**A Computer Aided Drawing System Evaluation With Early And Late Blind Users**

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**Abstract**

The present lack of suitable and efficient graphics creation technique may place limitations on career progression and life contentment of blind students. It is challenging for a BVI person to draw diagrams or art, which are commonly taught in education or used in industry. SETUP09 graphics creation system was developed to address blind users' need to be able to create such content. SETUP09 method enables graphics manipulation through a natural language and intuitive movement to a screen location using matrix-style compass directions with graphics creation capabilities. The SETUP09 system consists of both navigation and a computer aided drawing technique for the people who are blind. The technique can facilitate user's ability to produce art, and scientific diagrams electronically. This paper presents a comparative system evaluation of digital (SETUP09) versus analogue drawing technique 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 with SETUP09 system. The results confirmed that the SETUP09 compass-based graphics creation technique facilitates higher accuracy in completing a drawing task with a noticeable reduction in effort compared to analogue drawing technique.

## 1. Background

Kurze explained that the most important characteristic of a picture is not it's 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 of real world images and interaction between those shapes to form meaning. The meaning of such image can be perceived by different modality such as haptic, speech or sound. The perception of blind people is based on the process of fitting sensory perceived information from the environment to an existing internal idea, the mental image. According to (Kurniawan et al., 2003) mental models are internal abstract models of users that have information of 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 today technology. Most BVI students and practitioners are in the habit of using tactile maps to recognise highlight 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 exists, this technology needs further improvement with complex and dynamic art production (Williams et al., 2014).

Analogue drawing systems established in the past are commonly used but do not provide 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], Swai Dot Inverter[4], Quick Draw Paper[5] and, Sewell EZ Write N Draw Raise Line Drawing Kit (MaxiAids, 2019). These products include rubber mat, drawing board pens, light and portable, emboss capability, inexpensive that requires some good motor skills to do the freehand drawing. Most analogue systems lack support with drawing objects, stepwise interaction such as changing properties, protection form critical functions such as delete, a frame of references such as grids, labelling, error correction, copy-paste, saving, help and the list can be more.

There are several digital systems introduced in the past such as (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 defined set of system shapes and the drawing and layout models is 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 reuse functionalities, limited availability of systems, modalities, and lack 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.

Early blind, late blind individuals 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 compared with early blind individuals; thus, their coping strategies are different as pointed 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 mirrors window's environment coping strategies discussed by Kurniawan (Kurniawan et al., 2003). Kurniawan investigated blind users metal/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 model perceive the desktop environment as strict columns and rows. Users with functional metal model 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 computer environment. (Saei et al., 2010). Not only the variations of the coping strategies among blind and sighted individuals were clear but also some difference demonstrated in mental imagery depend on the modality they channel as discussed by Albert Postma (Postma et al., 2008).

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 $\mathbf{N}^{2}$ chart. However, the system does not keep track of layout information of 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 domain of use 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.

The system technique (SETUP09) introduced in this research uses a command-line language that converts text to screen navigation and 2D art production. The technique uses a compass based location navigation technique with multi-points cell referencing system to draw shapes and arts. The following section contains the procedure and comparison outcome of different techniques and also groups of blind individuals.

## 2. Methodology

We evaluate 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 early and late blind. Participants from different age groups and different education levels were appointed. This experiment presents a systematic evaluation of the analogue method that is famously used in special needs education establishments versus 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 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, where four of them were late blind individuals and others four were blind from birth and further information is given in table

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, images; labeling and defining an image.

The analogue toolkit consists 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 1 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' conception of the tactile view.

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

*3.1 Introduction to the Analogue System and Digital System (SETUP09)*

Figure 1:Rubber mat, Embossing Film Papers (RNIB, 2019) and the screen layout of SETUP09 system on the right

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. 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 drawing by calling its commands. The commands enable it to produce art. The formal detail specification is not discussed in this paper. Using SETUP09 prototype, users can enter one or many commands at the user prompt to manipulate an image. Figure 2 demonstrates pictures of a rhombus, 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: arc [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 2: Art produced by SETUP09 System: a rhombus shape graphic creation on the screen location Centre calling Centre points, the right image shows graphics creation on the screen location East using system keyboard keys and shortcut keys to input system commands that is generated on the picture

*3.1 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: a four-sided shape on the screen using any nine cardinal/compass reference points, a given 2D cabinet on the screen and to a specific size and a given flowchart on the screen. The early and late blind individuals then experimented with a paper toolkit drawing kit and the SETUP09 system.

We measure performance by an examination of the variations between different groups and (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. Time was recorded from the start of the system used until the end of a task.

**3. Results and Discussion**

We evaluated the results of the experiment tasks by accuracy, errors made and other observations. The achievement of a given task measures the accuracy during tasks. The errors counted with a number of times a mistaken made on the interface as a result of forgetfulness of commands or incorrect mental perception to what is presented on the task. We also recorded the time spent on tasks. However, we realised that it is a difficult indication of achievement as not all quick attempts were correct.

Participants were tested individually, and experiments were conducted in different locations at different times. A percentage score was given for the actual drawings to measure accuracy. 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, and unwritten letters. 80% was given with incorrect sizes, shapes and moderated levels of the incompleteness of lines and shapes.

During task one, non-instructed production of 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 SETUP09 system. The IBM usability questionnaire with a seven-point 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 (paper drawing and system drawing) of two trials from eight participants for a total of (3x2x8) = 48 trials were recorded with accuracy, errors time and other observation. Two attempts had to be redone due to the confusion of instruction, and it was as requested by participants themselves. One erroneously trails due to the incorrect time needed repeating. There was no difference in performance by gender. However, we observed that some participants were thorough when following instruction than the others.

Participants were tested with three designed tasks. An image of a cabinet and Data flow diagram images were given to participants for two and three drawing tasks whereas task one was not instructed but to draw a four-sided shape on the screen using any nine cardinal/compass reference points therefore no image was given.

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 measure against their intended shape and given a score.

Figures 3 presents the output of paper toolkit and SETUP09 by early blind individuals. Overall, there is not much of a considerable output difference comparing 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 are inline of H1 (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 results section.

Figure 3: Image of a Data Flow Diagram by participants using paper toolkit on the right and SETUP09 system output on the left.

### *3.1 Accuracy, Errors and Time*

Figure 4: The Accuracy of Tasks of SETUP09 and Swell Paper Kit

As illustrated in figure 4,5 bar charts Blind individuals managed to complete non-instructed shape drawing, image (cabinet) drawing and flowchart drawing in SETUP09 system with 97% of average accuracy and with the standard deviation = 6. The results evidenced that both early and late blind groups evidencing H2 successfully completed SETUP09 technique that compass-based graphics creation method is an effective drawing method among early and late blind individuals.

Figure 5: The accuracy of task of late and early blind individuals with SETUP09.

A few reported minor issues with flowchart drawing activity and ended up scoring slightly low. However Swell Paper Kit reported with considerable difference in average accuracy with 70% and standard Deviation = 13 in achieving intended tasks. The early and late blind people performed equally well with 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 not statistically significant (P = 0.214).

Section Output Comparison; illustrate the difference in paper toolkit versus SETUP09 system of early blind group, which is very similar to the output of late 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 of image accuracy between the two methods was statistically significant, with the P-value of 0.050 proving the hypothesis H1 that compass-based graphics creation method is an effective drawing method compared with a tactile graphics creation method for creating shapes.

The 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 6. 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 tasks errors were all visible and impacted with accuracy.

Figure 6: Errors between early blind participants with paper toolkit and 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 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 endpoints 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 those were clearly correlated with the accuracy of the task as the error correction mechanism was not available with paper toolkit system, so errors were left uncorrected.

Performance was measured on time taken by examining shapes, locations and sizes. The SETUP09 system was recorded with more extended time in all three drawing tasks than swell paper 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 with 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 paper 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 SETUP09. Not only had the new system operational time and learning memory had impacted the outcome but also extra time was added to cover functionalities such as error correction and system help. The valid question to interrogate 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.

### *3.2 Findings of Post-experiment Survey*

The post SETUP09 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. Level 1 signifies agreeing strongly, and Level 7 signifies disagreeing strongly with questions asked. Five questions were posed at the end of the three tasks.

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

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

(Q3) The SETUP09 technique is supportive than 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 7: Post Study survey

As illustrated in the Figure 7 bar chart, levels one and the majority of participants with the exception of the late blind individual predominantly selected two. Participants suggested features such as auto text correction redo and undo options and better system feedback for error correction as some potential improvements. Five out of eight participants strongly agreed that the SETUP 09 technique is effective and the technique builds a good navigational model in participants' minds, and four out of eight participants strongly agreed that the SETUP 09 technique is effective and the technique builds a good layout model in participants' minds by picking Levels 1of the Likert scale.

Six out of eight participants agreed that the SETUP09 technique is SETUP09 technique is effective and easy to use by picking L1 and L2 of the Likert scale. Participants repeatedly selected 1 to 4 of the Likert scale showing high positivity and suggestions for improvement. However, the majority of participants thought that the system could be more supportive in terms of error detection, correction, input and output functionalities.

The data demonstrates that participants who were early blind predominantly selected Levels 1 and 2 of the Likert scale, whereas late blind participant thought the prototype could be further improved to accommodate late blindness; therefore they predominantly picked 2, 3 and 4. 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 feedbacks of the two groups (early blind versus late blind participants). 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 confidence and efficiency.

**4 Conclusions**

An experiment was conducted to compare and evaluate the effectiveness of 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 method's performance times were different, but that did not reach significance. 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. 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 high number of errors while drawing on paper/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 late blind individuals made fewer numbers of errors compared to the early blind individuals, but the figure was not statistically significant. Our basic observation of SETUP09 is that it is an effective drawing technique compared with an analogue drawing graphics creation method for creating images with early blind and late blind participants that helps to achieve tasks, to navigate on the screen and produce art.

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% of accuracy in completing a task whereas the analogue paper toolkit recorded 70% accuracy with lots of helpful landmarks such as grids and points. However early and late blind individuals both scored identical levels of accuracy for all three tasks with SETUP09, and the late blind participants scored a slightly higher level of accuracy with drawing paper kit method. Some participants did not like to draw using swell paper toolkit at all as they found it was very difficult and did not enjoy the drawing. 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. SETUP09 system recorded with 97% with enabling successful task completion. 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 competitive and similar performance compared to late blind participants when using SETUP09 with high accuracy, completion, and fewer errors in all of the assigned tasks. 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 a digital drawing tool for academic or general purposes. All BVI participants were highly determined to achieve the given tasks irrespective of time considerations. Overall, BVI participants 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 film paper drawing kit. This research suggests the need for system help with completing art; shapes are necessary to help blind individuals with diagram production in the STEM field, and also a haptic technology for on-screen validation would improve the efficiency of scientific and non-scientific drawing in future.

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