A Computer Aided Drawing System Evaluation with Early and Late Blind Users

Sandra Fernando, James Ohene-Djan, 27 of August 2020

Abstract

The present lack of suitable and efficient graphics creation techniques may place limitations on the career progression and life contentment of blind students. It is challenging for a BVI (Blind and Visually Impaired) person to draw diagrams or art, which are commonly taught in education or used in industry. The SETUP09 graphics creation system was developed to address a need for blind users to be able to create such content and consists of both navigation and computer aided drawing techniques, enabling graphics creation and manipulation through command language and intuitive, matrix-style movement. The technique can facilitate a user's ability to produce art and scientific diagrams electronically. This paper presents a comparative system evaluation of digital versus analogue drawing techniques with early and late blind individuals. Users were tested using different graphics creation tasks to assess the accuracy and efficiency of an analogue drawing technique compared with the digital SETUP09 system. The results confirmed that the SETUP09 compass-based graphics creation technique allows greater accuracy in completing a drawing task, with a noticeable reduction in effort compared to analogue drawing techniques.

1. Introduction

The potential of drawing for blind people has been experimented with in the past (E. Ricciardi, 2009; Ishihara, Takagi, Itoh & Asakaw, 2006; Kamel & Landay, 2000; Kamel & Landay, 2002; Lambert, Sampaio, Mauss & Scheiber, 2004). This work has gathered new momentum with the advent of 3D printing (Williams, Zhang, Lo, Gonzales & D. Baluch, 2014), Hyperbraille (Leo, Cocchi & Brayda, October 2016), haptic and speech technologies (Zhang, Duerstock & Wachs, February 2017), and sonification (Walker & Mauney, March 2010). But the expression of pictorial thinking for blind users through computers is limited and most seek the help of a support worker to draw pictures or diagrams, or they avoid drawing because they find it difficult to believe that they would be able to create pictures or diagrams without guidance from a sighted person. Consequently the need for self-reliant blind drawing techniques and technology has been recognised and highly valued among blind communities.

This study introduces a compass-based location tracking approach together with interactive friction gaming text communication styles to develop the user's concept of drawing, and is called the SETUP09 system as demonstrated in Figure 2. An experiment was conducted involving early blind and late blind participants to compare manual paper kit drawing with a command-driven drawing technique, in the absence of any established digital drawing system.

Our evaluation of SETUP09 suggests that the system supports blind participants better in completing a drawing task compared to the use of an analogue drawing toolkit. Both early and late blind participants were able to use this navigation and drawing technique with high accuracy and efficiency. SETUP09 enables BVI users to navigate to a particular location and manipulate shapes with confidence, without the assistance of a support worker, and there is a high level of accuracy reaching a given location and completing a drawing activity using the SETUP09 system.

This paper is structured as follows. In the background section, we give a general overview of the mental models of early and late blind people, and a comparison of different navigation and drawing technologies. In the system introduction section, we explain the proposed system, SETUP09, and set out an experiment. In the methodology section, we discuss the experiment. We then present our discussion and conclusion sections.

2. Background

Most BVI students and practitioners are in the habit of using tactile maps to recognise highlighted raised line art or objects (N.Takagi, 2009). However, there are limitations to the information that tactile graphics can convey. Since Bach-y-Rita (B-y-Rita, 2004) presented the idea of tactile-vision sensory substitution in 1969, similar technology applications have seen rapid growth. From tactile-vision perception and understanding to voice-vision substitution, this has been incorporated in various ways, helping BVI people in their daily living, academic lives and careers. Even though tactile images and 3D printing exist, this technology needs further improvement for complex and dynamic art production (Williams et al., 2014).

Analogue drawing systems established in the past are commonly used, but do not provide the required accessibility features recommended by Ergonomics of Human-system Interaction (ISO, 2006). Some examples of analogue drawing tools are InTACT SketchPad[1], Sensational Blackboard[2], TactiPad[3], Swail Dot Inverter[4], Quick Draw Paper[5] and Sewell EZ Write N Draw Raise Line Drawing Kit (MaxiAids, 2019). These products involve the use of rubber mats, a drawing board and pens, are light and portable, have the capability to emboss, are inexpensive but require some good motor skills to do the freehand drawing. Most analogue systems lack support with drawing objects, stepwise interactions such as changing properties, protection form critical functions such as delete, a frame of reference such as grids, labelling, error correction, copy-paste, saving, help, and the list can go on.

There are several digital systems that were introduced in the past (H. M. Kamel, 2001; Rassmus-Grohn et al., 2007; Huissen, 2016; Gardner et al., 2002; Cook and Polgar, 2015; Blenkhorn and Evans, 1998; Calder et al., 2007; Rassmus-Gröhn et al., 2013) and many more other special-purpose digital drawing systems are discussed by Bornschein and Weber (2017). Even though some systems pay attention to layout information and screen navigation, they are operated by a defined set of system shapes and the drawing and layout models are not necessarily easy to use in practical situations. Some systems do not provide a graphical interface, but simply a means to communicate the purpose, no re-use functionalities, limited availability of systems, modalities, and lack of compatibility with other assistive technologies. Further to this, the efficiency and practicality of these in an educational environment are limited due to the need for special equipment or lack of system efficiency and effectiveness.

Kamel and Landay (Kamel and Landay, 2000; H. M. Kamel, 2001; Kamel and Landay, 2002) have also introduced IC2D products that divide the screen into nine navigable smaller workspaces. IC2D is developed with fixed system functionalities and modalities. System "Kevin" (Blenkhorn and Evans, 1998) enables users to read, edit and create diagrams using an $\mathbf{N}^{\mathbf{2}}$ chart. However, the system does not keep track of layout information relating to the diagram, therefore when it is imported to another tool, transformation and connection must be moved. System PLUMB (Calder et al., 2007) uses linked lists and Heaps algorithms to store data in a data structure and to access them in a sequential manner. The system has no clear indication of layout information or shapes. Many digital products were built with different modalities such as haptic, audio or command-driven for particular domains such as charts, diagrams or mathematics but not necessarily art creation in general. There is a recent development in command-driven drawing among blind drawing products and also sighted drawing products. Recently introduced systems BPLOT3 (Fujiyoshi et al., 2014) and BPLOT2 (Fujiyoshi et al., 2008) use system dialogue to create a drawing using command language that is accepted in the blind community.

Kurze explained that the most important characteristic of a picture is not its channel of perception (visual or non-visual) but the methods of arranging information in space (Kurze, 1996). An arrangement of information requires spatial knowledge and shapes representing real world images and interaction between those shapes to form meaning. The meaning of such images can be perceived by different modalities such as haptic, speech or sound. The perception of blind people is based on the process of fitting sensorily perceived information from the environment to an existing internal idea, the mental image. According to Kurniawan et al. (2003) mental models are users' internal abstract models that have information about where things are located, how things work or behave. And he points out that blind computer users' mental models are based on the use of day to day technology.

Early blind, late blind and sighted individuals use different space exploration, coping strategies, and mental imageries in task performance. Late blind individuals and sighted individuals have demonstrated similar behaviours, which are different compared with early blind individuals; thus, their coping strategies are different as pointed out by Ungar (Ungar, 2000). He elaborates on different coping strategies used by early blind and late blind individuals (late blind individuals are those who at least had their sight from three months to three years of age) during different spatial tasks. Those space exploration strategies somewhat mirror Windows environment coping strategies discussed by Kurniawan (Kurniawan et al., 2003). Kurniawan investigated blind users' mental/cognitive models in the Windows environment and their coping mechanisms. It was found that there is a clear relationship between their adaptability to new systems and preconceived mental models (Kurniawan et al., 2003). He categorises three different mental models based on experiment and observation. Blind users with structural mental models perceive the desktop environment as strict columns and rows. Users with functional mental models identify the Windows environment as a set of functions and commands and do not pay attention to interface layout. Some blind users associate functional commands and structure in the Windows environment, identified as a hybrid mental model. Blind users explore, take action, and configure during the interaction with new software as their coping mechanism. Saei further extends the mental model analysis by introducing other contributing factors for system design, such as user's skill set (skills-based), knowledge (knowledge-based), domain (domain-user expert) and system help features to improve BVI users' experience of the computer environment (Saei et al., 2010). Not only were the variations of the coping strategies among blind and sighted individuals clear, but also some differences were demonstrated in mental imagery depending on the modality they channelled as discussed by Albert Postma (Postma et al., 2008).

The following section gives an introduction to the SETUP09 system, followed by a comparison of the outcome of using different techniques and also different groups of blind individuals.

3. Introduction to the SETUP09 System

The motivation for SETUP09 introduced in this research is led by the fact that existing analogue systems lack features such as computer support with art production, techniques to navigate a given interface, error correction, re-use and saving of images. SETUP09 was also motivated by the fact that existing digital systems could be improved with the introduction of a drawing language for people with visual impairment that informs screen layout information and helps with screen navigation, drawing, re-grouping and re-using. The SETUP09 system uses a command-line language that converts text to 2D art production. The technique uses a compass-based screen grid location naming system, with multi-point cell referencing, to draw shapes and art as illustrated in Figure 1.

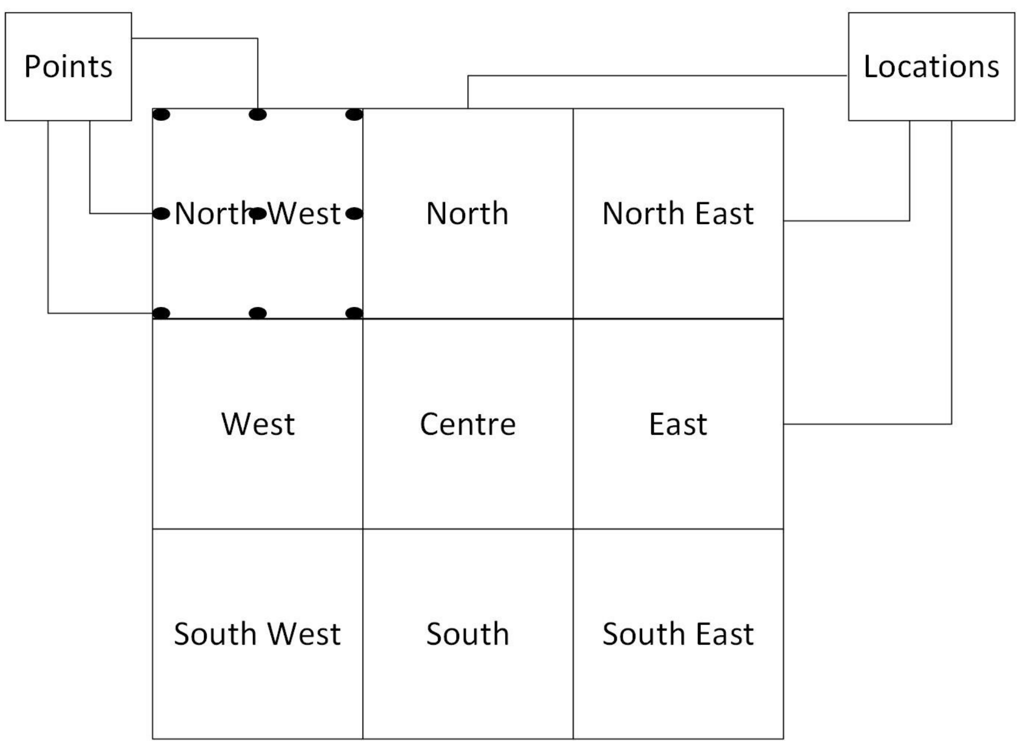

Figure 1: SETUP09 Screen Layout

Screen location points are beneficial for point referencing; however they are difficult to remember when many screen grids are presented to create art. A blind researcher (Kamel et al., 2001) introduced a telephone keypad style cell referencing system to track screen location with centre point cell referencing. A single cell reference system can be time consuming and memory intensive for a blind/sighted person compared to a solution such as the multiple points referencing system that is introduced by SETUP09. A multi-cell reference system with a compass-based naming convention on cells and points is easy and fast to navigate. Cell recursion is another technique that allows a user to refer to a point in one location to points in other locations. Zoom size is the size of the current location that can be set as the default size of a shape if a shape is called on to a location, rather than creating a shape with lines or curves using cell points. The SETUP09 system is designed with a formal language. A formal language delivers comprehension of the software requirements and design, stands as a verification mechanism to prove that a programme conforms to its specifications, allows automatic codes to be generated to build the system or a quick prototype system, and elements of a formal language can be analysed using mathematical methods and used as a criteria during testing. However formal language is not widely used because of its complexity, or the pay off is not immediately clear. Formal models in assistive technologies can provide consistency across multiple platforms, providing reachability and completeness, and can be used for formality-based software design in the development process (Bowen and Reeves, 2007).

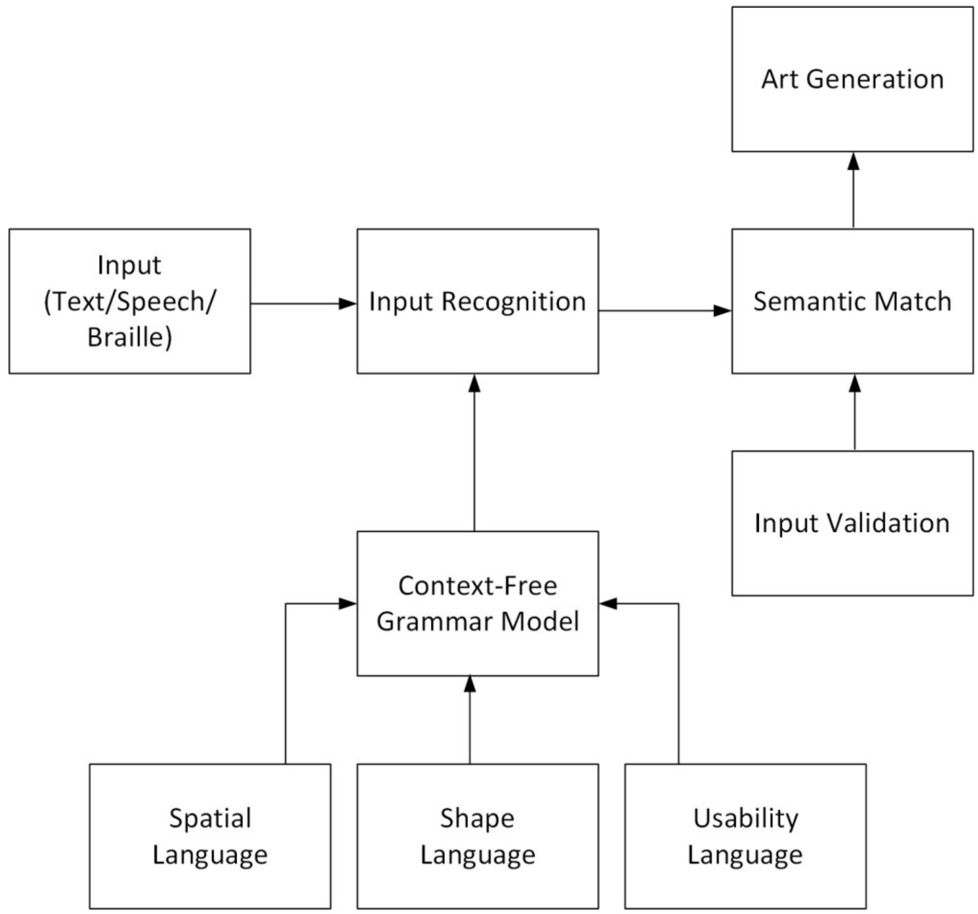

Figure 2: Components of the SETUP09 Model

As depicted in Figure 2 it is assumed that the context-free grammar model of the SETUP09 system prototype is coupled with input interfaces such as text, speech or braille and output with art/diagrams in tactile form. The context-free grammar consists of shape language, space language and usability language. In short, shape language consists of requirements to identify points, draw lines, curves between points, produce primitive or arbitrary shapes, group and re-use them. Space language consists of requirements to navigate to and from a screen area, reference to a screen area, reference to a point, reference to a route and describe art. Usability language consists of requirements to allow users to work without help, learn quickly, get support during drawing, recover work, to work with ease and with minimal cognitive load.

A programming language needs a compiler or interpreter to design its core syntax and semantics (Apple, 2002) in order that the programmer/user can write their programs by calling its commands accommodated by a language. Similarly, SETUP09 is a program that has a programming language to be used by blind people in order to produce drawings by calling its commands. User commands are passed through a lexical analyser to retrieve tokens and semantic analysis to identify the type and meaning of tokens at the input recognition stage. Parser functions perform semantic matching, including error tackling, and art generation is the last order of component links to get the desired representation of diagrammatic images. The commands enable it to produce art, however the formal detail specification is not discussed in this paper.

Using the SETUP09 prototype, users can enter one or many commands at the user prompt to manipulate an image. Figure 3 demonstrates an image of a 2D face. For the purpose of this paper, only some commands are discussed. For example: To get the focus of an area of a screen: Zoomin [name of the area], to extract the focus out of an area: Zoomout, users can directly call library objects by their primitive names (such as circle, rectangle, etc.), a line/lines can be manipulated by calling it: line [point1][point2] or [any number of points], a curve/curves can be manipulated by calling it: curve [point1][point2][point3] or [any number of points], a drawing can be defined by giving it a name and a set of commands, users can directly call user-defined objects by their given names (such as mycircle, myrectangle, etc.), a point on the screen can be assigned to a variable. These variables can be used as a reference point to draw lines and write text, text can be written on the screen by directly calling a point or user-defined point.

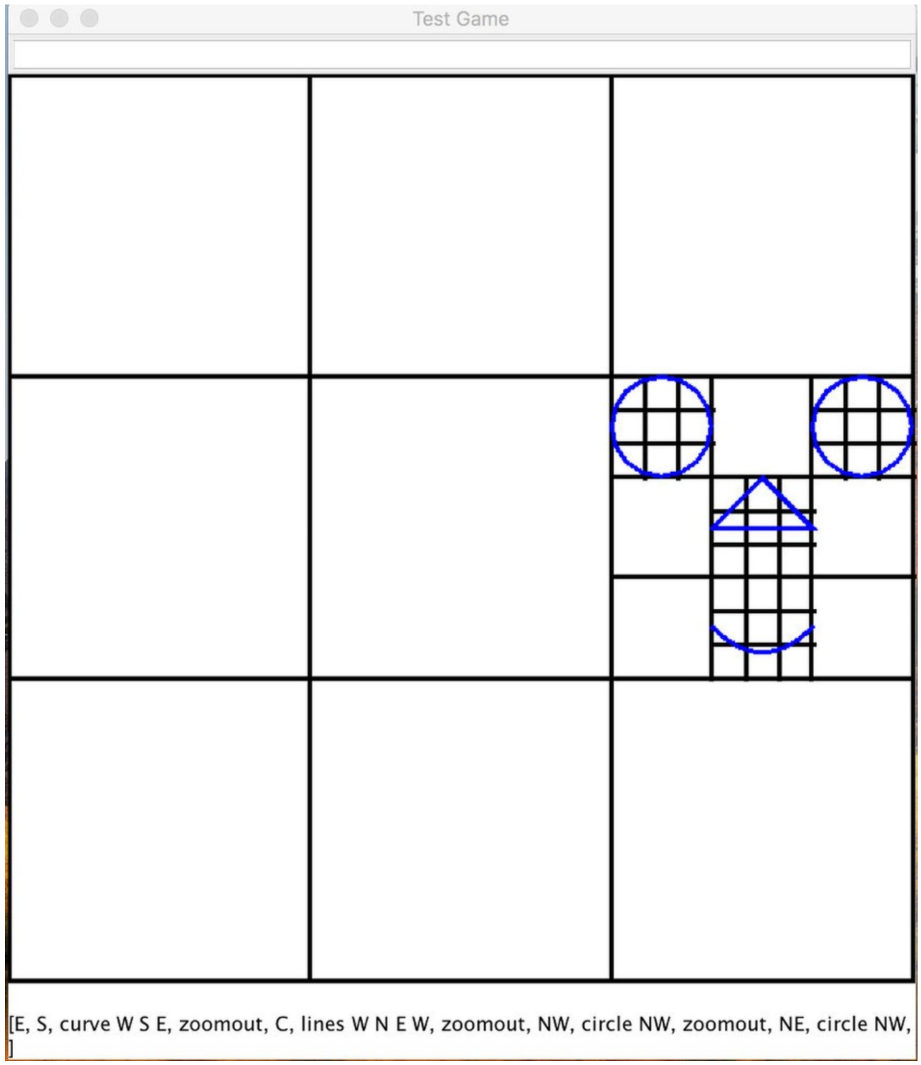

Figure 3: Art produced by the SETUP09 System: An image shows graphics creation on the screen location East using system keyboard keys and shortcut keys to input system commands that are generated on the picture.

3.1 User Interaction with SETUP09

System Commands to produce the image in Figure 3: *[E, S, curve W S E, zoomout, C, lines W N E W, zoomout, NW, circle NW, zoomout, NE, circle NW]*

Step 1: E - Navigate to East location

Step 2: S - Navigate to South of East location

Step 3: *curve W S E* - Draw a curve linking the points West to East with South angle

Step 4: Zoomout - go back to East location, one zoom level up

Step 5: C- Navigate to Centre of East area

Step 6: lines W N E W – draw a triangle by calling points West, North, East and West

Step 7: Zoomout - go back to East location, one zoom level up

Step 8: NW - Navigate to North-West of East location

Step 9: circle NW – draw a circle on the North-West location starting from North West point

Step 10: Zoomout - go back to East location, one zoom level up

Step 11: NE - Navigate to North-East of East location

Step 12: circle NW – draw a circle on the North West area starting from North West point

The user inputs these commands using a keyboard (the currently presented input mode), one command at a time, whereupon the system executes either the appropriate screen navigation or produces 2D shapes/art at the selected location. The system gives voice feedback after every command to confirm the operation. There are system help commands such as description, help, route and erase, as part of the usability command language to help the user to request orientation information, ask for names of labels and shapes on the screen, and provide instructions to reverse a drawing or navigation. Users can save the image or get it printed using a raised line printer to verify the image. One of the future developments is to add a tactile layer on an external device to give real-time feedback and add a speech recognition API (Application Programming Interface) to input commands.

The SETUP09 navigation and art production system is useful in many ways. Blind students in educational establishments such as secondary and primary schools can use the software to learn simple and complex

2D shapes, construct images using screen points and compass directions, or programme a sequence of commands to get the desired picture output without the need of a support worker. Blind students can be better included in the design aspect of the STEM field with scientific drawings such as flowcharts, data flow diagrams, wireframes, structure charts, and many more technical diagrams. Spatial skills development is essential for blind people to achieve a degree of independence. This requires conceptualised thinking of space with some kind of referencing system, such as a reference to a location, spatial points, shapes or distance. Blind people who are interested in art production for leisure, work or community purposes can benefit by using the software to produce art as a method of communication, such as designing a leaflet or banner, and visualising life events and experience through art when the software is provided to them. Those who own swell papers, a printer and a fuser can also benefit from tactile printed images.

Sighted people can benefit from many more practical and general applications, not just as a navigation technique for drawing but also as an easy on-screen navigation technique with everyday applications. For example, to move the cursor to a specific location on a word processing application without having to use a mouse or tracker pad, but instead use the compass grids to over-layer with keyboard keys or speech. Another example would be the ability to move the cursor to a location on a webpage for software such as screen readers; reading can then begin or resume from the newly selected grid location. A third example is to find a location on a map using a 3*3 compass-based grid overlayer. This technique traces the navigation path and remembers to navigate back and forth. Compass-based navigation takes the cursor to the intended screen location without having to rely on a tracker pad, mouse, or visual perception. To check navigation and art production ability, an experiment was conducted to test the SETUP09 technology with an analogue toolkit with early and late blind participants in section 4.

4. Methodology

We evaluated the suitability of the command-driven drawing technique and virtual navigation system with early and late blind individuals. An earlier study of SETUP09 navigation revealed that blind computer users were able to successfully navigate to screen locations without the help of a support worker (Ohene-Djan and Fernando, 2018). This study experiments with both drawing and navigation methods with early and late blind individuals. Participants were collected via contacting different charities for both the early and late blind. Participants from different age groups and different education levels were chosen. This experiment presents a systematic evaluation of the analogue method that is famously used in special needs education establishments versus the digital method SETUP09. The system is not just a computer drawing system but also a text to diagram conversion technique that has compass-based grid naming and a multi-cell referencing system. The focus of this does not explore modality mechanisms but a system that is adaptable to different modality mechanisms if expansion is needed. This experiment had eight blind participants, four of whom were late blind individuals and the other four were blind from birth. Further information is given in Table 1.

We presented each participant with three tasks to complete and measured their performance. Each participant had roughly 30 minutes of training on the system. The training was split across three experimental tasks and included: Introduction to SETUP09 and drawing and navigation language; Hotkeys and help keys; Hands-on practice using the prototype and different drawing commands; Steps to draw simple shapes and images; Labelling and defining an image.

The analogue toolkit consisted of a rubber mat as a backing sheet when making the raised drawing, embossing film papers and a pen instead of an embossing tool. We used the light inked pen for the experiment to get a visual effect for readers. The toolkit gives a negative raised image. Figure 4 is a picture of a rubber mat, embossing film paper kit and the drawing interface of system SETUP09. Some adjustments were made to the analogue toolkit to enhance the sense of location and size experience of participants when drawing on the film paper. Film papers were embossed with 3 x 3 grids to provide guidance with location and size. Finding locations and sizes otherwise would have been a very time consuming and hectic task using the analogue toolkit. Some participants needed further grid marks and point marks on the film paper to replicate an exact image of the tasks below. However, film paper does not come with embossed grids on the surface. Too many grids confuse blind participants' concept of the tactile view.

Table 1: Information on the early and late blind participants in the experiment

Person	Gender	Age	Reason	Residual Vision	Age of Blindness	Education	Computer Literacy
1	F	37	Microphthalmia	None	Birth	Manager	High
2	M	70	Microphthalmia	None	Birth	Graduate	High
3	F	56	Optic nerve damage	None	Birth	Graduate	Moderate
4	M	29	Retinopathy	None	Birth	Graduate	High
5	F	65	Retinitis Coloboma	None	17	Graduate	High
5	F	65	Retinitis	None	17	Graduate	High
7	F	68	Glaucoma	None	22	Graduate	Low
8	M	57	Ocular Atrophy	None	56	College Leaver	High

4.1 Experimented Tools: Analogue System and Digital System (SETUP09)

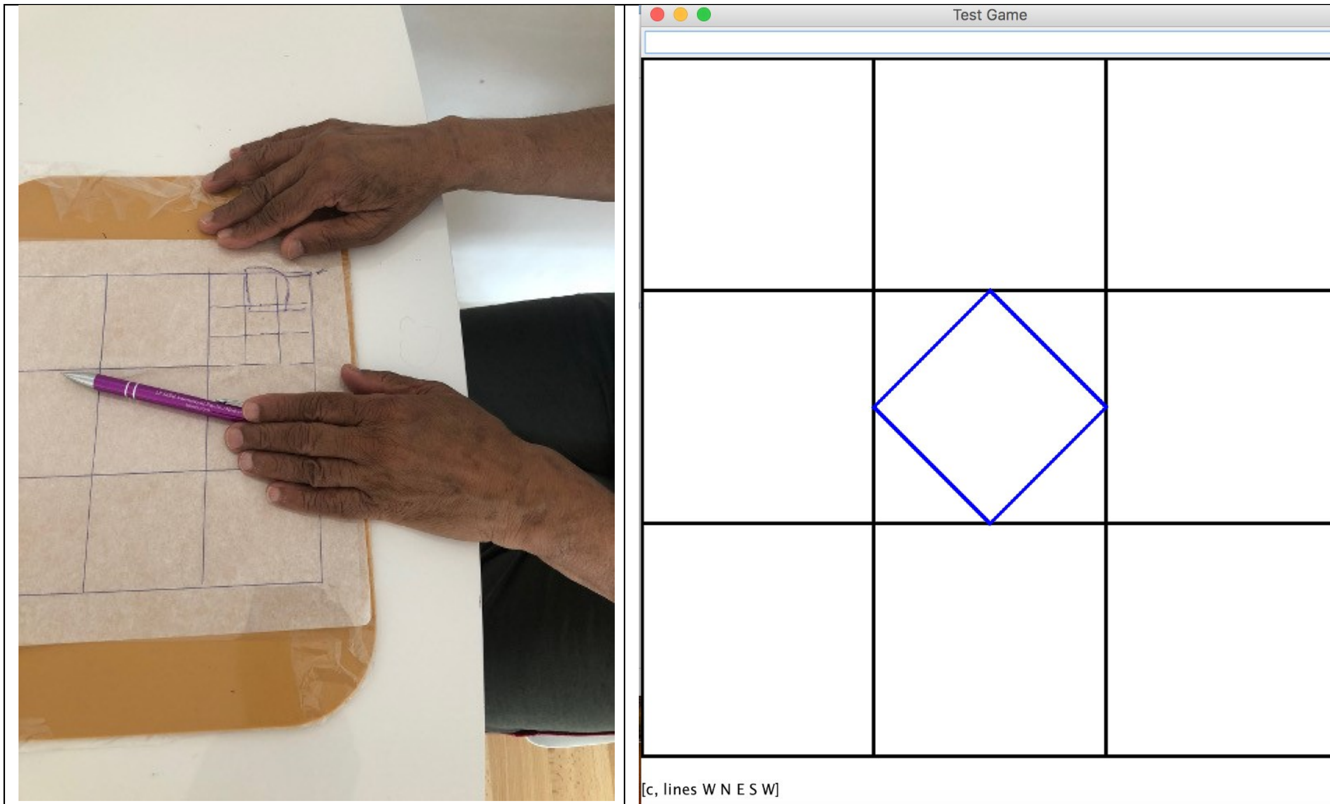

Figure 4: Rubber mat, Embossing Film Papers (RNIB, 2019) on the left and SETUP09 system on the right with a 2D shape (rhombus) on the screen location centre. System Commands for SETUP09 image: *[C, Lines W N E W]* User navigation to centre location and draw lines connecting West-North-East- and West point again.

The system SETUP09 prototype works on both Mac and Windows operating systems, a TTS (text-to-speech system) and Zuyfuse Heater with Zuyfuse papers to produce tactile images. To ensure higher accuracy in tactile image recognition, we created simple images with thick lines and sufficient space between shapes. The text was produced in braille letters and the English alphabet as required. The main program consists of a command language for navigation and drawing, written in Java and using class graphics such as java.awt.Graphics and java.awt.Graphics2D [Oracle, 2019] for shapes in image processing.

4.2 Hypotheses

H1: A compass-based graphics creation method is an effective drawing method compared with a tactile graphics creation method for creating shapes.

H2: A compass-based graphics creation method is an effective drawing method among both early and late blind individuals.

We designed three tasks to test H1 and H2: The three tasks are as follows: create a four-sided shape on the screen using any nine cardinal/compass reference points, create a given 2D cabinet on the screen of a specific size, and create a given flowchart on the screen. The early and late blind individuals then experimented with a paper drawing toolkit and the SETUP09 system. The first task was presented as a question/instruction, whereas tasks two and three were presented in swell-papers so that participants could feel them and understand the presented image.

We measured performance by an examination of the variations between different groups (early blind and late blind) and phases (activities). We gauged accuracy by giving a score, based on errors made during activities and time taken, including time for errors. Accuracy was rated by the ability to produce a given task. For task one, any four-sided shape anywhere on the screen or raised line-kit was counted as 100% accurate, whereas open shapes or crooked/curved lines were given a low percentage of accuracy by the observer. For tasks two and three accuracy was measured by the ability for them to complete the given shape. For example, 90% accuracy was given when participants produced the given/intended image with minor errors, such as drawing with distorted lines, non-completed shapes, or unwritten letters. 80% was given for incorrect sizes, shapes, wrong locations, and moderated levels of the incompleteness of lines and shapes both in the raised line-kit and the SETUP09 system. Time was recorded from the start of the system used until the end of a task.

5. Results and Discussion

We evaluated the results of the tasks by accuracy, errors made and other observations. The success was measured by the accuracy during tasks. Errors included the number of times a mistake was made on the interface as a result of forgetfulness of commands or misunderstandings as to what the task required. We also recorded the time spent on tasks. However, we realised that time taken is a difficult indication of achievement as not all quick attempts were correct.

During task one, the non-instructed production of a 2D shape, individuals spoke about the intended shape, location and size of their mental model prior to the activity that was recorded. The same shape was reproduced using the SETUP09 system. The IBM usability questionnaire with a seven-point Lickert scale was used to access participants' perception of system suitability, ease of use and cognition (Lewis, 1993).

Times were recorded for all three tasks using a stopwatch. Three blocks of two trials (paper drawing and system drawing) from eight participants for a total of (3x2x8) = 48 trials were recorded with accuracy, errors, time and other observations. Two attempts had to be redone due to confusion arising from the instructions, as requested by the participants themselves. One had to be repeated due to an inaccurate recording of the time. There was no difference in performance by gender. However, we observed that some participants were more thorough when following instructions than others.

Participants were tested with three designed tasks. An image of a cabinet and a data flow diagram were given to participants for drawing tasks two and three, whereas task one was simply to draw any four-sided shape on the screen using any nine cardinal/compass reference points therefore no image was given.

A possible four-sided shape is displayed in Figure 4, a 2D shape (rhombus) and the cabinet image is displayed in Figure 4 using the rubber mat toolkit, whereas the data flow diagram is in Figure 5. For example, one method to draw a cabinet in the South East location is: *[SE, C, lines NW NE E W, line W SW, line E SE]* [navigate to the Southeast, and navigate to the center of Southeast. Draw a rectangle with lines connecting four points, then draw left leg connecting two points and right leg connection another two point]

During task one, early blind participants were asked to draw a four-sided shape on the screen using any nine cardinal/compass reference points. They were then asked to repeat the same shape in the same area they selected on a plastic embossing film. The output was measured against their intended shape and given a score.

Figure 5 presents the output from the paper toolkit and SETUP09 by early blind individuals. Overall, there is not much of a considerable output difference compared to the previous output of early blind individuals, except early blind individuals took slightly longer than late blind individuals. The output produced by early and late blind individuals is in line with H1 (A compass-based graphics creation method is an effective drawing method compared with a tactile graphics creation method for creating shapes), which is further evidenced with statistics in the section 5.1- Accuracy, Errors and Time.

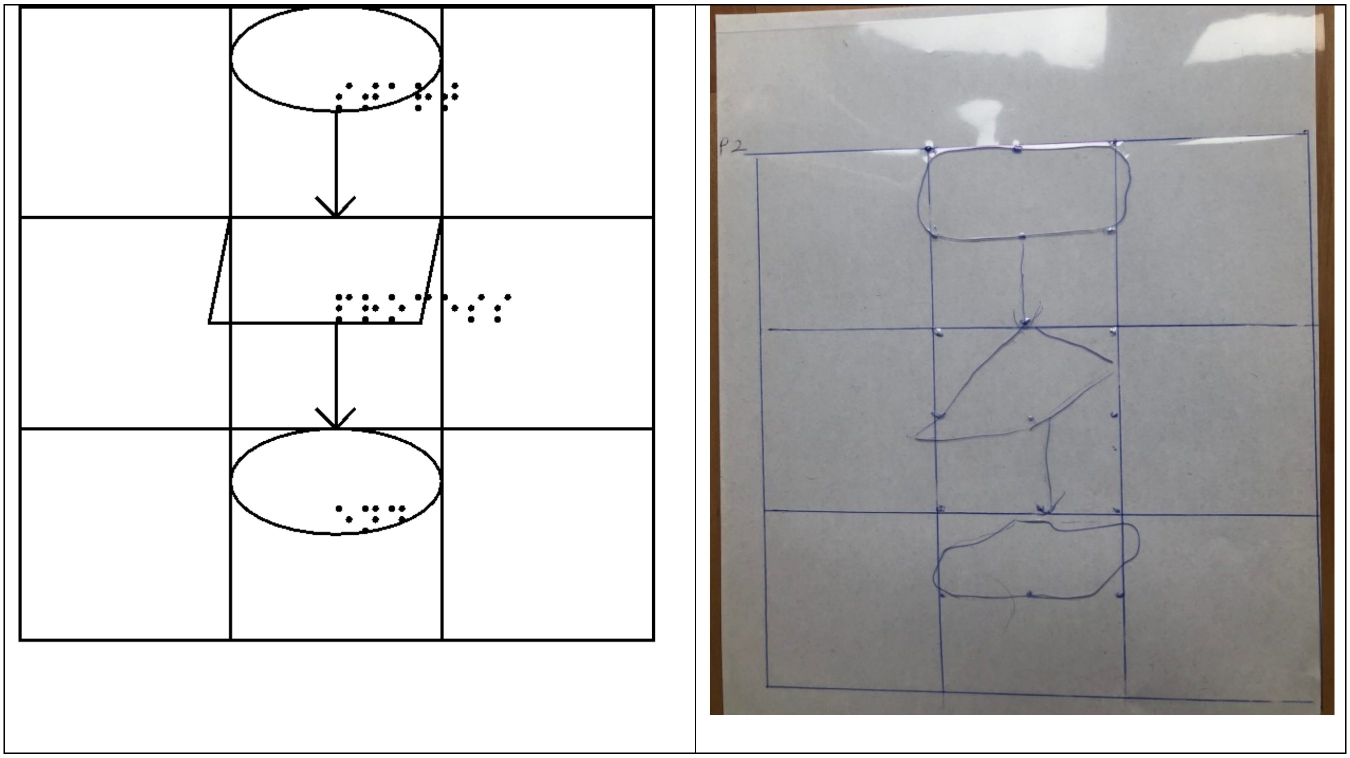

Figure 5: Image of a Data Flow Diagram by participants using SETUP09 system output on the left and paper toolkit on the right.

5.1 Accuracy, Errors and Time

As illustrated in the bar charts in Figures 6 and 7, blind individuals managed to complete non-instructed shape drawing, image (cabinet) drawing and flowchart drawing in the SETUP09 system with an average accuracy of 97% and with the standard deviation = 6. Accuracy was rated by the ability to produce a given task. The results showed that both early and late blind groups successfully completed the tasks using SETUP09 technique, evidencing H2 that a compass-based graphics creation method is an effective drawing method among early and late blind individuals.

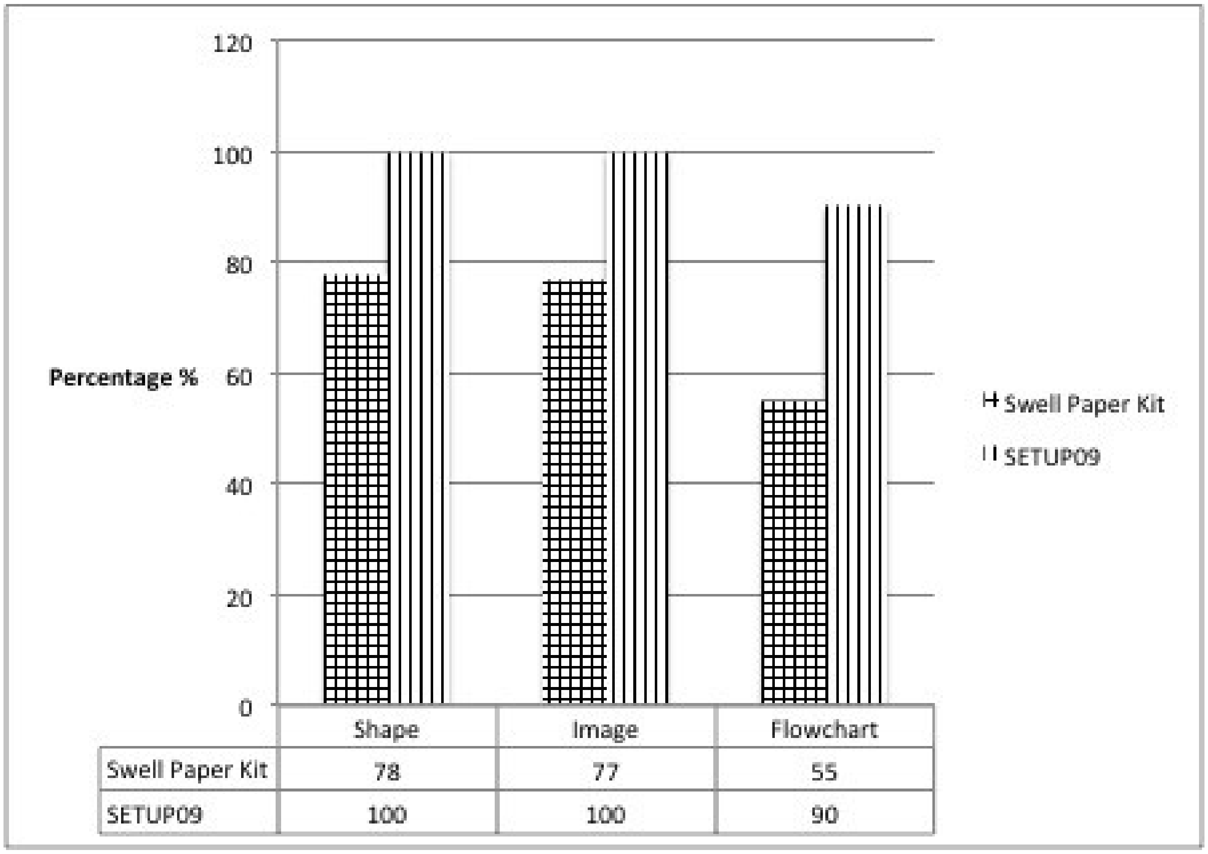

Figure 6: The Accuracy of Tasks using SETUP09 and Raised-line kit

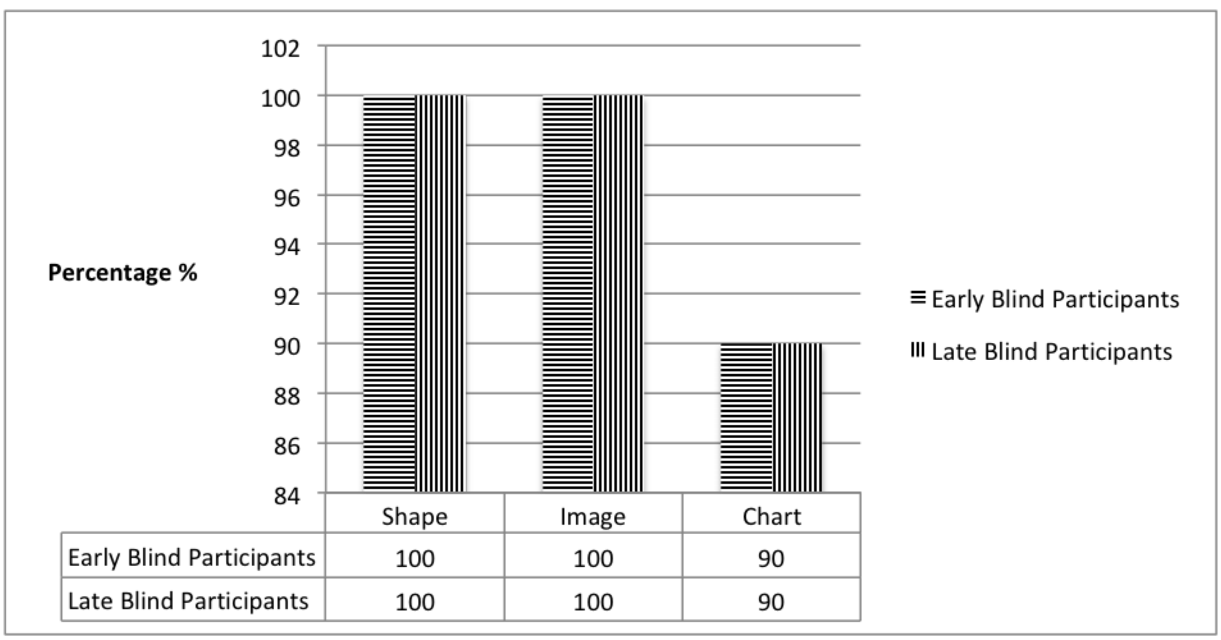

Figure 7: The accuracy of tasks of late and early blind individuals with SETUP09.

A few reported minor issues with the flowchart drawing activity, which ended up with some scoring slightly low. However the raised-line paper kit reported a considerable difference in average accuracy with 70% and standard Deviation = 13 in achieving the intended tasks. The early and late blind people performed equally well with the SETUP09 system tasks, recording mostly 100% accuracy. However, the late blind group performed slightly better than the early blind group in paper toolkit drawing but this was not statistically significant (P = 0.214).

Section Output Comparison illustrates the difference between the paper toolkit versus the SETUP09 system of the early blind group. The paper images might not have been successful at all if paper grids were not presented to support with landmarks and sizes. The difference in image accuracy between the two methods was statistically significant, with the P-value of 0.050 proving the hypothesis H1 that a compass-based graphics creation method is an effective drawing method compared with a tactile graphics creation method for creating shapes.

Errors during the experiments were recorded, such as incorrect shape, wrong location, wrong size and incomplete images. Overall 17 errors were recorded when using the SETUP09 system and 54 errors with paper drawing as illustrated in Figure 8. The late blind individuals made 35 errors overall, and early blind participants made 36 during the experiment. The SETUP09 system errors were corrected, but unfortunately paper kit errors were all visible and impacted on task accuracy.

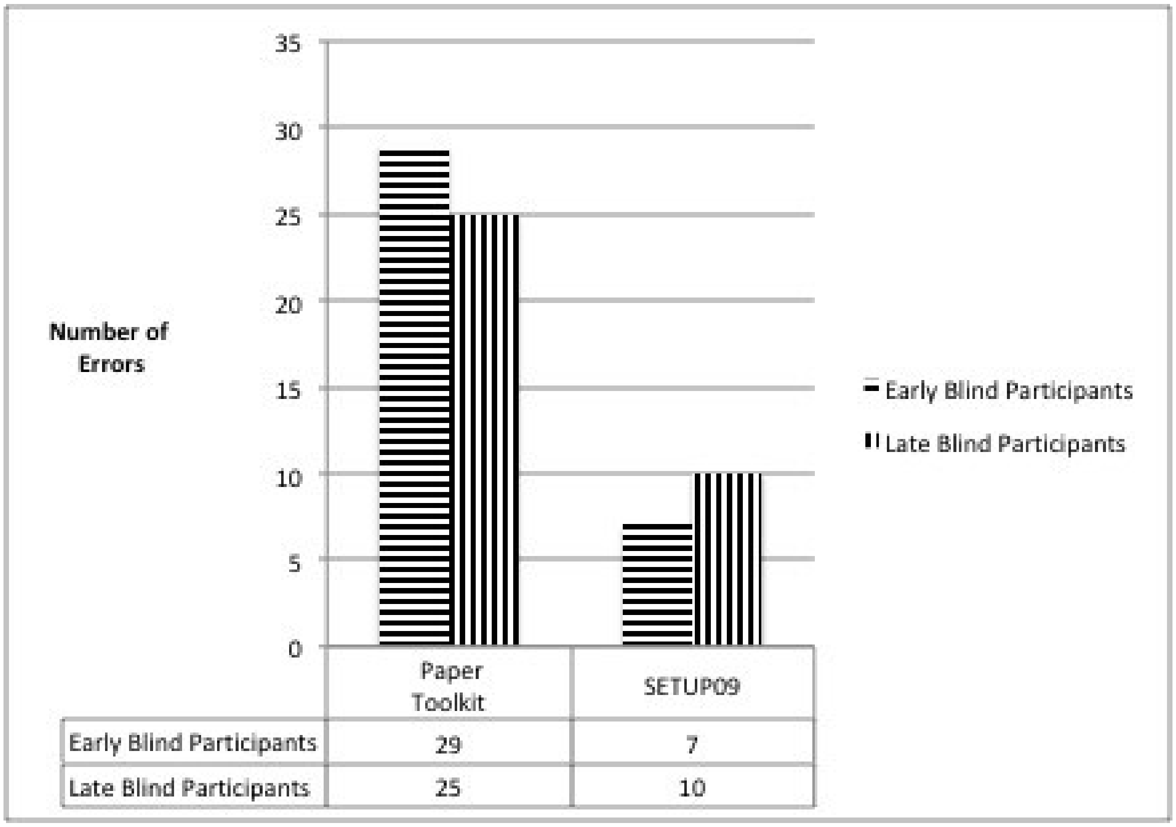

Figure 8: Errors between early blind participants with the raised-line kit and the SETUP09 system.

Participants were only given one amount (30 minutes) of system training before the test period. Therefore, the errors were mainly due to forgetting commands and focus screen area, and lack of prior system knowledge. However, errors were rectified using system commands such as erase, help, position and achieved successful outcomes (97%) as discussed in the system accuracy section.

Errors made during paper drawing activities were clearly visible on film papers, but unfortunately the participants were not aware of their errors. The nature of errors was different from SETUP09 errors. It was not about the forgetfulness of system commands but about incorrect reproduction of the intended drawing. The shapes, images and flowcharts produced on the paper were mostly incomplete with distorted lines, incorrect shapes, incorrect sizes, and variation in locations. Some participants were disoriented without sufficient landmarks such as start and end points of lines and found drawing flowcharts very difficult. Some participants knew that their drawings were not correct but did not know how to correct them. They clearly needed external help. Participants produced incorrect images and mentioned “This is what I think the image is in my mind”. The mistakes were obvious to the observer and were clearly correlated with the accuracy of the task, as the error correction mechanism was not available with the paper toolkit system so errors were left uncorrected.

Performance was measured on time taken by examining shapes, locations and sizes. The SETUP09 system recorded more extended time in all three drawing tasks than the raised-line kit. The mean time taken to draw a shape, an image and a flowchart using SETUP09 was 2.42 (m:ss) with standard deviation equal to 2.34 with both groups. The mean time of the same activities using paper drawing was recorded as 1.34 (m:ss) and standard deviation equal to 1.47. The P-value recorded was P=0.541, and the difference was not statistically significant even though participants took a shorter amount of time in drawing with the raised-line kit. As illustrated in the section on output comparison, the late blind participants completed both paper kit drawing with (P = 0.875) and SETUP09 drawing with (P = 0.678), which was faster than early blind individuals even though there is no significant difference.

However, it is clear that the participants completed the paper drawing activity faster than when using SETUP09. Not only did the new system add operational time and require more learning and memory which impacted the outcome, but also extra time was added to cover functionalities such as error correction and system help. The valid question to ask is whether the extra time with SETUP09 is acceptable in the successful completion of tasks. Participants’ views were collected at the end to analyse the validity of extra time when using SETUP09.

Even though the paper drawing activities were completed faster, the accuracy was poor. The paper activity was therefore incorrectly completed, and in some cases the errors were known but were unable to be corrected and in other cases participants were not aware of their mistakes. Thus we only provide time differences to inform the completion time in relation to the paper drawing activity.

5.2 Findings of Post-experiment Survey

The post-experiment questionnaire reports Cronbach's alpha value as 0.90 of scale reliability with acceptable internal consistency, mean = 2 and SD = 0.99. All participants who completed all three tasks successfully also completed post-task questions. Five questions were posed at the end of the three tasks; level one signifies agreeing strongly with the questions asked, and level seven signifies disagreeing strongly.

(Q1) The SETUP09 technique is more effective than a film paper kit.

(Q2) The SETUP09 technique is easier to use than a film paper kit.

(Q3) The SETUP09 technique is more supportive than a film paper kit.

(Q4) The SETUP09 technique builds a better navigation model in the participant's mind than a film paper kit.

(Q5) The SETUP09 technique builds a better layout model in the participant's mind than a film paper kit.

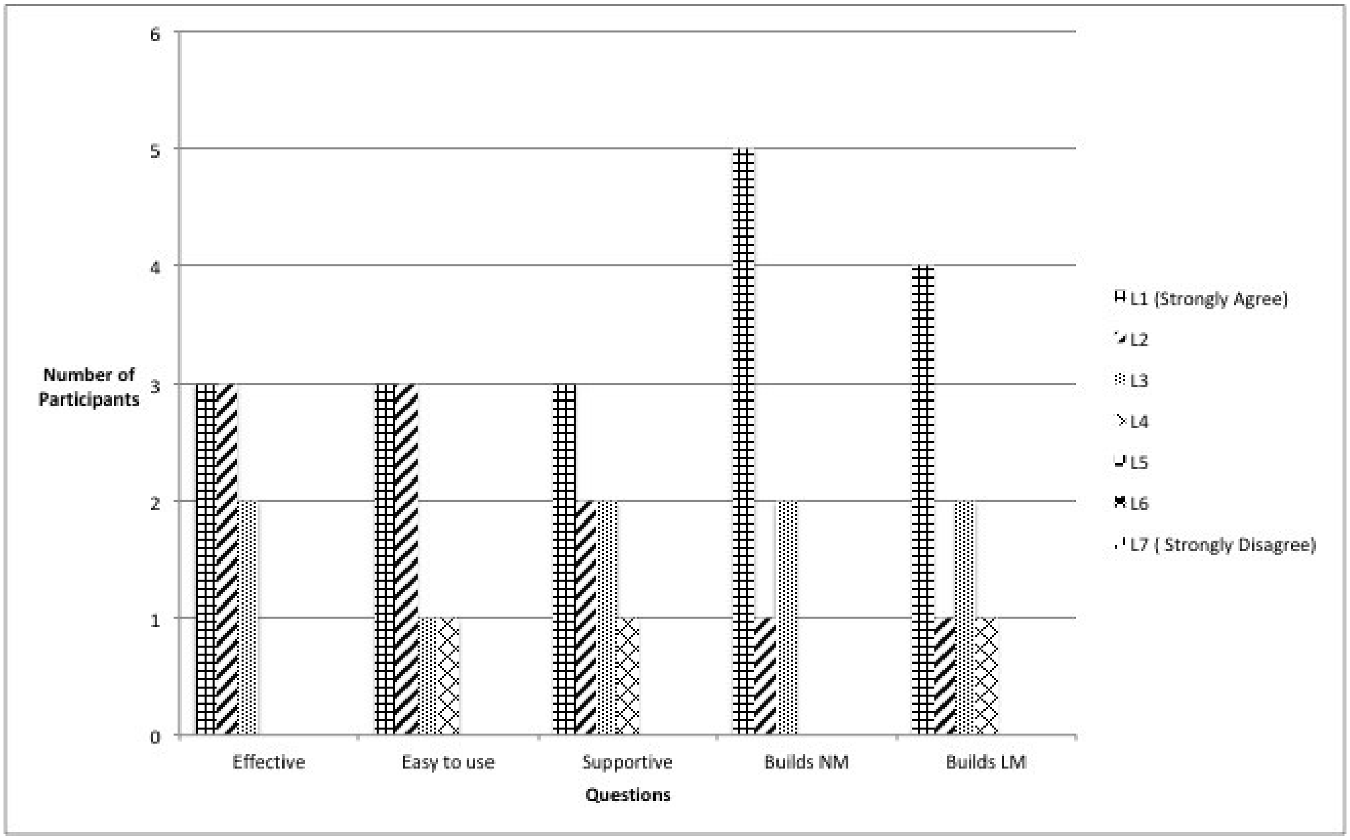

Figure 9: Post-Study Survey

The data in the Figure 9 bar chart demonstrates that participants who were early blind predominantly selected levels one and two of the Likert scale, whereas late blind participants thought the prototype could be further improved to accommodate late blindness, and therefore they predominantly picked levels two, three and four. The P-value of early and late blind individual groups is 0.015, which is $P < 0.05$ and demonstrates that there is a difference between the post-experiment feedback of the two groups (early blind versus late blind participants). Five out of eight participants strongly agreed that the SETUP09 technique is effective and the technique builds a good navigational model in participants' minds, and four out of eight participants strongly agreed that the SETUP09 technique is effective and the technique builds a good layout model in participants' minds by picking level two of the Likert scale.

Six out of eight participants agreed that the SETUP09 technique is effective and easy to use by picking levels one and two of the Likert scale. Participants repeatedly selected one to four of the Likert scale showing high positivity and suggestions for improvement.

5.3 User Feedback and Other Observations

Majority of participants thought that the system could be more supportive in terms of error detection, correction, input, and output functionalities. Participants suggested features, such as auto text correction, redo and undo options, and better system feedback for error correction as some potential improvements. Some participants suggested the system should have the facility to add an alternative text attribute to images, so that the system remembers and provides a full description of an image rather than simply the name of the shape or piece of art. Some participants didn't like smaller text; text with less space and braille text and many grid lines confused them during the recognition of shapes. Many participants agreed that enough time for system familiarisation is the key to using the system confidently and efficiently.

There was a suggestion that the system could be improved with changes to the system voice, by allowing the user to pick from multiple available sources or even recording a voice they like. Another suggestion was to implement different levels of system feedback. One level where there is limited automatic system feedback on user action, a second level where the system's default feedback confirms every user action, and another level where only the drawing is confirmed but not navigation actions. There could also be a level for expert users where the drawing is confirmed using a specific command rather than conformation for every user interaction.

We observed that late blind participants were better with drawing shapes and writing letters on a raised-line kit because they used the retained memory from a period when they had sight. However both late and early blind participants performed equally well with keyboard input commands to create art, meaning the retained memory did not disadvantage early blind participants, and both groups possessed equal visualization skills when producing art using the system. The experiment method of identifying the image using tactile modality, visualizing the art in their mind and reproducing images using sequential style keyboard commands produced promising results among both groups in spite of their unique condition.

6 Conclusions

An experiment was conducted to compare and evaluate the effectiveness of the SETUP09 drawing method compared with a tactile graphics creation method for creating shapes with early blind and late blind participants, in the absence of established digital drawing and navigation methods for BVI computer users to create graphics.

The SETUP09 system was driven by a set of commands to navigate and create shapes. The analogue and digital drawing methods' performance times were different, but not significantly so. The SETUP09 digital drawing technique was far more accurate in achieving the task, even though the analogue drawing time was shorter than the digital drawing time. Overall, late blind participants performed slightly better in terms of time than early blind participants, even though the difference was not statistically significant.

Participants made a higher number of errors while drawing on paper using the analogue method compared to the SETUP09 method, but they were unable to correct those errors, and in some cases the errors were not realised. The early blind individuals made fewer errors compared to the late blind individuals when using SETUP09, but the figure was not statistically significant. Our basic observation of SETUP09 is that it is an effective drawing technique, compared with an analogue graphics creation method, for creating images with early and late blind participants that helps to navigate on the screen, produce art and achieve tasks.

The results demonstrate that the SETUP09 navigation and drawing technique is not only effective among early blind participants, but also among late blind participants by evidencing better performance compared with early blind people. Late and early blind individuals were both in favour of the future possibility of speech input and a real-time tactile feedback mechanism.

The SETUP09 system recorded 97% accuracy in completing a task, whereas the analogue paper toolkit recorded 70% accuracy with lots of helpful landmarks such as grids and points. Some participants did not like to draw using the raised-line kit at all as they found it was very difficult and did not enjoy the process. Drawing was not something they readily did without external help or system help. However, participants were thorough, and they closely followed instructions and performed well in all drawing activities.

In support of H1 and H2, the results confirmed that the SETUP09 system supports blind participants better in completing a drawing task compared to the use of an analogue drawing toolkit. The SETUP09 system recorded a successful task completion rate of 97%. Almost all SETUP09 drawing activities were completed with an average time of 2.42 (m:ss), including the diagram-drawing task. Six out of eight participants strongly agreed that the system technique was easy to use, and built a navigation model. Early blind participants demonstrated identical performance to late blind participants when using SETUP09, with task completion but slightly low number of errors in all of the assigned tasks. But the figure was not statistically significant. Task completion was a success for blind individuals in the context of the lack of availability of a digital blind drawing system and they had never before attempted to use any other digital drawing tool for academic or general purposes. All BVI participants were highly determined to achieve the given tasks, irrespective of time considerations and demonstrated their drive and motivation to manipulate graphics independently without any help from a support worker.

Overall, our results confirmed that the SETUP09 2D drawing and navigation technique is reliable and effective, and facilitates the reproduction of a given task better than a film paper drawing kit. This research suggests the need for a digital system to help blind individuals with completing 2D art and diagram production in the STEM field, and also haptic technology for on-screen validation would improve the efficiency of scientific and non-scientific drawing in future.

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