Problems with control devices experienced by people with intellectual disabilities using virtual environments: a systematic evaluation

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ABSTRACT

Virtual environments have a role to play in facilitating the acquisition of living skills in people with intellectual disabilities, improving their cognitive skills and providing them with entertainment. However, the currently recommended devices to allow navigation in and interaction with the environments are difficult to use. Using a methodology established in an earlier study, the study aims to systematically document the performance of users with the currently recommended devices in order to i) inform the design of a usable control device or devices and ii) act as a baseline against which they can be evaluated. 40 people with severe intellectual disabilities aged between 21 and 67 years used four environments with an equal number of sessions with the different devices being evaluated. Results suggest that for navigation, the joystick is better than the keyboard but that for interaction the mouse is better than using the fire button on the joystick. Preventing slippage of the joystick base would make its use much easier and it is suggested that separate devices are retained for navigation and interaction.

1. INTRODUCTION

In the UK around 25 people in every thousand have mild or moderate intellectual disabilities and about four or five per thousand have severe intellectual disabilities (DH, 2001). These proportions are similar in many developed countries and where lower rates have been reported, for example in Taiwan, it is acknowledged that they are increasing (Lin, Wu &Yen, 2004). For the most disabled of these help will always be needed with almost every aspect of daily living yet even those who are more able will still need a degree of support to achieve the things the rest of society takes for granted. According to the 2001 White Paper (DH, 2001), people with intellectual disabilities are amongst the most socially excluded and vulnerable groups in Britain. The intention of current policy is to enable them to have as much choice and control as possible over their lives, be involved in their communities and to make a valued contribution to the world at work.

Virtual environments (VE) have a role to play in this process (Cromby, Standen & Brown, 1996). The benefits of using virtual environments (VE), for people with intellectual disabilities have been described by Cromby, Standen & Brown (1996). Initial work suggests that they are effective in facilitating the acquisition of living skills for example shopping and navigating new environments (Standen, Cromby & Brown, 1998) by children with severe intellectual disabilities. Their three-dimensional nature allows the creation of ecologically valid settings to promote activities like choice making (Standen & Ip, 2002) which people with intellectual disabilities have limited opportunity to practice (Cooper & Browder, 2001). Finally, they can provide an engaging activity for people who are frequently under occupied and denied real world opportunities (Standen, Lannen & Brown, 2002).

The work carried out so far has employed desktop VE where the environment is displayed on an ordinary computer monitor. Utilising control devices, the user's tasks are to navigate their way around the environment and interact with it. Navigation in a VE can have two meanings. Primary navigation is finding one's way in the environment. Secondary navigation is manipulating the viewpoint as seen through the computer screen. Navigation can be on a continuum between automatic, where the user is taken through the environment without any action on their part and self-controlled. In reality it is usually semi automatic, i.e. constrained by the software. So, for example, many environments employ terrain tracking where the user can only move on a horizontal plane. Within this plane there are usually 2 degrees of freedom, i.e. forward /back, turning left or right. Turning can be as for a person (pivoting on the spot) or for a car (the user must always move forward to turn). Interaction can activate objects (select item on supermarket shelf and move it into trolley), move them or cause one object to interact with another (e.g. put key in lock). These latter two functions would involve drag and drop.

A variety of devices are employed for controlling the software but Hall (1993) recommended that for navigation a joystick limited to two degrees of freedom had the greatest utility. The more functions a device possesses, the more difficult it is to operate. So, for example, when using a spaceball which has six degrees of freedom, the user with intellectual disabilities frequently became lost. Brown, Kerr & Crosier (1997), evaluating a range of affordable and robust interaction and navigation devices, also favoured use of the joystick finding it more suitable for navigation tasks than the keyboard. For interaction tasks, if drag-and-drop was not required, the touch-screen and mouse were equally effective, although the touch-screen was difficult to calibrate.

However, even the preferred devices of joystick for navigation and two button mouse for interaction are not without their problems. The two main reasons for this are the level of cognitive ability of the users and motor difficulties they experience.

Standen, Brown, Proctor & Horan (2002) tried to identify what strategies tutors employ in teaching people with intellectual disabilities to use VE designed to teach independence skills and how effective these are. Much of the time spent by the tutor in the learner's early sessions was on providing assistance with the input devices. Users experienced problems in remembering what tasks were accomplished by each device and in moving from one device to the other as many used the same (dominant) hand for both devices.

Many people with intellectual disabilities have fine motor difficulties as they suffer from conditions where damage has been caused to the central nervous system, such as cerebral palsy, multiple sclerosis, muscular dystrophy and dyspraxia. They therefore find the devices difficult to control. Lannen, Brown & Powell (2002) carried out a detailed analysis of the difficulties experienced by fourteen school aged students with intellectual disabilities using a joystick for navigation and a mouse for interaction to complete specified navigation and interaction tasks within the virtual city (Brown, Neale, Cobb & Reynolds, 1999). Many of the difficulties users experienced were due to physical ability and device construction. Finally, difficulties arose as a result of the design of the VE. With problems like these, users can become frustrated and demotivated. Using a methodology established in an earlier study, the aim of this research is to systematically document the performance of users with the currently recommended devices. This information can 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.

2. METHODS

2.1 Design of study

Performance data were collected on the currently used control devices which could be compared with similar data collected on any prototype developed. To reduce the effect of learning on performance, participants were allowed several practice sessions with the currently used devices before data collection started and the order in which devices were used was balanced.

2.2 Participants

40 people (17 men, 23 women) aged between 21 and 67 years who regularly attended a day centre for people with intellectual disabilities volunteered to take part and all met the requirement of having sufficient visual ability to see the VE on the computer monitor. Although they varied considerably in their ability, on measures of verbal and non verbal IQ, they all scored within the severely disabled range. For motor control and co-ordination, five were in the normal range, 27 showed moderate discrepancy and five showed severe discrepancy.

2.3 Virtual environments

Four training VE were constructed (see Figure 1), in order to evaluate the currently used devices as well as any prototypes that were developed. They were built using 3D Studio or Plasma and then imported into

Director so that all interactive elements and lighting could be coded in. In order to increase their attractiveness to users and facilitate the acquisition of navigation and interaction skills 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. Additionally, feedback in the form of scores was available to the user. 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. Interaction was limited to activating an object. In three of the environments the user followed an avatar. The software also collected information on task achievement (scores), time taken and collisions.

Figure 1. *Dolphins, Asteroids, Temple and Road Crossing.*

2.3.1 Dolphins: the user's view was a position behind a dolphin which they had to steer through a series of underwater hoops while avoiding natural obstacles. This required a device for up/down and left/right movement only as forward movement was provided by the software. The devices evaluated were the joystick or the arrow keys on a normal keyboard.

2.3.2 Asteroids similarly required use of a device for up/down and left/right movement only as the user's view was from a spaceship with asteroids flying towards them from different angles. Additionally interaction was required to shoot at the asteroids to destroy them before they hit the spaceship. The devices evaluated were the joystick or mouse. Each of these devices was used for both navigation and interaction i.e. when using the joystick to navigate, the fire button was used for interaction and when using the mouse the left hand button was used for interaction.

2.3.2 Temple and Road crossing required a device for movement forwards and left/right in the horizontal plane and interaction to pick up or interact with objects. The devices evaluated were the joystick or the arrow keys on a normal keyboard. Whereas for *Asteroids* the same device was used for navigation and interaction, in these environments different devices were used for interaction and navigation. The *Temple* has six levels and the user has to find an object that allows them to open a door taking them to the next level. The computer records the time taken to complete each level and the number of collisions. In *Road crossing* the user has to cross the road at a different point in each of three trials: a zebra crossing (no interaction), a pelican crossing with auditory warning and two pelican crossings with no auditory signal at a cross roads. Density of traffic was kept constant. Table 1 summarises the characteristics of each environment.

Table 1. *Characteristics of training environments*

	Forward movement provided	Interaction required	Same device for interaction	Follow avatar
Asteroids	■	■	■	
Dolphins	■		N/A	■
Temple		■		■
Road crossing		■		■

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. The devices used were a standard 3 axis games joystick (Microsoft sidewinder, Saitek ST200 ambidextrous); standard two button mouse and keyboard. The order in which they worked through the environments was the same for each participant starting with the environment which required fewest functions from the control devices. The order in which they used the different devices varied between participants to counteract the effects of increasing familiarity on performance. 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. This was described as concerning the devices (whether for navigation or interaction) or the environment and was also categorised according to whether it was verbal (information) or physical (giving assistance). Assistance is usually given where the user experiences difficulties due to the physical mismatch between their ability and the device requirements. Information is predominantly given to explain how to use the device or to negotiate the environment. 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 information on scores and collisions was adjusted for length of session. Video collected data were expressed as a percentage of session duration. Comparisons between the devices was made using the Wilcoxon test for paired data.

3. RESULTS

3.1 Games where forward movement was provided

3.1.1 Mouse versus joystick. Using the mouse allowed participants to gain significantly ($p<0.006$) higher median scores initially with the joystick and on the second (final) session ($p<0.001$) in *Asteroids* (Table 2).

By the second trial using the mouse they needed significantly ($p<0.006$) less information about navigation and less assistance when navigating on both the first ($p<0.002$) and second ($p<0.001$) trials than they did with the joystick. The amount of information given on interaction was significantly lower on the second trial with the mouse ($p<0.005$), as was the median for the tutor giving assistance with interaction ($p<0.007$).

Table 2. *Medians of performance measures for Asteroids*

	Joystick		Mouse	
Trial	1	2	1	2
Score (adjusted)	4.24	4.05	7.09	12.23
Information on navigation	13.07	6.81	9.24	0.45
Tutor assists navigation	25.96	10.25	4.46	0
Information on interaction	11.82	2.08	6.06	0
Assistance with interaction	2.34	0	1.59	0

3.1.2 Keyboard versus joystick Participants gained significantly higher scores (see Table 3) with the joystick than with the keyboard on all trials (first: $p<0.001$; second: $p<0.001$; third: $p<0.005$). There were no differences in collisions but with both devices these became more frequent with increasing exposure. No significant differences were found between the devices on any of the data obtained from the video recording.

Table 3. *Medians of performance measures for Dolphins*

Trial	1		2		3	
Device	Keyboard	Joystick	Keyboard	Joystick	Keyboard	Joystick
Score (adjusted)	1.42	2.97	2.05	2.72	2.00	2.75
Collisions (adj)	15.13	16.27	16. 71	15.59	21.55	21.52

3.2. Games where user has to effect forward movement with the navigation device.

Participants were faster with the joystick than the keyboard on each level of *Temple* (see Table 4) for which data were available and on the zebra and pelican crossings in *Road Crossing* (see Table 5). This difference was significant for level 1 ($p<0.05$) and level 5 ($p<0.02$) of *Temple* and for the zebra ($p<0.02$) and pelican crossing ($p<0.01$). There was no difference between the devices in the rate of collisions.

In terms of help given by the tutor, for *Road crossing* participants received much less information about navigation with the joystick for all three parts of the game but this was only significant ($p<0.005$) for the pelican crossing (see Table 6). When playing *Temple* they received the same amount of information about navigation with both devices. In this game more assistance was given with navigation when the joystick was being used but this difference was only significant on the last three trials (trial 4: $p< 0.035$; trial 5: $p<0.007$; trial 6 $p<0.01$) (see Table 7). In *Road crossing*, they received less assistance with the joystick but this was not significant (see Table 6).

Table 4. *Median time in minutes to complete first five trials of Temple*

Trials	1	2	3	4	5
Keyboard	4.11	4.08	3.43	3.19	3.54
Joystick	3.24	3.31	2.29	3.03	2.85

Table 5. *Median times in minutes for Road crossing*

Device	Zebra	Pelican	Crossroads
Keyboard	0.54	0.54	0.58
Joystick	0.45	0.39	0.58

Table 6. *Median percentage of time in which help was given with Road crossing*

Help given	Navigation				Interaction			
	Information		Assistance		Information		Assistance	
Device	Keyboard	Joystick	Keyboard	Joystick	Keyboard	Joystick	Keyboard	Joystick
Zebra	35.42	29.76	20.34	18.14	N/A		N/A	
Pelican	11.43	0	2.86	0	26.19	9.09	5.13	3.23
X roads	0	0	0	0	3.64	0	6.02	6.90

Table 7 *Median percentage of time in which assistance with navigation was given with Temple*

	Trial					
	1	2	3	4	5	6
Keyboard	8.82	8.67	6.63	3.56	2.8	3.92
Joystick	15.34	14.73	11.76	10.55	10.72	8.84

A comparison of the time spent receiving help with interaction suggests that less information about interaction is required with the joystick and this was significant for pelican crossing ($p<0.001$). Similar results were found for *Temple* (see Table 8) where the joystick required significantly less information about interaction on first trial ($p<0.001$), second trial ($p<0.05$) and sixth trial ($p<0.033$). Assistance with interaction was given significantly less for the joystick on the pelican crossing ($p<0.042$) and on the first ($p<0.05$) level of the *Temple*.

Table 8 *Median percentage of time in which information was given on interaction for Temple*

	Trial					
	1	2	3	4	5	6
Keyboard	8.14	0.98	0	0	0.7	0
Joystick	4.19	0.56	0	0	0.26	0

3.3 Additional information

For all four games, slippage of the base of the joystick was a problem for 25 to 37% of participants. Even on the last trial of the *Temple* when participants had considerable exposure the joystick was slipping for 13 out of 30 people for whom this information was available. The number of people using too much force with the joystick increased from 5 on the first trial to 13 on the last trial.

4. DISCUSSION

When navigation in the virtual environment is in the vertical plane only, as for *Asteroids*, use of the mouse allows better performance both initially and after exposure. Participants using it also needed less information and assistance with both navigation and interaction when using the mouse. As use of the joystick could be avoided by writing forward movement into the software this option should be explored further. The joystick was not at a disadvantage when compared with the arrows on the keyboard as the joystick enabled participants to gain consistently higher scores than they did with the keyboard.

When the user had to initiate forward movement with the navigation device, the joystick permitted better performance than did the arrows on the keyboard in terms of speed of achieving tasks. Participants required less information about using it to navigate which suggests that they are more likely to understand its function. There is a tendency for them to need more assistance using it and frequent occurrences of the joystick slipping were recorded. If it slips, the researcher or tutor has to hold the base steady and the lack of feedback from the device makes it less likely that the user will learn the appropriate amount of force to exert. When using the joystick, participants required less information and assistance with interaction even though for these environments a separate device was being used for interaction. This may be because if the navigation device is easier to understand and use, the user has more cognitive capacity available to handle the challenge of interaction.

These advantages of the joystick suggest that the most promising design solution would be to modify the basic games joystick to avoid some of the obvious difficulties that participants experienced, for example the slipping of the device over the surface on which it stood. It is more difficult to decide whether the joystick should combine both functions of navigation and interaction or whether separate devoices be retained for each function. Lannen (2002) evaluated a prototype two handed device that combined both navigation and interaction but found that young people with intellectual disabilities were confused about which action caused interaction, which navigation. The present study found that the mouse was easy to understand and use for interaction supporting Lannen's (2002) findings that for interaction the mouse was quicker to use than a button on her prototype two handed device. This suggests that the functions of navigation and interaction should be provided by two separate devices.

In summary, when navigation is required in a three dimensional environment the joystick once mastered does allow even some of the most disabled users to achieve better performance. These results suggest that 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.

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