Designing a device to navigate in virtual environments for use by people with intellectual disabilities

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ABSTRACT

As part of the process to design a device that would enable users with intellectual disabilities to navigate through virtual environments, an earlier study had collected baseline data against which to evaluate prototype design solutions. This study describes the evaluation of three design solutions: two modifications to a standard games joystick and a two handed device. Evaluation data were collected while 22 people with intellectual disabilities worked through four VE designed using a games format. None of the prototypes gave significantly improved performance over the standard joystick and some actually led to the user receiving more help from the tutor to use the device. This difference was significant for the two handed device in all four games. However there was considerable variation in results such that with some devices there was a reduction in the variability of scores between individuals. Future research needs to focus on the design of environments and how best to match the user with the device.

1. INTRODUCTION

There is a growing body of work to indicate the usefulness of virtual environments (VE) for people with intellectual disabilities (Cromby, Standen and Brown, 1996; Standen, Brown and Cromby 2001; Standen and Brown 2005; Standen and Brown in press). They have been shown to be effective in facilitating the acquisition of living skills for example shopping (Standen, Cromby and Brown, 1998) and navigating new environments in children with severe intellectual disabilities and have been developed to prepare young people for the potentially distressing experience of giving evidence in court (Laczny et al, 2001). Their three-dimensional nature allows the creation of ecologically valid settings to promote activities like choice making (Standen and Ip, 2002) which people with intellectual disabilities have limited opportunity to practice. Finally, they can provide an engaging activity for people who are frequently underoccupied and denied real world opportunities. (Standen, Lannen & Brown, 2002).

The work carried out so far has employed non-immersive VE where the environment is displayed on an ordinary computer monitor as developments could rapidly be made available for end users with limited budgets, limited technical expertise and limited backup. With the increasing power of entry level computers and the more recently commercially available platforms, the possibilities for interactive three dimensional environments have greatly increased. Developers can offer considerable choice and structure environments in order to exploit advances in educational theory (Shopland et al, 2004). There are also a variety of interfaces commercially available for interacting with three dimensional environments but these have been described as "mostly adequate…rather obstrusive and require some amount of training to use" (Bing Kang, 1998). The problems for people with intellectual disabilities in using these devices have been reported by Standen, Brown, Anderton and Battersby (in press). Using a methodology established in an earlier study they set out to systematically document the performance of a group of people with severe intellectual disabilities with the currently recommended devices (standard 3 axis games joystick or the arrow keys on a keyboard) to navigate through several interactive three dimensional environments. The results confirmed the problems reported in earlier studies (Trewin and Pain, 1999; Brown, Kerr and Crosier, 1997) and they cautioned that with problems like these, users can become frustrated and demotivated and fail to benefit from the advantages of using VE.

One solution to the problem of interfaces is to develop "natural interfaces that are intuitively simple and unobstrusive to the user" (Bing Kang, 1998). These are interfaces that have the capability to capture human gestures or biodata and translate it into code to replace standard interfaces. Bing Kang (1998) described an approach that used the orientation of the user's face to move and orient the VE. Coyle et al (1998) have developed a non contact head controlled mouse emulator for use by quadriplegic operators to control VE; whilst Bates and Istance (2004) are developing a reliable system for eye based VE interaction. More recently, Hochberg et al (2006) implanted a 96 microelectrode array in the primary motor cortex which allowed a patient with tetraplegia to control the position of the cursor on a computer screen. These systems are more easily suited to replace a single function of the mouse either the right or left click or the control of the arrow thus limiting their usefulness in interactive educational VE. Additionally they are often difficult to calibrate and can be tiring for disabled users. Their utility will ultimately depend on how affordable they will be to a target population who also experience multiple disadvantages due to the added impact of low resources and income.

The study by Standen et al (in press) was conceived as the first step in a process to design a device that would enable users with intellectual disabilities to navigate through and interact with structured educational virtual environments. The intention was to collect information which could then be used to inform the design of a usable control device or devices and to act as a baseline against which they can be evaluated. 40 people attending a day centre for people with intellectual disabilities aged between 21 and 67 years used four environments with an equal number of sessions with the different devices being evaluated. Results indicated that first, due to the cognitive load of discriminating between the functions on one device, separate devices are retained for navigation and interaction. Secondly, resolving some of the physical difficulties with the joystick may reduce the likelihood of demotivation on initial usage and also allow better performance once use of the device has been mastered. This paper describes the evaluation of a series of design solutions for a navigation device that met the criteria set out by Brown, Kerr and Crosier (1997) that future input device design or modification should ensure that they should be operable by people with fine motor difficulties, modifiable, robust and affordable. However it was also recognised that it is highly unlikely that one device will suit all.

2. METHODS

2.1 Design

The study followed the five stage process proposed by Lannen et al (2002):

- Understand and Specify the Context of Use
- Specify User and Organisational Requirements
- Technology Review
- Produce Concept Designs and Prototypes
- Carry out a User-Based Assessment

This process is complemented by a Usability Team and a User Team. The role of the Usability Team is to guide the application of this user sensitive inclusive design methodology. The User Team should represent a cross section of the target audience and they contribute to the design process by considering design requirements and how these could be met in potential design solutions.

The earlier study (Standen et al, in press) brought the work to the beginning of the fourth stage and at this point a review of the results by the usability team decided upon two possible design solutions. The first was to modify the joystick as it allows better performance but takes time to master and secondly to devise a two handed device. This second solution had arisen from the pilot work being carried out by Lannen (2002).

The sequence of prototypes evaluated was therefore as follows:

1. Attaching a Sensitrac Flat Pad (*www.traxsys.com*) to the base of the joystick to affix it firmly to the desk. This was because during baseline evaluation, so many participants had to have the base of the joystick held to limit slipping of the device.
2. In addition to the flat pad an aluminium plate with a milled cross was fixed to the base of the joystick to limit movement to four directions (-Y, +Y, -X, +X) instead of the usual eight (additional 4 XY variants). This was because during baseline evaluation much of the help being given with the joystick

resulted from the participant moving in unintentional directions and because the keyboard arrows had helped in road crossing (see Figure 1).

3. Finally, a device was made which had to be controlled with both hands by mounting a Saitek wheel onto a 3 axis joystick. They were connected with a specially constructed spring loaded stock that pivoted at both ends via a ball joint to enable a floating action (see Figure 2)..

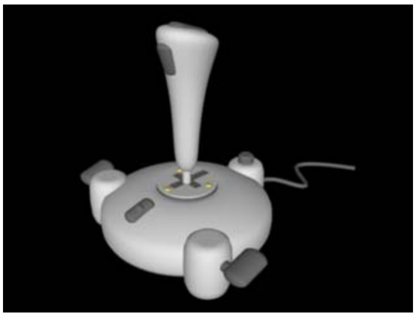

Figure 1. *A computer generated image of the joystick with the plate fixed to the base.*

Figure 2. *The two handed device.*

These were evaluated using a repeated measures design. Each member of the user team worked through four VE with each of the design solutions to enable performance data from each design solution to be compared with their own data from the currently used navigation devices.

2.2 Participants

A usability team was formed from the research team which included a computer scientist, two psychologists and a software engineer with a background in design. All worked in the area of disability. They were joined by the manager of a company that produced interfaces for people with disabilities and a manager of a day centre for people with intellectual disabilities. The user team included 22 volunteers (10 men and 12 women) aged between 21 and 67 years who regularly attended a day centre for people with intellectual disabilities and all met the requirement of having sufficient visual ability to see the VE on the computer monitor. They were selected to represent a wide range of ability within the severely disabled category. Their verbal IQ ranged from 9 to 113 and non verbal IQ from 0 to 28 so their combined scores all fell within the severely disabled range. For motor control and co-ordination, three were in the normal range, 13 showed moderate discrepancy from normal and five showed severe discrepancy with one being unable to complete the assessment.

The level of verbal ability of the user team prevented most of them from participating in group discussions so their involvement was on an individual level.

2.3 Virtual environments

Four training VE (*asteroids, dolphins, temple and road crossing* Figure 3) had been constructed in order to evaluate the currently used devices and these were once again used for this part of the study. A full description is given in Standen et al (in press). They were all designed using game format in that they consisted of varying levels of difficulty with access to each level only allowed once the correct level of performance had been achieved at the previous level and each environment constrained different possibilities in order to test a range of uses of the control devices but without presenting the user with too many options initially. The software also collected information on task achievement (scores), time taken and collisions. For two environments the device was not required to provide forward movement. Table 1 summarises the characteristics of each environment.

2.4 Data collection

Data collection took place in the day centre attended by the participants. Participants had sessions scheduled for once a week, which lasted a maximum of 30 minutes but could be terminated earlier if they wished. One of the researchers (NA) sat alongside them to give assistance and encouragement. Each session was recorded on videotape, with the camera positioned to view both the participant and the researcher sitting next to them. The videotapes were analysed using a method established in an earlier study (Standen et al, 2002) which yielded measures of help given by the researcher. For the present evaluation only the percentage of time physical assistance with navigation was used. The researcher also kept a diary to record any other information that might be useful but that would not be picked up by video analysis or the software data gatherer. Computer collected data (scores and collisions) were adjusted for length of session. Video collected data were expressed as a percentage of session duration. Statistical comparisons between the devices were made using the Wilcoxon test for paired data.

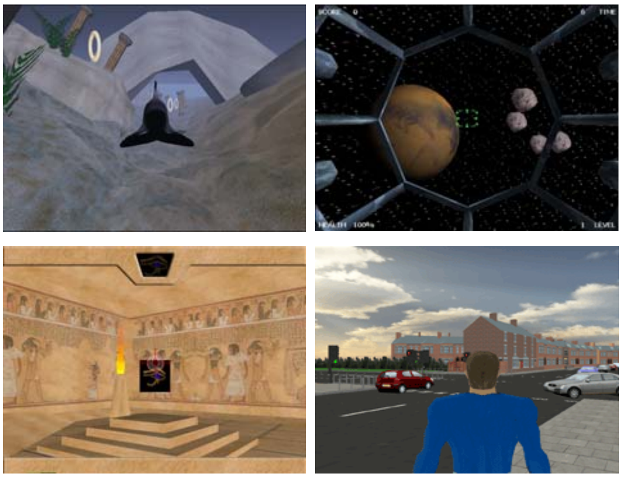

Figure 3. *Screen shots from each of the four virtual environments.*

Table 1. *Characteristics of training environments.*

	Devices used for forward movement	Devices used for up/down and left/right movement	Devices tested for interaction	Follow avatar
Asteroids	None required	joystick	joystick button	no
		mouse	LH mouse button	
Dolphins	None required	joystick	None required	yes
		arrow keys		
Temple and Road crossing	joystick	joystick	LH mouse button	yes
	arrow keys	arrow keys	LH mouse button	

3. RESULTS

Scores or collisions and percentage of session during which the tutor gave physical assistance are shown in Table 2.

Table 2. *Median adjusted scores/collisions and median percentage of session spent by tutor help.*

measures	scores		collisions	Help with navigation			
devices	dolphins	asteroids	temple	dolphins	asteroids	temple	road crossing
joystick	2.87	4.54‡	9.65	0	15.12‡	14.55‡	6.2
keyboard	2.32		8.88	0		4.22	8.41
mouse		10.64			0		
Sticky base	3.44‡*	3.57‡	8.62	11.77‡*	13.73	9.6	11.31
plate	3.18‡	3.12‡	11.44‡	8.34‡*	3.98	8.66	6.36
2 hand	3.69‡	1.93‡*	8.82	27.50‡*	33.61‡	48.67‡	27.23‡*

* Significantly different from joystick
‡ significantly different from keyboard/mouse

3.1 Addition of Sensitrac Flat Pad to the base of the joystick.

This modification did allow users to achieve higher scores in one of the environments than with the standard joystick ($p<0.017$) or the keyboard ($p<0.009$) but they were still significantly lower than those achieved with the mouse ($p<0.0003$). Where collisions were recorded there was no significant improvement and in one game users actually needed significantly more help than they did with either the original joystick ($p<0.02$) or the arrows on the keyboard ($p<0.002$). However, in two of the environments although not significant the medians for amount of help received are lower with the addition of the sticky base.

3.2 Attaching the aluminium plate

Attaching a plate to the base of the joystick that limited movement to four directions gave no improvement in scores or collisions over the addition of the sticky base. However it allowed the user to gain better scores ($p<0.05$) than they did with the arrows in the keyboard but at the same time more collisions ($p<0.05$). Medians suggest that the tutor spent less time helping users with this modification than they did with the original joystick, keyboard and sticky base but these differences did not reach significance. This lack of a significant difference is largely due to the huge variation in scores. An examination of individual scores: revealed that with the addition of the aluminium plate only 2 people received help more than 40% of time as compared to 6 people using the standard joystick.

3.3 Two handed device

On the easiest environment this prototype enabled participants to achieve higher scores than with all the other devices significantly ($p<0.005$) so when compared with the keyboard but by the time this prototype was being tested, participants were very familiar with this environment. When collisions were recorded it was no different to any of the other devices. However, with the more complicated environments participants gained fewer scores than with any of the other devices and needed more help than they did with any of the other devices. For example, significantly ($p<0.001$) more help was received than with the standard joystick in road crossing.

4. DISCUSSION

These results are disappointing as after all the consultation and testing the only clear cut result was that the two handed device, in spite of being the last one that was evaluated, was no better on performance and was worse in terms of help required to use it when compared with the standard joystick it was intended to replace. The single most effective solution was the addition of the Sensitrac flat pad to prevent the joystick base slipping. While there is no evidence in the results presented here, observations from the researcher's diary also support the use of this modification. This is a low cost solution that did not have a major impact on group results but gave many individuals confidence to experiment with the force they exerted on the joystick.

These disappointing results may be because the team was unrealistic in aiming to achieve a low cost solution: simple modifications to mass produced devices are perhaps not the way to meet the needs of this group of users. The intention to produce affordable solutions was a priority as this makes such devices available to a poorly resourced client group. Basing solutions on already available components increases the chances that the design solution would be manufactured. These requirements necessarily constrained the possible solutions to the design challenge.

In addition to the constraints imposed on the solution before the study began it was probably inappropriate to look for one solution for all the participants and also to use group results to evaluate each prototype. Although the measures recorded from each user were compared with their own measures on the other devices, an examination of individual results indicated that some individuals did much better with some prototypes than with others. This may be due to their levels of cognitive or motor ability but also to an interaction between their ability and the different requirements of each environment. For example, some participants navigated well with the cross plate attached to the joystick in the *road crossing* environment. This environment was characterised by perpendicular lines (edges of pavement or crossing) and most movement was required in straight lines with 90 degree turns. However, not all participants grasped this but those who did, performed well in this situation.

From the previous study (Standen et al, in press) it was clear that constraining the tasks for the participant (eg providing forward movement) was beneficial but this obviously constrains the situations that can be depicted in the environment and restricts the freedom to explore. In spite of these disadvantages, the immediate solution may be to focus on the design of the environments to avoid disorientation (Ruddle and Jones, 2001) and make it possible for the more disabled user to employ the easier devices such as mouse emulators. Flexible software is easier to achieve than flexible hardware.

An obvious disadvantage of an evaluation of this nature is that participants spent regular sessions throughout two years using the environments. Even allowing an initial period in which participants can become familiar with the set up and the software, their performance did not plateau and an increase in ability to play the games was taking place throughout the study. This should have led to better performance with the later prototypes whereas in fact the opposite was the case. An unforeseen advantage of this was that many participants who returned to using the standard joystick at the end of the study, appeared to have much better motor control and hand eye co-ordination. This should not be surprising given the work already reported on the use of VE for motor rehabilitation (Holden, 2005) and future work should focus on this advantage for this user group.

Acknowledgements: This research was carried out with the support of EPSRC award number GR/R21851

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