Sudoku access: A Sudoku game for people with motor disabilities

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Sudoku Access: A Sudoku Game for People with Motor Disabilities

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ABSTRACT

Educational games are a beneficial activity motivating a large number of students in our society. Unfortunately, disabled people have reduced opportunities when using a computer game. We have created a new Sudoku game for people whose motion is impaired, called *Sudoku Access*. This special interface allows the control of the game either by voice or by a single switch. We conducted a user study of the Sudoku Access that shows that people can play the game quickly and accurately. With this special Sudoku puzzle we can help more people to get involved in computer games and contribute to develop logic thinking and concentration in students. Our research aims at building enabling technologies that increase individuals' functional independence in a game environment.

Categories and Subject Descriptors

H.5.2 [**Information Interfaces and Presentation**]: User Interfaces—*Graphical user interfaces*; K.3.1 [**Computers and Education**]: Computer uses in Education—*Computer-assisted instruction (CAI)*; K.4.2 [**Computers and Society**]: Social Issues—*Assistive technologies for persons with disabilities*.

General Terms

Human Factors

Keywords

Sudoku puzzle, accessibility, speech recognition, scanning systems

1. INTRODUCTION

Over the years computer games have expanded, increasing a focused attention on game accessibility. The Game Accessibility Special Interest Group (GA-SIG) of the International Game Developers Association encourages researchers to investigate computer games to assist disabled people [8].

Figure 1: 13-year old Fátima has *Spina Bifida*. She is operating her PC with the "Space" key by using one hand to control the Sudoku Access game.

The main problem for people with motor disabilities is the ability to access computer controls and the capacity to control pointing devices like a mouse. There are many types of disabilities and limiting conditions that can affect a person trying to play a game. The major limitations encountered in gaming are related to vision, hearing, mobility, or cognitive issues.

This paper presents a suitable user interface for people with motor impairments to play the Sudoku puzzle. We named our interface as *Sudoku Access*. Unfortunately, many people with motor disabilities have severe limitations when interacting with the computer. Each person with a disability has its own unique limitation to use computer systems. Virtual tools can facilitate the manipulation of computer devices and some types of accessibility are currently becoming standard parts of operating systems.With a virtual environment we can offer the possibility to operate in the real world, partly alleviating physical limitations [11, 21]. People with motor impairments can use alternative devices to interact with computer games. Some of the major alternatives include switch devices, head-mounted pointing devices, speech-recognition systems, eye tracking and glove devices. A person who has a disability should have the same access to equal services and leisure as others in society. Why can't we have games that are accessible to those with disabilities? This becomes a quality of life issue. There is still a lot of work ahead concerning accessibility technology and the building of computers more accessible to citizens with disabilities and learning difficulties. However, there is a reduced amount of work focused on making all games universally accessible to all, regardless of disability.

In the next section, we outline accessibility principles in game design and the use of educational games in learning environment. Then, section 3 presents the Sudoku Access game and its development. Section 4 presents usability tests performed with 3 students. Finally, we describe future work in section 5, and provide conclusions in section 6.

2. ACCESSIBILITY IN GAME DESIGN

Designing interfaces for people without disabilities is already a difficult task. With disabled people the methodology becomes even more complex. It is important to identify the abilities and limitations of the users. Special cognitive and perceptual abilities are relevant to design but sensor and motor abilities are equally important. A number of requirments are supplied intended for creating accessible games:

- Provide various features to adapt to different users' requirements in terms of size, color, contrast and number of items displayed on the screen.
- Support a wide range of input devices, such as: mice, joysticks, switches, trackballs, gloves, webcams, microphones [7].
- Support different forms of output, including text, graphics, sound and speech.
- Provide extra attention and concentration on the task. Some designs can break concentration with needless distractions, such as animations, popup windows, and intrusive sound effects.
- Give simple designs which can be quickly understood and thus support instantaneous use, or encourage further exploration [17].

In order to design an interface with good quality and accessibility it is essential to understand the skills and behavior of its users. Simplifying an interface is one of the most important principles in interface design [15].

With the accessibility provided by the Internet, new teachers focus on the value of animations for presenting different concepts and various have combined this approach with the use of games [3]. Previous works have shown that animated pedagogical agents amplify the student's motivation and engagement [9]. Students who are having fun work harder, longer, and are more apt to increase on what is taught than those who simply wish to conclude the course [14]. The virtual worlds of games are rich contexts for learning because they make it possible for students to develop a set of effective social practices. Students learn better by direct experience, activity and discovery [1].

Sudoku has become an educational tool for school teachers, because it provides an excellent aid to the development of analytical and lateral thinking. The first author of this paper has used the Sudoku puzzle at a middle school to assist students both in being focused and in developing reasoning skills, since this sort of puzzle helps them improve logic thinking and concentration. The most beneficial aspect is that it teaches children about problem-solving. You only need to bear in mind some information, and set out a strategy to play the game. Most times students' major problem in the classroom is lack of confidence. Although computer games have definitely the potential of modifying the landscape of education, some schools are not yet technically or pedagogically equipped so as to encourage teachers to use these technologies on a regular and sustained basis in order to enhance students' learning.

3. THE SUDOKU ACCESS GAME

The Sudoku game is a puzzle of 81 squares placed on a 9x9 board where each row and each column contains the digits 1 to 9. The rule of the game is simply to fill in the puzzle board so that the digits 1 through 9 occur exactly once in each row, column, and 3x3 box. The initial game board consists of several digits that are already placed, and cannot be changed. The goal is to fill in the empty squares following the simple rule above, as shown in Figure 2. To solve the game, no special math skills or calculations are required. It is a simple and fun game of logic, all that's needed is concentration.

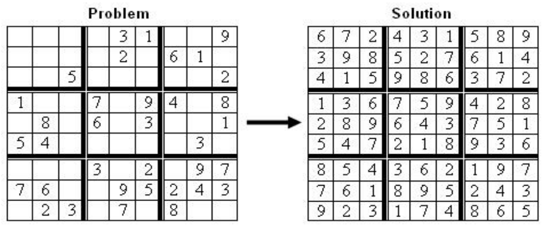

Figure 2: A Sudoku puzzle and its solution. The goal is to fill in the blanks with entries 1-9 so that each digit occurs once in each row, once in each column, and once in each of the nine 3x3 squares indicated by bold lines.

The usual 81 cell Sudoku grid is not the only possible board. With any positive integer a, we can represent an order-a Sudoku grid with a^2 rows, a^2 columns and a^2 blocks. The grid has a total of a^4 cells, which are to be completed with integers in the range from 1 to a^2.

Many people reach a point in the solution process at which they make an intelligent guess about a new fill in the grid, and follow the effects of that guess to the solution. Sometimes an error occurs in solving the puzzle and forces a backtracking search. The use of backtracking can be viewed as a logical process. When a person makes an input in one cell and realizes that some other cell has no correct solution, then he/she has discovered a logical relation between the cells. Most people use a conventional mouse or keyboard to fill in cells in a Sudoku computer game, but that type of interaction can be a major problem for people with motor disabilities [6, 22].

3.1 Development of the Game

The design of the interface has been carefully developed to provide an easy interaction for handicapped people. The Sudoku Access contains an adjusted environment to support different kinds of aids. A person with disabilities can interact with the game using the keyboard, switch control and speech recognition. A user who has one or two reliable physical movements may be able to use switches to input information and interact with the game.

Speech recognition provides another option for individuals with disabilities. Speech input allows users to control the Sudoku Access by saying numbers. We use the Speech Application Programming Interface (SAPI), an API developed by Microsoft to allow the use of speech recognition and speech synthesis within Windows applications.

All the features of the puzzle can be used and configured without an assistant's help. The user can configure the difficulty level, scanning velocity, number of repeat scanning cycles, scanning sound, scanning color, input device (mouse, switch, space key, or speech recognition), and Sudoku size. All these options can be controlled with a single switch device, microphone or by a standard mouse. The interface contains organized buttons to provide an easy utilization and configuration. Figure 3 shows a screenshot of the Sudoku Access.

To play the Sudoku puzzle different techniques were used to provide support in the interaction with the game.

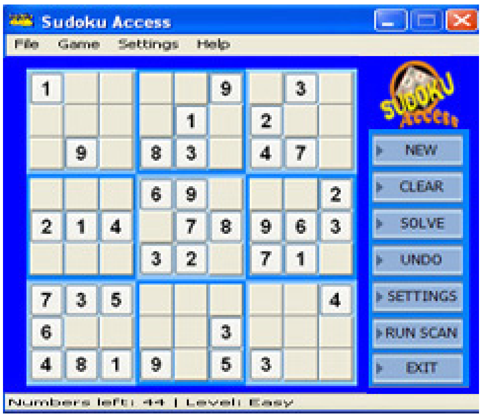

Figure 3: The Sudoku Access.

3.1.1 *Switch Access*

One of the techniques that is usually used to help people with motor impairment to interact with computers is the so called scanning method [12, 20, 2]. We used the scanning method to allow the user to employ a single key or switch to make choices. The idea is to move from one item (or group of items) to another after a predefined time. There are two principal scanning groups as shown in Figure 4. The first is used to select the Sudoku grid; the second to select the menu options.

After the user has selected one of the groups, the whole selection set is divided into groups of items and these are then individually highlighted (focused). The user first selects a group, after which the individual items from that group are scanned. The hierarchy of subgroups is scanned until one reaches the level of single items [18, 19, 16]. When the item is selected on a Sudoku cell, it is highlighted and waits for the user to make the numeric choice. At this stage, another scan is activated in the numeric keyboard, then the next click will be the choice of the desired number. To use the scanning system, the user needs to use a single switch or press the "Space" key [4]. Figure 5 shows the process described above.

Through the scanning mechanism, the Sudoku puzzle can be controlled by a user with motor impairment. The *SETTINGS* option is not an exception. Each feature is controlled by another scanning system. At this stage, the scanning proceeds at the top of the column from one item to another. In this phase the next click will be the choice of the desired configuration option. Figure 6 shows an example of how to configure the scanning color with only two switch presses.

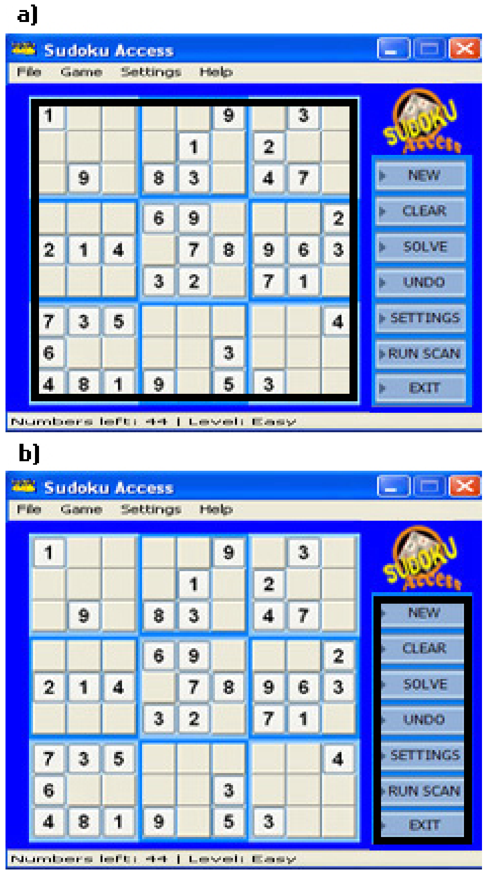

Figure 4: An example of the scanning system. The idea is to move from one item (or group of items) to another after a predefined time. There are 2 major groups: a) the first is to select the Sudoku grid and b) the second is used to select the menu options.

3.1.2 *Voice Access*

Speech recognition can be applied in a variety of areas to help people with motor impairments [10, 5]. Speech recognition has also proven to be a useful interaction tool both for a multiplicity of users and tasks [13]. Individuals who need freehand solutions may benefit from effective speech-based techniques.

To allow physically impaired people to manipulate all the functions of the puzzle we provide a speech-to-text system to interact with the Sudoku grid and configure several of its

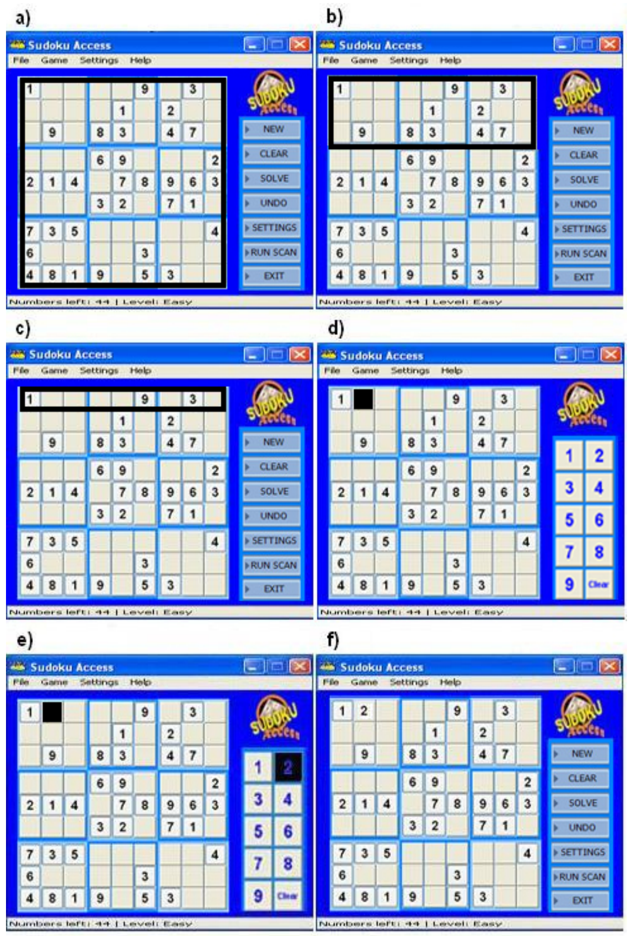

Figure 5: The scanning system enables the user to make choices by filling numbers in a cell using a single switch or pressing the "Space" key. a) The first group is focused, b)The first subgroup is selected, c) The first row of the first subgroup is selected, d) The scanning system is focused on the selected item of that row, e) Another scan is activated in the numeric keyboard (shown on the right side of the puzzle). In this phase the next click will be the choice of the desired number, f) Finally, the number is sent to the desired cell.

options. To input numbers inside the grid the user needs to select the desired row (1-9) by saying the number. If the chosen number is not recognized correctly, the user should say "No". If it is correct the user should say "Yes". If the answer is positive the next step is to choose the column (1-9) using the same mechanism. Finally, the user can say a number to fill in the cell. Figure 7 shows an example of the Sudoku Access controlled by voice.

The speech recognition system allows the user to configure other features. The menu options such as *New*, *Clear*, *Solve*, *Undo*, *Settings* and *Exit*, can be selected in a similar manner using the numbers 10 through 15. There are other options such as *Difficulty Level of the Puzzle*, *Row and Column Color*, and *Sudoku Size*, which can also be controlled through voice. Sudoku Access also allows the configuration

Figure 6: In this example, the scanning color was selected, and now the scanning system focuses on sub-items of that group, with the cursor advancing through each of the color options, one at a time.

of the Microsoft speech recognition training. The process of teaching the computer to recognize the voice is called "training". The training process takes only a few minutes for most people and extra training can significantly improve results. After choosing the correct number ("14") to select the "Settings" option the user needs to say other numbers between 1 and 5 to choose the desired options (see Figure 8).

4. USABILITY TESTS

To ensure that our design iteractions were beneficial, we performed short checkpoint studies with students of a middle school. The participants of the study consisted of three students between the ages of 13 and 15. The students who have been investigated have different characteristics. One of them does not have any motor impairment although the others present serious motor coordination problems affecting their ability to move, manipulate objects and interact with the physical world.

To help these children to play the Sudoku puzzle we explained them how to use the interface and spent some time describing all features. After the explanation each student chose and then tried the preferred device to interact with the game. Throughout the experiment the students interacted positively with the interface and all users showed a strong motivation.

Jorge

Jorge is a fifteen-year-old boy with no motor impairments. Although he is very skilful with computers, he feels reluctant to use a conventional mouse when playing games. Jorge prefers using a keyboard or a joystick. He played a number of Sudoku games for three weeks (`http://www.sudoku.com/`), revealing difficulties in interacting with the puzzles using just the keyboard. Only in one out of ten Sudoku games was he able to use it. His main complaints about Sudoku have to do with his enormous difficulties in interacting with the keyboard to input numbers in the Sudoku grid, because the games were not adapted to be played using only a keyboard. The configuration of several options revealed the

Figure 7: Using the voice the user selects the desired row (1-15) and column (1-9). Finally, the next step is to choose the number to fill in the Sudoku cell (row 5 column 4, in the example).

same interaction problem. He was forced to use the mouse to arrange features as the keyboard did not allow this task.

Jorge played the Sudoku Access game using a microphone in the classroom. He used the Microsoft speech recognition training to obtain a better performance and managed to successfully complete the Sudoku grid. He was able to use and configure all the features of the puzzle only by saying numbers.

To evaluate the total number of speaking numbers/words and the time taken by him to input numbers in cells he was asked to complete a 9x9 grid after he had previously seen it solved. Jorge filled all the 55 cells within 7 minutes 32 seconds by speaking 330 times with the computer.

Jorge enjoyed the game very much. He commented: “With this Sudoku game I can use my voice to play and configure all the features of the puzzle just saying numbers”.

Figure 8: Using the voice the user selects other numbers between 1 and 5 to choose the desired options.

Fátima

Fátima is a thirteen-year-old girl with a developmental birth defect involving the neural tube: incomplete closure of the embryonic neural tube results in an incompletely formed spinal cord. This malformation is called *Spina Bifida*. She presents a severe limitation to move, manipulate objects and to pronounce words. She needs the aid of a wheelchair to be able to move. Her interaction with computers is difficult and she does not like to use a conventional mouse. To play the Sudoku Access she tried the scanning system but she had difficulties in understanding the mechanism. Figure 1 shows Fátima operating her PC with the “Space” key by using one hand to control the Sudoku game.

After some experiments we realized that she presents cognitive problems. She admitted some problems using numbers in the game and the 9x9 Sudoku grid presented another difficulty; it was too complex for her.

Fátima tried the speech recognition system but she reveals voice pronunciation problems. She motivated us to add new features to the Sudoku game so that an easier puzzle could be made. Consequently, we have decided to produce both a 4x4 grid and add two new options in order to settle on the matter of the use of the numbers.

We have started by using colors instead of numbers. Each color was inserted in a small circle to differentiate the cells able to be altered. The cells having a blue ring can suffer adjustments at any time of the game whereas the black ones cannot be adjusted at all. Secondly, the simultaneous combination of numbers and colors was also included. To each number placed in its respective cell corresponds a particular color (see Figure 10). The opening of these alternatives led Fátima to progress significantly her understanding as well as complete a 4x4 Sudoku grid. Not only did her confidence grow but also her own limitations were exceeded through the use of the scanning system with a smaller grid and colors as an alternative to numbers.

Throughout the tests Fátima took interest in trying again the 9x9 grid after she had previously seen it solved. But she reveals difficulty in finishing the entire Sudoku grid. Fátima filled all the 55 cells within 19 minutes 27 seconds by pressing the "Space" key 275 times. Nevertheless she completed the 4x4 grid easily in 2 minutes 5 seconds by using the "Space" key 50 times.

Daniela

Daniela is a fourteen-year-old girl with a degenerative disease characterized by slowly progressive paralysis of the voluntary muscles. This disability prevents her from going to school. Therefore she uses a webcam to interact with the classroom. Her interaction with the computer is hard and she uses an onscreen keyboard whenever she needs to enter a few words. At one time she used *Click-N-Type* (`http://www.lakefolks.org/cnt/`) and *REACH Interface Author 5* (`http://www.ahf-net.com/`), however when we met her she had switched to Microsoft's Accessibility Keyboard. She was very excited to play the Sudoku game. Using the Sudoku Access scanning system she was able to play the game and complete an entire 9x9 Sudoku grid. To activate the scanning system she used the "Space" key to interact with the game.

Daniela was able to use and configure the software without an assistant's help. She configured useful options to improve better interaction with the puzzle such as: difficulty level, the scanning velocity, scanning color and Sudoku size. Daniela prefers using the 9x9 Sudoku grid with numbers and colors. She unveiled very good results as confirmed through her direct quote: "What I appreciated most was the scanning system because it gave me the possibility to fill the Sudoku grid".

Unfortunately Daniela was unable to perform input rate tests due to health reasons.

At the end of the experiment, students also filled out a short questionnaire to gauge their opinion of the game. Figure 9 illustrates the degree of satisfaction.

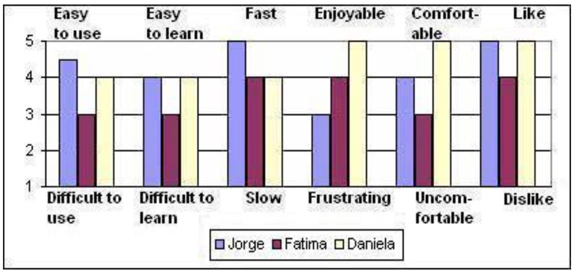

Figure 9: Subjective ratings concerning the satisfaction of the students in using the Sudoku Access. Ratings were provided on a scale from 1 (weak) to 5 (good).

5. FUTURE WORK

There is large interest in the creation of educational design interfaces for people with motor disabilities. In the near future, we intend to continue to test the Sudoku Access with more individuals with motor impairment including people with cerebral palsy. We would like to continue to improve the Sudoku Access with new options to help people with visual impairments. Our current goal is primarily focused on expanding the use of educational interfaces among people with disabilities.

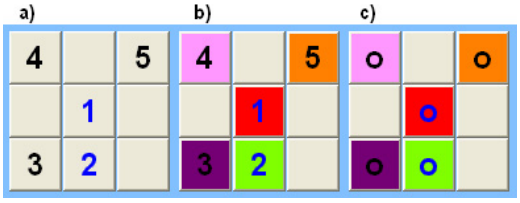

Figure 10: The Sudoku Access game can be played by: a) using only numbers; b) combining simultaneously numbers and colors, c) making use of colors instead of numbers.

6. SUMMARY AND CONCLUSIONS

This paper presents the Sudoku Access, a system to help individuals with physical disabilities to play the Sudoku puzzle. The software is available for free use and can be downloaded from `http://w3.ualg.pt/~snorte/SudokuAccess.htm`. The interactions and observations with the students proved to be very useful to understand the problems and needs in the Sudoku game. From the tests we verified that the Sudoku Access was beneficial to assist the users positively by increasing their performance, speed and accessibility to play the game. We observed that the scanning process can create a longer delay to fill a cell in the Sudoku grid. However both practice and the configuration of the scanning rate will increase the velocity of the game.

An important aspect observed during the usability tests with the scanning system was the value of the scanning sound. The sound proved to be helpful in the game once it offered a better choice in the selection of the desired item (or groups of items) thus focusing positively the player in the task. Indeed, the motion and the sound of the scanning process cause concentration and enthusiasm. The users use the scanning system as if it was a game itself.

The scanning system may appear a simple technique but is extremely useful to help people with motor impairments. Without this system people like Daniela or Fátima would not have a chance to be able to play the Sudoku game. It is extremely rewarding to provide simple techniques in applications that can change the quality of life of people with disabilities.

The users who can use the speech recognition system can potentially improve their overall input rate. The students have found success in using the training process to improve results. However, we verified that it is beneficial to use the same microphone for dictation that was used for the training process. The voice recognition system was very useful for filling the Sudoku cells as well as to choose among the various menu options. Sometimes the Speech Application Programming Interface (SAPI) does not recognize very well. We have minimized this problem by reducing the complexity of the words through the spelling of numbers which has increased greatly the success of the voice system.

Our work should encourage researchers to explore new ways in which common input devices can be used to improve computer game access for users with motor impairments.

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7. REFERENCES

[1] T. Barnes, H. Richter, E. Powell, A. Chaffin, and A. Godwin. Game2learn: building CS1 learning games for retention. In *Proceedings of the 12th Annual Conference on Innovation and Technology in Computer Science Education (ITiCSE 07)*, pages 121–125, New York, NY, USA, 2007. ACM Press.

[2] Communication Aids for Language and Learning. `http://www.callcentrescotland.org/`. (accessed September 26, 2007).

[3] C. Conati and X. Zhao. Building and evaluating an intelligent pedagogical agent to improve the effectiveness of an educational game. In *Proceedings of the 9th International Conference on Intelligent User Interfaces*, pages 6–13, New York, NY, USA, 2004. ACM Press.

[4] P. A. Condado, P. F. Miquelina, S. Norte, N. Castilho, F. G. Lobo, and H. R. Shahbazkia. Information and communication technologies for people with disabilities. In *Interactive Computer Aided Learning International Conference*, Carinthia Technology Institute, Villach, Austria, 2004.

[5] L. Dai, R. Goldman, A. Sears, and J. Lozier. Speech-based cursor control: a study of grid-based solutions. In *Proceedings of the 6th International Conference on Computers and Accessibility*, pages 94–101, New York, NY, USA, 2004. ACM Press.

[6] J. Gilligan, B. M. Namee, and P. Smith. Interface design requirements for playing pong with a single switch device. In *Proceedings of the 9th International Conference on Computer Games: AI, Animation, Mobile, Educational and Serious Games*, 2006.

[7] C. Holbrook. Input methods for notification systems: A design analysis technique with a focus on input for dual-task situations. Master's thesis, Faculty of Virginia Polytechnic Institute and State University, June 2003.

[8] International game developers association. `http://www.igda.org/`. (accessed May 17, 2007).

[9] L. L. Johnson, J. W. Rickel, and J. C. Lester. Animated pedagogical agents: Face-to-face interaction in interactive learning environments. *International Journal of Artificial Intelligence in Education*, 11:47–78, 2000.

[10] A. S. Karimullah and A. Sears. Speech-based cursor control. In *Proceedings of the Fifth International Conference on Assistive Technologies*, pages 178–185, New York, NY, USA, 2002. ACM Press.

[11] S. J. Kerr, H. R. Neale, and S. V. G. Cobb. Virtual environments for social skills training: the importance of scaffolding in practice. In *Proceedings of the Fifth International ACM Conference on Assistive Technologies*, pages 104–110, New York, NY, USA, 2002. ACM Press.

[12] P. Majaranta and K. J. Räihä. Twenty years of eye typing: systems and design issues. In *Proceedings of the 2002 symposium on Eye Tracking Research Applications*, pages 15–22, New York, NY, USA, 2002. ACM Press.

[13] Y. Mihara, E. Shibayama, and S. Takahashi. The migratory cursor: accurate speech-based cursor movement by moving multiple ghost cursors using non-verbal vocalizations. In *Proceedings of the 7th International ACM Conference on Computers and Accessibility (ASSETS-2005)*, pages 76–83, New York, NY, USA, 2005. ACM.

[14] A. Mitrovic and P. Suraweera. Evaluating an animated pedagogical agent. In *Intelligent Tutoring Systems*, pages 73–82, 2000.

[15] J. Nielsen. *Usability Engineering*. Morgan Kaufmann Publishers Inc., San Francisco, CA, USA, 1995.

[16] P. Nisbet, C. Gray, G. Taylor, and S. Townend. An introduction to switch access technology. In *Communication Matters National Symposium.*, 1998.

[17] D. A. Norman. *The Design of Everyday Things*. Basic Books, September 2002.

[18] S. Norte and F. G. Lobo. A virtual logo keyboard for people with motor disabilities. In *Proceedings of the 12th Annual Conference on Innovation and Technology in Computer Science Education (ITiCSE 07)*, pages 111–115, New York, NY, USA, 2007. ACM Press.

[19] F. Shein. *Towards Task Transparency In Alternative Computer Access: Selection Of Text Through Switch-Based Scanning*. PhD thesis, Department of Mechanical and Industrial Engineering, University of Toronto, 1997.

[20] C. E. Steriadis and P. Constantinou. Designing human-computer interfaces for quadriplegic people. *ACM Transactions on Computer-Human Interaction*, 10(2):87–118, 2003.

[21] J. A. Valente. *Creating a Computer-Based Learning Environment For Physically Handicapped Children*. PhD thesis, Massachusetts Institute of Technology, September 1983.

[22] J. Wobbrock and B. Myers. Trackball text entry for people with motor impairments. In *Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI 06)*, pages 479–488, New York, NY, USA, 2006. ACM Press.