.0046$). That is, the time necessary to reach the target object decreased as subjects experienced more trials; this was expected and appropriate to include in our model.

Wand trials were completed significantly faster than dance mat trials ($p < 0.0001$). There was not, however, a significant difference in completion time between wand and glove trials. Results are shown in figure 5.

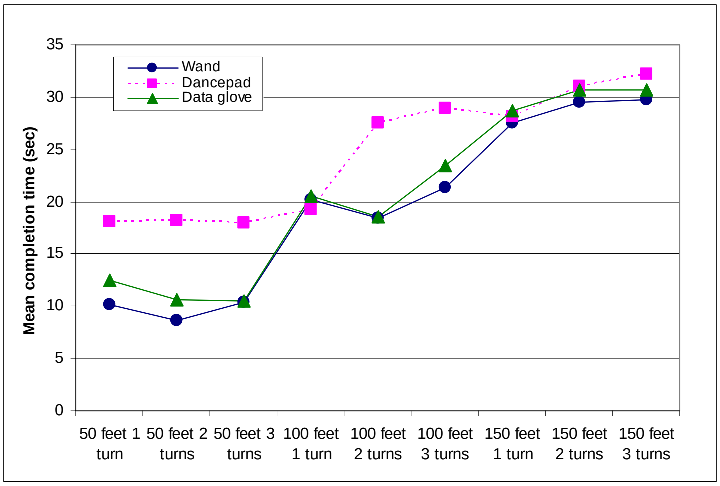

Figure 5. Time comparison

Accuracy. In general, wand trials showed a lower number of errors than dance mat trials (adj. $p < 0.0001$) and glove trials (adj. $p < 0.0011$). Results are shown in figure 6.

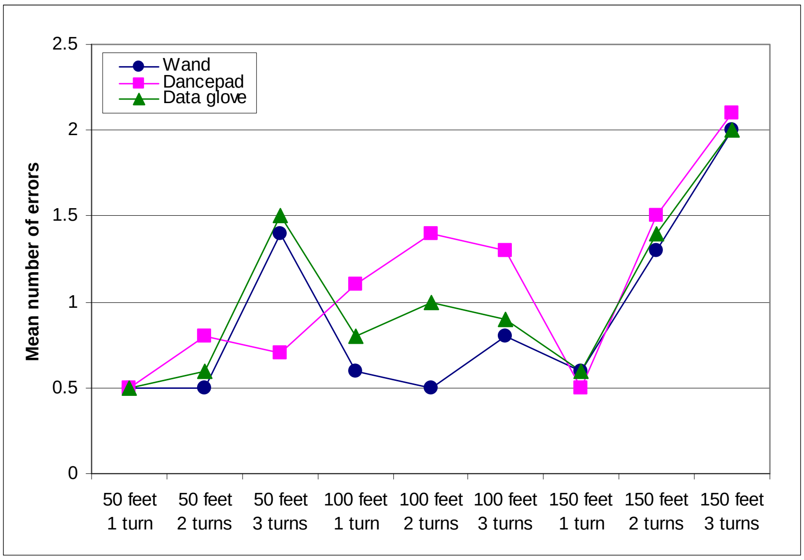

Figure 6. Comparison of number of errors

Gender differences. Results show a statistically significant interaction effect between gender and device ($p = 0 .0012$) at the 1% level. No such effect was identified in regard to trial and gender; in other words, gender affected performance difference between the two devices, but it did not affect performance difference across the different paths.

Gender difference in time. Results show that males completed the dance mat trials significantly faster than females ($p = 0.0111$) (see figure 7).

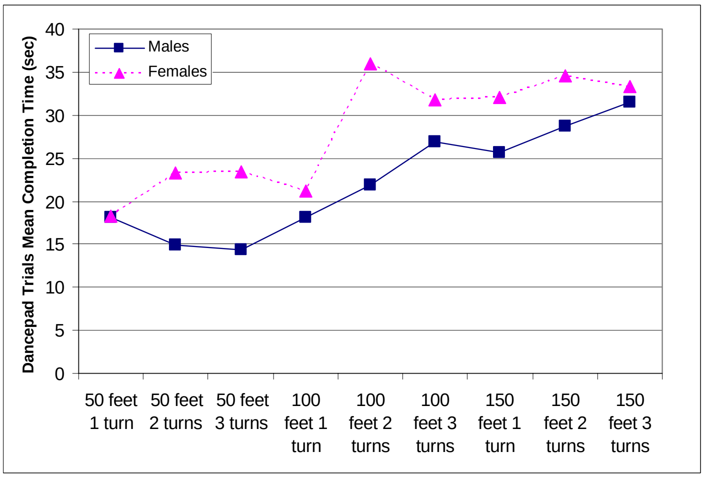

Figure 7. Comparison of completion time between male and female subjects (Dancepad)

There was not, however, a significant gender difference in completion time for the wand trials (see figure 8) and for the glove trials (see figure 9).

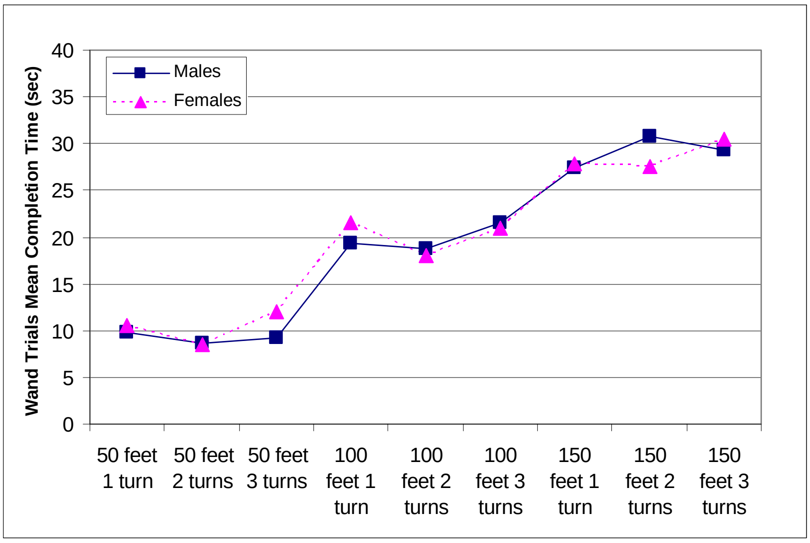

Figure 8. Comparison of completion time between male and female subjects (Wand)

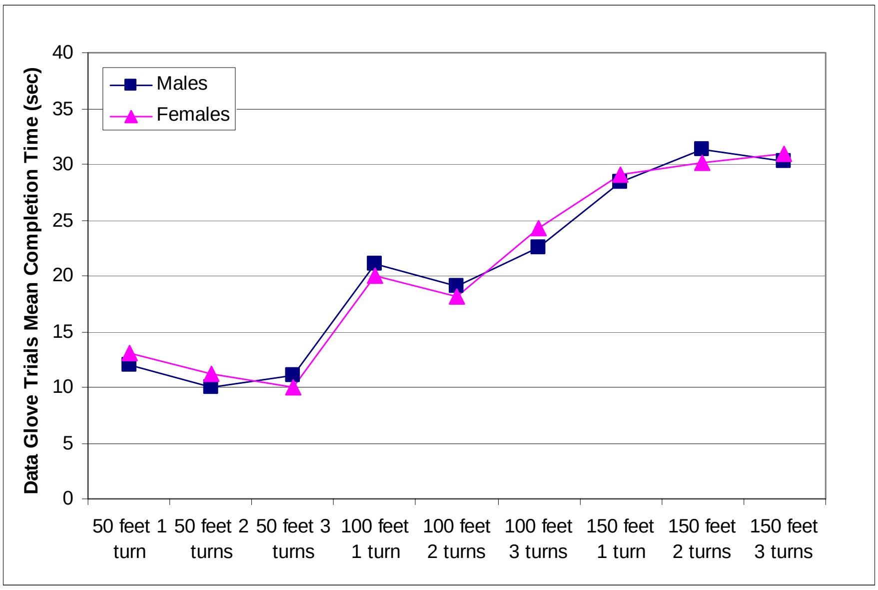

Figure 9. Comparison of completion time between male and female subjects (Data glove)

Data related to solely females show that female subjects completed wand trials significantly faster than dance mat trials ($p < 0.0001$) and glove trials ($p < 0.0003$). Data related to solely males show that, in general, male subjects completed wand trials faster than dance mat trials (p = 0 .1033), and faster than glove trials (p = 0 .1231); however these differences are not quite significant.

Gender difference in accuracy. When factoring in the three (3) device trials, no relevant difference in errors between males and females was identified. In particular, statistical results show no difference between males and females in respect to the amount of errors with the wand and with the glove. However, there was a substantial gender difference in errors for the dance mat trials, with a significantly lower number of errors for male subjects.

Data related to solely females show a significantly lower number of errors during wand trials as opposed to dance mat trials (adj. $p < 0.0001$) and glove trials (adj. $p < 0.0002$). Data related to solely male subjects also show a lower number of errors with the wand as opposed to the dance mat (adj. $p = 0.0236$), and to the glove (adj. $p = 0.0247$).

Learning time and appeal. In regard to learning time, there was no relevant difference between wand and dance mat; however there was a significant difference between wand/dance mat and glove ($p < 0.0001$). This is due to the fact that subjects took significantly longer to memorize the five (5) navigation gestures. No significant difference was identified between males and females. All subjects found the three interfaces easy to learn and use, and enjoyed traveling in the virtual environment. However, 70% of the subjects found the wand 'more fun' than the dance mat and the glove.

In conclusion, the wand appears to be a more effective travel technique for the intended target audience and usage scenario. Results show that *learning time*, *speed of travel* and *accuracy* are generally higher for the wand-based interface.; in addition, as far as *appeal*, the majority of the subjects preferred the wand.

5. CONCLUSION

This paper describes three (3) travel interfaces developed for an immersive VLE for deaf and hearing children. It also reports the results of a study comparing children's use of the three (3) travel techniques. The study aimed to assess hearing children's performance using each interface with the main goal of determining which travel method seems most appropriate for the hearing target audience and usage context.

Results of the study demonstrate that, for hearing children, first person navigation in immersive environments has high appeal. While all travel interfaces were perceived as easy to comprehend and use, evaluation results showed that the wand interface is the most effective of the three in the context of our application. The comparison of the two travel methods has provided critical data that has informed the final decision on which interface method to adopt in SMILE™ when the target users are hearing children. The authors believe that more frequent use of these kinds of studies in the development of immersive Virtual Learning Environments could substantially improve the usability, and thus the effectiveness, of immersive, interactive applications for K-12 education.

Future work involves repeating the experiment with non-hearing children, analyzing the results and identifying differences between deaf and hearing users.

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