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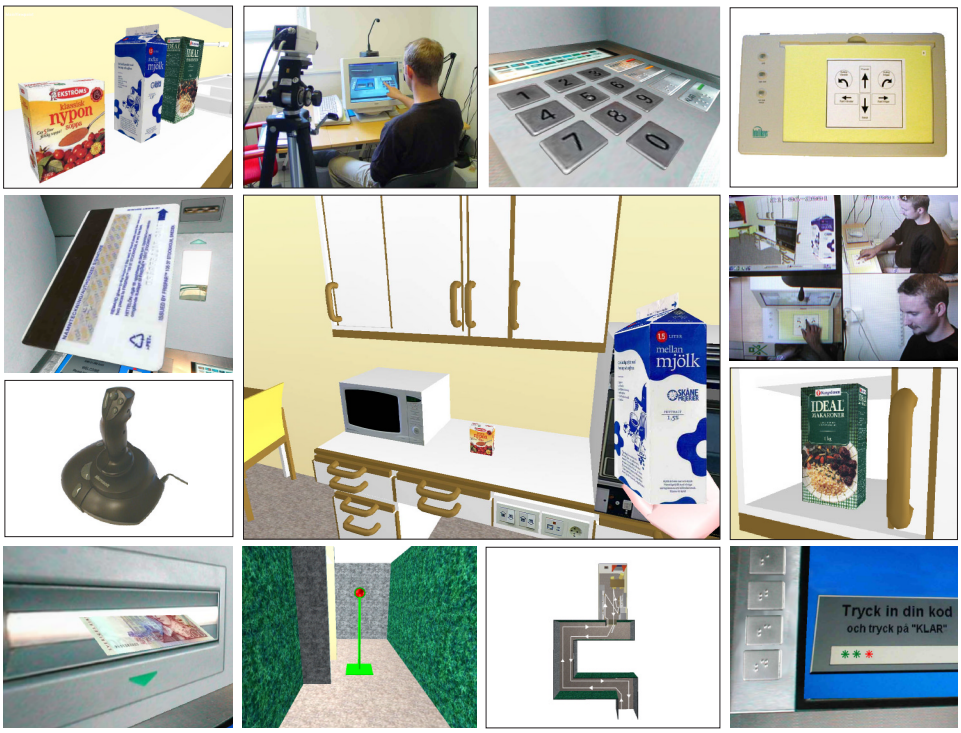
Designing Virtual Environments for Brain Injury Rehabilitation



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Licentiate Thesis

DIVISION OF ERGONOMICS AND AEROSOL TECHNOLOGY, EAT
DEPARTMENT OF DESIGN SCIENCES
LUND UNIVERSITY, SWEDEN

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Abstract

Virtual Reality (VR) has shown great potential in various training applications. In the field of cognitive rehabilitation it has been shown that VR technology can become a useful complement to conventional rehabilitation techniques (e.g. Rizzo et al. (2002), Brown et al. (2002) and Kizony et al. (2002)). An important part of a brain injury patient's rehabilitation process is practicing instrumental activities of daily living (IADL), such as preparing meals, cleaning, shopping and using a telephone. A pilot study by Lindén et al. (2000) came to the conclusion that activities like these can be practiced using desktop VR. The question addressed in this thesis is how a Virtual Environment (VE) should be designed to be a usable tool in brain injury rehabilitation. The thesis consists of three papers that describe three different studies that have been performed in order to further explore this area of research.

Paper I describes the design of a practical VE application in the shape of a cash dispenser. A paper prototype was constructed which was first used to generate ideas from three occupational therapists. The prototype was then tested on six people with little or moderate computer knowledge and no experience of 3D computer simulations. The results from the evaluation were then used to implement a computer prototype with the VR development tool *World Up*. The computer prototype had automatic navigation, which meant that the position and orientation of the viewpoint, the user's view into the VE, was controlled by the computer. The point-and-click method, which allows the user to move and manipulate objects with single mouse clicks, was used for interaction with objects. The computer prototype was then tested on five brain injury patients. The results of this evaluation are not included in paper I but are described in the thesis summary. Overall, all five subjects learned to handle the computer prototype sufficiently well. However, the interaction with objects posed some problems for them. For example, they initially tried to move the bankcard with drag-and-drop instead of point-and-click. Three subjects also pointed out that some parts of the VE, for example the display and the keypad, were unclear. All five subjects showed a positive attitude to the virtual cash dispenser

The aim of paper II was to find a usable navigation input device for people with no experience of 3D computer graphics. After an initial discussion about various input devices it was decided that a Microsoft Sidewinder joystick and an IntelliKeys keyboard, both programmed with two and three degrees of freedom (DOF), should be compared in an experiment. Sixty able-bodied people with no experience of 3D computer graphics were divided into four groups. Each group was to perform a navigation task in a VE consisting of a kitchen and a corridor using one of the four input devices. The navigation task was designed to evaluate both fine adjustments of the viewpoint (maneuvering task) and transportation of the viewpoint from one location to another (search task). Each subject performed the task five times in a row and then answered a questionnaire

consisting of five questions. Data logging and video recording were used to collect data. The study showed that both keyboard and joystick have their advantages and disadvantages. The keyboard seemed to be easier to control than the joystick for the maneuvering task. The keyboard was slightly easier to control also for the search task but was much slower than the joystick, which might make it an inconvenient input device for VEs that only involve search navigation. No significant difference could be found between two and three DOFs for the maneuvering task, but the 3rd DOF (sideways movement) seemed to facilitate the subjects' navigation in some situations. Two DOFs was found to be slightly easier to control than three DOFs for the search task.

The study described in paper III aimed at 1) evaluating a method for interaction with objects in VEs on people with no 3D computer graphics experience, and 2) finding a sufficiently usable input device for this purpose. After an initial discussion of possible methods for interaction with objects and various input devices, an experiment was conducted with 20 able-bodied people with no experience of 3D computer graphics. Our experiences of point-and-click from paper I and the pilot study (Lindén et al., 2000) made us think that maybe people have a more inherent understanding for drag-and-drop. Also, we had discussed using a virtual hand for carrying objects to simplify object movement. We therefore wanted to evaluate the following method for interaction with objects: 1) A virtual hand was used for carrying objects, 2) drag-and-drop was used for moving objects, 3) a single click was used for activating objects, and 4) objects were given a proper orientation automatically. Ten subjects used a regular desktop mouse and the other ten a touch screen to perform four interaction tasks in a kitchen VE five times in a row. Video recording was used to document the trial and the interview that was conducted afterwards. Broadly, the method for interaction with objects worked well. The majority of the subjects used the virtual hand for carrying objects. However, the fact that some subjects needed information before they started to use it indicates that its visibility and affordance needs to be improved. Opening and closing cupboard doors caused some problems, especially for the subjects in the touch screen group who tried to open them with drag-and-drop in a manner that resembled reality. No large difference in performance, except from the problem with the cupboard doors, could be seen between the mouse group and the touch screen group.

The three studies described in this thesis is a step closer towards understanding how a VE should be designed in order to be a usable tool for people with brain injury. In particular, knowledge on how to make it as easy as possible for the user to navigate the viewpoint and interact with objects has been achieved. The work has also provided a deeper understanding on what effects the choice of input device has on the usability of a VE.

Sammanfattning

Virtual Reality (VR) har visat sig ha stor potential för olika tränings-tillämpningar. Vad gäller kognitiv rehabilitering har en rad forskningsgrupper visat att VR-teknik kan utgöra ett bra komplement till konventionella rehabiliteringsmetoder (t ex Rizzo et al. (2002), Brown et al. (2002), & Kizony et al. (2002)). En viktig del av en hjärnskadepatients rehabiliteringsprocess är att träna *instrumentella aktiviteter i det dagliga livet* (IADL), såsom att tillreda en måltid, städa, handla och använda en telefon. En pilotstudie av Lindén et al. (2000) har visat att aktiviteter som dessa kan tränas med hjälp av desktop VR. Frågan som behandlas i denna licentiatuppsats är hur en virtuell miljö (VE) ska utformas för att bli ett användbart verktyg i hjärnskaderehabilitering. Uppsatsen består av tre artiklar som beskriver tre olika studier som har utförts för att utforska detta forskningsområde.

Artikel I beskriver utformningen av en praktisk VE-applikation i form av en bankomat. En pappersprototyp, som först användes för att generera ideér från tre arbetsterapeuter, togs fram. Pappersprototypen testades sedan på sex personer med liten eller medelhög datorvana och ingen erfarenhet av tredimensionell datorgrafik. Resultaten från utvärderingen låg till grund för en datorprototyp som implementerades med VR-utvecklingsverktyget *World Up*. Datorprototypen programmerades med automatisk navigation, vilket innebar att användarens vy i den virtuella miljön kontrollerades av datorn. Point-and-click-metoden, vilken låter användaren interagera med objekt genom musklick, användes för interaktion med objekt. Datorprototypen testades sedan på fem hjärnskadepatienter. Resultaten av denna utvärdering ingår inte i artikel I men finns beskrivna i denna sammanfattning. Samtliga fem testpersoner lärde sig att hantera datorprototypen. Interaktionen med objekt innebar dock vissa problem för dem. T ex så försökte de till en början att flytta bankkortet med drag-and-drop istället för point-and-click. Tre av testpersonerna påpekade att vissa delar av den virtuella bankomaten, t ex skärmen och knappsatsen, var otydliga. Samtliga fem testpersoner visade en positiv attityd till den virtuella bankomaten.

Målet med studien i artikel II var att hitta ett användbart navigeringsstyrdon för personer med hjärnskada. Efter en inledande diskussion av olika styrdon bestämdes det att IntelliKeys manöverplatta och Microsoft Sidewinder joystick, båda programmerade med två och tre frihetsgrader (DOF), skulle jämföras i ett experiment. Sextio friska personer utan erfarenhet av tredimensionell datorgrafik delades in i fyra grupper. Varje grupp fick utföra en navigationsuppgift med en av de fyra styrdonsvarianterna i en virtuell miljö som bestod av ett kök och en korridor. Uppgiften var utformad för att utvärdera både finmanövrering av vyn (manövreringsuppgift) och transport av vyn från en punkt till en annan (sökuppgift). Varje försöksperson utförde uppgiften fem gånger i rad och fyllde sedan i en enkät bestående av fem frågor. Dataloggning och videoinspelning användes för insamling av data. Studien visade att både

manöverplattan och joysticken har sina sina för-och nackdelar. Manöverplattan föreföll vara enklare att kontrollera än joysticken för manövreringsuppgifterna. Den verkade vara något enklare att kontrollera också för sökuppgifterna men var mycket långsammare, vilket eventuellt gör den opraktisk för virtuella miljöer med bara sökuppgifter. Ingen skillnad kunde ses mellan två och tre DOF för manövreringsuppgifterna, men den tredje frihetsgraden (sidledes förflyttning) verkade ändå förenkla försökspersonernas navigation i vissa situationer. Två frihetsgrader visade sig vara något enklare att kontrollera än tre frihetsgrader för sökuppgifterna.

Studien som beskrivs i artikel III syftade till att 1) utvärdera en metod för interaktion med objekt i virtuella miljöer på personer utan erfarenhet av tredimensionell datorgrafik och 2) hitta ett tillräckligt användbart styrdon för detta ändamål. Efter en inledande diskussion om möjliga metoder för interaktion med objekt och möjliga styrdon utfördes ett experiment med 20 friska personer utan erfarenhet av tredimensionell datorgrafik. Våra erfarenheter av point-and-click från pilotstudien (Lindén et al., 2000) som föregick detta projekt och studien i paper I ledde oss att tro att drag-and-drop eventuellt är en mer naturlig interaktionsmetod. I pilotstudien hade vi även diskuterat att använda en virtuell hand för att underlätta för användaren att röra sig och bära objekt samtidigt. Vi ville därför utvärdera följande metod för interaktion med objekt: 1) En virtuell hand för att bära objekt, 2) drag-and-drop för att förflytta objekt, 3) ett klick för att aktivera ett objekt och 4) objekt ges automatiskt en lämplig rotation. Hälften av försökspersonerna använde pekskärm och den andra hälften mus för att utföra fyra interaktionsuppgifter fem gånger i rad i en virtuell köksmiljö. Videoinspelning användes för att dokumentera försöket och intervjun som genomfördes efteråt. I grova drag fungerade metoden för interaktion med objekt bra. Majoriteten av försökspersonerna använde den virtuella handen för att bära objekt. Dock antyder det faktum att en del försökspersoner behövde informeras om den innan de började använda den att dess synlighet och affordance behöver förbättras. Något som orsakade en hel del problem var att öppna och stänga skåpsdörrar, speciellt för försökspersonerna i pekskärmsgruppen. De försökte nämligen öppna skåpsdörrarna med en drag-and-drop-rörelse som påminner om hur man öppnar en skåpsdörr i verkligheten. En virtuell miljö för detta ändamål borde därför programmeras med flera olika interaktionssätt. I detta fallet borde det vara möjligt att öppna en skåpsdörr både med ett klick och med drag-and-drop. I övrigt observerades inga stor skillnader i utförande mellan mus-och pekskärmsgruppen.

De tre studier som beskrivs i denna licentiatuppsats är ett steg närmare en förståelse för hur en virtuella miljö ska utformas för att bli ett användbart verktyg för personer med hjärnskada. Speciellt så har kunskap om hur man ska göra det så lätt som möjligt för användaren att navigera och interagera med objekt i en virtuell miljö framkommit. Studierna har även resulterat i kunskap om hur valet av styrdon påverkar användbarheten hos en virtuell miljö.

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Other work by the respondent

Wallergård, M., Cepciansky, M., Lindén, A., Davies, R. C., Boschian, K., Minör, U., Sonesson, B. and Johansson, G. (2002). Developing virtual vending and automatic service machines for brain injury rehabilitation. *Proceedings of the 4th International Conference on Disability, Virtual Reality and Associated Technologies* (pp. 109-114). University of Reading, Maidenhead, UK.

Davies, R. C., Löfgren, E., Wallergård, M., Lindén, A., Boschian, K., Minör, U., Sonesson, B. and Johansson, G. (2002). A summary of three applications of Virtual Reality for brain injury rehabilitation of daily task performance. *Proceedings of the 4th International Conference on Disability, Virtual Reality and Associated Technologies* (pp. 93-100). University of Reading, Maidenhead, UK.

Lindén, A., Boschian, K., Minör, U., Sonesson, B., Davies, R., Johansson, G. and Wallergård, M. (2002). An investigation of the usability of Virtual Reality as a complement in brain injury rehabilitation. *13th World Congress of Occupational Therapists*, Stockholm, Sweden, 23-28 June.

Johansson, G., Davies, R., Wallergård, M., Lindén, A., Boschian, K., Minör, U., Sonesson, B. (2001). Optimising a Virtual Reality interface for brain injured people. *Proceedings of the International Conference on Computer-Aided Ergonomics and Safety 2001*, ISBN: 84-931134-7-6.

Lindén, A., Davies, R. C., Boschian, K., Minör, U., Olsson, R., Sonesson, B., Wallergård, M., & Johansson, G. (2000). Special considerations for navigation and interaction in virtual environments for people with brain injury. *Proceedings of the 3rd International Conference on Disability, Virtual Reality and Associated Technologies* (pp. 287-296). University of Reading, Maidenhead, UK.

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List of included papers

I. **A Virtual Cash Dispenser for Persons with Acquired Brain Injury**
Wallergård, M., Davies, R. C., Lindén, A., Boschian, K., Minör, U., Sonesson, B., & Johansson, G. (2001). *Proceedings of the International Conference on Computer-Aided Ergonomics and Safety 2001*, ISBN: 84-931134-7-6.

This conference paper describes the design of a VE for brain injury rehabilitation. The work was done as a master thesis by the respondent in the research project "Virtual Reality – a possible tool for prople with brain injury?". The respondent performed the paper prototype tests, implemented the VE application and was responsible for writing the conference paper. Dr. Davies, Kerstin Boschian, Ulf Minör, Dr. Sonesson and Prof. Johansson provided valuable input during the design process.

The VE was tested on five brain injury patients after the submission of the conference paper. The results from these tests are thus not included in the paper but are discussed in the thesis summary. The respondent and Anita Lindén performed and analysed these tests.

II. **Virtual Environments for Brain Injury Rehabilitation – Finding a Usable Navigation Input Device for Novices**
Wallergård, M., Lindén, A., Davies, R. C., Boschian, K., Minör, U., Sonesson, B., & Johansson, G. (2003). Submitted to *Presence – Teleoperators and Virtual Environments*.

The study described in this paper aimed at finding a usable navigation input device for people with no 3D computer graphics experience and it was part of the research project "Virtual Reality – a possible tool for people with brain injury?". The respondent and Anita Lindén were responsible for the execution of the experiment, analysis of the data, and writing the article. Dr. Roy Davies implemented the VE that was used in the experiment and also performed the initial analysis of the quantitative data. The whole research group participated in the initial planning of the study, the design of the experiment, and the discussion of the results.

III. **Virtual Environments for Brain Injury Rehabilitation – Testing a Method for Interaction with Objects on Novice Users**
Lindén, A., Wallergård, M., Davies, R. C., Boschian, K., Minör, U., Sonesson, B., & Johansson, G. (2003). Submitted to *Presence – Teleoperators and Virtual Environments*.

This paper describes the third study that was performed in the research project “Virtual Reality – a possible tool for people with brain injury?” It aimed at 1) evaluating a method for interaction with objects in VEs on people with no 3D computer graphics experience, and 2) finding a sufficiently usable input device for this purpose. Anita Lindén and the respondent were responsible for the analysis of the data, and for writing the article. Dr. Roy Davies implemented the VE and was responsible for the execution of the experiment. The whole research group participated in the initial planning of the study, the design of the experiment, and the discussion of the results.

1 INTRODUCTION

When Alexander has entered his code and waits for the money, the cash dispenser informs him that the wrong code has been entered three times in a row and that the card will be confiscated. Alexander, who is convinced that he entered the right code, becomes completely cold inside and bites his lip. Exactly the same thing happened a couple of weeks ago! Now he has no money for buying food and starts to walk home, sad and tired.

Alexander is an assumed person but is nevertheless an example of a person with brain injury. After his motorcycle accident he easily forgets things, has some attention problems and sometimes he doesn't recognize things. He is slowly getting better thanks to his rehabilitation program but he still has problems with some activities in his daily life. A recently finished project called "Virtual Reality – a possible tool for people with brain injury?" has tried to find out if Virtual Reality (VR) technology can be used to help people in Alexander's situation. The project is a collaboration between the Department of Design Sciences at Lund University and Department of Rehabilitation at Lund University Hospital and combines competence in human-computer interaction (HCI), VR, occupational therapy and neuro-psychology.

One of the first assignments Alexander was given by his occupational therapist Lena was to brew a cup of coffee. Lena could obtain a lot of information about Alexander's cognitive and motor skills by observing how he solved this task. In the next step Lena and Alexander decided what activities Alexander should practice and made a schedule for his rehabilitation program. The first weeks Alexander practiced activities of daily living (ADL) like eating, dressing, and taking care of his personal hygiene. When he mastered these activities it was time for him to practice more advanced tasks that involved complex thinking and problem solving abilities. These activities are called instrumental activities of daily living (IADL) and in Alexander's case they involved, amongst other things, grocery shopping, cooking, using a telephone, and using a cash dispenser.

Could it be possible for Alexander to practice activities like these in a virtual environment (VE) by using VR technology? Our research indicates that it is indeed possible. With VR it is for example possible to

- practice hazardous situations;
- simulate a situation in a structured manner and repeat it;
- choose what stimuli are presented to the user;
- practice activities in an independent manner; and
- practice a certain activity despite motoric impairment.

However, VR also brings two disadvantages:

- If Alexander is to practice the activity of using a cash dispenser in a VE he must handle the computer *and* the cash dispenser at the same time. This might be too hard for him since he has enough problems just using a cash dispenser.
- Most VR systems don't give the user proprioceptive or tactile feedback. If Alexander for example is pushing a button in the cash dispenser VE he will only see and hear it being pressed but he will not feel it.

The former disadvantage is connected to the fact that the interface of the VE will inevitably put some extraneous cognitive load on the user. For example, in a cash dispenser VE Alexander would move the virtual card with some sort of input device instead of moving it directly with his hands. This is a sort of abstraction that might be hard for some brain injury patients to overcome.

So, the question one must ask is: *How should a VE be designed in order to put as little cognitive load as possible on a person with brain injury?*

1.1 AIM

The aim of this thesis was therefore to gain knowledge on how a VE should be designed in order to be a usable tool in brain injury rehabilitation.

2 HUMAN-COMPUTER INTERACTION

Why do some people become irritated at the little paper clip in Microsoft Word? It is only trying to help them and the thanks it gets is that they curse at it and try to shut it down. And why do some people feel that their new Nokia mobile phone is so much easier to use than the Ericsson phone they used to have? These are examples of issues that researchers active in the field of human-computer interaction (HCI) are working with. In other words: HCI is about designing computer tools that support the users so that they can carry out their activities productively and safely (Preece, 1994).

2.1 THE TOOL, THE USER AND USABILITY

So, how do we know that the tool supports the users so that they can 'carry out their activities productively and safely'? Well, first we should try to clarify the terms tool and user:

- A tool is something that someone can use to do something. A mobile phone is a tool that can be used by a person who wants to talk with someone who is not present. A VE for brain injury rehabilitation is a tool that a brain injury patient can use to practice the ability to perform a daily task, like for example using a train ticket machine.

- A user is a person that is using the tool. The people for whom the tool has been designed are called end-users.

But what happens when the user starts to use the tool? Will he be able to handle it? Can the tool do everything he wants to do? Will he enjoy using the tool? One way to deal with these issues is to introduce the concept of usability. There are many definitions of usability but none of them explains the term as concisely as Eason (1984). He states that if a tool is used then it is usable. However, this definition is only helpful if the product has been available for a time. An approach that can help us during the design process is the so-called REAL model (Löwgren, 1993). He believes that usability is a result of *relevance*, *efficiency*, *attitude* and *learnability* (REAL):

- The relevance is how well the system serves the users' needs.
- The efficiency describes how efficiently the user can perform their tasks with the system.
- Attitude is the users' subjective feelings towards the system.
- Learnability describes how easy the system is to learn for novice users and also how well the users remember how to use the system over time.

2.2 HUMAN-COMPUTER INTERACTION THEORIES

***"Find an explanation, and we are happy"* (Norman, 1988)**

A human being is constantly trying to understand and explain what is happening around her. She automatically and unconciously builds up so-called explanation models using her earlier experiences and other available information. A person using a computer system is building up an explanation model by interacting with the interface of the system. The trick to designing a usable interface is therefore to offer the user a good explanation model that reflects the functionality of the system.

Norman (1988) has proposed the concept of 'knowledge in the world' as a way to support the explanation models of the user. Knowledge in the world is basically about putting the information about how an object is operated in the

object itself by using the principles of *visibility*, *affordance*, *mapping* and *feedback*:

- Visibility is what the user can and cannot see in the interface. An example of good visibility is the drop down menus of Microsoft Word that only shows the menu selections that have been recently used (Figure 1a).

- Affordances are properties of an object that give the user a cue as to what it is for, how it is operated and what state it is in. For example, a Windows button looks three-dimensional to make the user understand that it should be clicked (Figure 1b).

- Mapping is the relationship between a control and its effect in the world. An example of good mapping is the arrow-keys that are used to represent the movements of the cursor on a computer keyboard (Figure 1c).

- Feedback is the information the system gives to the user regarding what actions have been performed and what the result became. The icon in Figure 1d, for example, gives feedback that the system is processing a request from the user.

(a) Visibility (b) Affordance (c) Mapping (d) Feedback

Figure 1. Examples of visibility, affordance, mapping and feedback.

Many computer systems of today use metaphors to simplify for the user. One of the most well known ones is probably the desktop metaphor first seen in the Star interface developed by Xerox (Smith, Irby, Kimball, Verplank, & Harslem, 1982). However, the disadvantage with metaphors according to Löwgren (1993) is that they say too much and too little at the same time. They say too much since they might activate too much background knowledge. An example of this is the Active Desktop technology that, among other things, allows the users to place web pages right on their desktops (Figure 2a). When the users are trying to make sense of this tool they might ask themselves “In what way is a desktop active?” What people usually know about desktops is that they can work and put things on them. Metaphors can also say too little because they do not help the user to find services that are particular for the computer system. An excellent

example of such a metaphor is the book metaphor that was used in many early multimedia productions (Figure 2c). What people usually know about books is that they can read them and that they should turn the page when they have come to the bottom of it. They might therefore miss the possibility to search and browse in more advanced ways which they cannot do with a real book.

(a) The Active Desktop metaphor

(b) The book metaphor

Figure 2. Examples of metaphors that say either too much or too little.

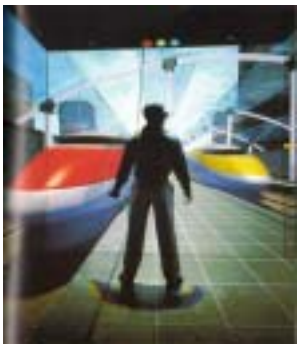
3 VIRTUAL REALITY

So, what is this thing called Virtual Reality? Well, one of the easiest ways to understand what this technology is about is to think about 3D computer games. In these games it is possible to move around in 3D fantasy worlds filled with people, creatures and objects. The player solves different tasks by interacting with the environment and this is what Virtual Reality is about: *to move around in and interact with three dimensional, computer generated environments.*

3.1 VR SYSTEMS

A 3D computer game played on a regular personal computer is one of the simplest and cheapest types of VR. There are several types of VR technologies and a basic distinction can be made between immersive and non-immersive VR systems. With an immersive VR system the user perceives the VE on a one to one scale and is completely surrounded by the VE. The CAVE™ (Figure 3a), is probably one of the most advanced immersive system that can be purchased today. The VE is projected in stereo on three opaque walls and the floor and thus completely encompasses the user. Some less advanced immersive systems, for example the Immersive Workwall™ in Figure 3b, use only large screen to display the VE. These two systems allow several users to interact with the VE at the same time. A head mounted display (Figure 3c), on the other hand, displays the VE for one single person using two small screens, one for each eye. In all

these cases the VE appears to be on a one to one scale. The VE is also often displayed in stereo, which means that the user experience a feeling of depth in the VE. The computer calculates one picture for each eye and special hardware is used to get the left image to the left eye and the right image to the right eye. The most common hardware for this is glasses with liquid crystal shutter lenses that close off one eye or the other at the same time as the screen shows alternatively the left or right image.



(a) A CAVE™. Picture reproduced from the SGI webpage.

(b) An Immersive Workwall™. Picture reproduced from the FakeSpace webpage.

(c) A head mounted display.

Figure 3. Examples of immersive VR systems

The most common type of non-immersive VR system is a standard desktop computer that shows the VE on a standard monitor (Figure 4a). A more advanced type of non-immersive systems projects an image on a large screen (Figure 4b). Systems like these can either be classified as immersive or non-immersive depending on how large the VE is in relation to the user and whether stereo is used or not.

(a) Desktop VR: a desktop computer with a standard monitor. Picture reproduced from the Dfn-Expo webpage.

(b) A Fakespace ImmersaDesk™. Picture reproduced from the FakeSpace webpage.

Figure 4. Examples of non-immersive VR systems

3.2 INPUT DEVICES

Output alone is not enough to make a computer system useful. The user must also be able to give input to the computer through one or several input devices. Input devices can be classified based on the types of events they produce. With a discrete-input device, for example a keyboard, the user generates one event at the time, whereas a continuous-input device like a joystick generates a stream of events. Input devices can also be categorized after the degrees of freedom (DOFs) they have. A degree of freedom is defined as the possibility to move along or rotate around one of the axes in a Cartesian coordinate system. For example, with a car it is possible to move forwards and backwards and also to turn around to the left or right, and the car can therefore be said to have two DOFs.

A large variety of input devices are used in VE applications today (see Youngblut, Johnson, Nash, Wienclaw and Will (1996) for a discussion of many input devices). The Spacemouse and the Spaceball (Figure 5a and 5b) allow the user to move around or manipulate objects in the VE using six DOFs. They are used by holding their movable part and lifting, pushing, pulling or rotating it in the direction to move or rotate, which makes them quite hard to use for inexperienced users. A joystick (Figure 5c) is more limited since it usually only has two or three DOFs. However, it is an adequate input device for VEs in which the user is walking or driving around. The dataglove (Figure 5d) is a more advanced input device that allows the user to interact with the VE using hand and finger motions. This is made possible by sensors in the glove that registers the flexion of the user's fingers. The magnetic field of a so-called tracking system keeps track of the dataglove's position and orientation. In immersive VR systems the dataglove is usually used both for navigation of the viewpoint (by pointing in the direction to move) and for interaction with objects.

There are also many input devices primarily designed for regular computer applications that can be used for VE interaction. For example, a very common navigation technique in many VRML browsers of today is based on a regular desktop mouse (Figure 5e). Different modes, for example walk mode and pan mode, are used to achieve several DOFs. The IntelliKeys keyboard (Figure 5f) is a programmable keyboard that simplifies computer interaction for people with physical, visual or cognitive disabilities. It doesn't require a high degree of fine-motor ability since it can be operated with simple press movements. It is also easy to create a clear interface layout for this input device that only contains the necessary information. The touch screen (Figure 5g) has an unrivalled immediacy that makes it a very usable input device for public-access systems like information kiosks and automatic service machines. It is easy to learn and makes the hand-eye coordination easier compared to a mouse or a keyboard (Schneidermann, 1991). However, the touch screen provides no proprioceptive

feedback, it costs more than alternative devices and the hand of the user may obscure the screen.

(a) A Spacemouse

(b) A Spaceball

(c) A joystick

(d) A dataglove (VTI cyberglove)

(e) A desktop mouse

(f) The IntelliKeys keyboard

(g) A touch screen

Figure 5. Examples of input devices

3.3 COMPUTER SYSTEMS

Today it is possible to walk in to any TV or radio store and buy a computer that is capable of running the most advanced 3D games. A computer with the same capacity would have cost ten times as much five years ago. This development can partially be explained by the constantly growing demands from the gaming community and it applies also for peripheral equipment. For example, cheap input devices with force feedback and tracking designed for 3D games are becoming increasingly available. Also, the game industry is putting more and more effort on realistic sound. The Environmental Audio Extension (EAX) is an extension of DirectSound3D, a part of the Microsoft DirectX API, and it has become the defacto audio standard for PC games. Computers equipped with a sound card that supports EAX can for example simulate different audio environments and effects of obstacles or partitions between rooms.

This development is of course great news for VR researchers. However, it might bring the temptation to use a system that is more advanced that necessary just because it is available.

3.4 PRESENCE AND TRANSFER OF TRAINING

Did you cry when Leonardo DiCaprio let go of Kate Winslet's hand and disappeared in the depths of the North Atlantic in *Titanic*? Or did you feel shivers down your spine when Max von Sydow tried to take the demon out of Linda Blair in *The exorcist*? Then you have experienced what in the cinema is known as *the diegetic effect*. This phenomena is believed to be related to what VR researchers call *presence*; a concept that has been defined by Slater and Wilbur (1997) as "a state of consciousness, the (psychological) sense of being in the virtual environment." The level of presence experienced by a VE user is believed to be a function of both individual and system factors (Stanney et al., 1998). Some of these variables include ease of interaction, user-initiated control, pictorial realism, length of exposure, social factors, and system factors.

Can training in a VE be transferred to a real situation? It seems to depend on the task that is to be trained. Kozak, Hancock, Arthur and Chrystler (1993) found no evidence of transfer of trained motor skills from a VE to a real-world task. Stanton, Wilson, Foreman and Duffy (2000), however, found that physically disabled children could transfer spatial knowledge from a VE to the real world. Also, in an experiment by Mendozzi et al. (2000) a positive transfer effect was found. A group of people with learning disabilities improved their performance on an assembly task after having practiced in a VE.

3.5 NAVIGATION OF THE VIEWPOINT

The user might want to move the viewpoint (navigate) for three reasons. Either he wants to *explore* the surroundings with no special target in mind, *search* to reach a special location or *maneuver* to give the viewpoint a more advantageous position and orientation for carrying out a specific task (Bowman, Kruijff, LaViola and Poupyrev, 2001).

There are basically three different ways in which the viewpoint can be moved. *Automatic navigation* means that the computer considers the input of the user and the state of the system to decide what the user wishes to look at. Consider for example a user that clicks on a microwave oven in a kitchen VE. The automatic navigation moves the viewpoint closer to the microwave oven since the computer assumes that the user wants to interact with it in some way. This type of navigation induces the least cognitive load since the user can concentrate completely on the interaction with objects. However, it works best when the whole VE can be viewed in one full-screen since it is otherwise hard for the user to initiate events outside the view. *Self-controlled navigation* means that the user controls the viewpoint through some input device such as joystick or a keyboard. There are two variants of self-controlled navigation called *walk through* and *fly through*. With walk through the height is fixed and the user can

move the viewpoint with two or three DOFs depending on the application. With fly-through the user can move freely in 3D space and may also tilt and pan the viewpoint. Finally, somewhere in between automatic and self-controlled navigation there is *half-automatic navigation*, which means that the user controls the viewpoint, and the computer assists in an intelligent way.

3.6 INTERACTION WITH OBJECTS

To be able to actually *do* something in the VE the user must also be able to interact with objects. So, can the VE user do everything he can do in real life, for example move objects, open doors and push buttons? Well, it depends on the type of task that is to be performed in the VE. There are at least three ways in which the user can interact with objects:

1. *activate* objects such as opening a door or pushing a button;

2. *move* objects from one place to another and rotate it if necessary; and

3. use one object with another (*object-object interplay*), for example, using a butter knife to put butter on a slice of bread.

How these three subtasks are performed in the VE depends on the techniques that are used for interaction with objects. For example, one possible technique for moving objects is drag-and-drop. To move an object the user simply drags the object to the location and places it there by releasing the mouse button. Another technique is point-and-click, which is based on the idea that the user should be able to interact with objects using single mouse clicks. Figure 6 illustrates how point-and-click works in the virtual cash dispenser, the VE described in paper I.

(a) (b) (c)

Figure 6. a) The user clicks on the bankcard, which is in the wallet. b) This makes the card move into the foreground to illustrate that it is being held by the user. c) Finally, the user clicks on the card reader, which makes the card go into the cash dispenser.

3.7 BRAIN INJURY AND BRAIN INJURY REHABILITATION

Annually a large number of people suffer from a severe brain injury. The damage can be caused by external violence to the head due to for example traffic accidents, falls, and sport activities. Other causes to brain injury may be stroke, tumours, brain tissue inflammation or anoxia (Kolb & Whishaw, 1996). The incidence in Sweden (nine million inhabitants) of severe or moderate traumatic brain injury (TBI) has been estimated at 40 per 100,000 inhabitants (Hårdemark & Persson, 2000) and of stroke at 235 per 100,000 (Johansson, Norrving & Lindgren, 2000). The nature of acquired brain injury (ABI) is a range of complex physical, cognitive behavioral, and emotional problems. The extent of these problems varies for each individual (Finlayson & Garner, 1994).

Memory problems are among the most commonly reported deficits after brain injury (McKinlay & Watkiss, 1999). These include difficulty in learning new information as well as retaining and later retrieving it. Another problem after brain injury is slowness in information processing. This may lead to reduced capacity to sustain attention when learning new tasks but also difficulties in keeping the mind on more than one task at a time. Executive problems are also common after brain injury and difficulties may arise with planning, initiation and problem solving.

Occupational therapy is focused on engaging people in meaningful and purposeful activities and enhancing their abilities to perform the daily tasks they need and want to perform (Fisher, 1998). One important part in the rehabilitation is to assess a patient's ability to perform, safely and effectively, daily living tasks to be able to plan and evaluate different actions. There are several methods for functional assessment and in comparison with questionnaires, checklists and rating scales, the most important method is observation (Giles, 1993).

3.8 VIRTUAL REALITY IN COGNITIVE REHABILITATION

Different types of Virtual Reality (VR) technologies have been used for assessment and rehabilitation of several diagnosis and different age groups. Rizzo et al. (2002), for example, have developed and evaluated VE applications for 1) assessment of attention processes in children with attention dificit hyperactivity disorders (ADHD) and 2) memory processes in people with traumatic brain injury (TBI). Brown et al. (2002) have designed a virtual travel-training environment for people with learning disabilities. Mendozzi et al. (2000) have developed three VEs in which mentally disabled people can practice factory tasks such as assembling and handling of materials and goods. The use of VEs for rehearsal of activities of daily living in stroke rehabilitation has been investigated by Hilton, Cobb, Pridmore and Gladstone (2002). Kizony et al. (2002) are using a unique approach to Virtual Reality for neurological

rehabilitation. They are investigating a projected, video-based VR system in which the patient can see himself interact with virtual objects on a display.

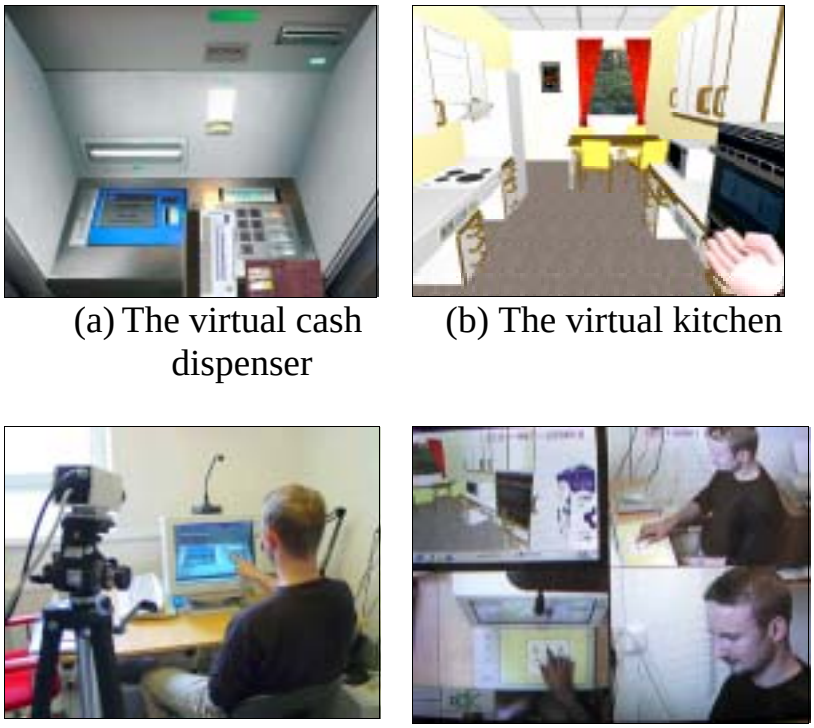
4 METHODOLOGY

The best way to gain knowledge about a human-computer interface is to test it on people. Both able-bodied people and people with brain injury participated as subjects in the experiments described in this thesis. Five brain injury patients participated in the evaluation of the virtual cash dispenser whereas the experiments described in papers II and III were conducted with 60 and 20 able-bodied people, respectively, with no experience of 3D computer graphics. These two experiments aimed at gaining basic knowledge about how VEs should be designed to be usable for brain injury rehabilitation. They were therefore designed to identify fundamental usability issues for an able-bodied population with no experience of 3D computer graphics. The hypothesis is that a difficult-to-use VE for able-bodied people would be impossible for people with brain injury, and conversely a usable VE by able-bodied people would hopefully also be easy for people with brain injury.

Both VEs used in the experiments were developed with the VR developers' toolkit *World Up*, which is an object-oriented environment equipped with a graphical user interface. There were two reasons why we chose this VR software. Firstly, since it works on ordinary personal computer such as those normally found in a hospital environment and secondly because the World Up player needed to run the VE application comes for free. The virtual cash dispenser (Figure 7a) was modelled from the Sparbanken Finn[1] cash dispenser, and it was programmed with all relevant actions that can be performed with a real cash dispenser. The virtual kitchen used in the experiments of paper II and III was designed to resemble one of the training kitchens at the Department of Rehabilitation (Figure 7b).

The experiments were conducted in a test laboratory at the Department of Rehabilitation (Figure 7c). The test laboratory was equipped with three video cameras, a microphone, video and audio mixer, video recorder and a TV. Three camera angles and the computer image were used to get an overall view of the test situation (Figure 7d).

[1] Sparbanken Finn is one of the biggest banks in the south-west part of Sweden.



(a) The virtual cash dispenser (b) The virtual kitchen

(c) The test laboratory (d) The overall view

Figure 7. The virtual kitchen, the virtual cash dispenser and the test laboratory.

Both quantitative and qualitative data were collected and analysed in the experiments. Video analyses were used in all three experiments. Two members of the research group analysed each subject's trial independently and thereafter discussed their observations. When a difference of opinion arose the video sequence of interest was analysed once again. In the experiments of papers I and III an interview was conducted after each trial to obtain information on the experience and attitude of the subjects. Data logging and a questionnaire were used to collect quantitative data in the experiment described in paper II. The data logged was the time, the position and orientation of the viewpoint, and the operations made with the input device by the user.

5 PAPER SUMMARIES

Paper 1: A Virtual Cash Dispenser for Persons with Acquired Brain Injury

This paper describes the design of the virtual cash dispenser, which is one of the practical applications that have been developed in the project. The aim was to design the VE so that it will put as little cognitive load as possible on the brain injury patient, so that he or she can focus completely on the task of withdrawing money. A paper prototype was built and tested in order to generate ideas

regarding the interface of the VE. The results from the paper prototype tests, in combination with feedback from three occupational therapists and a HCI specialist, formed the basis for a computer prototype implemented with the VR developers' toolkit *World Up*.

The virtual cash dispenser was then tested on five brain injury patients. A touch screen was used as input device. These tests were not included in the paper but are discussed below. The aim of the evaluation was to see how the virtual cash dispenser and the touch screen worked in a real situation when used by the end-users. Another purpose was to learn more about the brain injury patients' attitude to the concept of practicing daily living tasks in a VE. Before the experiment the subjects were asked if they had any problems using a real cash dispenser (Table 1).

Table 1. The subjects' problems using a cash dispenser

Subject	Problems using a cash dispenser
1	Problems remembering the code
2	Problems remembering the code and turning the card right
3	No experience of cash dispensers
4	No problems
5	Problems remembering the code

The task of the subjects was to withdraw 500 SEK and a receipt using the virtual cash dispenser. The task was repeated until the test leader felt that the subject mastered the task, and then an interview was made with the subject. Overall, all five subjects learned to handle the virtual cash dispenser after five to eight trials, and none of them had any problems using the touch screen. However, the interaction with objects posed some initial problems for all of them. For example, some of them tried to move the bankcard with drag-and-drop instead of point-and-click. One of the subjects had problems interacting with objects throughout the whole experiment. Also, three subjects commented during the interview that some parts of the VE were unclear. Interestingly, one of the subjects tried to physically grab the money with her hand as it came out of the virtual cash dispenser, which might indicate that she experienced a high degree of presence in the VE. The experiment was conducted in a more thorough way with subject number five. She was observed withdrawing money from a real cash dispenser and then practiced with the virtual cash dispenser at three occasions. After the VE training she managed to withdraw money from a real cash dispenser without problems. All five subjects showed a positive attitude to the virtual cash dispenser. Some comments were *It's good that you can test (to use a cash dispenser) in peace and quiet*, *Very good, but it is difficult to read the text and the screen is unclear*, and *The idea is very good, it only need some final touches*.

Paper 2: Virtual Environments for Brain Injury Rehabilitation – Finding a Usable Navigation Input Device for Novices

One of the main assumptions in the project is that the VE should cause as little cognitive load as possible so that the patient can concentrate completely on the task that is to be practiced in the VE. The aim of the study described in this paper was therefore to find a usable input device for navigation in VEs. The Microsoft Sidewinder joystick and IntelliKeys keyboard, both programmed with two and three DOFs, were compared in an experiment. The subjects were sixty able-bodied people with no experience of 3D computer graphics. The navigation task, which was to be performed five times in a row by each subject, was designed to evaluate both fine adjustments of the viewpoint (maneuvering task) and transport of the viewpoint from one location to another (search task). Time, distance and number of direction changes were registered and afterwards the subject was asked to fill in a questionnaire consisting of five questions.

The results suggest that the keyboard is easier to control than the joystick for the maneuvering task. The keyboard was slightly easier to control also for the search task but was much slower than the joystick, which might make it an inconvenient input device for VEs that only involve search navigation. No significant difference could be found between two and three DOFs for the maneuvering task, but the 3rd DOF (sideways movement) seemed to facilitate the subjects' navigation in some situations. Two DOFs was found to be slightly easier to control than three DOFs for the search task.

Paper 3: Virtual Environments for Brain Injury Rehabilitation – Testing a Method for Interaction with Objects on Novice Users

The user must also be able to interact with objects in the VE in an intuitive way so that he can concentrate on the task that is to be performed. This study aimed at evaluating a method for interaction with objects and finding a sufficiently usable input device for this purpose. The method for interaction with objects consisted of the following parts: 1) A virtual hand was used for carrying objects, 2) drag-and-drop was used for moving objects, 3) a single click was used for activating objects, and 4) the objects were given a proper orientation automatically. An experiment was conducted with twenty able-bodied people with no 3D computer graphics experience. The task was to move four packages in a kitchen VE. The subject was to perform this task five times in a row and was then interviewed by the test leader. Half of the subjects used a regular mouse for interaction with objects and the other half used a touch screen.

Overall, the method for interaction with objects worked well. The concept of using a virtual hand for carrying objects seemed to be comprehensible for the majority of the subjects. However, comments from some subjects during the interview indicated that its visibility and affordance needed to be improved.

Also, comments about the somewhat unrealistic behaviour of the objects emerged during the interviews. Some subjects for example pointed out that the objects sometimes changed size. Opening and closing cupboard doors caused some problems, especially for the subjects in the touch screen group who tried to open them with drag-and-drop in a manner that resembled reality. To eliminate these difficulties, the VE should be programmed to allow several interaction styles. In this particular case it should be possible to open the cupboard doors both with a single click and drag-and-drop. No large difference in performance could be seen between the mouse group and the touch screen group. However, the touch screen subjects showed a tendency to resemble real life object interaction more than the mouse subjects.

6 DISCUSSION

The research described in this thesis has provided new knowledge regarding the design of VEs for brain injury rehabilitation. However, making a VE usable is only half the battle. What remains is to convince the potential users, in this case the brain injury patients and the occupational therapists working with brain injury rehabilitation, to start to use it. Their attitude towards practicing daily living tasks using VR technology is very important to consider. The evaluation of the virtual cash dispenser provided valuable feedback from the former user group. All the patients believed the virtual cash dispenser to be a useful training tool in brain injury rehabilitation and seemed to enjoy the VE training. For example, a middle-aged woman, who had never used a cash dispenser since her injury, managed to handle the virtual cash dispenser and seemed to be very proud of herself.

An important component in designing a usable tool is to make sure that the user builds up a good mental model of how the tool works, which probably is very hard for a person with brain injury who has memory problems or difficulties with problem solving. An example on this was observed in the evaluation of the virtual cash dispenser described in paper I. One of the patients had problems understanding the point-and-click method. This was due to the fact that once an object was moving, it was not possible to make it return or change its destination. For example, at one occasion she clicked at the wallet while the card was moving into the foreground. When nothing happened she seemed to be confused; the lack of feedback from the VE clearly disturbed her mental model.

The fact that memory problems are among the most commonly reported deficits after brain injury (McKinlay & Watkiss, 1999) is very important to consider when designing VEs for brain injury rehabilitation. These problems

include difficulty in learning new information as well as retaining and later retrieving it. It is therefore not enough that it is *possible to learn* how to use the VE. The VE should be as *self-explanatory* as possible since it is possible that the patient might forget how to use it between and maybe also within training sessions. For example, some subjects in the experiment of paper III misunderstood the concept with the virtual hand. They described it as an artificial limb, a hand that showed the way, and as a helping hand. Ideally, the virtual hand should be modelled in such a way that is apparent that it is a hand that carries things.

The results from papers I and III suggest that people seem to have an inherent understanding for drag-and-drop for moving objects. However, the action of activating an object seems to be more complex, which became very apparent in the study described in paper III. Some mouse subjects and the majority of the touch screen subjects had problems to open the cupboard doors, since they tried to open them with drag-and-drop instead of with a click. It is possible that several factors influence what people perceive to be the most natural way of activating an object in a VE. Two conceivable factors are the properties of the object that is to be activated and the input device. One way to make activation of objects easier is to allow more than one interaction style. It should, for example, be possible to open or close a cupboard door both with a single click and drag-and-drop.

The choice of input devices for interaction with the VE is very important. For example, paper II showed that the IntelliKeys keyboard is more suitable than a joystick for fine manoeuvering of the viewpoint. The main idea is that brain injury patients shall practice daily living tasks in the VE and the navigation of the viewpoint and interaction with objects are just means for this. Results from paper I and paper III suggest that the touch screen is an input device that brings the user very close to the VE. Consider for example the subject that tried to physically grab the money with her hand as they came out of the virtual cash dispenser. The touch screen proved to work well with point-and-click in the evaluation of the virtual cash dispenser. However, a problem with touch screen when combined with drag-and-drop was revealed in the study described in paper III. Some subjects dropped or had problems getting hold of objects due to insufficient electrical contact with the screen. Nevertheless, this problem can be overcome using touch screens based on either surface wave or resistive technology, since they don’t require electrical contact between the user and the screen surface.

Cost and availability are important factors to consider when introducing VR technology in the hospital environment. It is probable that the average rehabilitation hospital only has a limited number of not so modern computers mainly intended for administrative work. However, it is reasonable to believe that this computer equipment slowly but surely is being replaced by modern computers. Computers that, equipped with a suitable 3D graphics card, are

capable of running almost any VR application. Also, advanced peripheral equipment is becoming increasingly available due to the progress of the game industry. For example, joysticks with force feedback and data gloves with tracking designed for 3D games can nowadays be bought for a reasonable price. Finally, the fast-developing open source game engines might become excellent tools for VE development in a not-too-distant future. Using free tools like these instead of conventional VE developers' toolkits could be another way to make this technology more available for rehabilitation hospitals.

What about the ethics of testing a new technology on people suffering from the traumatic consequences of a brain injury? The patients' rehabilitation must not be delayed in order to test a new method if it is not guaranteed to at least be of some use. The evaluation of the virtual cash dispenser, described in paper I, was performed as a training session. The occupational therapist gave feedback and suggestions just like in a real training situation, and discussed the training session with the patient afterwards. We therefore assume that the patients, at least to some extent, benefited from the evaluation.

Able-bodied people were used as subjects in the experiments as described in papers II and III, since we first wanted to identify fundamental usability issues. Our hypothesis is that a difficult-to-use VE for able-bodied people would be impossible for people with brain injury, and conversely a usable VE by able-bodied people would hopefully also be easy for people with brain injury. Also, testing directly on people with brain injury has two drawbacks in this context. Firstly, it would be hard to find a sufficiently large group of suitable subjects, who have the time and possibility to participate in the experiment. Secondly, how do we know that the problems we observe are caused by the VE interface and not by the brain injury patient's specific cognitive or motor problems? In the next phase of the project "Virtual Reality – a possible tool for people with brain injury?" we will learn more about how our results apply for this population.

7 FUTURE RESEARCH

Much can be done to further develop the concept of using VR technology in brain injury rehabilitation. We would, for example, like to investigate if a VE could be used as an assessment tool in the early stage of the rehabilitation process. It would also be interesting to investigate if it is possible for a person with brain injury to use the VE tool independently from the occupational therapist. What sort of help functions must be included in the VE to make such training possible?

The fast development of computer processors will soon make it possible to run VE applications on a hand-held computer. Can this technology be used as a help tool in everyday situations for brain injury patients? Take Alexander, who

has memory problems after his motorcycle accident, as an example. He has big difficulties using the train ticket machines on the central station. With his new hand-held computer he can go through the sequence of buying a train ticket, and even practice a couple of times, before doing it in real life.

Another idea is to investigate the possibility to develop a tool that an occupational therapist can use for developing new VEs or modifying existing ones. The basis for such a tool could be modules of code written in World Up. The question is if it is possible to put a graphic user interface on top of these modules to create an application that is both easy to use and advanced enough to produce interactive VEs.

Finally, we want to investigate how much and in what way people with brain injury can transfer training from a VE to a real situation. We are currently conducting an experiment in which people with brain injury get to practice on the task of finding their way to a location in a virtual model of the Department of Rehabilitation. The subjects are then observed as they try to find their way to the location in the real hospital environment.

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Paper I:

A Virtual Cash Dispenser for Persons with Acquired Brain Injury

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A Virtual Cash Dispenser for Persons with Acquired Brain Injury

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Abstract. Brain injury rehabilitation is a long and difficult process that includes training of so-called instrumental activities of daily living (IADL). This type of training involves activities like preparing meals, doing housework, grocery shopping etc. and it is often used by occupational therapists when they teach brain injury patients how to manage their daily life.

A computer-generated Virtual Environment (VE) that is to be used as a tool in IADL training has been designed. The VE has the shape of a cash dispenser and it can be used by a brain injury patient that wants to practice the activity of withdrawing money. The aim was to design a VE interface that puts as little cognitive load as possible on the brain injury patient, so that he or she can focus completely on the task of withdrawing money. A low-fidelity paper prototype was built and evaluated in order to generate ideas regarding object behaviour, navigation of the viewpoint, interaction with objects and other features. The result of the project so far is a computer prototype built with a Virtual Reality (VR) development kit called WorldUp, a personal computer based VR system. The computer prototype behaves exactly like a real cash dispenser and it has a function that allows the patient to learn his or her banking code. Feedback and clues will be provided by the occupational therapist that sits next to the patient during the training sessions.

At present tests are in progress with voluntary brain injury patients in a usability laboratory. These tests aim to evaluate the virtual cash dispenser in order to get ideas on how to increase its usability. The tests also aim to collect ideas on future functions and features and also to get clues on how VE training can be integrated into the rehabilitation process.

1 INTRODUCTION

The use of Virtual Reality (VR) technology in cognitive rehabilitation is a vital area of research that treats application areas like phobia treatment (for example, Weiderhold and Weiderhold, 1999), treatment of post-traumatic stress disorder (Hodges *et al*, 1999), cognitive assessment (and rehabilitation) (Riva *et al*, 1999), training of people in daily living tasks (Brown *el al*, 1999) and many others.

In this paper a Virtual Environment (VE) that is to be used as a tool in the rehabilitation of people with brain injury is described. The work is part of the research project "Virtual Reality – a possible aid for people with brain injury" (Davies *et al*, 1999; Davies *et al*, 2000) which aims to develop a methodology to allow people with brain injury to use computers and VR as a tool in the rehabilitation process and also in their daily lives. Recovering from a brain injury is a long and difficult process, and if it is possible to introduce VR technology as a complement to present rehabilitation techniques it will probably be worthwhile. The VR technology best suited for a rehabilitation context is desktop VR, i.e. standard PCs equipped with modern 3D graphics cards and regular monitors, due mainly to cost and availability of such machinery in the hospital environment. The VE are built with a PC-based VR development kit called WorldUp and the program that is used to play the VE is called WorldUp Standalone Player. This player program comes for free, which further reduces the cost for the rehabilitation hospital.

The project, which is a co-operation between the Division of Ergonomics at Lund University and the Department of Rehabilitation at Lund University Hospital, has the following goals:

- to investigate whether a VE tool can be a useful complement to present brain injury rehabilitation techniques;
- to find a VE interface that puts as little cognitive load as possible on the user;
- to find out which groups of brain injured people that might benefit from a VE tool;
- to investigate how much knowledge of practical tasks that can be transferred from the VE to the real world;
- to develop at least three practical applications of VEs that can be used in brain injury rehabilitation.

The virtual cash dispenser is one of these three applications and the idea is to use it as a tool in training of instrumental activities of daily living (IADL). IADL training, which is a time-consuming part of the rehabilitation process, involves practice of activities like preparing meals, doing housework and grocery shopping, and it can be stressful since the patient often has to go into the

outside (unprotected) world. Some of these activities may be possible to practice in a VE, such as using a cash dispenser.

2 PURPOSE AND METHOD

The purpose of this work was to design and evaluate a VE in which the brain injury patient can practice the task of using a cash dispenser, i.e. a VE tool that the patient can use in his or her IADL training. The users of the tool are the brain injury patient and his or her occupational therapist, and it is assumed that the occupational therapist will be present during the training sessions.

First, a paper prototype (Figure 1) was built and evaluated in order to generate knowledge regarding:

- what virtual objects to include in the VE, and their behaviour;
- the navigation of the viewpoint;
- the users interaction with virtual objects; and
- functions and features.

The paper prototype was then tested on six persons that had as little computer knowledge as possible and no experience of 3D computer simulations. The prototype was also reviewed by three occupational therapists with a lot of experience of brain injury rehabilitation and a Human-Computer Interaction (HCI) specialist.

The results from the evaluation served as a basis for a computer prototype that was built with WorldUp. At present tests of the computer prototype on voluntary brain injury patients in a usability laboratory are in progress. These tests aim to evaluate the virtual cash dispenser in order to get ideas on how to increase its usability. They also aim to generate ideas on future functions and features and also to collect clues on how VE training can be integrated into the rehabilitation process. The VE application is collecting data about the patient's actions in the VE and video cameras and sound recording equipment registers his or her behaviour and comments.

Figure 1. The paper prototype

3 RESULTS

During the construction of the paper prototype a lot of different ideas were discussed. Some of them seemed good enough to be implemented in the paper prototype, while some others were rejected.

The credit card, money bills, the withdrawal receipt, the wallet and of course the cash dispenser itself are quite obvious virtual objects. A less obvious object to include in the cash dispenser VE is a manikin hand. A manikin is a computer model of a human, and consequently a manikin hand is a computer model of a human hand. In the virtual cash dispenser it would be used as a kind of virtual instructor that shows the patient how to perform certain actions. For example, if the user has forgotten his or her credit card code, the manikin hand would appear and show the patient which buttons to press.

The navigation method chosen for the paper prototype, i.e. the way in which the viewpoint is manipulated, is automatic navigation which means that the "computer" tries to decide what the user wishes to look at. This form of navigation is expected to put a minimum amount of cognitive load on the user, since the only interaction with the computer is to initiate events (Davies *et al*, 2000).

The interaction with objects is based on an interaction method that Davies *et al* (1999) calls point-and-click. With this type of interaction clicking an object either means "pick up this object and carry it" or "activate the object". Clicking another object whilst holding the first means to "perform an operation using the first object on the second".

A feature that the VE must have is a function that forces the user to figure out the orientation of the credit card and then turn it right, so that it can be inserted into the card-reader of the cash dispenser.

Even though an occupational therapist will be present, a clue-function might improve the quality of the training with the VE. This clue-function might for example help a patient with memory problems to learn his or her credit card code.

3.1 Paper prototype test results

The paper prototype has been tested on six healthy persons with as little computer knowledge as possible and no experience of 3D computer simulations. The test person was told to make a simulated money withdrawal with the paper prototype, without knowing anything about its functionality.

The most important result from the tests was that the manikin hand, that was supposed to provide the user with clues, was completely misunderstood by five out of six test persons. Four of the test persons tried to move objects by dragging and then dropping them on the target (drag-and-drop). Three of the test persons

had initial problems with the point-and-click interaction, but none of them had any problems once they had understood it.

3.2 Paper prototype expert reviews

The experts all agreed that the manikin hand is a bad idea. The HCI expert for example believed that it belongs to a higher level of abstraction compared to the other virtual objects.

The occupational therapists thought that a clue-function that helps the patient learn the credit card code is absolutely necessary. This function must give immediate feedback to prevent the patient from repeatedly making mistakes, which might worsen his or her motivation. They suggested feedback based on colours, which is common in other training programs used in brain injury rehabilitation.

The HCI expert was slightly uncertain about the point-and-click interaction method, as he thought that it probably demands that the user has a quite well formulated strategy.

3.3 The computer prototype

The results from the tests and reviews served as a basis for the computer prototype (Figure 2) that was built with WorldUp, a PC-based VR development kit. It uses automatic navigation, point-and-click interaction and it has a function for code learning based on colour feedback, and also a function for setting the orientation of the credit card right. The function for code learning sets the colour of the asterisks that appears on the screen of the cash dispenser to either green (right digit) or red (wrong digit).

According to Davies *et al* (1999) the level of abstraction from the image on the screen to the real world has to be minimized in order to decrease the cognitive load. Therefore the textures on the objects were scanned from the real objects (or from photos of them) to give them added realism.

Sound also is important to make a VE realistic, and therefore sound effects were included for all objects.

Figure 2. The virtual cash dispenser

4 DISCUSSION

The results from the paper prototype evaluation indicate that the point-and-click interaction takes some time to learn. It seemed as if the abstraction of carrying an object with an invisible hand were hard to understand. All of the test persons were able to learn it though, but if this is true for persons with brain injury remains to be seen.

The fact that four of the six test persons wanted to move objects with drag-and-drop might indicate that it is a more intuitive interaction method than point-and-click.

The test person's problems to understand the manikin hand might perhaps be related to their expectations. Since manikin hands normally don't appear when people are using cash dispensers they have problems understanding its functionality in a VE.

The code learning function has some disadvantages. Firstly, it will not be useful for colour-blind users since it is based on colour feedback. Secondly, it might confuse the user since it makes the asterisks behave in an unrealistic way. Davies *et al* (2000) suggests that disparities between virtual objects and real ones can cause misunderstandings, and therefore this function is critically reviewed during the ongoing computer prototype tests with brain injury patients.

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Paper II:

Virtual Environments for Brain Injury Rehabilitation

- Finding a Usable Navigation Input Device for Novices

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Virtual Environments for Brain Injury Rehabilitation

- Finding a Usable Navigation Input Device for Novices

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Abstract

It is speculated that Virtual Environments (VE) might be used as a training tool in brain injury rehabilitation. The rehabilitation process often involves practicing so-called instrumental activities of daily living (IADL), such as shopping, cooking, and using a telephone. If a brain injury patient is to practice such activities in a VE he must be able to navigate the viewpoint and interact with virtual objects in an understandable way. People with brain injury may be less tolerant to a poor interface and a VE might therefore become unusable due to for example an unsuitable input device. This paper describes a study that aimed to find a usable navigation input device for people with no 3D computer graphics experience. An initial discussion resulted in four candidates: the IntelliKeys keyboard and the Microsoft Sidewinder joystick, both programmed with two and three degrees of freedom (DOF). These four candidates were then compared in an experiment in which 60 able-bodied subjects with no experience of 3D computer graphics performed a navigation task in a VE. The navigation task was designed to evaluate both fine adjustments of the viewpoint (maneuvering task) and transportation of the viewpoint from one location to another (search task). The study showed that both keyboard and joystick have their advantages and disadvantages. The keyboard seemed to be easier to control than the joystick for the maneuvering task. It was slightly easier to control also for the search task but was much slower than the joystick, which might make it an inconvenient input device for VEs that only involve search navigation. No significant difference could be found between two and three DOFs for the maneuvering task, but the

3rd DOF (sideways movement) seemed to facilitate the subjects' navigation in some situations. Two DOFs was found to be slightly easier to control than three DOFs for the search task.

Keywords: virtual environment, brain injury rehabilitation, navigation, input device

1 Introduction

1.1 Virtual Reality in cognitive rehabilitation

The use of Virtual Reality (VR) for cognitive rehabilitation is an active area of research with application areas like assessment and training of people in daily living tasks. Rizzo et al. (2002) have developed and evaluated VE applications for assessment of attention processes in children with attention deficit hyperactivity disorders (ADHD) and memory processes in persons with traumatic brain injury (TBI). Brown, Shopland and Lewis (2002) have designed a virtual travel-training environment for people with learning disabilities. Mendozzi et al. (2000) have developed three VEs in which mentally disabled people can practice factory tasks such as assembling and handling of materials and goods. The use of VEs for rehearsal of activities of daily living in stroke rehabilitation have been investigated by Hilton, Cobb, Pridmore and Gladstone (2002). Kizony, Katz, Weingarden and Weiss (2002) are using a unique approach to Virtual Reality for neurological rehabilitation. They are investigating a projected, video-based VR system in which the patient can see himself interact with virtual objects on a display.

However, few thorough studies regarding what effect the navigation method has on usability have been made. People with a cognitive disability may be less tolerant to a poor interface and therefore it is essential that the VE tool does not become unusable due to for example an unsuitable input device.

1.2 Brain injury and brain injury rehabilitation

Brain injury can be caused by external violence to the head in for example traffic accidents, falls, and sport activities. Other causes to brain injury may be stroke, tumours, brain tissue inflammation or anoxia (Kolb & Whishaw, 1996). The incidence in Sweden (nine million inhabitants) of severe or moderate TBI has been estimated at 40 per 100,000 inhabitants (Hårdemark & Persson, 2000) and of stroke at 235 per 100,000 (Johansson, Norrving & Lindgren, 2000). The nature of acquired brain injury (ABI) is a range of complex physical, cognitive, behavioural, and emotional problems. The extent of these problems varies for

each individual (Finlayson & Garner, 1994). Memory problems are among the most commonly reported deficits after brain injury (McKinlay & Watkiss, 1999). These include difficulty in learning new information as well as retaining and later retrieving it. Another problem after brain injury is slowness in information processing. This may lead to reduced capacity to sustain attention when learning new tasks but also difficulties in keeping the mind on more than one task at a time. Executive problems are also common after brain injury and difficulties may arise with planning, initiation and also problem solving.

Occupational therapy is focused on engaging people in meaningful and purposeful doing and enhancing their abilities to perform the daily tasks they need and want to perform (Fisher, 1998). One important part in the rehabilitation is to assess a patient's ability to perform, safely and effectively, daily living tasks to be able to plan and evaluate different actions. There are several methods for functional assessment and in comparison with questionnaires, checklists and rating scales the most important method is observation (Giles, 1993).

1.3 Project description

The Division of Ergonomics at the Department of Design Sciences, Lund University and the Department of Rehabilitation, Lund University Hospital are currently collaborating in a long-term project. The overall goal of the project is to investigate if VR can have a role in brain injury rehabilitation as a complement to conventional rehabilitation techniques. More specifically the project aims to:

- find a usable interface between a VE and the user, with emphasis on navigation of the viewpoint and interaction with objects;
- investigate transfer of training from a VE to the real world; and
- develop at least three practical applications of VE for rehabilitation

The Division of Ergonomics is performing research on the interplay between man and technology and has expertise in human computer interaction and development of VEs for various applications. The Department of Rehabilitation is specialised in the practical and theoretical aspects of rehabilitation of people with acquired brain injury. The rehabilitation team consists of several professions that work in an interdisciplinary manner. Two occupational therapists, a neuropsychologist, and a computer engineer, with many years experience of how technology can be used in rehabilitation, participated in this project.

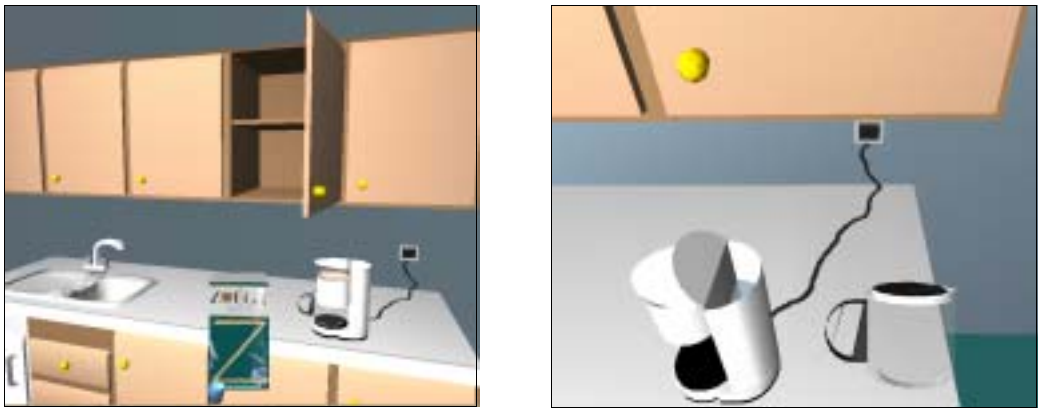
Desktop VR was used in this project mainly because of the cost and availability of such computer equipment in the hospital environment. Also, Brown, Neale and Cobb (1999) have shown that people with learning disabilities can learn

well using desktop VR. Another fact in favour of desktop VR is that immersive VR may induce cybersickness upon the user (Cobb, Nichols, Ramsey, & Wilson, 1999).

1.4 Navigation in VEs and input devices

Navigation in a VE can have two meanings; a motor aspect called *travel* and a cognitive aspect called *wayfinding* (Bowman, Kruijff, LaViola and Poupyrev, 2001). Travel is the movement of the viewpoint from one location to another, whereas wayfinding can be described as the cognitive process of determining a path through the environment to the desired destination. The study described in this paper is only concerned with the travel aspect of navigation. Bowman et al. (2001) have also defined three categories of navigation tasks. In an *exploration task* the user is investigating the surroundings with no special target in mind. In a *search task* the user is moving to reach a special target location. Finally, a *maneuvering task* is performed when the user wants to give the viewpoint a more advantageous position and orientation for carrying out a specific task. Most IADL tasks take place in spatially limited environments like for example a kitchen, a laundry room or a supermarket. Therefore, we have only considered the maneuvering and search task in this study.

There are basically three methods for moving the viewpoint: automatic, half-automatic and self-controlled. With automatic navigation the VE application uses the input of the user to calculate a suitable position and orientation for the viewpoint. We investigated this navigation method in a pilot study in which two brain injury patients and four able-bodied subjects performed the task of brewing coffee in a virtual kitchen environment (Lindén et al., 2000) (Figure 1a). The navigation appeared to provide no difficulties for the subjects except when the viewpoint was close to the kitchen bench and the subject wanted to move backwards in order to take a whole view again (Figure 1b). The coffee brewing VE is small enough to be viewed in one screen-full, but some IADL tasks, for example shopping and doing the laundry, are performed in larger environments. A VE like this requires some sort of self-controlled navigation since the user might want to perform an action in a part of the VE that is not visible in the view. There are basically two types of self-controlled navigation; fly-through and walk-through. In the former case the user can move freely in 3D space and may also tilt and pan the viewpoint. However, this type of self-controlled navigation is not necessary for our particular application. The navigation of the viewpoint is just a means for practicing tasks in the VE and therefore walk-through navigation with fixed viewpoint height is more suitable in this context.



(a) **(b)**

Figure 1. The coffee brewing VE: a) Overview b) The viewpoint is close to the kitchen bench.

The usability of a VE is also governed by the input device that is used. A large number of input devices for VE applications are available today, and many of them can be categorized in groups due to common properties. One way to roughly categorize input devices is to divide them in discrete and continuous input devices (Bowman et al., 2001). The former group of input devices produces one event at a time while the latter generates a continuous stream of events. Input devices can also be categorized according to the degrees of freedom (DOFs) they have. With walk-through navigation two DOFs are usually permitted, allowing the user to move forwards, backwards and turn to the left or right, but sometimes a third DOF is added to allow sideways movement.

2 Aim

The study described in this paper was part of a project that aimed to find out if and how VEs can be used as a training tool by people with brain injury. The aim of this study was therefore to find a usable input device for navigation in VEs for people with no 3D computer graphics experience.

3 Method

The study was performed in two steps:

1. The research group started the study with a discussion on what properties an input device should have to be usable for navigation in VEs by people with brain injury. This discussion resulted in a list of desirable qualities that was used to select four candidates.

2. The four candidates were then tested on people with no 3D computer graphics experience. This population was chosen since we wanted to first identify *fundamental* usability issues.

In the last step we will investigate how the results from the experiment apply for people with brain injury, and eventual usability problems will be attended to. This work is currently in progress and will not be discussed in this article.

3.1 Step 1: Considered input devices

The research group used its experience of brain injury rehabilitation and human computer interaction to produce the following list of desirable properties for a navigation input device:

1. The most obvious property is that it should be an input device primarily designed for navigation and not for interaction with objects.
2. A person with brain injury might have problems to separate different properties of an object, and therefore the input device should not have different modes of operation.
3. A brain injury also often results in decreased motor performance. Therefore the input device should be one that can be operated by people with fine-motor difficulties.
4. Memory problems are among the most commonly reported deficits after brain injury. The input device should therefore only allow a limited set of different forms of input.
5. For the same reason the input device should have a limited number of DOFs.
6. It is essential that the input device give necessary feedback to the user to make him understand that the action has been registered.
7. The mapping of the input device should be as natural as possible.
8. The input device should have good affordance, i.e. it should provide the user with clues about how it is used through its appearance.
9. A more practical, but not less important, detail is that the input device should be available in the sense that it should be easily found in retail trade and it should not be too expensive.

Various multi DOFs input devices were discussed, including the SpaceMouse and the SpaceBall. There are several reasons why these input devices are not suitable for this particular application:

- According to Zhai, Kandogan, Smith, and Selker (1999) six DOFs hand controllers such as the SpaceBall "are designed primarily as 'manipulation', not as 'navigation' devices".
- A study by Hall (1993) revealed that the SpaceBall was not sufficiently robust for students with learning difficulties.
- These input devices are quite expensive. Cost and availability are factors that must be considered when introducing VR technology in the hospital environment.

The mouse is used as navigation input device by many VRML browsers of today. Usually the 2 DOF mouse cursor movements are mapped onto various translation and rotation degrees of freedom by using two different modes: walk mode and pan mode. This technique has many disadvantages where the following are the most noticeable (Zhai et al., 1999):

- The result of the mouse movement depends on the current mode. This breaks point two in the list of desirable properties above, namely that the input device shouldn't have different modes of operation.
- Usually the cursor motions are mapped to movement speed, that is the farther the mouse is moved from the initial click position the faster the movement is. Experiments have shown that input devices as the mouse that lack a self-centering mechanism are poor in rate control tasks (Zhai et al., 1999).

An input device related to the mouse is the trackball. It has proved to be a usable input device for people with severe motor impairments, see for example Anderson (1999) and Jacobs et al. (1997). However, in a study by Cress and French (1994) trackball and locking trackball were more likely to be failed by children with mental retardation than were touchscreen, mouse and keyboard.

The IntelliKeys keyboard is a programmable keyboard whose look and functionality can be changed by sliding in different overlays (Figure 2a and 2b). It has been used at the Department of Rehabilitation to simplify computer interaction for brain-injured people, and the research group assumed it to be a usable input device for this user group for the following reasons:

- The input device is based on the principle of "knowledge in the world" (Norman, 1988), i.e. it has good affordance since the knowledge of how it is used is visible to the user.
- It does not require a high degree of fine-motor ability since it can be operated with simple press movements.
- It is easy to create a clear interface for it that only contains the necessary information.

The Microsoft Sidewinder is a joystick that can be set to control up to three DOFs (Figure 2c). Its stick can be moved forwards, backwards and sideways and it can also be rotated. We considered it to be a usable input device for people with brain injury for the following reasons:

- Brown, Kerr and Crosier (1997) concluded that joystick is a better input device for navigation in VEs than keyboard and mouse.
- It does not require fine-motor capabilities since it can be operated with a transverse volar grip.
- It is an input device that most people recognize and in some cases probably also have experience of.
- It can be used both as a two and three DOFs input device since its stick can be rotated.

Nevertheless, the Sidewinder joystick has a property that might be a drawback for this user group: it allows activation of several DOFs at the same time. The user can for example make a forward movement and rotate to the right at the same time. This might disturb the users mental model of how the joystick works since it is also possible to control it by activating only one DOF at the time.

(a) (b) (c)

Figure 2. The IntelliKeys keyboard with a) two DOFs and b) three DOFs respectively and c) the Microsoft Sidewinder joystick.

We also discussed how many DOFs the input device should have. We wanted as few DOFs as possible in order to minimize the users' cognitive load, but we also wanted sufficient to enable convenient navigation. Two DOFs is the minimum number for walk-through navigation in a VE. This allows the user to move the viewpoint backwards and forwards and to rotate it to the left and to the right. By adding a third DOF it would be possible for the user to also move sideways, which might lead to a more convenient navigation. The user could for example use the third DOF for moving sideways along a kitchen bench.

Finally, we decided to evaluate the following four input device variations: IntelliKeys keyboard with two and three DOFS and Microsoft Sidewinder joystick with two and three DOFs.

3.2 Step 2: The experiment

The purpose of the experiment was to compare the following four input device variations: IntelliKeys keyboard and Microsoft Sidewinder joystick, both programmed with two and three DOFs.

3.2.1 Subjects

Sixty hospital personnel and students at the Department of Rehabilitation, aged 21 – 58, participated in the study. The subjects were informed about the project and were asked to fill in a questionnaire concerning their computer experience. People that had experiences of 3D computer graphics, like 3D computer games and CAD applications, were excluded. Then four groups, one for each input device, were formed. Each group consisted of 15 subjects and was assembled so that the subject variables age, gender and computer experience were as similar as possible for all four groups (Table 1).

Table 1. Demographic data. N=60.

Group	Input device	Subjects		Age (median)	Age (range)	Computer use h/week (median)
1	Keyboard 2 DOFs	9 females	6 males	31	23-58	4
2	Keyboard 3 DOFs	9 females	6 males	33	22-56	4
3	Joystick 2 DOFs	10 females	5 males	37	21-58	3,5
4	Joystick 3 DOFs	9 females	6 males	38	21-52	4

3.2.2 Experimental setup

The VE was developed using World Up, an object-oriented VR developers kit in which virtual environments and objects with complex behaviours can be created. The main reason for choosing this VR software was that it works on ordinary personal computers, such as those normally found in a rehabilitation hospital. Another advantage is that the WorldUp player needed to run the VE application comes for free. The VE consisted of a U-shaped corridor and a kitchen, and it contained 11 targets (Figure 3a and 3b). The purpose of the corridor was to study how the subjects solved a search task, i.e. how they transported the viewpoint from one location to another when collecting targets. The purpose of the kitchen was to study the subjects when solving a series of maneuvering tasks, in which they had to give the viewpoint a correct position and orientation to be able to collect the targets. The kitchen was designed to look like the real training kitchen at the hospital and contained various kitchen fittings such as stove, dishwasher, refrigerator and kitchen furniture. The corridor contained no objects except the targets.

The subjects' task was to collect targets in the VE by walking into them in a right angle. The 11 targets were placed along a path starting in the corridor, leading into the kitchen and then back to the end of the corridor again (Figure 3c). When one target had been collected the next one appeared which meant that the subject could only see one target at the time. A plan drawing illustrating the placement of the targets in the VE was placed next to the computer to prevent the subject from getting lost. Each subject was asked to complete the navigation task five times in a row and then to fill in a questionnaire consisting of five questions. The questionnaire aimed at establishing the subjects' experiences of the navigation in the corridor and the kitchen, degree of control of the movements, orientation in the VE, and the input device. The subjects graded their experience of these issues on a five point Likert scale reaching from "very easy" to "very hard". The subject also had to comment each of the answers. A World Up script was used to log data on the navigation of the subjects in the VE. The script logged time, position and orientation of the viewpoint, and the operations made with the input device by the user.

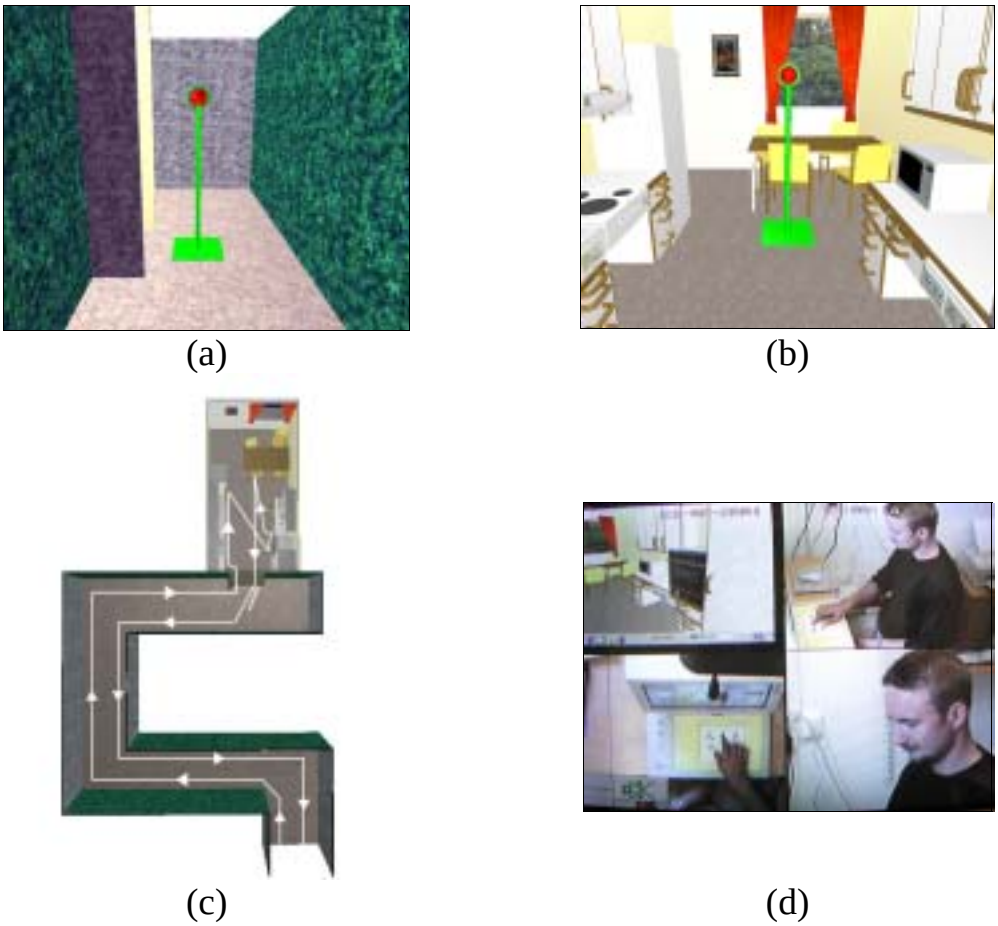


Figure 3. a) The virtual corridor, b) the virtual kitchen, c) the path of the navigation task, and d) the video signal from the quad mixer.

Three video cameras were used to capture facial expressions, body language and hand movements of the subject when performing the navigation task in the VE. The monitor signal was converted into an analogue video signal and mixed with the three video camera signals using a video quad mixer (Figure 3d). In this way all four signals could be recorded on the same videotape to facilitate the analysis. A microphone was used to record the subjects' comments.

3.2.3 Analyses methods

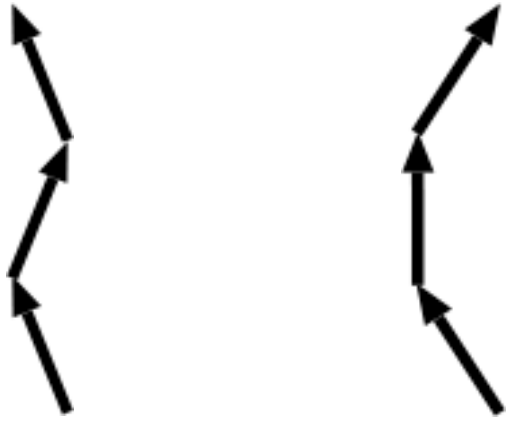
The analysis of the quantitative data was performed in three steps. In the first step a program analysed each of the five trial files and generated a single file for each of the 60 subjects, and then summarised the data for each subject group. In the second step, Excel spreadsheets containing tables and diagrams were made. Finally, the statistics package SPSS was used to make comparisons between the four subject groups regarding three dependent variables: distance, time and number of direction changes (Table 2). Distance and number of direction changes (Figure 4) were used as measures for the subject's control over the input device, whereas time was used as a complementary measure. We considered time to be a less vital factor for this particular application since the important thing is that the user is able to perform the activities in an easy and intuitive way. Our hypothesis was the lower the values on the dependent variables, the better the subject's control over the input device. The total value, that is the sum of each subject's performance over the five trials, was used for the dependent variables in the statistical analysis.

A qualitative analysis of the subjects' performance was performed from the video material. Two members of the research group analysed the video material independently of each other and thereafter discussed their respective findings. When difference of opinion arose the video sequence of interest was analysed once again. The following three items were used as a basis for the observations:

- How is the subject navigating in the VE?
- How is the subject handling the input device?
- In what way is the subject using his hands?

Table 2. The dependent variables

Variable	*Description*
Distance	Distance covered when collecting the targets
Time	Time to collect the targets
Number of direction changes	Number of times the subject changes direction when collecting the targets



(a) (b)

Figure 4. a) The movement changes from clockwise rotation to counterclockwise rotation and is therefore registered as a direction change. b) The movement only has clockwise rotation and is hence not registered as a direction change.

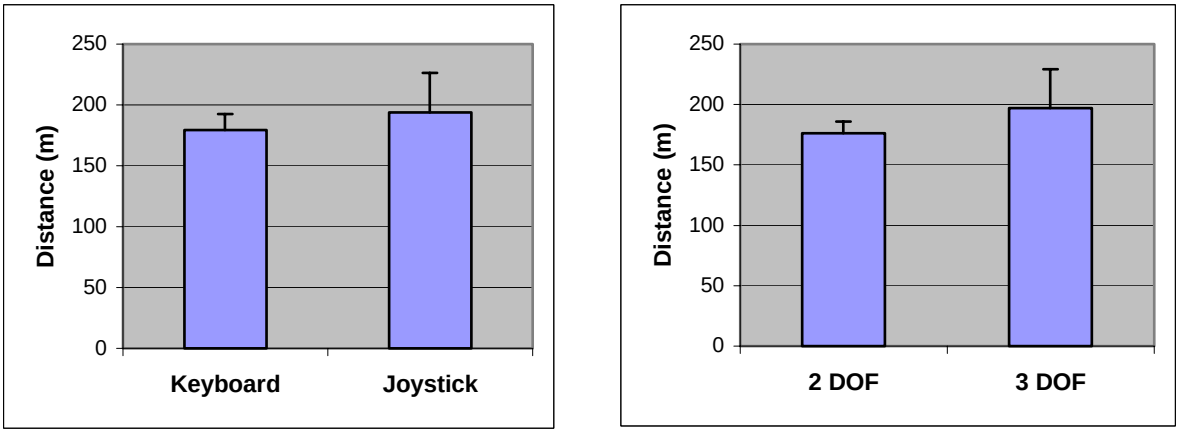
4 Results

4.1 Results of the statistical analyses of the quantitative data

In this section the results from the statistical analyses of the quantitative data are presented.

4.1.1 Distance, time and number of direction changes in the corridor

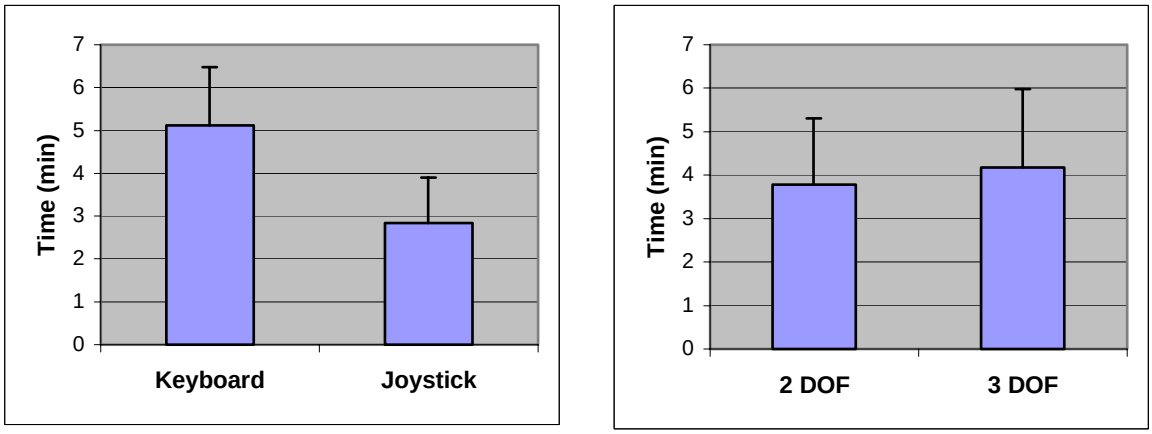
Mean and standard deviation for distance in the corridor for keyboard (M = 179.3, SD = 13.0) and joystick (M = 193.8, SD = 32.8) are shown in Figure 5a. A two-tailed Student´s t-test confirmed the difference to be significant ($t(58) = 2.25$, $p < .05$). Figure 5b shows mean and standard deviation for the distance for two DOFs (M = 176.2, SD = 9.7) and three DOFs (M = 197.0, SD = 32.1), respectively. Also this difference was significant ($t(58) = 3.40$, $p < .05$).



(a) (b)

Figure 5. Mean and standard deviation for distance in the corridor when comparing between a) keyboard and joystick and b) two and three DOFs.

Figure 6a shows mean and standard deviation for time in the corridor for keyboard (M = 5.12, SD = 1.36) and joystick (M = 2.84, SD = 1.06). The difference proved to be significant (t(58) = 7.26, $p < .05$). No significant difference was found (t(58) = 0.90, $p < .05$) between two DOFs (M = 3.78, SD = 1.53) and three DOFs (M = 4.17, SD = 1.80) regarding time in the corridor (Figure 6b).



(a) (b)

Figure 6. Mean and standard deviation for time in the corridor when comparing between a) keyboard and joystick and b) two and three DOFs.

Figure 7 shows mean and standard deviation for the number of direction changes in the corridor. The difference between keyboard (M = 29.9, SD = 11.2) and joystick (M = 32.4, SD = 10.4) were not significant (t(58) = 0.91, $p = .05$). No comparison was made between two and three DOFs regarding the number of direction changes. This would be a biased comparison since the three DOFs

subjects had the possibility to correct their course not only by rotating the viewpoint but also by moving it sideways.

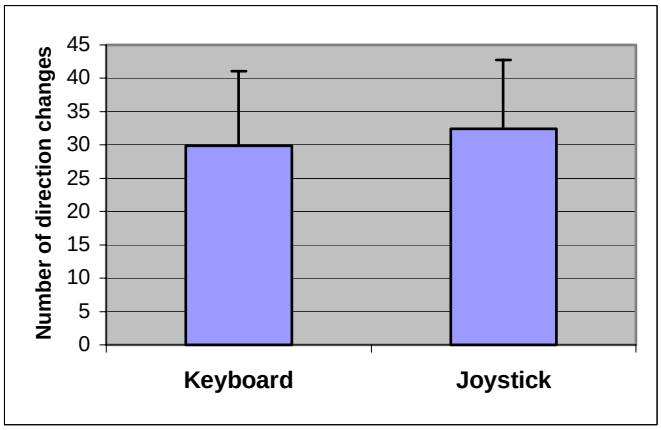
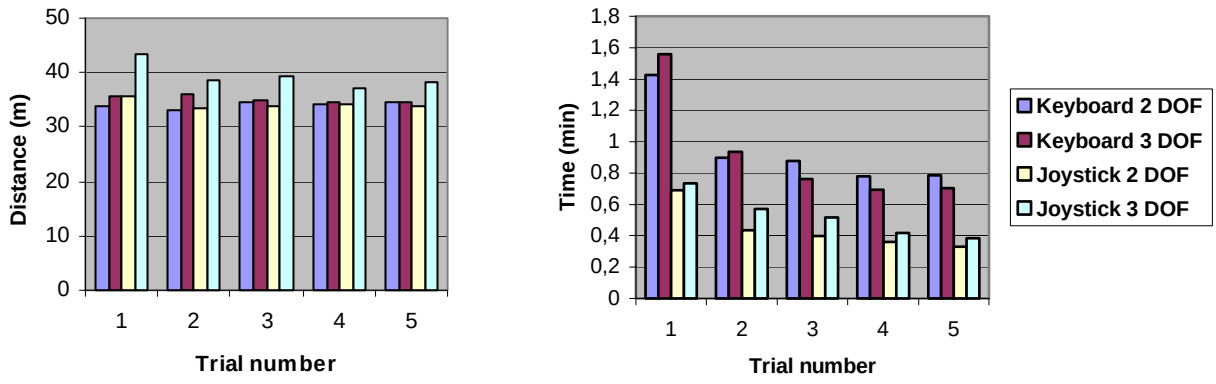


Figure 7. Mean and standard deviation for number of direction changes in the corridor

As can be seen in Figure 8a the trend for the median distance was approximately flat for all four groups over the five trials. The only exception was the value for the joystick 3 DOFs group in the first trial, which was approximately ten percent higher than the values in the other four trials. The median time exhibited a decreasing trend for all four groups over the five trials (Figure 8b). The median time for the keyboard groups was approximately between 40 and 50 percent longer than for the joystick groups in all five trials.



(a) (b)

Figure 8. a) Median distance and b) median time in the corridor for the four groups, trial 1-5.

Figure 9 shows the trend regarding median number of direction changes for keyboard and joystick respectively. There were no obvious differences between keyboard and joystick except for in trial 2 and 4.

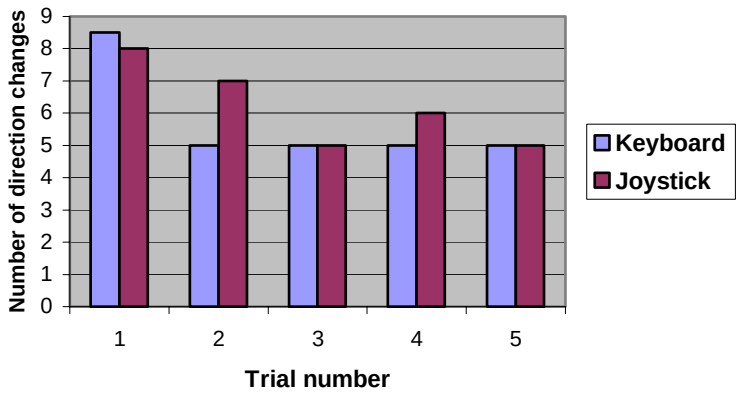
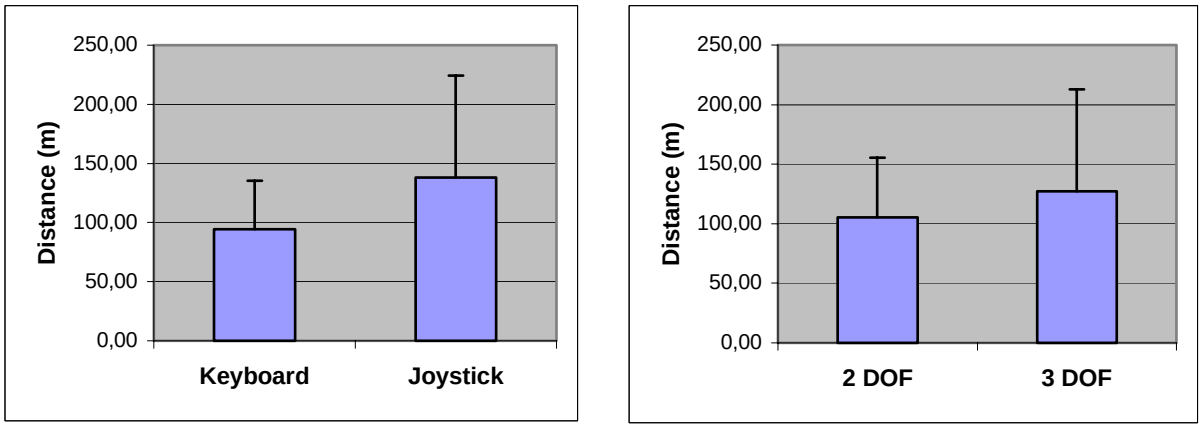


Figure 9. The median number of direction changes in the corridor for keyboard and joystick, trial 1-5.

4.1.2 Distance, time and number of direction changes in the kitchen

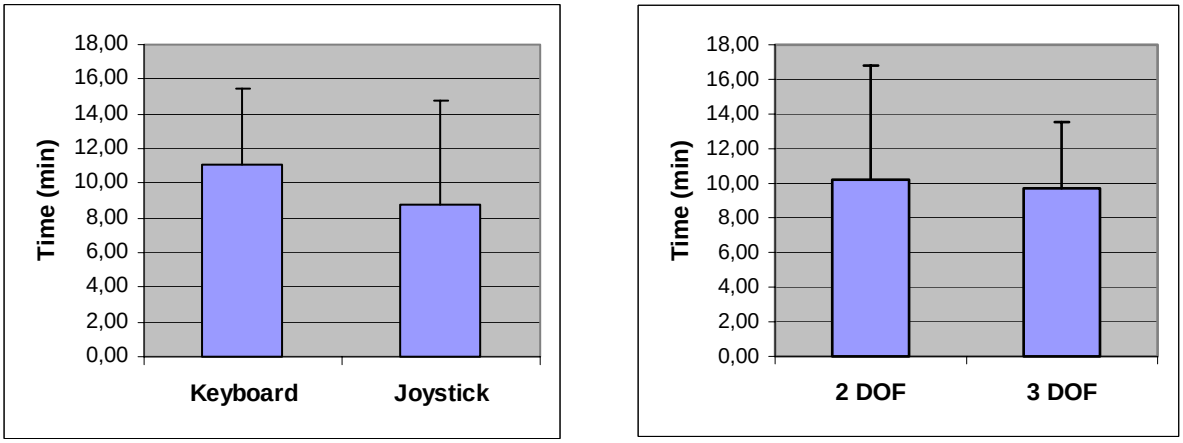
Figure 10a shows the mean distance and standard deviation for keyboard (M = 94.2, SD = 41.3) and joystick (M = 138.2, SD = 86.1) respectively. A two-tailed t-test confirmed the difference to be significant ($t(58) = 2.52$, $p < .05$). The mean and standard deviation for distance for two DOFs (M = 105.1, SD = 50.5) and three DOFs (M = 127.3, SD = 85.6) can be seen in Figure 10b. No significant difference was found between two and three DOFs for distance ($t(58) = 1.22$, $p < .05$).



(a) (b)

Figure 10. Mean and standard deviation for distance in the kitchen when comparing between a) keyboard and joystick and b) two and three DOFs.

The same sort of analysis was made for the variable time. Figure 11a shows the mean time and standard deviation for keyboard (M = 11.1, SD = 4.4) and joystick (M = 8.8, SD = 6.0) respectively. A t-test revealed no significant difference between keyboard and joystick (t(58) = 1.71, $p < .05$). The mean time and standard deviation for two DOFs (M = 10.2, SD = 6.6) and three DOFs (M = 9.7, SD = 3.8) is shown in Figure 11b. A t-test showed that there are no significant difference between the time for two DOFs and three DOFs (t(58) = 0.36, $p < .05$).



(a) (b)

Figure 11. Mean and standard deviation for time in the kitchen when comparing between a) keyboard and joystick and b) two and three DOFs.

Figure 12 shows mean and standard deviation for the number of direction changes for keyboard (M = 58.4, SD = 32.4) and joystick (M = 86.4, SD = 53.3), respectively. The difference between keyboard and joystick was found to be significant (t(58) = 2.45, $p < .05$). No comparison was made between two and three DOFs, for the reasons described above.

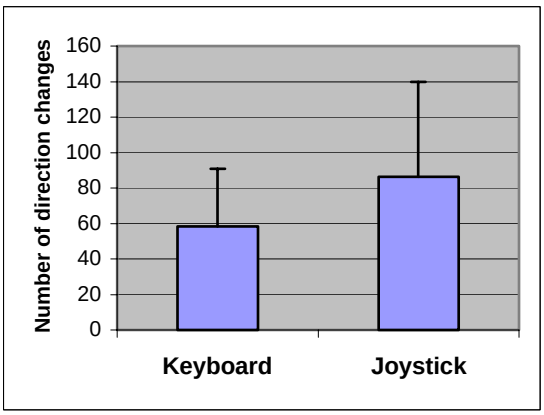
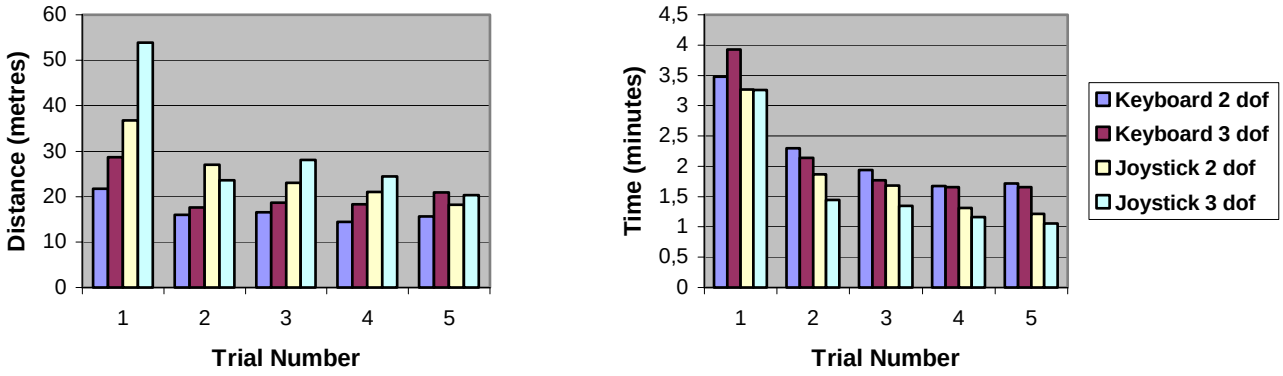


Figure 12. Mean and standard deviation for number of direction changes in the kitchen.

The median distance was exhibiting a decreasing trend for all four groups over the five trials (Figure 13a). The difference between the groups was relatively big in trial 1 but decreased gradually. In the last trial the median distance was approximately the same for all four groups. The trend for the median time was decreasing and levelled out after trial 3 for all four groups (Figure 13b).



(a) (b)

Figure 13. a) Median distance and b) median time in the kitchen for the four groups, trial 1-5.

Figure 14 shows that the trend regarding median number of direction changes was decreasing over the five trials both for keyboard and joystick. However, the decrease was more apparent for the joystick.

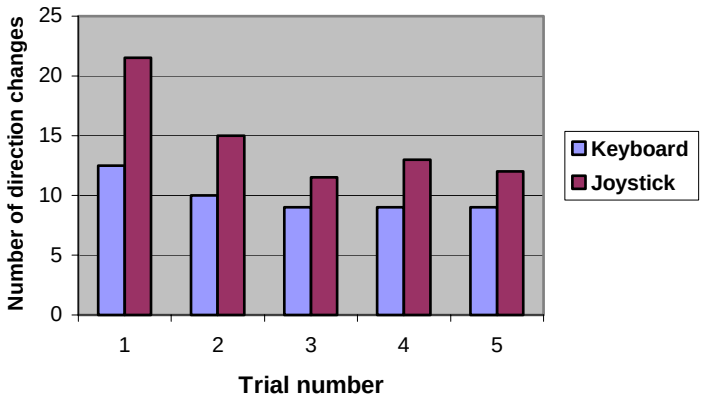


Figure 14. Mean for number of direction changes in the kitchen for keyboard and joystick, trial 1-5.

4.1.3 The questionnaire

The results from the questionnaire are presented in Table 3. The Mann-Whitney U test was used for making comparisons between keyboard and joystick and two and three DOFs, for each of the five questions in the questionnaire. No significant difference could be found between keyboard and joystick or between two and three DOFs for any of the five questions.

Table 3. The results from the questionnaire

Question	Mean		Mann-Whitney	Mean		Mann-Whitney
	Keyboard	Joystick		2 DOFs	3 DOFs	
How did you feel about moving in the corridor?	3.6	3.5	0.470	3.7	3.4	0.121
How did you feel about moving in the kitchen?	3.5	3.2	0.175	3.3	3.4	0.884
To what extent did you feel that you had control over your movements in the VE?	3.8	3.7	0.359	3.7	3.7	0.423
How did you feel about finding your way in the virtual environment?	4.1	3.8	0.112	4.0	3.9	0.756
How did you feel about using the input device?	3.6	3.5	0.498	3.5	3.6	0.577

4.2 Results of the video analyses

In this section the results from the video analyses are presented.

How the subjects navigated the viewpoint

The general impression from the video analyses was that there were differences in how the keyboard and joystick groups navigated the viewpoint. The joystick subjects tended to navigate in a wobbly manner and sometimes overshot the targets by for example walking past them. The keyboard subjects navigated the viewpoint in a more controlled way. Below, the navigation for the subjects that were judged to have the worst performance in each group is described. Also, the first trial's navigation path in the kitchen for each of these four subjects is shown in Figure 15.

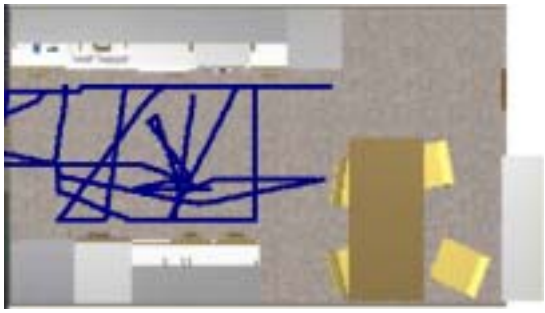
- The keyboard 2 DOFs subject had problems to place and orientate the viewpoint in a good way on some occasions. The problems appeared in all five trials.

- Also the keyboard 3 DOFs subject had problems to place and orientate the viewpoint in a good way at some occasions, but the problems gradually disappeared over the five trials.

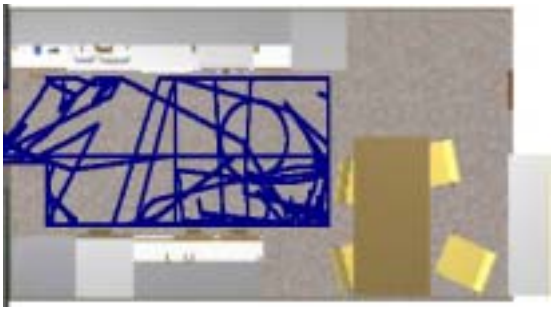
- The joystick 2 DOFs subject controlled the joystick with rather jerky movements and sometimes moved or rotated in the wrong direction. The subject had vast problems in placing and orientating the viewpoint in a good way, especially in the kitchen, and only improved her performance slightly over the five trials. She commented at several occasions how hard it was to navigate the viewpoint.

- Also the joystick 3 DOFs subject controlled the joystick with jerky movements and had some problems in placing and orientating the viewpoint in a good way. The subject improved his performance over the five trials but had some problems also in trial five. He commented how hard the navigation task was and also how hard it was to control the joystick.

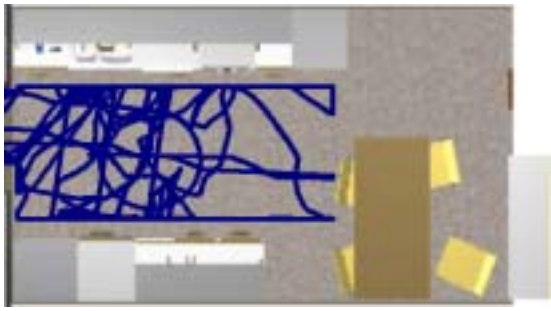
(a) Keyboard 2 DOFs



(b) Keyboard 3 DOFs



(c) Joystick 2 DOFs



(d) Joystick 3 DOFs

Figure 15. The first trial's navigation path in the kitchen for the subjects who were judged to have the worst performance in each group.

How the subjects used the DOFs

Three out of 15 subjects in the keyboard 3 DOFs group used all three DOFs in their navigation. Three subjects gradually went from only using two DOFs to also using the 3rd DOF, and had incorporated it completely in their navigation from the fourth trial. Three subjects used the 3rd DOF occasionally and one of them commented that two degrees of freedom were enough. Six subjects only used two of the three DOFs. In the joystick 3 DOFs group the 3rd DOF was used by five out of 15 subjects. Seven subjects used it occasionally, and the remaining three subjects did not use the 3rd DOF at all.

With the joystick it was possible to activate more than one DOF at the same time. Five out of 15 subjects in the joystick 2 DOFs group used this possibility whereas five subjects chose to use one DOFs at the time. The remaining five subjects occasionally used the two DOFs simultaneously but never learned to do this in an efficient way. In the joystick 3 DOFs group six subjects used one DOFs at the same time, whereas nine subjects used more than one DOF simultaneously.

Physical aspects on how the subjects used the input devices

Two different methods of using the hands were observed among the keyboard subjects. Eight out of 30 subjects in the keyboard 2 DOFs group operated the keyboard with both hands, whereas the remaining seven subjects only used their dominating hand. In the keyboard 3 DOFs group eight subjects used both their hands and seven chose to operate the keyboard with one hand. Five keyboard subjects reported that the keyboard buttons were hard to press. One of the subjects spontaneously commented that further use of the keyboard would have caused pain in her arm. None of the joystick subjects reported something similar. One of the subjects in the joystick 2 DOFs group thought that it would have been more natural to rotate the stick of the joystick in order to rotate the viewpoint instead of moving it sideways.

The subjects' orientation in the VE

Three joystick 3 DOFs subjects had problems with their orientation in the VE, and one of them needed information from the test leader at one occasion to be able to find his way.

Subjects that became stuck

One subject from each group except the keyboard 2 DOFs group had problems getting out of the kitchen two times during the experiment. They got stuck with

the virtual shoulder in the doorframe and did not seem to understand what was hindering them.

Nausea

Two subjects in the joystick 2 DOFs group and three in the joystick 3 DOFs group spontaneously reported that they became nauseous during the test. One of the latter subjects also complained over dizziness. Also, one keyboard 2 DOFs subject reported nausea during the first trial but made no comment about it when filling in the questionnaire.

5 Discussion

Overall, most subjects managed to solve the navigation task and improved their performance over the five trials. The distance covered in the kitchen part of the VE was significantly shorter for keyboard compared with the joystick. This, in combination with the fact that also the number of direction changes was significantly smaller for keyboard, might indicate that the keyboard is easier to control than the joystick for a maneuvering task. The observations from the video analyses support this. The joystick subjects tended to navigate in a wobbly manner compared to the keyboard subjects. Also, some of the joystick subjects never fully learned how to control the joystick in a good way.

Interestingly, the mean time was longer for the keyboard compared to the joystick. This might be due to the fact that the keyboard is controlled with discrete input events whereas the joystick is a continuous input device. A similar discussion has been made by Cress and French (1994). They compared touch screen, mouse, keyboard, locking and non-locking trackball for an object interaction task and found the keyboard to be the slowest input device. They concluded that “the number of discrete motions required to move a screen object using keyboard cursor keys restricts the speed with which the whole movement can be completed.”

The distance covered in the corridor part of the VE was significantly shorter for the keyboard compared with the joystick, whereas no significant difference regarding number of direction changes could be found between the two input devices. These results suggest that the keyboard is slightly easier to control than the joystick also for a search task. However, the keyboard was found to be approximately 80% slower than the joystick. Even if we consider time to be a less vital factor this might make the keyboard an inconvenient input device for VE applications that only involve search navigation. An example of such an application is a VE developed in this project, in which brain injury patients can practice the task of finding their way in a virtual replica of the Department of Rehabilitation (Löfgren, 2002).

Broadly, all four groups improved their performance over the five trials, and the improvements were especially apparent for the maneuvering task in the kitchen. In trial one, the joystick groups' mean distance was around 40% larger than the keyboard groups'. However, it decreased over the five trials and was at a level with the keyboard groups' mean distance in trial five. A similar pattern was observed for the number of direction changes. This indicates that the joystick is harder to use in the beginning but gradually becomes as easy to use as the keyboard. However, we only know that this holds true for people with no experience of 3D computer graphics. A brain injury patient with memory problems, on the other hand, might forget how the input device works between and maybe even within training sessions. It is therefore not enough that the navigation input device is learnable in the aspect that it is possible to learn how to use it; it must also be easy to use without training. Nevertheless, brain injury patients in lower ages might have a lot of joystick experience from playing computer games, and it is therefore possible that the joystick is a sufficiently usable input device for this group.

Approximately half of the joystick subjects used the possibility to activate several DOFs simultaneously by for example rotating and moving forwards at the same time. Zhai et al. (1999) point out that when people are manipulating objects in real life the DOFs tend to be integrated, whereas they seldom use all the DOFs simultaneously when moving. They mainly stay on a 2D surface, move in a given direction, turn around or move up and down when for example climbing the stairs. This speaks in favour for the keyboard since one of our main assumptions is that the VE interface should resemble reality. Also, controlling several DOFs at the same time might induce higher cognitive load in people with brain injury that have problems with simultaneous capacity.

The only significant difference that could be found between two and three DOFs was a higher mean distance for three DOFs in the corridor. This suggests that two DOFs is better for VE applications that only involve search navigation. In contrast, the 3rd DOF (sideways movement) seemed to facilitate the subjects' navigation in the kitchen when they for example were moving along the kitchen sink or became stuck with their virtual shoulder when passing through the doorway. This implies that three DOFs are preferable for VEs that involve maneuvering tasks. Nevertheless, it is important to remember that the 3rd DOF might mean increased cognitive load for some people with brain injury since it makes the keyboard more visually cluttered and the mapping of the joystick more complex.

Sixteen out of 30 keyboard subjects operated the keyboard with both hands. The possibility to operate the keyboard with both hands might be an advantage due to a more natural mapping. If the user wants to turn or move to the *left* he use his *left* hand and if he wants to turn or move to the *right* he uses his *right* hand.

Surprisingly enough, several joystick subjects spontaneously reported nausea or dizziness, without being asked about it. This might indicate that the subjects experienced cybersickness, a phenomenon usually associated with immersive VR (Cobb, Nichols, Ramsey, & Wilson, 1999). The cybersickness experienced by the joystick subjects might be connected to the fact that the frame rate was approximately 30% higher in the corridor than in the kitchen. The joystick was therefore more sensitive in the corridor, resulting in larger and less controlled movements of the viewpoint. It is highly likely that the effects of cybersickness, for example nausea and vomiting, would be augmented and unpredictable on people with brain injury. Therefore, if a joystick is used as navigation input device its sensitivity must be chosen with great care.

Some subjects experienced discomfort when pressing the keyboard, which may be a result of its inelastic surface. This problem might be even larger for long-term use and we therefore suggest that the buttons of the keyboard are covered with some sort of elastic material. Another disadvantage of the keyboard‘s inelastic surface is that the user does not receive proprioceptive feedback. It does, however, give auditive feedback through a beep, which might compensate for this flaw, at least to some extent.

It is important to remember that the VE user not only will navigate the viewpoint but also interact with objects. We have recently evaluated a method for interaction with objects using two different input devices: mouse and touch screen (Lindén, Wallergård, Davies, Boschian, Minör, Sonesson, & Johansson, 2003). How will the choice of navigation input device influence the choice of input device for interaction with objects? An advantage of the combination joystick and mouse/touch screen is that the user will most likely only use his dominant hand and therefore never navigate and interact with objects at the same time. We think that mixing these two subtasks might increase the cognitive load, especially for brain injury patients that have problems to keep the mind on more than one task at a time. It is also possible that is advantageous if the two input devices have similar properties. The IntelliKeys keyboard and the touch screen, for example, are both flat and rectangular input devices that the user controls with one or several fingers.

6 Conclusions

When designing VEs for people with brain injury it is important to make it easy for the user to navigate the viewpoint in an understandable way. The aim of this study was to find a usable navigation input device for people with no 3D graphics experience. Four input device variations were identified in an initial discussion: the IntelliKeys keyboard and Microsoft Sidewinder joystick, both programmed with two and three degrees of freedom (DOFs). The four input device variations were then compared in an experiment in which 60 able-bodied

people with no 3D computer graphics experience participated as subjects. Two sorts of navigation tasks were investigated: fine adjustments of the viewpoint (maneuvering task) and transport of the viewpoint from one location to another (search task).

The study showed that both keyboard and joystick have their advantages and disadvantages. Nevertheless, the keyboard seems to be preferable for VEs that involve maneuvering tasks, whereas the joystick is more suitable for VEs with search tasks. Another result from the study was that three DOFs were found to be more suitable for VEs that involve maneuvering tasks, while two DOFs might be slightly better for VE applications that involve search tasks. Both input devices were found to have a problem with physical ergonomics. Long-term use of the keyboard might cause fatigue in the fingers, due to its inelastic surface. One way to solve the problem could be to cover the buttons of the keyboard with an elastic material. The joystick might induce cybersickness if its sensitivity is not chosen with great care.

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Paper III:

Virtual Environments for Brain Injury Rehabilitation

- Testing a Method for Interaction with Objects on Novice Users

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Submitted to *Presence – Teleoperators and Virtual Environments*

Virtual Environments for Brain Injury Rehabilitation

-Testing a Method for Interaction with Objects on Novice Users

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Abstract

Virtual Environments (VE) are presumed to have the potential to become a complement to conventional training tools in brain injury rehabilitation. An important part of a brain injury patient's rehabilitation process is practicing instrumental activities of daily living (IADL), such as preparing meals, doing housework and grocery shopping. To perform these activities in a VE the patient needs to be able to navigate the viewpoint and interact with virtual objects in an intuitive way, particularly as people with brain injury may be less tolerant to a poor interface. The aim of the study described in this paper was to evaluate a method for interaction with objects, and to find a sufficiently usable input device for this purpose. An experiment was conducted with 20 able-bodied people with no experience of 3D computer graphics. Half of the subjects used a desktop mouse and the other half used a touch screen. The subjects performed four interaction tasks in the VE five times in a row. Video recording was used to document the trials and the interview that was conducted afterwards. Broadly, the method for interaction with objects worked well, and no large differences in performance could be seen between the mouse group and the touch screen group. However, the touch screen subjects showed a tendency to resemble real life object interaction more than the mouse subjects.

Keywords: brain injury rehabilitation, virtual environment, interaction with objects, input device

1 Introduction

1.1 Brain injury and brain injury rehabilitation

Annually a large number of people suffer from a severe brain injury. The damage can be caused by external violence to the head due to for example traffic accidents, falls, and sport activities. Other causes to brain injury may be stroke, tumours, brain tissue inflammation or anoxia (Kolb & Whishaw, 1996). The incidence in Sweden (nine million inhabitants) of severe or moderate traumatic brain injury (TBI) has been estimated at 40 per 100,000 inhabitants (Hårdemark & Persson, 2000) and of stroke at 235 per 100,000 (Johansson, Norrving & Lindgren, 2000). The nature of acquired brain injury (ABI) is a range of complex physical, cognitive behavioral, and emotional problems. The extent of these problems varies for each individual (Finlayson & Garner, 1994).

Memory problems are among the most commonly reported deficits after brain injury (McKinlay & Watkiss, 1999). These include difficulty in learning new information as well as retaining and later retrieving it. Another problem after brain injury is slowness in information processing. This may lead to reduced capacity to sustain attention when learning new tasks but also difficulties in keeping the mind on more than one task at a time. Executive problems are also common after brain injury and difficulties may arise with planning, initiation and problem solving.

Occupational therapy is focused on engaging people in meaningful and purposeful activities and enhancing their abilities to perform the daily tasks they need and want to perform (Fisher, 1998). One important part in the rehabilitation is to assess a patient’s ability to perform, safely and effectively, daily living tasks to be able to plan and evaluate different actions. There are several methods for functional assessment and in comparison with questionnaires, checklists and rating scales the most important method is observation (Giles, 1993).

1.2 Virtual Reality in cognitive rehabilitation

Different types of Virtual Reality (VR) technologies have been used for assessment and rehabilitation of several diagnosis and different age groups. For example Rizzo et al. (2002) have developed and evaluated VE applications for 1) assessment of attention processes in children with attention deficit hyperactivity disorders (ADHD) and 2) memory processes in people with TBI. Brown, Shopland and Lewis (2002) have designed a virtual travel-training environment for people with learning disabilities. The use of VEs for rehearsal of activities of daily living in stroke rehabilitation have been investigated by Hilton, Cobb, Pridmore and Gladstone (2002). Kizony, Katz, Weingarden and Weiss (2002) use a unique approach to Virtual Reality for neurological

rehabilitation. They have investigated a projected, video-based VR system in which the patient can see himself interact with virtual objects on a display.

However, few thorough studies regarding the effect the interaction method has on usability for people with cognitive disabilities have been made. People with cognitive problems may be less tolerant to a poor interface and therefore it is essential that the VE tool does not become unusable for example due to an unsuitable input device.

1.3 Project description

The Department of Rehabilitation, Lund University Hospital and the Division of Ergonomics at the Department of Design Sciences, Lund University are currently co-operating in a long-term project. The main goal of the project is to investigate if a VE can be a useful complement in brain injury rehabilitation and an efficient tool in everyday life. More specifically the project aims to:

- find a suitable interface between the VE and the user, with emphasis on navigation of the viewpoint and interaction with objects;
- investigate transfer of training of practical tasks learnt in a VE to the real world; and
- develop at least three practical applications of VE for rehabilitation.

The Division of Ergonomics performs research on the interplay between man and technology and has expertise in human-computer interaction (HCI) and development of VEs for various applications. The Department of Rehabilitation is specialised in the practical and theoretical aspects of rehabilitation of people with acquired brain injury. The rehabilitation team consists of several professions that work interdisciplinarily. Two occupational therapists, one neuropsychologist, and one computer engineer, with several years experience of how technology can be used in rehabilitation, participated in the project.

Desktop VR was used in this project mainly because of the cost and availability of such computer equipment in the hospital environment. Furthermore, in a study by Brown, Neale, Cobb and Reynolds (1999) it was found that people with learning disabilities can learn well using this VR technology. Another fact in favour of desktop VR is that immersive VR may induce cyber sickness upon the user (Cobb, Nichols, Ramsey, & Wilson, 1999).

A study regarding navigation of the viewpoint has recently been conducted in this project (Wallergård et al., 2003). The aim of the navigation study was to find a usable input device for navigation in VEs for brain injury rehabilitation. An experiment, in which four different input devices were compared, was conducted with 60 able-bodied persons with no experience of 3D computer graphics.

1.4 Interaction with objects in a VE

A number of guidelines for VE interaction have been published. The problem with most of these guidelines is that they are either too general or based on experience and intuition, and not from empirical results (Bowman et al., 2001). Also, guidelines for VE design may not be suitable for all types of user groups (Neale, Cobb & Wilson, 2000). However, regarding interaction with objects in VEs for people with learning disabilities Neale et al. (2000) have made the following recommendations:

- Task design should be realistic, equally as complex as in the real world, and flexible (allowing users to carry out sub-tasks in any order).
- Metaphors used to interact with objects should reflect real world behaviour.
- Representations of objects in the VE must be obvious.
- Use set viewpoints to focus attention to objects.
- Highlight objects to indicate interactivity.

Interacting with objects when performing an activity in a VE can be done in at least three ways (Lindén et al., 2000):

1. activate objects such as opening a door, turning on a switch or turning on or off a tap;
2. move objects from one place to another and rotate it if appropriate; and
3. use one object with another (object-object interplay), for example, using a coffee scoop to take coffee from a packet to put into a filter.

We investigated these three ways of manipulating objects in a pilot study in which two people with brain injury and four able-bodied people prepared coffee in a coffee brewing VE (Lindén et al., 2000). In this VE a virtual object could be moved by clicking on it which placed the object in the foreground as though carried by an invisible hand (Figure 1). The object could then be placed by clicking on the location. To activate an object, for example turning on the coffee machine, the user simply clicked on it. This interaction method is called point-and-click and was also used in a cash dispenser VE (Wallergård et al., 2001), which is one of the applications that has been developed in this project. The coffee brewing study revealed the following problems regarding interaction with objects:

- The area around the object that is sensitive to clicking (the active area) was often missed.
- Some subjects had problems understanding that the object was being held.

- Object-object interplay sometimes caused problems when a click could be interpreted in more than one way.

Figure 1. The coffee package is being held in the coffee brewing VE

These results indicated that there was a need for more work on interaction in VEs for people with a brain injury. A more natural interaction technique that avoids abstractions seemed to be desirable for this population. An example of such a natural interaction technique is the tangible interface developed for stroke patients described in Hilton et al. (2002). The tangible interface was developed for a coffee brewing activity and allows the user to interact with the objects in the VE through real world objects such as an electric kettle, jar of coffee etc. Another observation made in the study by Lindén et al. (2000) was that the subjects initially tended to try to drag and drop the objects, which inspired us to investigate if drag-and-drop is a more natural interaction technique.

The coffee brewing environment is a fairly small VE and therefore automatic navigation of the viewpoint worked well for this application. However, in a VE that is too large to be viewed in one screen-full some form of self-controlled navigation must be used. This poses a problem when the user wants to move an object to a location outside the view since he then both has to carry the object and navigate the viewpoint at the same time. This led to the idea of investigating if the concept of carrying the object in a virtual hand could make these object movements easier. The reason for choosing a virtual hand was to resemble reality. A similar concept was used in the Supermarket VE developed by Brown et al. (1999). During the payment procedure the user can put coins and notes in a representation of the user's hand and then pay when the hand holds the sufficient amount of money. The input device used in the coffee brewing environment was a regular desktop mouse, which none of the subjects had any significant problems controlling. Nevertheless, there is a need for further work on what effects the choice of input device has on the usability of the VE.

2 Aim

The study described in this paper was part of a project that aimed to find out if and how VEs can be used as a training tool by people with brain injury. The purpose of the study was therefore to evaluate a method of interacting with objects in VEs on people with no 3D computer graphics experience, and to find a sufficiently usable input device for this purpose.

3 Method

The study was performed in three steps:

1. The research group started the study by discussing different methods for interaction with objects. This discussion resulted in a proposed method for interaction with objects.

2. The next phase concerned what properties an input device should have to be usable for people with brain injury, for the purpose of interaction with objects in a VE. Aspects of occupational therapy, human-computer interaction and VR were considered in the discussion, which resulted in a list of desirable qualities. This list was then used to select two input devices: mouse and touch screen.

3. Our proposed method for interaction with objects was then tested with mouse and touch screen on able-bodied people with no experience of 3D computer graphics. This population was chosen since we wanted to first identify *fundamental* usability issues.

The results will then be applied to people with brain injury, and eventual usability problems for this user group will be attended to. This work is currently in progress and will not be discussed in this article.

3.1 Step 1: The method for interaction with objects

As described above, interacting with objects in a VE can be performed in at least three ways: activate objects, move objects and use one object with another (object-object interplay). We chose to limit this study to the former two; object-object interplay will hence be investigated later in the project.

Activating objects with a click posed no problems for the brain injury patients in the pilot study (Lindén et al., 2000). However, two ideas concerning moving objects evolved during the pilot study: the use of drag-and-drop for moving

objects and a virtual hand for carrying objects. Finally, our proposed method for interaction with objects consisted of the following four parts:

1. Drag-and-drop for moving the object
2. A virtual hand for carrying the object
3. A single click for activating the object (for example turning a tap or opening a door)
4. Automatic rotation of the object (to give it a proper orientation)

3.2 Step 2: Considered input devices

We used our experience from the pilot study and knowledge of brain injury rehabilitation and human computer interaction to produce the following list of desirable input device properties:

- An injury to the brain may result in various cognitive disabilities. The injured person might for example have problems differentiating properties of an object, and therefore the input device should not have different modes of operation.
- The short-term memory problems of some people with brain injury mean that the input device should only allow a limited set of different input forms.
- It is essential that the input device gives necessary feedback to the user to make him understand that the action has been registered.
- A brain injury may also result in decreased motor performance. Therefore the input device should be one that can be operated by people with fine-motor difficulties.
- It should be an input device that most people recognize.
- A more practical, but not less important, detail is that the input device should be available i.e. it should be easily found in retail trade and it should not be too expensive.

A basic distinction can be made between input devices that offer (1) direct control on the screen surface, such as touch screen, and (2) indirect control away from the screen surface, such as mouse and track ball (Shneiderman, 1998). Input devices can also be grouped according to the degrees of freedom (DOF) they have. Two of the most common six DOF input devices are the Spaceball and the Spacemouse. The problem with these input devices are that they are designed for multi DOF interaction and therefore might be hard to use for people with limited motor and cognitive abilities. The fact that they are relatively expensive (approximately $500) is another drawback since cost and availability are important factors to consider when introducing VR technology in a hospital or home environment.

Another input device considered was the desktop mouse. Young students with learning difficulties coped very well with the mouse when performing a VE interaction task in a study by Lannen, Brown and Powell (2002). Also, Mendozzi et al. (2000) used a desktop mouse for interaction with objects in a training VE for mentally disabled people. No major difficulties were reported for this user group.

Also discussed was the touch screen that according to Shneiderman (1991) has an unrivalled immediacy, a rewarding sense of control and the engaging experience of direct manipulation. Shneiderman writes that touch screens have several advantages over other pointing devices:

- Interacting with a touch screen is a type of direct manipulation that is easy to learn.
- Hand-eye coordination is easier with a touch screen compared to a mouse or a keyboard.
- The touch screen is the fastest pointing device.

However, touch screens also have some disadvantages:

- The hand of the user may obscure the screen
- In order to reduce arm fatigue the touch screen needs to be tilted and placed at a lower position.
- Some reduction in image brightness may occur.

Another flaw of the touch screen is the lack of proprioceptive feedback (Bender, 1999). For example, selecting an object on the screen does not give the same feedback as pressing down the button of a mouse. There are basically three types of touch screen technologies: capacitive, resistive and surface wave technology. The basic difference between them is the way in which they register the touch of the user. Unlike capacitive touch screens, resistive and surface wave touch screens don't require electrical contact between the user and the screen and can therefore be controlled with an object (for example a pencil) as well as a finger.
Traditionally, touch screens have been quite expensive but are now becoming more affordable. For example, a 19" CRT touch screen based on surface wave technology cost around $500.

An input device related to the desktop mouse is the trackball. It has proved to be a usable input device for persons with severe motor impairments, see for example Anderson (1999) and Jacobs et al. (1997). However, a study by Cress and French (1994) suggests that the trackball is harder to use than mouse and touchscreen. They compared touchscreen, mouse, keyboard, trackball and locking trackball for three subject groups: computer-experienced adults, normally developing children and children with mental retardation. Three different measures were used: speed, user characteristics and mastery, where mastery was defined as the minimum operational competence for handling the

various input devices. Among other things the results suggest that trackball and locking trackball were more likely to be failed by children with mental retardation than were touch screen, mouse and keyboard.

For the reasons above we finally decided to evaluate our interaction method with touch screen and mouse respectively.

3.3 Step 3: The experiment

3.3.1 Subjects

Twenty hospital staff with no experience of 3D computer graphics participated in the experiment. They were selected from the study on navigation of the viewpoint (Wallergård et al., 2003) in such a way that subjects with extreme values (best and worst) were excluded. The subjects were then divided into two groups. The first group used a mouse for interaction and the second group used a touch screen. Both groups used the IntelliKeys keyboard with three DOF for navigation of the viewpoint (Table 1).

Table 1. Demographic data and input devices. N=20.

Group	Input device	Subjects		Age (median)	Computer use hrs/week (median)
1	Touch screen	6 females	4 males	36	6,8
2	Mouse	6 females	4 males	31,5	6

3.3.2 Experimental setup

World Up, an object-oriented VR world-building environment, was used to create the VE. The reasons for choosing this VR software were that it works on ordinary personal computers, such as those normally found in a rehabilitation hospital, and that the WorldUp player needed to run the VE application comes for free. The VE, which was designed to look like the real training kitchen at the Department of Rehabilitation, including various kitchen fittings such as stove, dishwasher, refrigerator, cupboards, and kitchen furniture (Figure 2a). Some parts of the kitchen fittings in the VE were programmed with two properties; “possible to activate with a mouse click” and “possible to place objects on”. The size of the area around an object sensitive to mouse events, referred to as the active area, was determined during the implementation of the VE. The doors of the cupboards could be opened and closed with a mouse click. A virtual hand was placed in the lower right corner of the screen (Figure 2b). An object placed in the virtual hand remained there until moved. Included in the VE were also three food packages that had the property “possible to move with drag-and-drop” (Figure 2c). The size of the packages differed depending on if they were

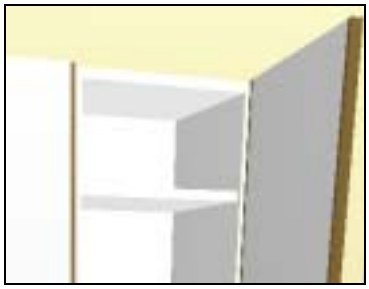
being moved, or if they were placed in the virtual hand or on a kitchen surface. When a package was being moved its size was approximately ten percent of the screen height and did not change (Figure 2d). When placed in the virtual hand the package had a predefined size in scale with the virtual hand, and when placed on a kitchen surface the size of the package varied with the distance from the viewpoint. These variations in size were due to the way in which the VE was programmed. When the cursor arrow was located over an object possible to interact with it changed to a pointing hand (Figure 2c). When the user moved or activated an object the cursor was transformed into a holding hand to give feedback to the user that the object was manipulated (Figure 2d).

(a) Overview of the VE

(b) The virtual hand

(c) The three packages

(d) Dragging an object



(e) The top shelf

(f) The mixed video signals

(g) The IntelliKeys keyboard

Figure 2. The kitchen VE, the mixed video signals and the IntelliKeys keyboard

Three video cameras were used to record the subject's behaviour during the trial. One camera was positioned to film the subject in half-figure, another one filmed the subject's hands from above and the third one was a close-up camera registering the subjects facial expressions. The video signal from the computer

was mixed with the camera signals to get an overall display on one screen to facilitate the analysis (Figure 2f).

Walk-through navigation was used, which means that the height of the viewpoint was fixed, and an IntelliKeys keyboard with three DOFs was used as navigation input device (Figure 2g). Ten of the 20 subjects had already used the IntelliKeys keyboard for navigation of the viewpoint in the study by Wallergård et al. (2003). To eliminate the differences between the subjects pre-knowledge of the keyboard as much as possible, each subject started the test session by using the keyboard in a navigation task that lasted for approximately two minutes.

The subjects were to perform four different interaction tasks (Table 2) a total of five times. The subject was told to use the mouse/touch screen for interaction with objects and the keyboard for navigation but received no other information about the functionality of the kitchen VE. If the subjects did not use the virtual hand in the first trial they received information on how to use it from the test leader, before the second trial.

Table 2. Description and purpose of the interaction tasks

Task	Description	Purpose
1	Move a packet of rosehip cream from the bench to the sink.	To study the procedure of moving an object within the view.
2	Move a carton of milk from the bench to the table.	To study the procedure of moving an object to a location that is outside the view.
3	Move a packet of macaroni to the opposite side of the kitchen, open the cupboard door, place the packet on the shelf and close the door.	To study the procedure of moving an object to a location that is outside the view and opening and closing a cupboard door.
4	Move the packet of rosehip cream to the opposite side of the kitchen, open the cupboard door, place the packet on the top shelf (Figure 2e) and close the door.	As above and additionally placing the object on a high location that might be out of view.

At the end of the session, an interview consisting of six categories of questions was conducted and video recorded. The questions concerned moving objects within and out of view, the virtual hand, placing an object on the top shelf,

opening and closing cupboard doors, the input device and also miscellaneous issues.

3.3.3 Analyses methods

Two members of the research group where responsible for the analyses of the experimental data. They analysed each subject's trial independently and thereafter discussed their observations. When a difference of opinion arose the video sequence of interest was analysed once again. The following seven points were used as a basis for the observations:

- Are the subjects spontaneously using drag-and-drop in the first trial?
- Are the subjects using the virtual hand for carrying objects *before* receiving information about it?
- Are the subjects using the virtual hand for carrying objects *after* receiving information about it?
- How does the subjects proceed to open and close the cupboard doors?
- How does the subjects proceed to place an object on the high shelf?
- Are the subjects having any problem with the input device?
- In what way are the subjects using their hands?

The main concepts of each subject's interview were also discussed and written down.

4 Results

4.1 Results from the video analyses

Nineteen subjects out of 20 managed to solve the four interaction tasks without help in all five trials. The 20th subject had to be given instructions on how to open the cupboard doors on one occasion.

Moving objects within the view (task 1)

All mouse subjects used drag-and-drop spontaneously in trial one, while four out of ten touch screen subjects tried point-and-click, that is they tried to move the object by first clicking on the object and then on the destination. Nine subjects used the virtual hand spontaneously when moving objects within the view in the first trial. In total, the virtual hand was used 37 times for the touch screen and 12 times for the mouse during task 1 (Table 3). Two touch screen subjects and three mouse subjects used another strategy. They held the object by holding down the

mouse button, moved the viewpoint (even if it was not necessary) and then dropped the object at the destination. The remaining subjects dragged the object directly to the destination.

Table 3. Number of subjects that used the virtual hand in each trial (N = 20; ten touch screen subjects and ten mouse subjects)

Trial	Task 1		Task 2		Task 3		Task 4	
	Touch screen	Mouse	Touch screen	Mouse	Touch screen	Mouse	Touch screen	Mouse
1	5	4	4	4	4	4	4	4
2	10	2	10	6	10	6	10	7
3	8	2	10	7	10	6	10	6
4	8	2	10	5	10	6	10	6
5	6	2	10	6	10	6	10	6
Sum	*37/50*	*12/50*	*44/50*	*28/50*	*44/50*	*28/50*	*44/50*	*29/50*

Moving objects out of the view (tasks 2-4)

Two strategies for moving objects out of the view were observed. The first strategy, called the hand strategy, was to put the object in the virtual hand, then navigate the viewpoint and finally put down the object at the destination. The subjects that used the second strategy, called the hold strategy, kept the object in drag mode by holding down the mouse button while navigating the viewpoint and then placed the object. All touch screen subjects used the hand strategy after having received information from the test leader (Table 3). Five mouse subjects applied the hold strategy and only used the virtual hand occasionally. On two occasions one person was observed to hold the object over the virtual hand without using it. One of the subjects using the hold strategy used the virtual hand twice to place objects when opening or closing cupboard doors.

Placing objects on the top shelf (task 4)

Occasionally, the subjects had to move backwards to be able to see the top shelf when standing in front of a cupboard. This did not cause any problems for the majority of the subjects; only one mouse subject had some problems placing the viewpoint in an appropriate way. However, when the subjects were to put the object on the top shelf a problem arose. The nature of the problem was that the subjects put the object on the edge of the top shelf. The edge did not have the property “possible to place objects on”, and the object therefore returned to its previous location. Each time the subject failed to place the object on the top shelf was counted (Table 4 and 5). Subject M_2, M_3, M_4 and T_6 stood for the majority of the problems in placing objects on the top shelf. Subject M_2 failed to place the object 15 times in the second trial. He had problems finding a suitable

position for the viewpoint when placing the object and therefore accidentally placed it on a lower shelf.

Table 4. Number of times touch the screen subjects (T_{1-10}) failed to place objects on the top shelf in trial 1-5, n=10.

Trial \ Subject	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	Total
1	1	0	3	0	2	5	1	0	0	0	12
2	4	0	1	0	0	0	0	0	2	1	8
3	0	0	0	0	0	0	0	0	1	0	1
4	1	2	1	4	0	6	0	0	1	0	15
5	0	0	0	3	1	0	0	0	0	0	4
Total	*6/20*	*2/20*	*5/20*	*7/20*	*3/20*	*11/20*	*1/20*	*0/20*	*4/20*	*1/20*	*40/200*

Table 5. Number of times the mouse subjects (M_{1-10}) failed to place objects on the top shelf in trial 1-5, n=10.

Trial \ Subject	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8	M_9	M_{10}	Total
1	2	1	3	1	0	1	2	3	0	5	18
2	0	15	4	3	1	0	0	0	0	1	24
3	2	1	3	2	0	0	0	1	0	0	9
4	0	1	0	3	0	1	0	3	0	0	8
5	3	1	3	4	2	1	0	0	1	0	15
Total	*7/20*	*19/20*	*13/20*	*13/20*	*3/20*	*3/20*	*2/20*	*7/20*	*1/20*	*6/20*	*74/200*

Open and close cupboard doors (tasks 3-4)

One touch screen subject and two mouse subjects opened and closed the cupboard doors without any problems during the five trials. The remaining subjects had problems in opening and/or closing the cupboard doors in one or several trials. As can be seen in Table 6, four touch screen subjects, T_1, T_3, T_4 and T_6, had problems in all five trials, whereas none of the mouse subjects had problems after trial 3 (Table 7). The nature of the problem was that the subjects tried to open and/or close the cupboard doors with drag-and-drop instead of clicking. The problem was registered in the following manner:
If the subject had problems opening as well as closing the cupboard door in task 3 this was counted as “two”. If the subject only had problems opening or closing the cupboard door this was counted as “one”. Task 4 was registered in the same way. This means that the maximum value for problems to open and close the cupboard doors was “four”.

Table 6. Registration of problems to open and close cupboard doors for touch screen subjects (T_{1-10}), trial 1-5. n=10.

Trial \ Subject	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	Total
1	3	2	2	3	0	3	2	3	1	3	
2	2	3	2	2	0	4	1	0	0	3	
3	2	0	2	2	0	2	0	2	1	3	
4	3	1	2	2	0	3	0	1	0	0	
5	2	1	1	1	0	4	0	2	0	2	
Total	*12*	*7*	*9*	*10*	*0*	*16*	*3*	*8*	*2*	*11*	*78*

Table 7. Registration of problems to open and close cupboard doors for mouse subjects (M_{1-10}), trial 1-5. n=10.

Trial \ Subject	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8	M_9	M_{10}	Total
1	0	3	3	2	2	1	1	0	3	2	
2	0	2	0	1	0	0	0	0	0	0	
3	0	0	0	1	0	0	0	0	1	0	
4	0	0	0	0	0	0	0	0	0	0	
5	0	0	0	0	0	0	0	0	0	0	
Total	*0*	*5*	*3*	*4*	*2*	*1*	*1*	*0*	*4*	*2*	*22*

Dropping and failing to get hold of objects (tasks 1-4)

In general, all subjects managed to drag-and-drop objects. However, two problems were noted: either the subject had difficulties getting hold of the object or dropped the object before it was placed. Table 8 and 9 describe how many times the subjects dropped or failed to get hold of objects for touch screen and mouse respectively. As can be seen in Table 8 two touch screen subjects had problems in all five trials. For the mouse subjects the problems appeared mainly in the first trial and none of them had problems in more than one trial.

Table 8. Number of times the touch screen subjects (T_{1-10}) dropped or failed to get hold of an object in trial 1-5. n=10.

Trial \ Subject	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	Total
1	0	0	2	0	2	0	3	1	0	0	8
2	0	3	10	0	1	0	1	0	0	1	16
3	0	1	2	0	1	0	1	0	0	0	5
4	0	0	4	0	1	2	1	0	0	5	13
5	0	0	8	0	1	2	0	0	0	2	13
Total	*0*	*4*	*26*	*0*	*6*	*4*	*6*	*1*	*0*	*8*	*55*

Table 9. Number of times the mouse subjects (M_{1-10}) dropped or failed to get hold of an object in trial 1-5. n=10.

Trial \ Subject	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8	M_9	M_{10}	Total
1	0	0	0	0	1	0	1	3	1	1	7
2	0	0	0	0	0	2	0	0	0	0	2
3	0	0	0	0	0	0	0	0	0	0	0
4	0	0	1	0	0	0	0	0	0	0	1
5	1	0	0	0	0	0	0	0	0	0	1
Total	*1*	*0*	*1*	*0*	*1*	*2*	*1*	*3*	*1*	*1*	*11*

How the subjects used their hands (tasks 1-4)

Six touch screen subjects used their dominant hand for both navigation and interaction and did not use their non-dominant hand at all. The remaining four subjects used both their hands when navigating and their dominating hand when interacting with objects. Six mouse subjects navigated with their non-dominant hand and interacted with their dominant hand. They only let go of the mouse in one or two occasions in the beginning of the trial. One mouse subject used the dominant hand for both navigation and interaction and did not use the non-dominant hand at all. The remaining three subjects used their dominant hand for both navigation and interaction and sometimes used both hands for navigation. Three mouse subjects navigated the viewpoint and interacted with objects simultaneously at one or several occasions. For example they dragged an object over the screen whilst navigating.

4.2 Interview results

The virtual hand

Both positive and negative comments about the virtual hand came to light during the interviews. Positive comments about the virtual hand were for example that it felt natural to use it since it was like putting objects in a real hand. Another test person experienced the hand as clear and useful to place objects in. Other comments were that it was easier to move objects using the virtual hand, and one of the subjects mentioned that he lost control a bit when he did not use the virtual hand. One subject felt that the virtual hand was completely unnecessary for the task. Another subject remarked that it was more natural to drag the object directly to the location rather than using the hand. Another comment was that it was disruptive that the objects became bigger when placed in the virtual hand. Further remarks concerning the virtual hand was that it was in the way,

unnecessarily big and blocking the view. Five subjects pointed out that it was not obvious how the virtual hand was to be used and that they would not have understood its meaning without information. The virtual hand was also experienced as an artificial limb and as being masculine. Further comments were that the virtual hand showed the way, was a guide and that it symbolized a helping hand.

The size of the virtual objects

None of the interview questions concerned the objects themselves, but five subjects nevertheless made remarks about their size. One subject pointed out that the objects became larger and blocked the view when they were placed in the hand, and another subject remarked that the objects had different size depending on if it was dragged by the cursor hand or if it was in the virtual hand.

Open and close cupboard doors

Four mouse subjects commented that it took a while to figure out how to open the cupboard doors, and seven touch screen subjects said that they found it difficult to open and close them. Three of these seven touch screen subjects said that they never found a good strategy for opening the doors. Another comment made by three touch screen subjects was that real cupboard doors are not opened with a click.

Placing an object on the top shelf

Four touch screen subjects and six mouse subjects said that they had difficulties in placing an object on the top shelf. Six subjects commented that they had to place themselves of a distance from the cupboard to be able to see the top shelf.

Reaching and placing objects far away

Seven subjects spontaneously commented on the possibility to reach for and place objects from distance. One of them made the following comment: “I do not have that long arms.”

Moving objects

Only a few comments regarding moving objects were made. One touch screen subject pointed out that it was much harder to move an object out of the view than within the view. Another touch screen subject remarked that the object did not follow when he tried to move it. One subject pointed out that the object did not change size until the cursor was outside the object, which made him unsure if the object followed or not.

The input devices

No negative comments regarding the two input devices were made during the interviews. Two of the touch screen subjects said that they never had used a touch screen before. One of them thought that it felt a bit strange in the beginning and the other one commented that the input device was ok after learning how to use it. One mouse subject remarked that it felt confusing using two input devices and would have preferred one input device.

5 Discussion

All the subjects carried out all four interaction tasks without major difficulties. The majority of them used drag-and-drop spontaneously when moving an object within the view in the first trial. However, some touch screen subjects tried to move objects with point-and-click. Two of these subjects participated in a previous study in which point-and-click was used (Lindén et al., 2000) and might have been influenced by this interaction technique. The fact that all mouse subjects used drag-and-drop spontaneously could be due to previous experience of MS Windows applications in which mouse and drag-and-drop are used.

Surprisingly, approximately half of the subjects used the virtual hand without information in the first trial. However, for some subjects it was not obvious how to use it. This might be explained by the concepts of visibility and affordance discussed by Norman (1988). It is possible that some of the subjects simply did not notice the hand due to bad visibility. The fact that some subjects interpreted the virtual hand as an inviting instead of a carrying hand indicates that it sends wrong signals to the user and thereby has flawed affordance. Its size, shape and color should be changed to make it more conspicuous and appear more like a hand to carry things. For an able-bodied person, information about the virtual hand might be enough to understand how to use it. However, the fact that memory problems are among the most commonly reported deficits after brain injury (McKinlay & Watkiss, 1999) is very important to consider. These problems include difficulty in learning new information as well as retaining and later retrieving it. It is therefore not enough that it is possible to learn how to use the virtual hand. The virtual hand should be as self-explanatory as possible since it is possible that the patient might forget how to use it between and maybe also within training sessions. Helping the user understand how the virtual hand works by giving it good visibility and affordance is probably the key to achieve this.

The usage of the virtual hand after information differed between the two subject groups. The touch screen subjects, in contrast to the mouse subjects, used the virtual hand every time when moving objects out of view and for the most part also within the view. Approximately half of the mouse subjects preferred the hold strategy, that is they kept the object in drag mode by holding

down the mouse button, and many of them did not release their hold of the mouse during the trials. This is probably connected to the mouse subjects' experience of using a mouse, but nevertheless indicates that it was more natural for the touch screen subjects to use the virtual hand.

More than half the subjects had problems placing an object on the top shelf due to difficulties in dropping it within the active area in the space above the shelf. They seemed to prefer to drop the object on the edge or the bottom of the top shelf. A possible explanation might be that these areas have the same color as the inside of the cupboard and therefore can be perceived as being the shelf surface. If the object was not dropped within the active area it returned to the place from where it was picked up. If the subject had moved the object with the hold strategy, it returned to its place of origin and possibly disappeared from view. This might pose a problem for a patient with memory problems since he might have forgotten where he picked up the object. One way to reduce the problem could be to include the edge of the shelf in the active area, or to place the top shelf so the user can see it without having to move backwards.

The most obvious interaction problem, especially for the touch screen subjects, was opening and closing the cupboard doors with a click. This partially contradicts one of the conclusions from our pilot study (Lindén et al, 2000), that people seem to have an inherent understanding for "click-to-activate". The mouse subjects learnt faster how to open the cupboard doors, none of them failed after the third trial, whereas most of the touch screen subjects had problems in four out of five trials. This indicates that activating an object with a click is more natural with the mouse than with the touch screen. This may be due to the subjects' previous experiences of clicking with the mouse when working with MS Windows applications. In contrast, the touch screen subjects tended to imitate the way things are done in real life, that is, they tried to open and close the cupboard doors with drag-and-drop. This came to light also in the interviews. Several touch screen subjects said that they did not find a good strategy for opening and closing cupboard doors and also commented that cupboard doors are not opened with a click in real life. It is important that the way activities are performed in a VE resemble the way they are done in reality. This seems to be extra important if a touch screen is used as input device for interaction with objects, which leads us to believe that VEs for brain injury rehabilitation should be programmed to allow several interaction styles. It should, for example, be possible to open or close a cupboard door both with a single click and drag-and-drop.

Interestingly, some subjects spontaneously commented on the possibility of placing objects far away. It seemed as if several subjects experienced this as being a bit unreal but also efficient since they quickly adopted this way of transporting objects. If realism of movement is a requirement, "magic" techniques not based on a natural movement metaphor should be avoided (Bowman et al., 2001). Also, Neale et al. (2000) suggests that "metaphors used

to interact with objects should reflect real world behaviour" in VEs for people with learning disabilities. Applied on the kitchen VE this would mean that the user would have to approach the kitchen bench to be able to place an object on it. However, we are not only striving to simplify the interaction with objects but also to make it sufficiently efficient. Once again, the best solution is probably to allow both interaction styles; it should be possible to place the object both when standing next to and far from the location.

Adequate feedback is of utmost importance in computer applications. Every action should result in some kind of response from the system (Shneiderman, 1998). The fact that the object did not change size until the cursor was outside the object means that the user did not get instant feedback that the object followed. The best way to solve this problem is probably to make the object change size immediately when the user is clicking on it.

Opinions regarding the variations in object size emerged during the interviews. These variations might be confusing for a patient with brain injury since they do not reflect real world behaviour. However, the variations in size are due to the way in which the object interaction is programmed. One must also consider what is possible to implement in reasonable time when discussing VE usability. Nevertheless, the objects should be smaller when placed in the hand. Then the difference in size would be smaller and it would also block the view less.

Part of the purpose of this study was to find a sufficiently usable input device for the evaluated interaction method. The opinions of the subjects regarding the two input devices were mainly positive. However, some problems came to light during the analysis. An interaction problem that was particularly obvious for the touch screen subjects was that they dropped or failed to get hold of the object. Several touch screen subjects had constant problems whereas the mouse subjects only had occasional problems. An explanation might be that the touch response varies due to the user's body size, ground path, or finger dryness and some people may therefore have problems getting sufficient contact with the touch screen surface (Elo TouchSystems, 2002). However, this could be avoided by using a touch screen built either with resistive or surface-wave technology since these types of touch screens do not require electrical contact between the screen surface and the user. Another issue connected to physical ergonomics is that a touch screen needs to be tilted and placed at a lower position in order to reduce arm fatigue in the user. However, none of the touch screen subjects spontaneously complained about fatigue, even though the touch screen was neither tilted nor lowered. Nevertheless, the test sessions were relatively short (approximately 15 minutes), and it is possible that long-term use might lead to fatigue in the arms.

All touch screen subjects used one input device at a time, whereas several mouse subjects used their non-dominant hand for controlling the keyboard and their dominant hand for operating the mouse. This indicates that it is more natural to remove the hand from the touch screen when the interaction is

finished compared to the mouse. Clearly separating navigation and interaction in the interface might facilitate for patients with limited simultaneous capacity, and therefore the touch screen might be a better interaction input device than the mouse for this group of people with brain injury.

Overall, we saw no large difference in performance between the mouse group and the touch screen group. However, it is important to remember that the mouse subjects had experience of the mouse, whereas the subjects in the other group had little or no experience of the touch screen. The mouse might be a sufficiently usable input device for people with brain injury who have experience of it. The fact that it is the de-facto standard input device, together with the keyboard, for personal computers is another advantage of the mouse. However, the touch screen might be an easier input device for some groups of people with brain injury. Shneiderman (1998) suggests that indirect control input devices, such as the mouse, require more cognitive processing and hand-eye coordination than direct control devices like the touch screen. Also, results from Cress and French (1994) indicate that mouse and keyboard present greater challenges to the pattern analysis abilities of children with mental retardation than touch screen, trackball and locking trackball. The mouse might therefore induce more cognitive load in people with brain injury that has poor abilities in this cognitive domain.

6 Conclusions

When designing VEs for people with brain injury it is important to make it easy for the user to interact with objects in an intuitive way. In this study a method for interaction with objects was evaluated on 20 people with no 3D computer graphics experience. Half of the subjects used a mouse as input device and the other half used a touch screen. Drag-and-drop and clicking was used for moving and activating objects respectively, and objects were automatically given a suitable orientation. The interaction method also included a virtual hand for carrying objects when moving in the VE. The following conclusions were made:

- No major differences in performance could be seen between the mouse and the touch screen group. Both input devices worked in a satisfactory manner for people with no 3D computer graphics experience.

- Drag-and-drop proved to be a well-working technique for moving objects within the view, as well as holding the object by pushing down the mouse button when moving.

- The concept of a virtual hand for carrying objects worked well. However, some subjects needed information before they started to use it. When an

object like a virtual hand is introduced in a VE it is important to provide it with good visibility and affordance to make the user notice it and understand how to use it.

- Opening and closing cupboard doors caused some problems for both subject groups. The problems were particularly obvious for the touch screen subjects who tried to open them with drag-and-drop in a manner that resembled reality. To eliminate these difficulties, the VE should be programmed to allow several interaction styles. In this particular case it should be possible to open the cupboard doors both with a single click and drag-and-drop.

- Delimitation of active areas is of importance when designing a VE. For example, it should be possible for the user to drop an object in the proximity of a surface to place it there.

- The variations in object size might be confusing for a patient with brain injury. One way to diminish the problem could be to reduce the size of the object slightly when placed in the hand.

- Some touch screen subjects had problems moving objects since they did not get sufficient contact with the touch screen surface. One way to avoid this problem could be to use a resistive or surface wave touch screen since these two types of technology do not require electrical contact between the user and the screen.

7 Future work

The project will be continued with an investigation of how our proposed interaction method works in combination with touch screen for people with brain injury.

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