institut für elektronische musik und akustik

IEM Report 29/05:

Spatial Auditory User Interfaces
Evaluation Test 2 – The Explorer

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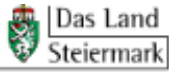

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Zusammenfassung

Dieser Bericht beschreibt den zweiten von zwei Hörversuchen im Rahmen der Arbeit von DI Veronika Putz im Zuge ihrer Diplomarbeit am IEM. Ziel des Tests war es, aufbauend auf die Erkenntnisse aus dem ersten Test, eine akustische Benutzeroberfläche für eine etwas komplexere Anwendung zu entwickeln, die die am IEM entwickelten 3D Audio Techniken ausnutzt. Solche virtuellen, räumlichen Benutzeroberflächen sollen die bisher verwendeten sequentiellen Techniken eines akustischen Zugangs (Screenreader) in Zukunft ersetzen und zu besserer Bedienbarkeit und höherer Effizienz führen. Auch zu diesem Test wurden blinde und normalsehende Benutzer eingeladen.
Dieser Test implementiert eine Anwendung ähnlich dem MS Explorer. Ziel war es die bestehende Applikation zu analysieren, sie in mode-independent interaction patterns zu beschreiben und daraus eine akustische Benutzeroberfläche zu entwickeln. Vorteil dieser Methode ist es, die einzelnen patterns im einzelnen evaluieren zu können und daher Usabilityprobleme eindeutig Teilen der Oberfläche zu ordnen zu können. Das Ergebnis bestätigte die Erkenntnisse aus dem ersten Test und zeigte einen wesentlich höheren Grad an Benutzerfreundlichkeit. Viele der Testpartizipanten konnten sich vorstellen dieses System auch in ihrer täglichen Arbeit zu benutzen.

Abstract

This report describes the second of two hearing tests conducted by Veronika Putz as part of her diploma thesis at the IEM. Based on the insights gained from the first test, the aim of test two was to develop an auditory user interface for a slightly more complex application that is using the 3D audio rendering techniques developed at the IEM. Such virtual, spatial user interfaces have the potential to replace commonly used sequential techniques such as screenreaders in the future because of higher usability and efficiency. Again, the test was also aimed at investigating the differences between normal sighted and visually impaired users.
This test implements a similar application as the MS Explorer. The aim was to analyse the existing application and describe it through a set of mode independent interaction patterns before transforming these patterns into the auditory domain. The advantage this approach is that usability problems can be assigned to certain parts of the interface. The results of this test confirmed the insights gained from the prior test, but produced a much higher level of user acceptance. Many test participants were responding that they could imagine to use the system in their daily work.

CONTENT

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1. Test purpose

The purpose of this test was to find out, if the content of a graphical user interface can be coded into the auditory domain and reproduced as 3D sound field only, without giving the user any optical information. The test layout is based upon the results derived from an earlier test which took place in March 2004. In this report, all references to this test are labelled as being from the pre-test. Test layout and test results of the pre-test can be found in a separate report.

In contrast to the pre-test, where a simple test application was invented for the testing purpose, for this test a real-world-application which was thought to be known well by the test users was transferred into the auditory domain, in order to test the applicability and usability of an auditory interface beyond simple test environments. As test application, the MS Data Explorer was chosen.

The main goal of the test was to watch a group of test users trying to fulfil different tasks with the test application to find out more about difficulties and problems hidden in the layout of the user interface rather than having a detailed statistical evaluation of one single task. According to this principle, the group size of the test participants was relatively small (7 blind/visually impaired and 8 normal-sighted participants). Nevertheless, a statistical evaluation is performed too, but it must not be overweighed, compared to the subjective verbal valuation by the participants.

2. Test application

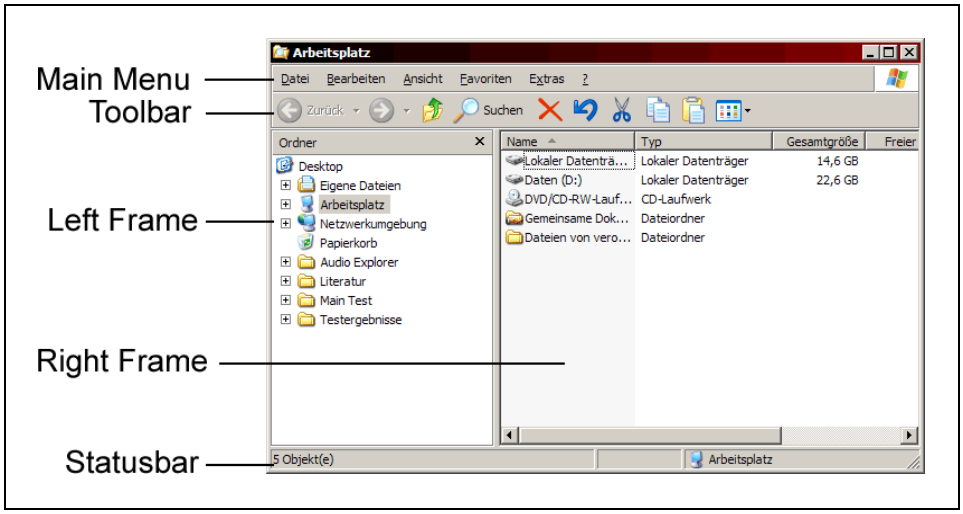
2.1 Content

For the implementation of the test application, the available functions of the MS Explorer were listed, and, for the testing purpose, the complexity of the application was reduced. Some of the rather complicated functions which cannot be assumed to be familiar to all test users have been crossed, and the basic functions remained.

This remaining content can be divided into eight major parts:

- Main menu
- Standard buttons toolbar
- Address bar
- Left frame (Folder hierarchy)
- Right frame (folder content)
- Status bar
- Context menu
- Emerging windows

[Fig 1] shows five of the major parts. The status bar and the address bar have not been implemented for the test application. The following section gives a short description of the remaining parts.



[Fig 1] Screenshot of MS Explorer with 5 of the major parts

2.1.1 Main Menu

The main menu bar shows the menu headers of the six sub-menus. For the test application, the following menus are used: File , Edit , View , Favorites , Extras and ?. The Extras -menu was crossed completely. Also within the sub-menus, some of the menu items were crossed. Within MS Explorer, the content of the menus is context-dependent. This dependency was implemented within the test application. [Tab 1] shows the remaining menu structure.

File	Edit	View	Favourites	?
New Folder	Undo	Statusbar	www.iem.at	Information
Delete	Cut	List	www.orf.at	Support
Rename	Copy	Details	www.google.com	
Properties	Paste	Sort		
Close	Select All	Change To		
		Reload		

[Tab 1] Implemented Menu Structure

2.1.2 Standard buttons toolbar

The standard buttons toolbar gives quick access to frequently used functions of MS Explorer. Type, number and order of the buttons can be customised. For the test application, this toolbar includes the following functions: Undo, Delete, Cut, Copy, Paste. Customisation is not possible within the test application.

2.1.3 Left and right frame

The major part of the screen space is divided into two frames. The left frame shows the hierarchy of folders in a tree structure representation with the desktop as root. The right frame shows the content of the folder which is currently selected within the left frame. The representation within the right frame can be customised by the user (list, details, miniature). For the test application, the possibilities list and details were implemented. Within the MS Explorer, the content of the left frame can be switched between the folder hierarchy, a search window, a view of favourite web pages and a window for different media players. From this possibilities, only the folder hierarchy is implemented.

The selections or modifications within the left frame determine the content of the right frame: It always displays the content of the folder which is currently selected within the left frame.

2.1.4 Emerging windows

Some of the menu items lead to separate windows, where information is presented or modifications can be performed. From this windows, only the properties-window is implemented. Again, the implemented version of this window is, unlike its realworld-counterpart, not context-dependent. It only gives information about type, size and the date of the last amendment of the selected file or folder.

Additionally, a second window has been implemented, which appears, if a file or folder is deleted. This window contains the question, whether the file or folder shall be deleted or not, and gives the possibility to answer with OK or Cancel .

2.1.5 Context menu

The context menu can be opened by clicking the right mouse-button. Its content depends on the current selection and is a collection of the most important functions of the MS Explorer. For the test application, only one version of the context menu is implemented ([Tab 2]).

Context
Cut
Copy
Delete
Rename
Properties

[Tab 2] Context Menu

2.2 The used structure of files and folders

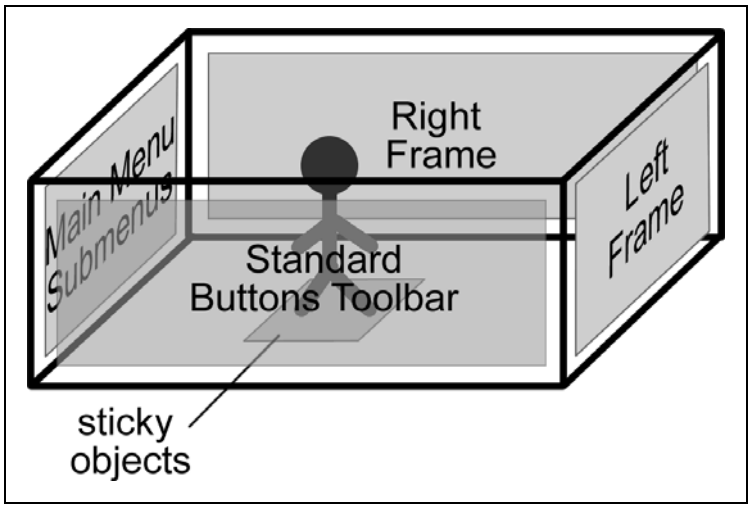
For the test application, a fictitious structure of files and folders was invented, similar to a typical windows-based file structure. Folders are printed in bold letters.

⊕ **Desktop**		
⊕ **My Files**	Folder	2004
Pictures	Folder	2004
Picture1.gif	10KB	2004
Picture2.gif	20KB	2002
Picture3.gif	82KB	2000
Picture4.gif	12KB	2001
Letters	Folder	2004
Letter1.doc	10KB	2003
Letter2.doc	12KB	2001
Letter3.doc	20KB	2004
Letter4.doc	82KB	2001
Letter5.doc	31KB	2002
Music	Folder	2004
Song1.mp3	82MB	2000
Song2.mp3	31MB	2001
Song3.mp3	10MB	2004
Videos	Folder	2004
Video1.mpeg	10GB	2003
Video2.mpeg	82GB	2001
Video3.mpeg	31GB	2000
⊕ **Workspace**	Folder	2004
⊕ **Harddisc C**	Folder	2004
Windows	Folder	2004
Programs	Folder	2004
Video4.mpeg	12GB	2004
Data D	Folder	2004
Trashcan		

2.3 Implementation

2.3.1 The Virtual Room

All items that occur in the graphical counterpart of the test application are represented through sound items, which are placed on the borders of a 3D virtual room. Within the virtual room, each wall hosts one of the major parts of the MS Explorer. The front side wall and the right side wall are reserved for the right and the left frame of the main window. The menu structure is placed on the left side wall, and the standard buttons toolbar can be found on the rear wall. Important objects which require immediate user attention are implemented as sticky objects - they move with the user and therefore are always placed directly in front of him ([Fig 2]).

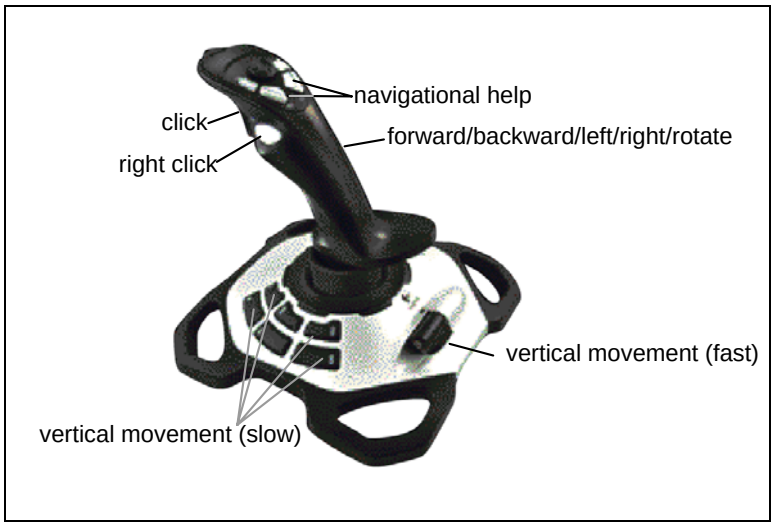


[Fig 2] Mapping of the major parts onto four walls of the virtual room

2.3.2 Input and feedback devices

For an auditory interface, it is advantageous to have an input device which is bounded not only with regard to the virtual room, but also bounded mechanically within the real world. A joystick fulfils this condition, because its sphere of action is limited to a square around the centre position, and the absolute position of the virtual pointer can be derived roughly from the angular position of the handle. Furthermore, if the handle of the joystick is released, it returns to a central position, therefore, relocation is simple.

The joystick is used for movements on the ground plane (including forward/backward and left/right movement and rotation around the vertical axis) and for vertical movements. For clicking and right-clicking, two of the buttons on the front side on the handle are used. Two further buttons on the top of the handle are used for a helping function that should ease navigation within the virtual room. A fast vertical movement is possible with the thrust control of the joystick. A slower vertical movement can be performed with the use of the buttons on the socket of the joystick. [Fig 3] shows the usage of joystick handle and buttons. The joystick is the only input device used for the test. Feedback is given via headphones.



[Fig 3] Joystick with input possibilities

2.3.3 The sound items

For each object within the graphical user interface, an acoustical counterpart is required. This means that several objects have to be represented acoustically. The sound items are not played concurrently (in contrast to the pre-test), but are triggered by the movement of the joystick: A grid with ten lines in x and y direction is projected onto the ground plane of the virtual room, producing a grid of 100 cells. In the midst of each cell, an auditory object can be placed. If the user moves the joystick across this cell, the corresponding sound item is triggered and played by the interface. To ease navigation, the audio sources are placed alongside the walls of the virtual room. With this restriction, all sources can be found by the user quickly. (See [Fig 4]). The sound items for the different parts of the MS Explorer are chosen as follows:

- Menu structure: Menu items (menu headers and sub menu items) are represented as combination of recorded speech and an instrumental tone. The menu headers are placed alongside the left wall. The first header item (file) is placed next to the front wall, the last one (?) next to the rear wall. Moving from the first item to the last one, the instrumental tone added to the spoken name of the menu item increases in pitch. If the user clicks on one of the menu headers, the sub-menu opens vertically. The desired sub-menu item can be selected by moving upwards next to it and selecting it with a click. Again, with an upward movement, the pitch of the instrumental sound increases. If the joystick moves away from the left wall, all submenus close.

- The left frame: Each folder within the folder hierarchy is spoken by a male voice. The hierarchy starts at the bottom of the virtual room with the desktop. A movement upwards brings the user to the further folders (My Files, Workspace). For parent folders, additionally a high pitched pling -sound is played (resembling the + -sign in the graphical tree structure). If the parent folder is selected with a click, the pling -sound is replaced by a lower-pitched version of itself. The hierarchic structure within the first region is represented by different spatial positions of the sources: The leftmost source has the highest hierarchic position, the rightmost source the lowest one.

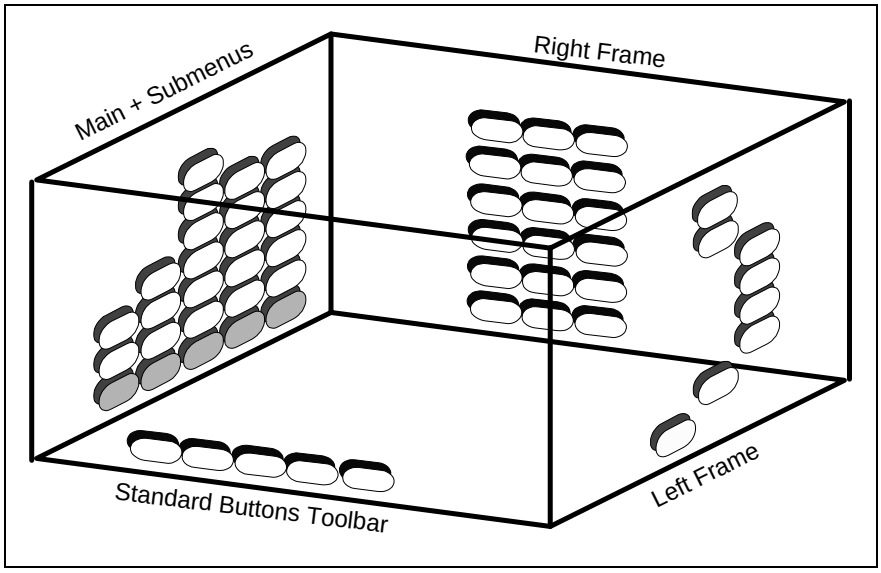
- Standard buttons toolbar: Each button is represented as a combination of a short sound file and, delayed, a spoken hint. The related function can be started with a single click.

- The right frame: Files and folders can be distinguished by the voice of the speaker: Files are spoken by a female voice, folders are spoken by a male voice. If the representation mode list is selected, only the names of the files and folders are spoken. If details is active, file properties are added after the name. Again, element selection is performed with a single click. To open a folder within the second region, double click is required.

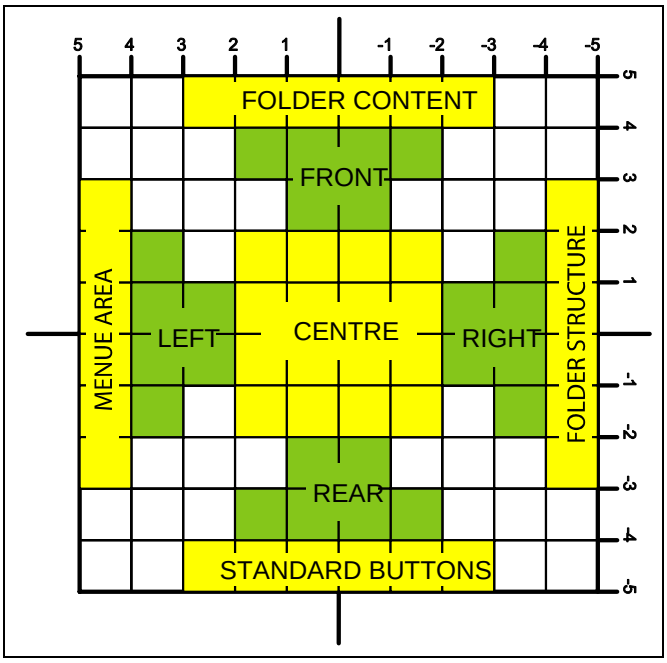
- The context menu: The context menu is opened with a right-click on a file or folder and opens vertically. The sounds and interaction processes of the context menu are chosen consistently to the menu structure on the left wall.

- The windows: Windows are implemented as sticky objects, which means, that they always stay in front of the user, no matter how the joystick is moved. Windows are distinguished from the normal environment by background music. When the window opens, the content message is spoken. To explore further content (details, buttons), the user has to move upwards.

- The navigational help: To ease orientation within the room, a navigational help function is implemented: Upon buttonpress, a rough information about the current position of the user is given. The ground plane of the virtual room is divided into nine areas (see [Fig 5]). The name of the area is uttered by the help function.



[Fig 4] Distribution of auditory sources within the virtual room



[Fig 5] Navigational help function

2.3.4 Spatial encoding

To obtain the spatial auditory representation within a virtual room, the sources are encoded with a 3D Ambisonic encoder of 3rd order. The angular head position is given through a head tracking system, mounted on the headphones. To ease the navigation and orientation for the participants, only the rotation around the z-axis is used.

To improve the localisation of the sources, a room model is used, where the virtual room (size 10 m x 10 m x 12 m) with all auditory sources is placed within a bigger surrounding room. The size of the surrounding room is 40 m in length and width and 20 m in height. Due to the room model, early reflections of 1st and 2nd order and a diffuse reverb are added to the source signal.

Finally, the Ambisonic signals are decoded to a virtual speaker layout, and a binaural mixdown for the left and the right ear is performed by using the KEMAR HRIR filter set.

3. Test

3.1 Test environment and test equipment

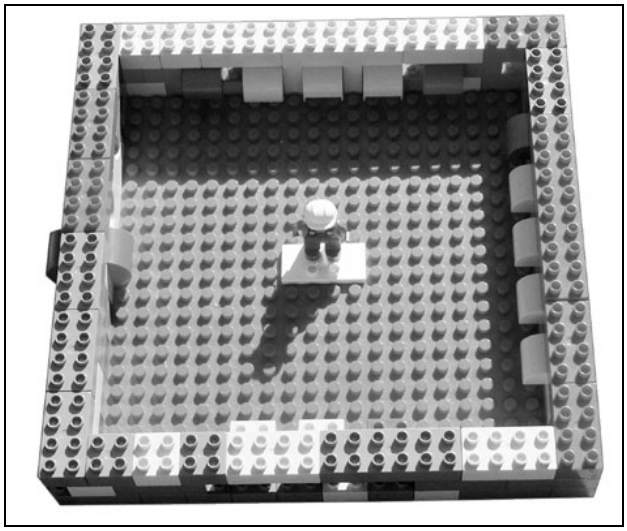
For the test, the experimental studio at the IEM was used. The following test equipment was required:

- Electrostatic headphones (Stax SR-007)
- Magnetic headtracker (Flock Of Birds)
- Customary PC with soundcard
- Joystick

3.2 Test procedure

The test was performed by a group of 15 test participants. Among them were seven participants who were blind or visually impaired. All participants got the same introduction before the test: The functionality of the application and the menu structure was presented, and the participants were introduced to the sound representation for the different elements of the application.

Additionally, a miniature room model ([Fig 6]) was built, which could be used by the visually impaired users and by those with normal seeing ability as well. The model contained the first level of the application, showing the main menu, the standard buttons toolbar and the first element of the folder hierarchy and the folder content.



[Fig 6] Room model given to the test participants

After the introduction, the participants got a maximum of 15 minutes training time to practise interaction with the application. In this time, all questions were answered and the participants were encouraged to try to open menu items, to select folders and files and to use the toolbar.

The test itself contained seven tasks which were presented verbally by the test administrator. During the test, people also were allowed to ask questions. All questions concerning the functionality of the MS Explorer itself were answered at any time. Questions that would have been answered by the navigational help were not answered, but the participants were encouraged to use the helping function. If the participants had major problems and could not solve them alone, the test administrator gave additional instructions. If this was necessary, it is also reported afterwards. To have equal conditions for the participants with normal seeing ability and the visually impaired ones, no optical cue was presented on the monitor.

3.2.1 Tasks

Task	Description	Results
1	How many files does the folder music contain? (The participants were told the location of the folder music).	1 correct answer (verbal)
2	Find out the size of the file music1 with the aid of the properties-window or by changing the view-mode from “list” to “details” .	1 correct answer (verbal)
3	Find the folder windows and name its position without the help of the search function.	1 correct answer (verbal)
4	Create a new folder directly on the hard disc C:.	1 new folder on correct location
5	From the folder letters , cancel the file with the name letter4	Report of deleting process
6	Undo task no. 5 with the aid of the menu structure or with the toolbar.	Report of undo process
7	Directly on the hard disc C:, a file with the name video4.mpeg can be found. Move this file to the folder videos .	Report of move/copy process

[Tab 3] Tasks

3.2.2 Collected data

Throughout the test, different types of data were collected. On the one hand, the hierarchic structure of files and folders *after* the test is stored in a textfile. Apart from that, two further lists report the whole test sequence, one list containing the movement of the joystick within the virtual room (x,y,z-coordinates, rotation around the z-axis) in a resolution of 50 ms, the other list reporting any action performed by the participants with a time index, so that both lists can be combined. With these two lists, the whole test performance of the participants can be reproduced and visualised. The list of reported events can also be used to compute the quantity of different events. Apart from that, the whole performance of the participants was attended by the test administrator via headphones who additionally took notes.

Additionally, the participants had to answer two questionnaires, one concerning the individual background of the participants, the other one trying to catch the subjective impression of the participants after the test.

4. Evaluation

4.1 Evaluation in groups

For the evaluation, the participants are divided into two groups: The eight participants with normal seeing ability together form group S (members S1 till S8), and the seven visually impaired or blind participants build group B (members B1 till B7). Throughout the evaluation, the results of the two groups will be compared. For all calculations, also an average between both groups will be given. The group containing all participants is labelled with All .

4.2 Evaluation of the two questionnaires

Each participant had to answer two questionnaires. The first questionnaire tried to find out the personal and technical background (PC experience) of the 15 participants. A complete listing of the results of the background questionnaire can be found in chapter 6. Here, only summarised results are presented.

- Group B: Four of the seven members are totally blind, the rest is visually impaired. Six members have taken the ECDL (European Computer Driving License), the other member absolved some other PC courses. All members have normal hearing abilities. Six members stated to need a PC for their job and to use it at least some hours a day. One member uses a PC only since ten months for few hours a week. All members need special hardware and/or software: Six members use screen readers, three members use a Braille-Line, three members also use enlarging software, and only one member uses a mouse sometimes. Six members use a later version of windows (98+), only one member does not use windows at all. Five members stated to use the MS Explorer often or very often, one member uses it seldom, and one member never uses it.

- Group S: All eight members of group S have normal seeing and hearing abilities. Seven of them are students at the technical university, and one member already has a university degree. All members have been using a PC for more than 8 years, seven of them for the job, one member for free time only. Five members use a PC more than five hours a day, the usage time of the other members differ from some hours a week to some hours a day. All members use a later version of windows (98+), five members stated to use the MS Explorer often or very often, the rest uses the explorer rather seldom.

The second questionnaire consisted of a set of questions concerning the subjective impression of each participant. The questions were asked after the test within an informal talk about the application without predefined answering possibilities. Therefore, many different types of answers (yes, no, suggestions) were given. Again, only a summarised version of the results of the questionnaire is presented. The detailed answers can be found in chapter 7.

- Spatiality: Ten participants clearly had the impression of being in a three-dimensional room, three participants partly had that impression too, only one answered with a clear no . For one participant, the spatiality was disturbing, the miniature model presented before the test was helpful for all participants.

- Layout: 13 participants found it easy to memorise the different meanings of the four walls, although three of them found the arrangement unintuitive. The different functions of the elements (files, folders, menu items) were easy to memorise for eleven participants, only one found it difficult. Eight participants distinguished the elements according to their different spatial positions, five participants used the different voices, and two participants used both.

- Sounds: 14 participants found none of the sounds annoying, only one participant was annoyed by the sounds of the standard buttons toolbar. Menu structure: Ten participants described their orientation within the menu structure positively (good, no problems, logical, ok), two found it more or less good, two found it initially difficult. Only one participant found it not good.

- Headphones: Eleven participants were not annoyed by working with headphones, one participant would prefer speakers.

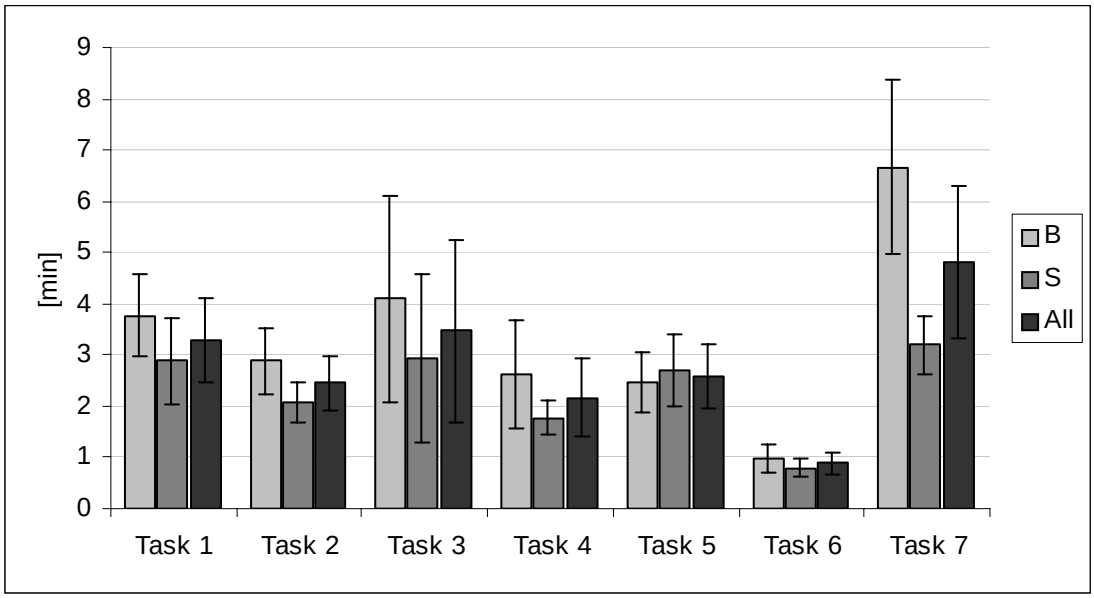
Some users also gave further comments and suggestions, they too can be found in chapter 7.

4.3 Evaluation of the required time

4.3.1 Required time for the single tasks

The required time for each task was extracted of the collected data and compared for all users, the averages for the groups B and S are shown in [Fig 7]. The standard deviations of the average values show, that there were great differences between the performances of the participants, especially for the tasks 3 and 7. The behaviour of the groups B and S is comparable, although the averages of group B are slightly higher than those of group S.

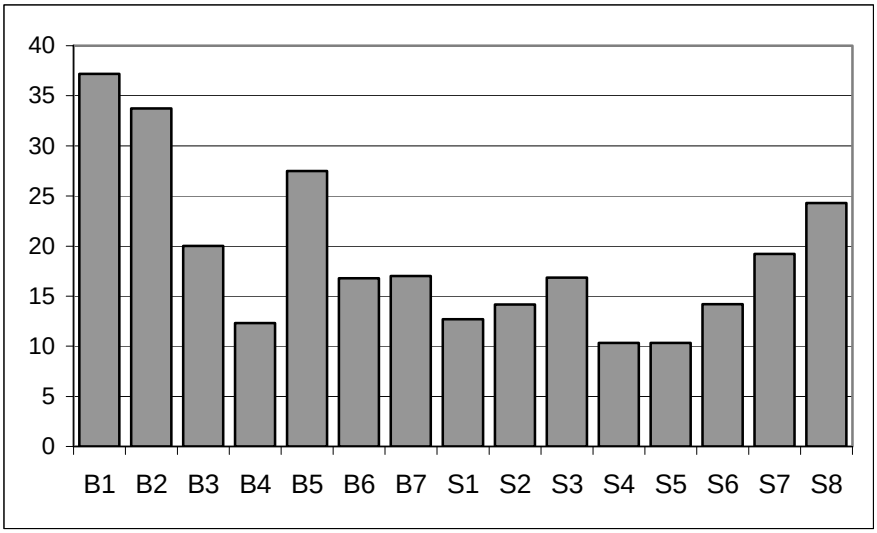
Note, that in the used data for time evaluation, the time for the explanations of the tasks by the test administrator is included.



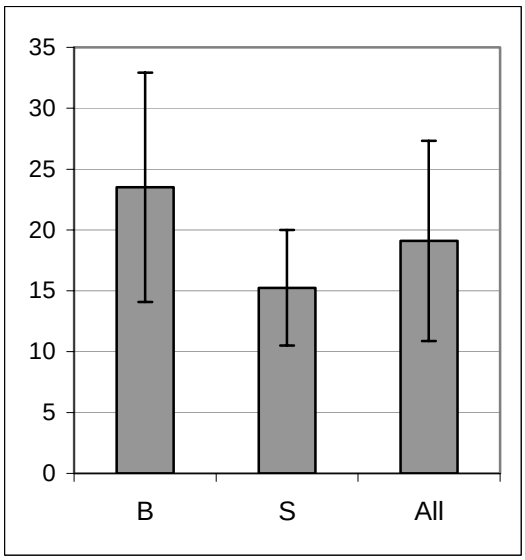
[Fig 7] Total required time for each task, group averages

4.3.2 Total required time

The required time for the fulfilling of all tasks was calculated for all users ([Fig 8]) and as averages for the three groups ([Fig 9]). The results show, that, on average, group B needed more time to fulfil the test, but also, that for this group the standard deviation is high, which is mainly caused by the users B1 and B2.



[Fig 8] Total test time for each user



[Fig 9] Total test time – averages

4.3.3 Data for time evaluation

Task	B1	B2	B3	B4	B5	B6	B7
1	6,07	5,38	3,78	3,47	2,13	3,94	1,55
2	4,97	2,35	4,18	2,01	1,50	2,01	3,21
3	9,33	1,05	1,76	1,63	10,43	3,40	1,02
4	3,28	6,99	2,02	0,41	1,85	1,39	2,50
5	2,36	4,74	2,39	0,78	1,95	2,69	2,40
6	0,76	1,88	1,30	0,22	1,20	0,46	1,06
7	10,44	11,35	4,49	3,79	8,45	2,89	5,28
Σ	**37,19**	**33,74**	**20,01**	**12,32**	**27,51**	**16,77**	**17,01**

Task	S1	S2	S3	S4	S5	S6	S7	S8
1	2,72	2,93	3,22	1,06	1,03	1,70	5,76	4,61
2	0,79	1,80	2,27	3,31	1,84	1,79	1,93	2,84
3	0,81	1,54	2,09	0,91	1,95	1,00	10,43	4,71
4	2,56	1,83	1,87	0,86	1,07	1,72	1,56	2,73
5	2,35	1,38	3,55	0,89	1,62	2,79	4,70	4,30
6	1,13	0,58	0,85	0,54	1,09	0,35	1,31	0,58
7	2,34	4,10	3,01	2,75	1,72	4,84	2,21	4,53
Σ	**12,70**	**14,15**	**16,86**	**10,32**	**10,32**	**14,19**	**27,90**	**24,31**

[Tab 4] Data for time evaluation

4.4 Evaluation of reported events

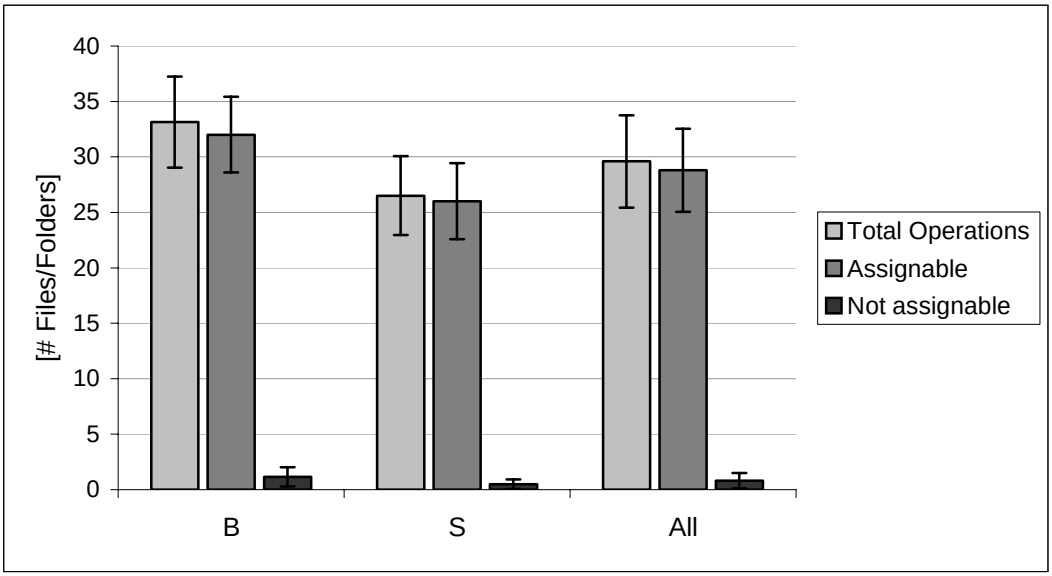
Throughout the test, all actions performed by the user caused events which were stored in a separate Events -list for each user. By evaluation of this list, further information about the working strategies of the participants can be extracted. For this evaluation, the reported events are separated into the following categories:

- Handling of files or folders
- Menu operations
- Selective operations

4.4.1 File/Folder handling operations

Within the Events -list, the names of selected files and folders are reported. Therefore, the total number of user actions concerning the handling of files and folders can be calculated. Furthermore, also the number of selected files and folders which can not be assigned to belong to one of the seven tasks (which means, their selection happened by mistake, when the user actually tried to select another item) is reported.

[Fig 10] shows, that group B required slightly more file handling operations to fulfil the tasks than group S. Hardly any file or folder was selected by mistake, the percentage of selected files that can be assigned to one of the tasks lies between 97% and 98% for all groups.

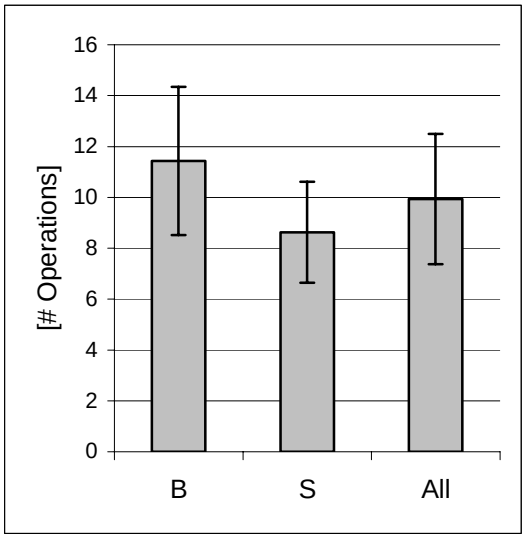


[Fig 10] Number of file/folder handling operations

4.4.2 Menu handling operations

Within the Events -list, the names of the entered menus are reported. [Fig 11] shows the total number of menu operations, including operations within the sub-menus, the context menu and the toolbar. If the menu operation consisted of two parts (selecting of one of the menu headers, then selecting the desired sub menu item), it is counted only one time.

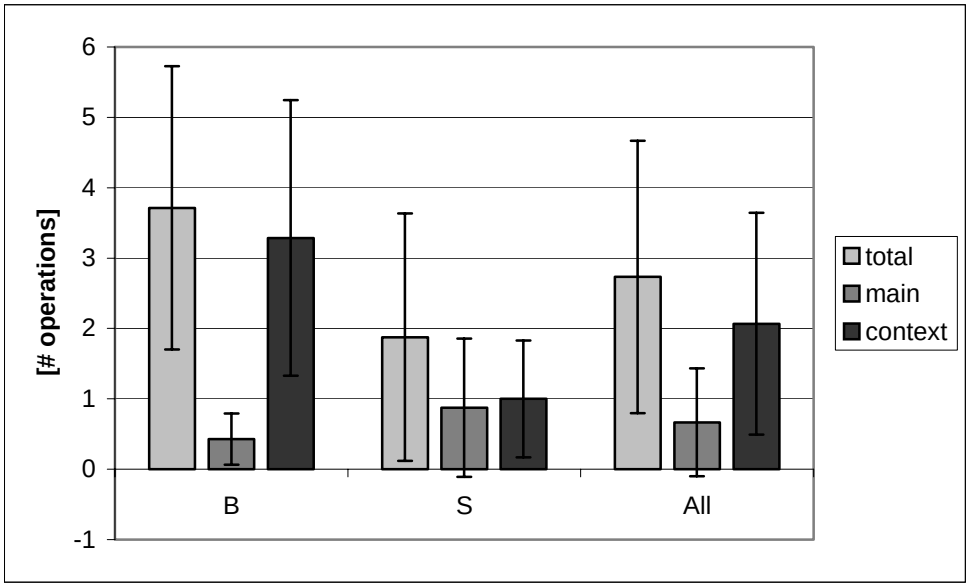
Comparable to the calculation of the file/folder handling operations performed by mistake, also for the menu handling operations the percentage of mistakably selected items was calculated: From all 15 participants, no one selected a menu item which could not be assigned logically to belong to one of the tasks!



[Fig 11] Menu handling operations

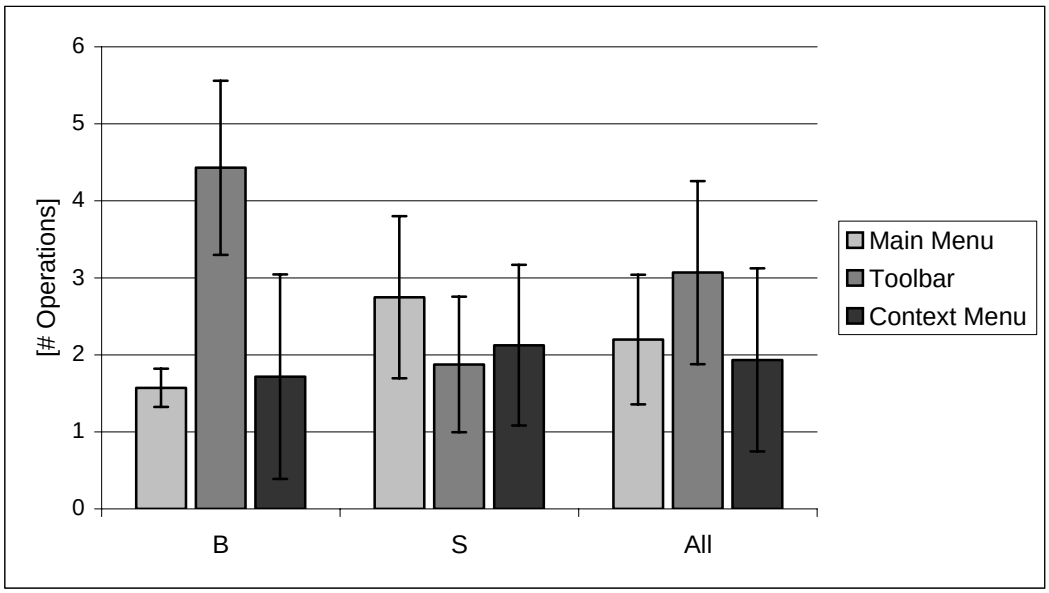
Apart from that, a measurement for the orientation within the menu structure can be found by comparing the number of selected menu headers and the number of selected submenu items belonging to this header. The selection of a menu header which is not accompanied by the selection of one of its submenu items is counted as unintentional selection. A similar procedure can be performed for the context menu. Note, that this value also includes searching processes of users who did not know in which main menu the desired submenu item could be found.

The number of intentionally and unintentionally performed menu operations can be seen in [Fig 12]. The graph shows that for group B, the total number of unintentional menu operations is higher than for group S, but the majority of unintentional operations is caused by unintentionally opening the context menu, which can be explained by mistaking the right-click button for the left-click-button. Some of the blind users had problems with the different meaning of those two buttons, which also can be seen from the high standard deviation for this group. The number of unintentional operations within the main menu is much lower for group B than for group S. Obviously, the blind users had a better knowledge of the menu structure of the MS Explorer than the users with normal seeing ability, which had to search the desired items within the menu structure more often.



[Fig 12] Unintentional menu operations

Throughout the whole test, the participants were free to choose how to fulfil the tasks: With the aid of the main menu, the standard buttons toolbar or the context menu. [Fig 13] shows, which option was preferred by the three groups. Group B had a clear preference of the toolbar, whilst group S had a slight preference of the main menu. The usage of the context menu is similar for the group averages. The standard deviation is high for all values.

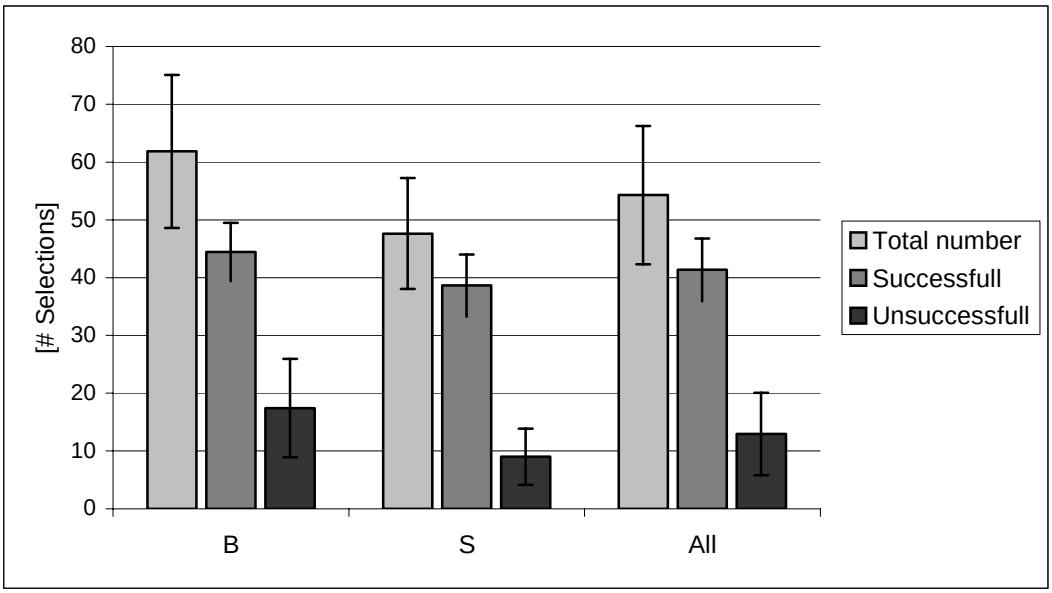


[Fig 13] Usage of the different menus

4.4.3 Selective operations

Within the Events-list, each selective interaction (click, double-click or right-click) is reported. The total number of selective events is shown in [Fig 14]. If this number is compared with the total number of file/folder handling operations and the total number of menu operations, the difference shows the number of unsuccessful selections. This selections include selections outside any active area and performed double -selections (e.g., if the participant tried to open a folder with a single-click instead of a double-click, and then had to repeat the selection). [Fig 14] also illustrates the number of successful and unsuccessful selections.

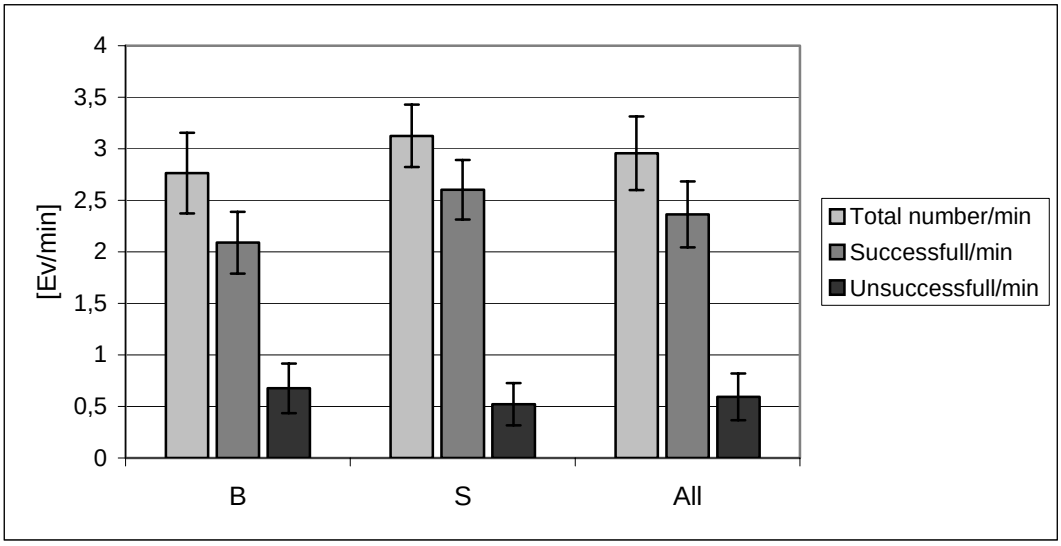
The percentage of successful selective events is 72% for group B, 81% for group S and 76% for both groups. An explanation of the lower percentage of group B are difficulties of blind users with regard to click/double click.



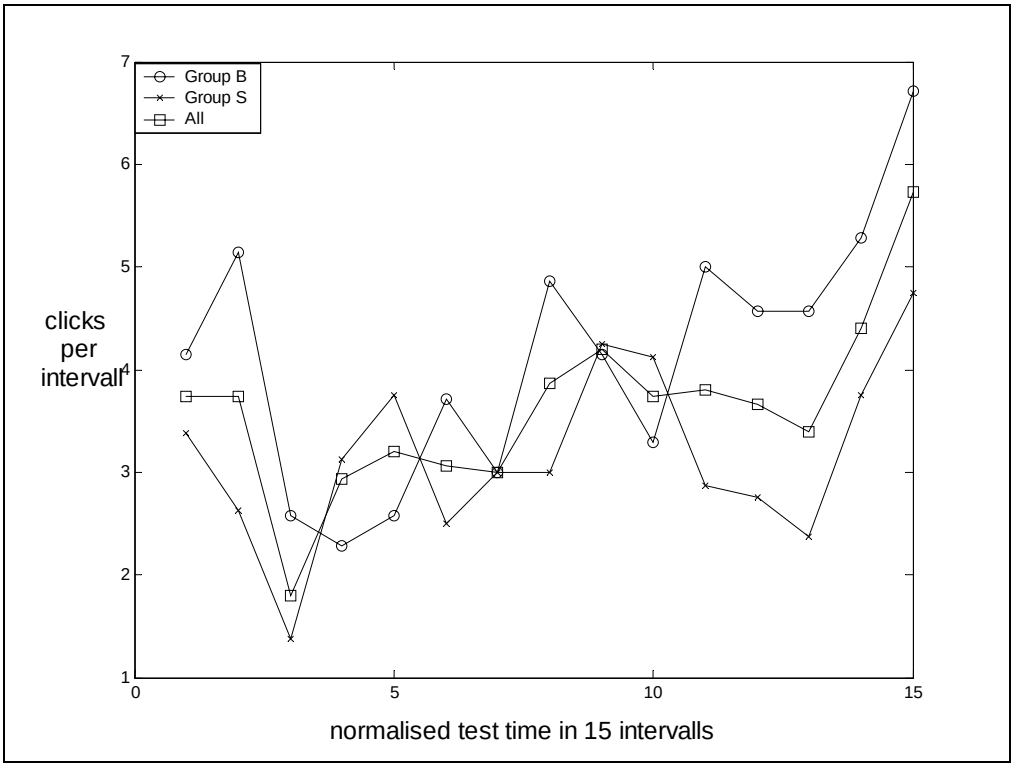
[Fig 14] Number of performed selections

The joystick was the only available input device. Therefore, each user interaction (except the use of the navigational help function) caused a selective event. These events, put into relation with the total performance time of the participants, can be used to get a comparable value for the working speed ([Fig 15]), expressed as number of selective events per minute. Between the working speed of the groups, there is only a small difference.

A measurement for a possible improvement of the working speed with increasing user experiment is the distribution of selective events over the total test time of each user. For the evaluation, the time index of the selective events was normalised to the total test time of each participant. Then, the time indices were added up for the groups B, S and All. A histogram was calculated for all groups and normalised to the number of group members ([Fig 16]). An improvement of the participants is equivalent to an increase of the number of selective events with increasing time index. Although the complexity of the tasks increases, an improvement can be seen for all three groups.



[Fig 15] Selection Events per minute



[Fig 16] Normalised distribution of click events vs. test time

4.4.4 Usage of the navigational help

The navigational help was barely used by the test users. Obviously, the rough orientation within the room was no difficulty for the users, and the feedback given by the joystick handle was easy to interpret also for the blind users. The results of the questionnaire show, that most of the users found it easy to memorise the meaning of the four surrounding walls, therefore the information the navigational help function provided was unnecessary.

4.4.5 Data for events evaluation

	B2	B3	B4	B5	B6	B7	B8
File operations total	24	44	39	26	36	27	31
File operations necessary	24	44	39	26	34	27	30
File operations unnecessary	0	5	0	0	2	0	1
Menu operations necessary	7	13	4	8	10	6	6
Menu operations unnecessary	6	12	5	0	0	2	1
Menu operations total	13	25	9	8	10	8	7
Usage Context menu	0	8	2	1	0	0	1
Usage Context Toolbar	5	4	0	6	8	4	4
Usage Main Menu	2	1	2	1	2	2	1
Usage Navigational Help	30	4	2	0	0	0	0
Selections, click	32	72	41	34	52	41	35
Selections, double click	9	15	7	11	21	6	3
Selections, right click	6	35	9	2	0	0	2
Selections, total	47	122	57	47	73	47	40
Missed clicks	13	56	10	10	24	9	0
Hit clicks	34	66	47	37	49	38	40

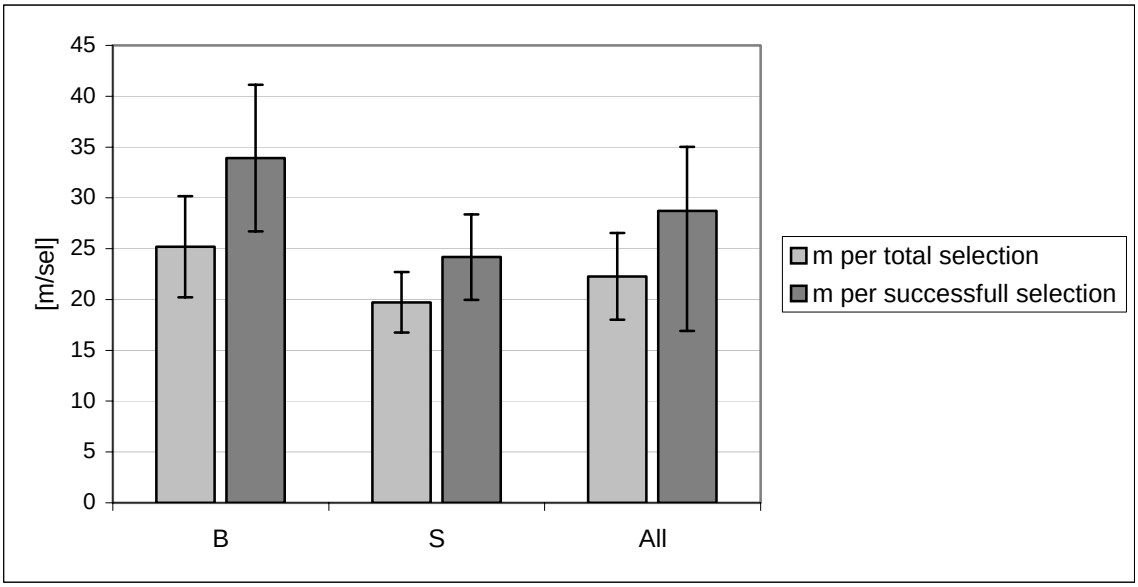
	S1	S9	S10	S11	S12	S13	S14	S15
File operations total	26	20	26	29	18	20	32	41
File operations necessary	26	20	26	29	18	18	32	39
File operations unnecessary	0	0	0	0	0	2	0	2
Menu operations necessary	6	6	6	7	6	8	7	8
Menu operations unnecessary	2	0	1	0	1	0	0	11
Menu operations total	8	6	2	7	7	8	7	19
Usage Context menu	0	4	1	0	2	5	5	0
Usage Context Toolbar	4	1	4	4	2	0	0	0
Usage Main Menu	2	1	1	3	2	3	2	8
Usage Navigational Help	0	1	0	6	0	0	0	0
Selections, click	37	21	36	38	22	26	35	63
Selections, double click	0	11	8	3	9	4	6	18
Selections, right click	4	5	4	0	5	5	5	16
Selections, total	41	37	48	41	36	35	46	97
Missed clicks	6	8	12	0	8	2	3	33
Hit clicks	35	29	36	41	28	33	43	64

[Tab 5] Data for events evaluation

4.5 Evaluation of the movement

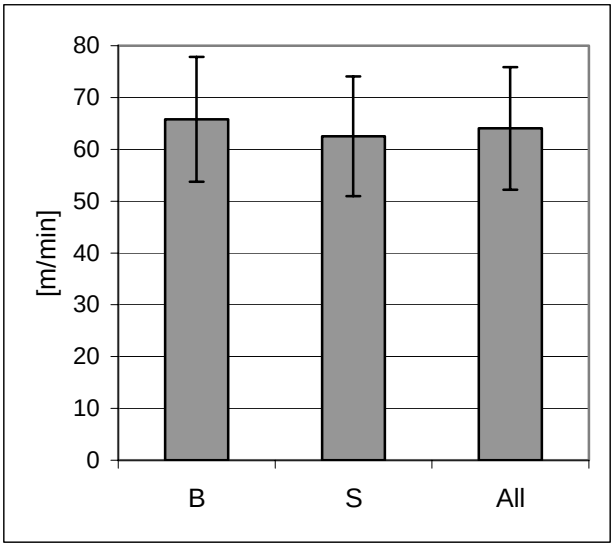
The movement of the joystick within the virtual room was reported in a resolution of 50 ms. From this movement, the travelled distance of the user for each selection can be calculated. [Fig 17] shows the necessary distance in meters for all selective events and for the successful ones. The calculation was performed for x,y and z values.

To compare the results with the room size: The virtual room has a size of 10 m in length and width and 12 m in height. A single diagonal crossing of the room on the ground floor is 14 m long, if the diagonal crossing is followed by a vertical browsing to maximum height, the travelled distance is 26 m. Some extra distance is caused by the automatically performed shift to the ground floor after leaving a wall and by the relocation of the system to the centre of the room, when the joystick handle is released. The required meters per selective event lie within the range of one movement through the whole room for all groups.



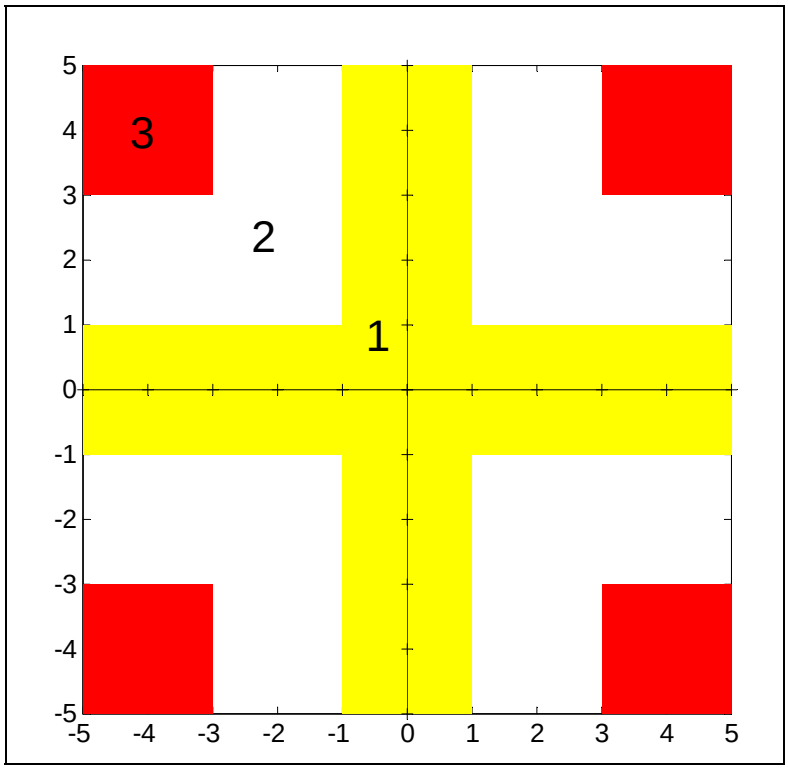
[Fig 17] Covered distance per selection

To compare the velocity of the joystick movement between the three groups, the travelled distance in meters was divided by the total test time. The results in [m/min] can be seen in [Fig 18]. The graph shows nearly equal velocity for the three groups, although there is a high difference between the group members, represented by a high standard deviation.



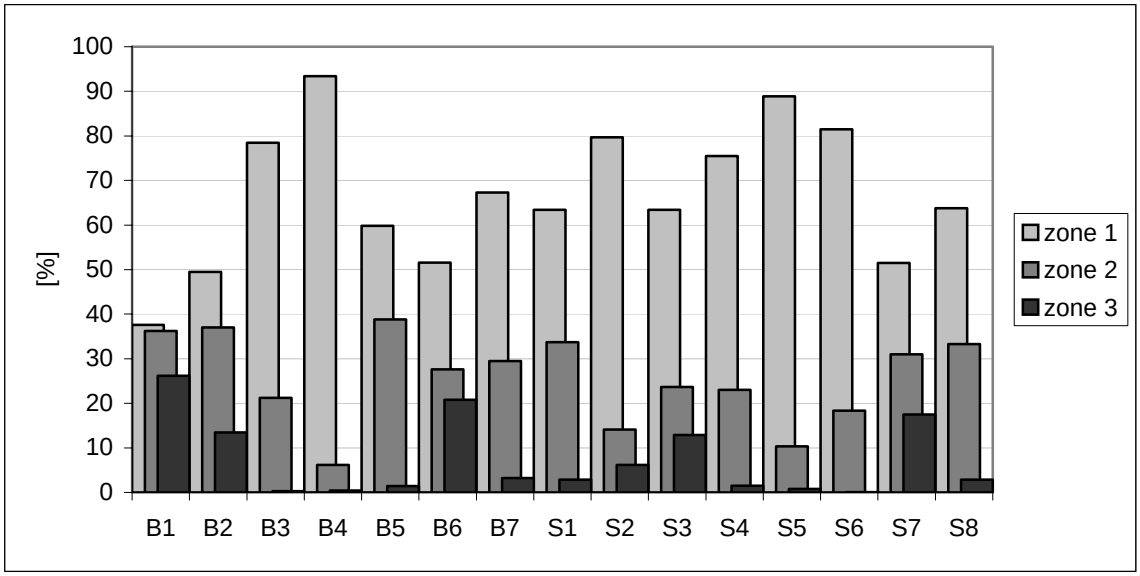
[Fig 18] Velocity of joystick movement

Another measurement of performance extracted from the joystick movement is the accuracy of the movement within the virtual room, or, how well-aimed the user moves towards the sound sources. A visualisation of the movement for all participants can be found in chapter 5. To compare the movement of all users and calculate an average for the three groups, the accuracy has to be expressed in numerical values. One possibility is to divide the ground floor of the virtual room symmetrically into three zones with different distances to the central axes ([Fig 19]). Note, that zone no. 3 does not include any sources, therefore movement within this zone is unnecessary.

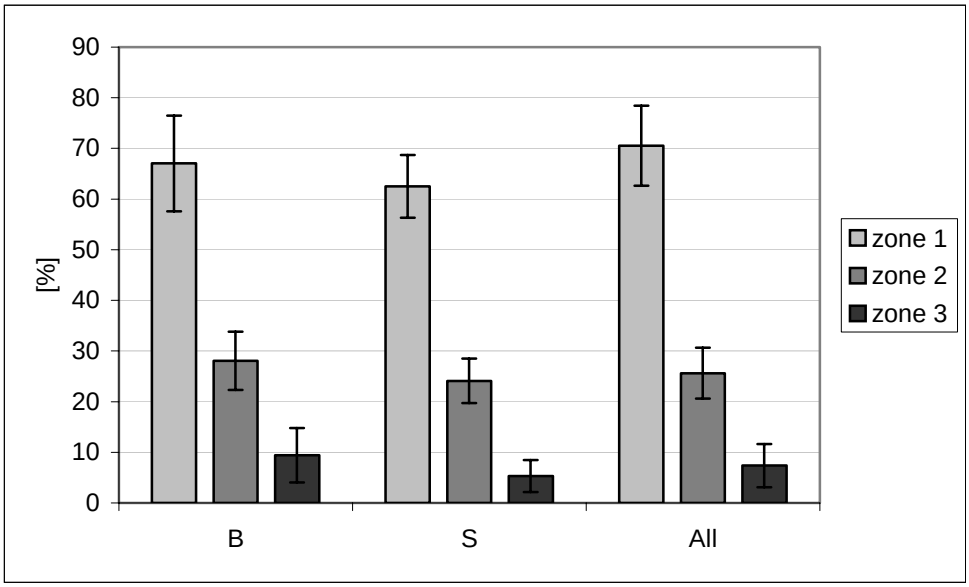


[Fig 19] Virtual room divided into three zones for further evaluation

For all participants, the percentage of the movement in the three zones was calculated ([Fig 20]), and the averages for the three groups were built ([Fig 21]). Although the averages of all groups are comparable, the standard deviations are high.



[Fig 20] Percentage of the movement within the three zones

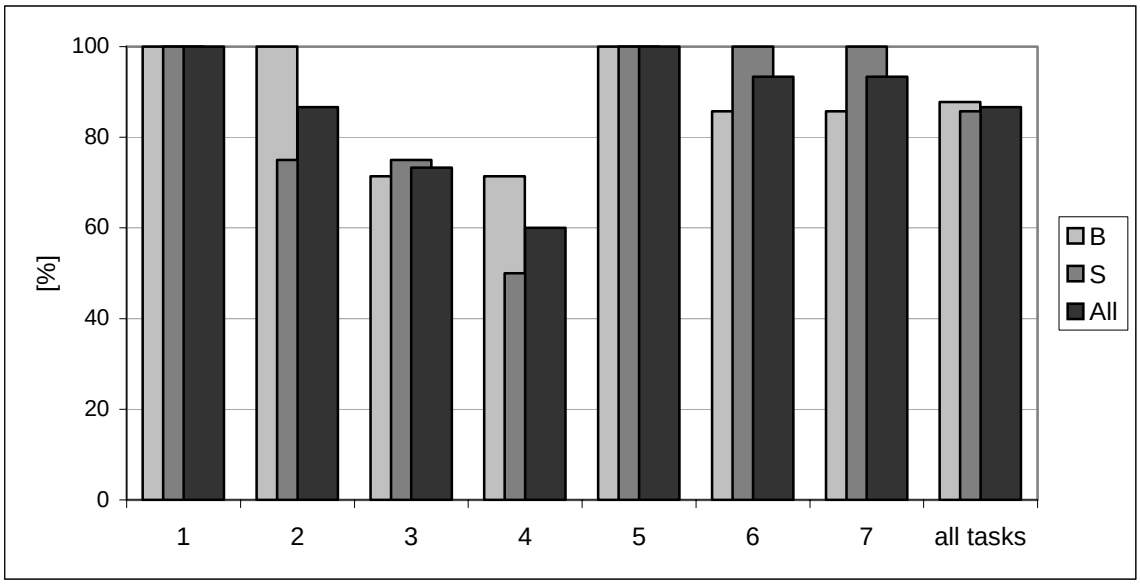


[Fig 21] Percentage of the movement within the three zones, averages

4.6 Evaluation of test results

The test consisted of seven different tasks, the fulfilment of each task produced a correct or false result. The evaluation of the test results must be examined with care, because not all of the results were reached under the same prerequisites by the users. Some users managed to perform the whole test without any additional instructions by the test administrator, some users needed instructions to continue their working process. Therefore, the total test time of each user is a better measurement of performance than an evaluation of the correct results. A detailed description of the observation of the test users and the additional help given can be found in chapter 5.

For this chapter, a rough statistical evaluation is done by the following scheme: For a completely correct result, a 1 was noted, for all other results, a 0 was given. For task no. 7 which consisted of more than just one action (copy a file and paste it into another folder), 0.5 points were given, if one of the actions was fulfilled correctly. A listing of all tasks can be found in chapter 3.2.1, [Tab 3]. The percentage of correct results for all three groups is illustrated in [Fig 22]). Note, that the over all average is nearly equal for all groups.



[Fig 22] Percentage of correct results

5. Conclusions of the test

In this chapter, the usability of the test application shall be summarised, and some proposals for future applications are added.

Usability of the virtual layout

The three-dimensional layout of the virtual room with the different meanings of the four surrounding walls and the two-staged movement (ground-plane movement towards the walls, vertical movement for selection) proved to be sufficient to host the elements of a real-world application. On the ground floor, at least 20 items (5 on each wall) can be placed. Also the thematic grouping of elements on the different walls was easy to memorise for the test users. The representation of the folder hierarchy is in need for improvement hardly any test user had a clear overview of the file and folder structure. The mapping of the folder hierarchy onto the spatial location of the sound item is unusable for this purpose.

Usability of temporal sound reproduction

The non-concurrent sound reproduction triggered by the movement of the joystick proved to be a good strategy for placing several sound sources within one virtual room. The relation between joystick position and triggering mechanism was obvious for the test users, and the spatial impression of the virtual room was enhanced. Hearing mainly one source a time was also far less stressful for the test users than a concurrent reproduction, and the subjective impression of the test administrator with regard to user acceptance was, compared to the pre-test, a very positive one. Most participants seemed to enjoy working with the application and were ambitious to fulfil the given tasks.

Usability of the interaction process

The joystick input mechanism proved to be usable for blind users as well as for sighted users, although the available feedback given through the handle of the joystick may be more helpful for the sighted ones. As [Fig 21] shows, the blind users tended to move in regions without any active areas more often than their sighted colleagues (9% group B, compared to the 5% of group S). The blind users, of course, had difficulties with the distinction between clicking, double-clicking and right-clicking. An estimation of how often clicks and double clicks were mixed up can be derived from [Fig 14], and [Fig 12] shows how often the context-menu was opened by unintentionally performed right-clicking.

Usability of the used sounds

The answers to the subjective questionnaire show, that the test users distinguished between the different functions of the sound items (menu item/file/folder) according to the different speakers and the different spatial positions to equal parts. Only one user was annoyed by the sounds namely by the auditory icons used for the standard buttons toolbar. Obviously, the usage of speech representation instead of auditory icons proofed to be a good idea.

Usability of the test application as a whole

The main goal of the application was to have equal usability for blind and sighted users. With regard to the main performance measurements (total test time [Fig 9], necessary file/folder handling operations [Fig 10], necessary menu handling operations [Fig 11], working speed [Fig 15] [Fig 18] and the percentage of correct results [Fig 21]), the two groups of users have reached similar results, although there is a high standard deviation for some values.