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Stimulation of Numerical Skills in Children with Visual Impairments Using Image Recognition

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Abstract

The learning process in training children with visual impairments and low vision requires the use of new devices that integrate image recognition and feedback on stimulation sequences with the senses of tactile and auditory responses into their design. Eighteen students with visual impairments (blind or low vision) between the ages of eight and twelve, who attend a school specialized in teaching children with visual impairments, completed three numerical stimulation routines. The software developed evaluates skills of addition and subtraction, identification of geometric shapes, and mental calculations to achieve a goal. The results of the test showed that the students performed better in the game dynamic than in the addition and subtraction routines. This study is a contribution to designing software for low-cost devices as it has been verified that this type of application works on both a laptop and a Raspberry pi device.

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1. Introduction

The stimulation process in children who are blind or have low vision should be focused on emphasizing perceptual and sensory development that supports inclusion in new educational models. Currently, there are

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touchscreen software for learning topics according to difficulty levels [8], braille learning devices, and artificial intelligence software to detect and recognize objects, faces, etc. as alternative technologies to stimulate the blind. In addition to these tools, we show the use of three applications designed to stimulate numerical calculations in children with visual impairments. The first one uses a camera to identify the number of units, tens, hundreds, and thousands on a plastic base and the number that has been written is verbalized; the second is a geometric shape detector that uses computer vision libraries to identify various objects; and the third involves a maze game that allows the children to move the computer cursor in grid logic to reach a target square. For the design of these developments, in-depth interviews were conducted with the teachers responsible for providing stimulations to the children, and the most relevant characteristics for children interacting with the application were determined. These developments contain two elements in conceptualization: receiving the signal activated by the student (either by detecting images or moving the cursor) and measuring the progress of the auditory feedback on a response to the proposed stimulus. These applications have been tested both on a laptop and a Raspberry pi device.

2. Reference framework

In laptop applications, it is very common to find that blind people's access to the various device functions facilitates interest for auditory feedback and that use of these technologies supplement teaching [3].

In terms of stimulation, emphasizing children's attention is important. "The effects of passive compared to active stimulation are weaker, so manipulating attention plays an important role" [18]. Moreover, creating virtual environments improves interaction for people with visual impairments, emphasizing sound when completing various assigned tasks. Three-dimensional environments have an additional advantage; they generate a very powerful stimulus in tactile exploration while helping strengthen memory. They also stimulate spatial location by differentiating sound sources. For this reason, blind people should be incorporated in the initial phase of design of any application to achieve more useful results [15].

Morrison et al. [12] identify social dimensions that must be considered when designing a solution related to visual impairment. They suggest using the dimensions of social participation, maintenance, and independence to create devices that contribute more to their users. Among technologies used for applications in artificial intelligence field for people with visual impairments, computer vision that has been used for various applications to improve the lives of these people stands out. For instance, Waisward et al. [19] describe the recognition functions of the OrCam device, which is added to the frames of the glasses, and how it incorporates image and audio processing technology to read and recognize objects, thereby, improving the quality of life of people with visual impairments. In the works by Sozim [16], devices with computer vision and object recognition are presented. These devices help recognize the faces of people who interact with people with visual impairments, while Jóhannesson [10] describe the importance of feedback using vibration as a response to visual sensors. Moreover, Zhao [20] introduce a device shaped like glasses that accesses a smartphone to give feedback whether the face of someone approaching is happy. Jeon [9] emphasize the algorithmic part of learning with convolutional neural networks and training in computer vision.

3. Methodology

3.1. Sample

To collect the data, permission was requested to the authorities of the educational institution and, since the study involve minors, parents' consent was requested. They were informed of the objectives of the study and explained in detail the tests to be evaluated, the anonymity and confidentiality of the results. Eighteen minors, including boys and girls, who are regular students at a school specialized in caring for blind children in the city of Lima, Peru, participated in the development of the learning experience, the sampling that was carried out was not probabilistic but for convenience since the selection of the participants depended on access to the educational institution [6].

They were in primary school and between eight and twelve years of age. The following table summarizes the characteristics of this sample group:

Table 1. Student sample details.

Quantity	Primary Education Level	Ophthalmological History
3	Third grade	Visual impairment (2) and low vision (1)
4	Fourth grade	Low vision (4)
6	Fifth grade	Visual impairment (4) and low vision (2)
5	Sixth grade	Visual impairment (3) and low vision (2)

For the practical part, Kline [11] states “one of the greatest advantages of psychometric testing using computers is the ease of recording interactions and conducting experiments tailored to the unit of analysis”. For this reason, the functionality of the tasks designed to evaluate the students were previously validated by the teacher responsible for providing the stimulation.

3.2. Procedure

Students performed three exercise routines of varying difficulty. The routines were held in the school’s technology laboratory in the presence of the teacher-in-charge and a specialist for recording results. To conduct the evaluation, the dynamics were explained to the students and a prototypical exercise was provided. The evaluation of the applications was conducted using a user evaluation. Mathematical ability was the cognitive ability that the exercise sought to stimulate, and the questions required students to perform mental calculations to obtain the correct answer.

In the first and second applications, image recognition and object detection algorithms were used, which generate a vector signal that then becomes an auditory feedback message to the children with visual impairments. The software developed runs on two environments. First, a laptop processor (five-core AMD), which was connected to a camera, a screen, a keyboard, and speakers that serve to hear the audible response, and an attachable headset with headphones. The second a raspberry pi 3b + device, using a Pi camera V2 8 mp. The second stimulation routine was carried out by giving the students geometric pieces with different shapes; and tasks were assigned by the class instructor to either identify a particular shape or choose two equivalent shapes.



Figure 1 Addition and Subtraction Device

The three dimensions considered in the stimulation process in children with visual impairments are tactile stimulation, auditory stimulation, and mathematical ability. The interface was developed using Python with the tkinter library. The three types of evaluations are described below.

3.3. Detecting and Recognizing Geometric Figures

In the figures, the results of the students’ performance level in test 1 are shown consisting of school-aged children with visual impairments identifying geometric shapes. In the tests carried out, the children receive an explanation on the number of angles in each piece used (triangle, square, rectangle, pentagon, hexagon, and circle). Then they are asked to add or subtract the number of angles in the various figures and then as a result, the student receive a verbal feedback from the computer.

3.4 Find the Treasure

The third application is a maze that the children navigate with the keyboard arrow cursor until they find a target square. With each cursor movement, the computer verbalizes a word that guides the student on the direction it is going. Unlike the two previous applications, the feedback verbalization for this one is the teacher's voice and it offers a game dynamic.

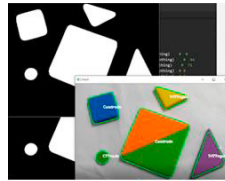


Figure 2. Student Interface in Application 1



Figure 3. Student Interface in Application 3

3.5 Adding and Subtracting with Shape Detection

In this test, the children are instructed to add and subtract. To do so, there is a base with separated units, tens, hundreds, and thousands. These holes represent the sequence of numbers that can be represented with the number of pieces that the child places. In this exercise, students are evaluated on memory capacity (by identifying where the circles are in the template) and numerical calculation (by adding or subtracting a number). The computer feedback is provided to the students when they press the space bar. A pyttsx3 library was used for number verbalization when the application runs on Windows. On Raspberry, it uses the “e-speak” library.

In all three applications, the teacher's role is to explain the task at the beginning of the game and to record the score obtained for the evaluation according to the level of difficulty. The teacher will also record the number of times that students need guidance because they cannot complete the assigned task.

4. Results

To process the results, the tool Tanagra [14], was used to carry out a projection analysis with the scores obtained by the students when taking the tests. In relation to completing the exercises with the students, the teachers in charge of administering each test recorded students answered questions posed with scores between one and five. Using the R language, prcomp library, the results of the component analysis with the logarithmic data are shown below

Importance of components:

	PC1	PC2	PC3	PC4
Standard Deviation	1.828	0.7064	0.29767	0.26918
Proportion of Variance	0.835	0.1248	0.02215	0.01811
Cumulative Proportion	0.835	0.9597	0.98189	1.00000
Standard deviations (1, ..., p = 4):				
[1]	1.8085070	0.7153373	0.3655066	0.2898269

Rotation ($n \times k$) = (4×4):

	PC1	PC2	PC3	PC4
Yupana	0.4853660	0.6191375	-0.1633744	0.5953129
Treasure	0.4680402	-0.7062907	0.3031061	0.4361405
Geometric	-0.5215502	-0.2700481	-0.6021241	0.5408383
Help	-0.5228228	0.2118873	0.7203347	0.4035815

The projecting loads of the eigenvalues provide the explanation of the variance between records that allow us to identify the presence of two dimensions and to create a scatterplot between the variables and the main components.

We can interpret this result as it is feasible to classify the experimental group considering that the recreational component for this experiment, represented by the “Find the Treasure” application along with a logic game like “Yupana,” explains more than 90% of the cumulative variance.

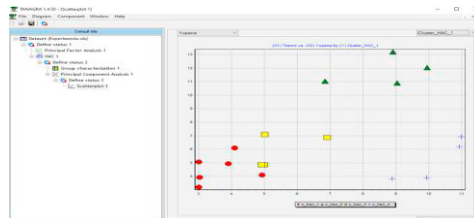


Figure 4. Scatterplot with Performance in Dominant Games

After completing a hierarchical classification analysis, we can observe on figure 5 four groups in the results based on which we observed that the use of treasure hunting and numerical logic tools are more relevant to analyze the results and help classify the students appropriately. This classification also allows the teacher to better focus the routines assigning different tasks to each group and increasing difficulty levels in the game if required.

Incorporating these applications has generated changes in the development of the laboratory session. The classes in the school technology workshop have a device for each student. The groups vary between five and ten students; and the children sit and receive instructions from the teacher on the type of game that she determines each should play. The teacher effusively highlights achievements when children obtain a result

5. Discussion

The tests conducted at the school show that students with visual impairments can use this type of application with the help of a person who accompanies the stimulation process. In the geometric shape application, it is very useful for children with low vision to use colors that are intense because the children reflexively bring the piece closer to their face. A theme to highlight in the three applications is the verbalization of the results. In the first two applications, this was done by libraries that synthesize voice. By modulating the parameters of frequency and wavelength, voice could be properly imitated, but it was clearly a synthetic voice. In the Find the Treasure application, however, the teacher's voice in mp3 format was used, meaning that for each indication, there was more than one expression that was executed randomly for the welcome and the various feedback indications, generating a better experience for the students. The teachers verified that the performance increased with the third application in the general results.

The importance of the physical part of the application is also relevant because it influences the students' performance. In the application of geometric pieces and in addition and subtraction that involved interacting with physical pieces, placing the piece on the board in a specific area from where it was to be picked up is a relevant detail since students do not have to strain to find the required piece. The camera lighting for the image capture process is a crucial variable for the satisfactory performance of the first two applications that use shape analysis (the Yupana game and the shape detection game). A module to calibrate brightness and sharpness was included as part of the application, in addition to making the distance between the worktable and the camera flexible.

6. Conclusion

Software applications for stimulation process in children with visual impairments require considering the various functions that teachers understand about their students from the design stage. Numerical stimulation applications designed for children with visual impairments and low vision must be built around the theme of play and the algorithmic part and must complement to the teacher's work, that is, these tools should assist specialists do not replace their work. Moreover, this work shows how this kind of applications are useful to get better classification of different numerical stimulation routines.

Computer vision has a great potential in recognizing shapes and completing stimulation drawings that has not been intensively used regarding stimulation yet. Due to the technology used, it is necessary to set parameters of the

lightning values according to the location of the stimulation unit so that the image captured by the camera can be properly processed. There are pedagogical concepts to consider in the design of new computer vision stimulation technologies for people with visual impairments, especially how to integrate the sense of tactile and auditory feedback in game participation and how learning levels can be designed with them.

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