An Empirical Evaluation of a Screen Navigation and Graphics Manipulation Technique for Blind and Visually impaired Individuals

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The representation of pictorial data by partially sighted and BVI (Blind and Visually Impaired) people has gathered momentum with research and development, however little research has focused on the use of screen layout to provide BVI users with spatial orientation to create and reuse graphics. This paper contributes an approach to navigating on the screen, manipulate computer graphics and user-defined images. The formal specification described in this paper enables features such as zooming, grouping and drawing by calling primitive and user-defined shapes. It enables blind people to engage and experience drawing and art production on their own. It is easy to learn, efficient and takes less time to complete. An empirical evaluation was conducted to validate the suitability of SETUP09 technique and to evaluate the accuracy, efficiency of the navigation and drawing techniques proposed. The experiment results confirmed high accuracy and competency with both sighted and BVI users. The BVI participants managed to successfully complete the drawing tasks with an average of 2.16 (m:s) without the help of a support worker.

CCS Concepts: Human-centered computing → Accessibility technologies;

Additional Key Words and Phrases: Blind Drawing, Diagram Drawing for Blind and Visually Impaired Users, Screen Navigation for Blind and Visually Impaired People, Formal specification of a Drawing tool, Image Perception, Sensory Substitution

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1 INTRODUCTION

The potential of drawing for blind people has been experimented on [E. Ricciardi 2009; Ishihara et al. 2006; Kamel and Landay 2000, 2002; Lambert et al. 2004] in the past. This work has gathered new momentum with 3D printing [Williams et al. 2014], Hyperbraille [Leo et al. 2016], haptic, speech technologies [Zhang et al. 2017] and sonification [Walker and Mauney 2010]. Research shows that most blind learners often 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 the guidance from a sighted person and would not even make an attempt. Hence,
expressing pictorial thinking for blind users through computers is limited. Subsequently, the need
for self-reliant blind drawing techniques and technology has been recognised and highly valued
among blind communities. Most people do not recognise the need for spatial information and
image drawing for Blind and Visually impaired (BVI) individuals. Our work does not address the
uncertainty but instead leverages the fact that matrix navigation systems enables the recognition
of location and image drawing. We focus on screen navigation and space arrangement that easily
facilitates drawing for BVI users.

Lack of drawing technologies is a roadblock for students who are blind and visually impaired
in the fields of Science, Technology, Engineering and Mathematics (STEM). The idea is to devise
a drawing technology for BVI people as a value-adding feature of learning and life in general.
Consider the question of how BVI students draw diagrams during classroom activities. Furthermore,
consider interactions which would be difficult if they have to draw on their own. Some of the
difficulties that fall in to this category include: completing a simple task quickly - a BVI computer
user may take much longer, making the drawing experience inefficient; navigating on the screen in
relation to start and end points, as blind computer users may not be able to orientate their mouse
movements; backtracking to the original point or remembering the start point; relating the size of
the art on the screen to other images on the screen; re-using previously created art that employs
repeated patterns, such as diagram drawing; creating a floor plan, as there is no way to differentiate
between regions on the screen and art on those areas. We propose an approach to overcome this
impediment by enabling BVI people to draw pictures and diagrams by a computer-aided drawing
technique which uses a middle-tier language to navigate on the screen and manipulate graphics,
dividing the screen into nine recognisable areas using a compass-based location recognition system.
The proposed system (SETUP09) demonstrated in Figure 1 is divided into locations based on compass
directions: north, south, east, west, north-west, north-east, south-east and south-west. This kind of
screen division can be easily comprehended by blind people and enables easy navigation back and
forth to different areas and zoom levels. Commands are extracted sequentially and verified as they
are read. The scope of this drawing technology, we argue, comprises an open language, input and
output interfaces to accommodate the diverse needs of blind users.

Most systems previously designed for blind drawing [Blenkhorn and Evans 1998; Calder et al.
2007; Kamel and Landay 2002; Petrie et al. 2002] extract information and display it in objects and
associations with sequential style communication using built-in command buttons. For example, a
drawing should enable the user to memorise a floor plan, easily navigate, relocate and backtrack
to the original point, and memorise the object arrangement. This minimises the processing of
information and the presence of a redundancy effect (redundancy refers to the repetition of content
in different formats), be easy to learn and easy to use, and take less time to complete a task [Hersh
et al. 2008]. The challenge is to develop technologies that are effective and easy to use in producing
graphics for the different needs of BVI people’s day-to-day lives. The research here is targeted to
respond to the difficulties of such a technology by producing a language that is consistent and
expandable in producing different art, and that supports the communication of floor plan and
navigation details to the BVI user effectively.

The research report here aims to respond to the above shortcomings by introducing a formal
language, input/output mechanisms and validation mechanisms to accommodate navigation and
drawing for BVI people. This contributes to overcoming the limitation of drawing due to the absence
of visual modality; it helps to draw scientific diagrams during classroom activities; it accommodates
graphics presentation and visualisation of imaginative thinking such as art in general; it contributes
to the image presentation of blind image processing; and sighted people could benefit using the
techniques when structuring images on non-visual surfaces.
This study investigates compass and compass-based location tracking approaches together with interactive friction gaming communication styles [games Ltd 2014] to develop the user’s concept of drawing. SETUP09 system demonstrated in Figure 1. This method of drawing does not need the help of a support worker, does not take an enormous amount of time to complete a task and is not expensive to use. The method is intuitive, interactive and easy to learn, and has functions for error detection. The approach taken to draw an image is a compass-based Interactive Friction (IF)[games Ltd 2014] style. Several studies [Kamel and Landay 2002; Zhu and Feng 2010] have introduced grids for easy navigation and finding places on maps accurately in an unknown environment. Game technologies such as IF (Interactive Friction)[games Ltd 2014] are purely based on text and command languages for user input tracking, voice feedback and sonification for interaction and a screen compass for object searches. IF gaming technology has been popular among blind game players for decades. This paper proposes a platform-independent method to construct an image using a set of grammar that is expandable.

The experiment was conducted to evaluate the suitability of command driven drawing technique and virtual navigation system. The system was tested with BVI and blind-folded participants in the absence of established drawing and navigation method for visually impaired people. Our evaluation of SETUP09 suggests that BVI participants are able to use this navigation and drawing technique with similar accuracy and competency as sighted participants. 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 SETUP09 system. However the degree of efficiency varies between participants groups. Hence we have discussed the implication and guidance for further research.

This paper is structured as follows. In Section 1 we give a general overview of navigation and drawing technologies. In section 2 we explain the proposed system SETUP09 and set out an interaction to middle tier language. In section 4 we discuss the experiment and results. We present our conclusion in section 5.

2 LITERATURE REVIEW
This section compares and constrasts different screen navigation and drawing techniques.

2.1 Interface Navigation Techniques
Screen navigation could be a time consuming activity for BVI individuals. Multimodal techniques are proven to be more effective when using a keyboard, stylus, or speech (Suhm et al., 2001), but this is not always viable. Hands-free speech-based solutions can allow faster and more robust experiences that traditional keyboards cannot [Sears et al. 2001].

Several navigation mechanisms were previously introduced to navigate text documents. Speech-based easy access to graphical interfaces was introduced by de Mauro [de Mauro et al. 2001] using a voice-controlled mouse. Subsequently direction-based navigation techniques manifested a discrete or continuous cursor movements. For example, in discrete direction-based cursor movements a “move left two words”command causes the cursor to find the new location by jumping two words left. Discrete direction-based commands can also be set as inches, centimetres, or letters on the screen. Continuous direction-based navigation primarily trigged by speech inputs for start and stop commands. For example, “move right ”moves the cursor to the right until the “stop”command is given. Since the cursor can move horizontally or vertically, such continuous cursor movements to a diagonal location is associated with higher error rates. Screen distance traversed has impacted
on selection time and errors. There is an additional complexity: with increased distance, the cursor travelled too far before the “stop” command was executed. [Sears et al. 2001].

MaNair and Waibel [Menair and A.Waibel 1994] have investigated and introduced an early version of target-based speech navigation, as well as immersed speech-based navigation on web documents. A user says a word that serves as a link to other web pages or menus or by saying a number that eventually takes them to another link. With target-based navigation, a speech command “Select Friday” in the text document can directly navigate to the word Friday. It also can be set to navigate to icons, menus, and regions on the screen. Even though this resulted in a minimum number of errors, it has a longer task completion time. There is also a difficulty with the higher number of similar possible targets and the user needing to know required targets in the document.

Grid-based navigation method was first studied by Kamal [Kamel and Landay 2002] and fine tuning and magnification research was studied by Feng and Zhu ([Zhu and Feng 2010]. The grid-based navigation system manoeuvres to an area on the screen without contextual information, using 3*3 matrix system navigation techniques. The formation of a nine-cell system works well with the intuition of BVI individuals as it organised in a similar layout to a telephone keypad. The cell numbers work from left to right and top to bottom. The system enables users to move to and from any of the nine cells. The unique point of a cell is the centre point, which is then selected to perform drawing. Different palette selection tools such as shape, type, colour and commands for saving support the main functionalities of drawing. Each palette provides nine choices where a user is able to navigate by selecting the palette options. A grid recursive schema allows users to make more precise selections. Users can find a unique position by further dividing into nine more cells and increasing zoom levels. Users can label the object for identification.

This paper introduces compass-based screen navigation, similar to Kamal’s grid-based method [Kamel and Landay 2002]. Compass based navigation is a new concept implemented with a formal language specification that is discussed in the next chapter.

2.2 Art/Diagram Manipulation Techniques

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 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 [B.Y.Rita 2004]. Even though tactile images and 3D printing exists, this technology needs further improvement with complex and dynamic art production [Williams et al. 2014].

Kamel and Landay [H. M. Kamel 2001; Kamel and Landay 2000, 2002] have have also introduced IC2D products that divide the screen into nine navigable smaller workspaces. IC2D product has palettes for users to select shapes, types and colours. In order to make more precise selections, each of the nine cells is then divided into a further nine cells, which in turn are divided into nine more cells. Annotations are given for meaningful semantics so that the user can build an accurate mental image. The IC2D interface relies on keyboard inputs and provides auditory feedback using a voice synthesiser. The main focus of IC2D drawing is to enable blind users to pick a cursor point on the screen that enables navigation from one point to the next point on the screen. The formulation of the 3x3 grid-based system works well with intended blind users’intuition. The arrangement of 3x3 is based on the numbers of a telephone keypad that blind users are familiar with and enables them to move to and from any of the nine cells as follows. Keyboard keys act as directional keys such as
Screen Navigation and Computer Graphics Manipulation Technique

up, down, left, and right. Also the numbers act as cell locations. The unique point of reference of a cell is the centre point, which is then selected to perform drawing. The main functionalities of drawing are supported by different palettes such as shape type, colour and file commands. Each palette provides nine options where users navigate using the same grid-based system. Hence keyboard keys can be used to operate these palette. Using grid recursive schema, it allows users to make more precise selections. Users can find their positions by further dividing into nine more cells and it goes up to two additional levels. IC2D also helps blind users to label their drawing by its shape and hierarchy to recognise them later. IC2D is very helpful in navigating and finding screen information and palette information without the help of a sighted user. The simplicity of keyboard input and synthetic voice output is helpful in learning and developing this technology. It is cost-effective and efficient. However, the system limits the shapes and colours to its colour palette and the system has no mention of making connections from one zoom level to another. This can limit the picture a user can draw. There are similarities between IC2D and the system we introduce (SETUP09). One of the main similarities is the grid-based navigation system. Keyboard and voice output are the main input and output sources of both systems, thus SETUP09 is not limited by those. However, SETUP09 uses compass direction-based navigation, where IC2D uses telephone keypad-based navigation. But they both represent 3x3 grids on the screen. When using IC2D the user recognises the top left cell as grid number one and SETUP09 recognises the top left cell as the north-west cell. SETUP09 has eliminated the limitation of a palette system and designed a compiler language for the drawing. Using the SETUP09 blind drawing language the user can define new drawings, reuse them in different locations and zoom levels, use primitive shapes and make connections to and from different zoom levels, labelling and linking objects as they wish. SETUP09 system not only have grids reference point but also multiple(9) compass points on a grid. Those cursor points enables the production of more sophisticated drawings by linking points on the same zoom level or different zoom levels.

System “Kevin” [Blenkhorn and Evans 1998] enables users to read, edit and create diagrams using an \(N^2\) chart. This system does not keep track of screen layout information but retrains the mandatory information needed for a simple DFD diagram. It has all the facilities of a typical case tool. For example, transformations of a DFD are located on the main diagonal of an N2 chart, leaving connections are written in the same row and entering connections are written in the same column. This is a talking tactile diagram and it has a tactile layer. Different speech messages are delivered as the user moves around the DFD. System Kevin has a data exchange facility through the standard CASE data exchange format, which means the system can read diagrams created by other case tools, however the system does not keep track of layout information of the diagram, so when it is imported to another tool transformation and connection must be moved. SETUP09 is designed specifically for retaining layout information, through techniques such as zoomin, navigation, and grouping, by marking absolute and relative positions.

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. This study displays diagrams, graphs and relational information to users who are blind. Given a drawn graph, the system uses auditory cues to help a blind user traverse the graph. The user can select the data structure to animate its operations, as the user steps through the algorithm for the operation and observes how each step affects the data structure. The system provides both graphical interfaces for sighted users and the PLUMB interface for blind users. The system uses synthesised speech to announce the selections and operations. When the user selects “insert node” a new node is inserted into the existing link list, which is then acknowledged to the user. Users can navigate forward and backward to explore the state change. The system uses GXL XML files to read and save information and this is a portable
format to modify and create data structures in a variety of different editors. The system explores vertex and edge at a given time. The intensity and the tone of musical sounds dictate the distance to vertices and distances of edges. With the keyboard activation system more details of vertex and edge are given. But no information is conveyed about the shape of the layout of the graph. The system also has pen mode, which requires a tablet PC. The application generates audio clues when the user moves the stylus over an element of the graph. But the system has no clear indication of layout information or shapes.

The main focus of the TeDUB system [Petrie et al. 2002] is that it focuses on importing images or diagrams in their visual form in a way that blind people understand. This is an automated interpretation and accessible presentation of technical diagrams for blind people. The TeDUB system was developed according to COTIS (Confederation of Transcribe Information Services) guidelines taking non-visual navigation of information space and verbal descriptions of diagrams into consideration. The images in formats such as BMP, PNG, JPEG and GIF first go through an image analysis process, identifying their related text. Then the system recognises basic geometric primitives such as lines, arcs and text regions. The second stage involves knowledge processing which interprets the image by network hypotheses. This stage could have the involvement of a sighted person, as the stage is error prone when identifying important image components. Some UML images can be encoded and fed into XML format to TeDUB, which makes it easier to be read by the system without error. The system also keeps track of the knowledge of its previous images to interpret new SVG (scalable vector graphics). The system uses synthesised speech and braille display to communicate the image to the user. Keyboards and joysticks facilitate system functions. The TeDUB system suggests that it could be improved with a numerical keypad for navigation, whereas SETUP09 is already using a compass-based keypad for navigation, which was developed similar to when Kamel and Landay [Kamel and Landay 2000] introduced a numerical keypad model. The TeDUB system is mainly focused on importing and analysing existing diagrams, whereas SETUP09 demonstrates a drawing of a diagram. SETUP09 is not designed to analyse images from other systems. However, SETUP09 retrieves its own images by executing a set of concrete commands. Therefore, the information analysis stage of an image would not be necessary, and finding the semantic meaning of diagrams or images is not necessary either. Blind users could interpret the image by 3D printing, image verbalisers or via braille.

We introduce compass-based navigation and drawing system, which is similar to Kamal’s matrix system. It is recorded that the user spends a considerable portion of time navigating the screen from one location to another within the document they create when using a navigation system such as hands-free or speech-based [Sears et al. 2002]. The cells are not identified by numbers but compass directions such as north, south, east, west, north-west, north-east, south-east and south-west. Compass-based navigation also has nine unique points in a cell rather than one centre unique point as in the grid-based navigation system. The system is named “SETUP09”. The system has drawing capability by user direct command input unlike the palette options in the grid-based navigation system for example: “zoomin centre”, or “zoomin north”. Drawing commands are either pre-defined or user-defined, and they also can be used later by simply calling its label. Speech input mechanism is one of many interfaces for input selections such as a keyboard, speech and braille. The experiment was conducted to evaluate the suitability of a command driven drawing technique and virtual navigation system with visually impaired and blind folded participants in the absence of established drawing and navigation method. This article proposes and validates a systematic technique to support screen navigation and shapes manipulation, driven by a set of compiler tokens.
3 INTRODUCTION TO SETUP09

Figure 1 demonstrates the screen division in a 3*3 grid system using symmetric locations. This is based on compass directions such as north, south, east, west, north-east, north-west, south-east and south-west. It also has the centre region named centre. Each region / location has nine points such as north, south, east, west, centre, north-west, north-east, south-east and south-west.

3.1 Navigation Path

Figure 2 demonstrates the compass grid visualisation of the navigation path for the intended navigation location which is the south centre of the east location.
3.2 Architectural Assumption

We assume that the open middle tier language for the navigation and drawing specification is a system loosely coupled with input devices. Examples of some input devices are: braille, microphone and keyboard; and examples of some output devices are: HyperBraille, raised-line printing, 3D printing and a screen output / screen reader.

Broadly speaking the work of the data-flow diagram is as follows. The main interaction class captures input from the user through interface classes. And the command specification is then passed to the tokeniser where the commands are broken down into tokens. Command specification may be as simple as a string or complex as a sequence of strings, which are sent for validation. Tokens are validated to match language syntax through parser function. Validated command specification then calls formal syntax that is written based on abstract syntax. Command specification should match up with formal syntax classes. If matching syntaxes are found, the drawing is performed using the interpret function of each formal class upon user command request [Apple 2002].

Command specification has a set of keywords. Conceptually a keyword could be a variable, system shape, user-defined shape, location on the screen, or point on the screen that is designed using the compass-based directions. This is further explained in Section Backus-Naur Form (BNF) grammar.

It is assumed that tokens can be personalised to match different languages, vocabulary, grammar and order. Therefore, the command specifications can vary according to user need. Different input and output interfaces can be plugged in to the main interaction class to improve personalisation of the drawing activity.

3.3 The Design of the Compiler

A programming language needs a compiler to design its core syntax and semantics [Apple 2002] in order that the programmer / user can write their programmes by calling syntax and semantics.
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 syntax. The syntax or the commands enable it to produce art.

Users can enter one or many commands at the user prompt to manipulate an image. This is referred to as a Statement or StatementList. The grammar can be improved by adding many more commands such as save, delete, undo, redo, erase, import, export, etc. For the purpose of this paper only some commands are discussed.

- To get the focus of an area of a screen: \texttt{Zoomin} [name of the area]
- To extract the focus out of an area: \texttt{Zoomout}
- Users can directly call library objects by their primitive names, such as circle, rectangle, etc
- A line can be manipulated by calling it: \texttt{line [point1] [point2]}
- An arc can be manipulated by calling it: \texttt{arc [point1] [point2] [angle]}
- 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

The formal language is designed mapping BNF grammar into several concrete classes by extending an abstract class [Apple 2002; Oracle and its affiliates 2015]. The abstract class is written to validate a single user command specification. The abstract class also has an interpret method for drawing the specification. The interpret method reads the current state of the system, performs the drawing and
sends back the modified state. The system state is maintained in an object name “state” demonstrated in Figure 3 illustrated using a class diagram. “StatementList” concrete class reads a sequence of commands and executes one command at a time. Therefore, users are able to input more than one command at the user prompt. “Define” concrete class reads user commands and defines a shape for a sequence of commands. System State object keeps track of the system state at any given time. Some of the attributes that consist of a state object are x co-ordinate, y co-ordinate, zoom size, zoom level, zoom location, image buffer and variable locations. Current system state is read before a new user specification and a new state is created as a result of user command execution.

3.4 Language Grammar from BNF (Backus-Naur Form)

The grammar below is demonstrated in Backus-Naur Form describing formal notation for encoding grammar intended for the blind drawing language in the Figure 4. This grammar shows the basic user inputs that are created by a java compiler, designed for the purpose of this paper [Apple 2002; Blackburn et al. 2006].

**System commands in BNF**

```
<StatementList> ::= <AbstractStatement> | <AbstractStatement>, < StatementList >
<AbstractStatement> ::= <zoomout> | <zoomin> | <line> | <assign> | <write> | <arc> | <shape> | <call> | <define> |<nullStatement>
<call> ::= 'call' <name>
<define> ::= 'define', <name>, < StatementList >
<zoomout> ::= 'zoomout'
<zoomin> ::= 'zoomin' <Location>
<assign> ::= <variable> = '<point>
<write> ::= 'write' <point> < variable >
<location> ::= N|S|E|W|NE|NW|SE|SW|C
<point> ::= N|S|E|W|NE|NW|SE|SW|C
<angle> ::= L|R|T|B
<shape> ::= circle|triangle|box
<variable> ::= String|integer
<name> ::= String
```

Fig. 4. Language Grammar from BNF.

The main syntax is broken down to terminals and non-terminals. Locations are direction on the screen where N is for north, S is for south, E is for east, W is for west, NE for north-east, NW for north-west, SE for south-east, SW for south-west, and C for centre. These are also called terminals which cannot be replaced with anything else. Each location has nine points, namely N for north, S
for south, E for east, W for west, NE for north-east, NW for north-west, SE for south-east, SW for south-west, and C for centre. Angles are to draw arcs: L is for left angle, R is for right angle, T is for top angle and B is for bottom angle. Geometric shapes are called from J2D library e.g. circle, triangle, and line. Non-terminal are variables that can be replaced and are not final. A variable can be a string or an integer and object names are strings. Examples of syntax classes are: call, define, zoomin, zoomout, write, Line and Arc. AbstractStatement is the main syntax statements of the program and StatementList consists of sequences of AbstractStatements that need resolving one at a time. The introduced grammar is open for expansion.

### 3.5 System Architecture

The architecture of SETUP09 is partitioned into back-end and front-end components. Given the user specification, a set of tokens is generated; lexical analysis, syntactic analysis and semantic analysis are performed as demonstrated in Figure 5. The front-end components are responsible for executing the user commands by calling JDK, libraries of Java toolkit, 2D / 3D library functions containing art [Oracle and its affiliates 2015]. Front-end components are also responsible for reading user specification / commands from diverse input devices such as microphone, braille and keyboard; they rewrite the commands into compiler recognisable format. Front-end components are also responsible for displaying the image for user verification using 2D braille and displaying the verified image output using 3D printing, raised line printing, 2D Braille or image verbaliser.

![Fig. 5. Compiler Components.](image)

### 3.6 Example Drawings

The following subsection describes the implementation of the processes of lexical analysis, syntactic analysis and semantic analysis of a user command by an example of drawing a stickman and a house. The parser has been implemented using Java [Oracle and its affiliates 2015].

The process of lexical analysis has been implemented as a function tokeniser. The function tokeniser takes input from the user and produces an output of a stream of space separated tokens. Figure 6, Figure 7 illustrate with examples of the use of the function tokeniser. Navigation commands such as Zoomin and Zoomout are also implemented using hot keys.
3.7 E.g. 1. Given the input specification / commands for a Stickman

```
define Stickman
zoomin N
circle
zoomout
zoomin C
line N C
line C SW
line C SE
line NW NE
```

Fig. 6. System output of the Stickman.

3.8 E.g. 2. Given the input specification / commands for a house

```
define House
zoomin C
line N W
line W E
line E N
line W SW
line SW SE
line SE E
```
4 EXPERIMENT AND EVALUATION

4.1 Method

The experiment was conducted to evaluate the suitability of command driven drawing technique and virtual navigation system. The system was tested with BVI and sighted participants in the absence of established drawing and navigation method for visually impaired people. An experiment was designed and conducted in a single session study with 20 participants. A previous pilot study of SETUP09 navigation revealed that blind computer users were able to successfully navigate to screen locations without the help of a support worker. This study evaluates more participants and experiment on both drawing and navigation method. Drawing methods such as simple shapes, images and diagrams could result in high efficiency if the technique is rehearsed for a while.

This study includes three tasks, the first of which is instructed drawing with 3 different drawing activities. The second task involved non-instructed drawing with another 2 activities with user-defined shapes and images. Final tasks assessed the users’ comprehension of system-produced shapes, images and diagrams. In designing the study tasks, our goal was to make each activity as realistic as possible while conducting a control performance experiment with sighted participants. The experiment designs underlines many of our previous observation decisions, such as to have a thorough training session of concept training with compass directions, its navigation and command language to manipulate shapes on the screen.

Participants were collected via contacting different charities that serves people with blindness or visual impairment. The experiment was designed to analyse sighted and BVI user performance variation and similarities. Some discussion is based on the level of blindness and age. Participants from different age groups and different levels of visual impairment were appointed. Ten sighted participants with an average age of 29.4 years and the standard deviation of 11.03, ages ranging from 12-40 years, which was 4 male and 6 female. Ten BVI participants were appointed whom 4 were completely blind and others predominantly diagnosed with Microphthalmia and Coloboma. All 10 BVI participants were registered blind and with an average age of 22 years old (5 males and 5 females) with standard deviation of 12.81 and age ranging from 7-49 years. Computer
literacy ranges from moderate to high. Computer literacy was measured by participants' confidence using computers at work, confidence using a keyboard, and confidence using word processing applications.

4.2 Apparatus

The custom experimental system consists of a Mac and Windows operating system, Intel Iris graphics 6100, 1536 MB, 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 enough space between shapes. The main compiler consists of a formal language for navigation and drawing, written in java and used a 2D library for image processing. The compiler has set of tokens for screen navigation and art manipulation. The tokens call abstract and concrete class methods for operations. Hence the user is able to see cursor movements and drawings on the interface by passing correct tokens. SETUP09 language is more of a navigation and art manipulation language on its own. For this experiment, prototype functions are as follows: (1) uses hot key and keyboard input (2) navigate to a specific location on the screen (3) display shapes when manipulated (4) save and label images (5) send images to printer and heater output for tactile images. Swell papers were used during the experiment to print haptic images for image recognitions tasks. Swell paper is a special kind of paper upon which images and art can be printed or sketched and turned in to tactile images or letters. It can be used with a marker pen, printer or photocopier to create images. When the paper is subjected to thermal treatment the dark areas create raised relief lines.

4.3 Procedure

This experiment has 20 participants, 10 VI participants, and 10 sighted participants. We presented each participant with three tasks to complete and measured their performances. Each participant had roughly 30 minutes of training on the system. The training was split across three experimental tasks and includes: introduction to SETUP09 and drawing and navigation language; familiarity with SETUP09 hotkeys and help keys; Hands-on practice using the prototype and different drawing commands; steps to draw simple shapes, images and to draw in different zoom levels, locations; labelling and defining an image. The user interface was hidden from sighted participants during the training. Sighted participants were blindfolded during image recognition activities and given 10 minutes of system introduction. If they needed assistant during the experiment, they were referred to the help menu. Participants were able to read the screen labels and seek system help with orientations to memories and build a layout map of the interface and complete instructed and non-instructed drawing task. Audio feedback was provided with help commands. Very few tasks were misunderstood and allowed to be retaken. Blind individuals needed more guidance and explanation than partially-sighted individual. Some participants were unable to name the diagram during the image recognition stage due to unfamiliarity with scientific diagrams. But they were able to identify shapes, letters, and direction details on the interface, which in later stage we called partial recognition. However blind individual performed with confidence when the concept and system commands were clearly understood. We used participants' performance, task feedback and usability questionnaire to decide on the suitability, ease of use and effectiveness of SETUP09 system.

4.4 Task 01: Instructed drawing

This was divided into three parts. We gave participants printed swell papers containing shapes of triangles on multiple screen locations, one inside the other and multiple zoom sizes. We then asked
participants to draw the given simple shapes using SETUP09 exactly as it was on the swell papers. Then we printed their produced output using swell papers to compare the original and produced drawings. Upon completion we asked them to describe the whole picture. The second part of this task was to give an image (e.g. house) on a swell printed-paper. We then asked participants to draw the given image using SETUP09 exactly as presented on the swell paper. The third part of this task was to give a system-produced DFD (Data Flow Diagram) on printed swell paper. We then asked participants to draw the given image using SETUP09 exactly as they feel it on the paper. The purpose of Task 01 was to find out the participants’ ability to reproduce system images with accurate recognition of shapes, locations, and sizes.

4.5 Task 02: Non-instructed drawing
This was divided into two parts. We asked participants to imagine a shape on selected screen location with a selected zoom size of their own choice. We asked them to describe the whole picture. We then recorded their mental image as they explained before they produced the imagined shape using SETUP09. It was printed after the end of each task using swell papers to compare it with the original idea. At the end of the task we recorded the accuracy of the user produced image based on prior recording. The second part of this task was that they produce a simple image of their choice using different shapes. We recorded their mental image prior to the task and compared the system-produced image after the task. The purpose of task 02 was to find out the participants’ ability to produce non-guided shapes with accuracy and efficiency.

4.6 Task 03: Image recognition
In the final task we presented participants with three system-produced images and diagrams. E.g. a table, a pet or a flowchart. We gave one image at a time on swell papers asking them to explore and verbally describe the images. The purpose of task 03 was to find out the accuracy of participants’ metal model of system-produced art and spatial representation of screen images.

4.7 Final Experiment design
The drawing and navigation study consist of instructed drawing, non-instructed drawing and image recognition activities with each user group as subject factors (sighted and BVI) task phase as a within-subject factor (instructed, non-instructed, recognition). The study uses SETUP09 prototype and system-produced swell images for all three tasks and its activities. Grid based navigation proved to be highly effective according to the experiment conducted by GUESS system and IC2D [H. M. Kamel 2001; Kamel and Landay 2000, 2002] system proved that grid-based drawing is user friendly and effective. We derived the following hypothesis:

- H1: SETUP09 2D drawing technique is an efficient drawing technique to draw images for BVI individuals
- H2: SETUP09 2D drawing technique produces accurate mental images as conceived by BVI individuals
- H3: SETUP09 2D system-produced tactile images are accurately perceived by BVI individuals

4.8 Performance measure and data analysis
We evaluated the results of the experiment tasks by task completion time, errors made and other observations. The accuracy is measured by achievement of a given task during the instructed-drawing task phase (task 01); accuracy of the non-instructed drawing phase (task 02) was measured...
H1 hypothesis (SETUP09 2D drawing technique produces accurate mental images as conceived by BVI individuals) was measured by instructed drawing (task 1 activities) accessing participants’ ability to efficiently complete a given task within a reasonable time.

H2 hypothesis (SETUP09 2D drawing technique produces accurate mental images of a BVI person’s mind) was measured by the non-instructed drawing (task 2 activities) accessing participants’ ability to efficiently complete an intended drawing task against recorded drawing.

H3 hypothesis (SETUP09 2D system-produced tactile images are accurately perceived by BVI individuals) was measured by the image recognition task (task 3 activities) accessing participants’ ability to efficiently recognise system-produced images.

The computer screen was hidden from the sighted participants during instructed drawing and non-instructed drawing task, sighted participants were blindfolded during image recognition activities in order to eliminate the advantage of vision accuracy. However, during non-instructed drawing, some sighted individuals sketched the imagined shapes/art on paper, taking notes of their mental model prior to the activity and then visually evaluated the output of their drawing at the end of the activity. Whereas BVI individuals spoke about shapes, location and size of their mental model prior to the activity that was recorded at the beginning and then the system printed swell images were used to crosscheck their art against the original idea. A score was given for the actual and intended drawings. The IBM usability questionnaire with seven-point scale was used to access participants perception of system suitability, ease of use and cognition. We assume that visually impaired participants were advantaged against completely blind participants due to some sight of lines and shapes which blind individuals did not have. Not all participants were familiar with the diagram recognition task due to not having prior knowledge of scientific diagrams. (e.g. flowchart, DFD). We assume with long-term system training the recorded times and errors could be twice as minimised in everyday use of SETUP09 navigation and drawing.

4.9 Data Analysis

Times were recorded for all three tasks using a stopwatch. We collected data from 20 participants. First task had 3 activities, the second task had 2 activities and task 3 had 3 activities each. 2 blocks of 9 trials and 1 block of 6 trials were collected from 20 participants for a total of (20*9*2) + (20*6) = 480 trials were recorded with accuracy, errors and efficiency. 6 attempts had to be redone due to confusion of instruction and it was as requested by participants themselves. 4 erroneously recorded trails were needed repeating. There was no difference in the performance by gender, however we observed that younger participants were much faster than older participants in both the control and experiment group.

4.10 Results

For all three tasks, Instructed drawing, non-instructed drawing and image recognition, we cover performance with examining the variations between different groups (experiment, control), phases (activities) and also visual acuity (partially blind, totally blind).

We have taken full performance time length which includes time taken for errors. Time was recorded from the time of the start of the system use until the end of a task. This measure is impacted by familiarity with the keypad, keyboard typing speed, memory of the system commands and speed of system feedback voice output messages.
4.11 Instructed drawing: task 01

The performance was measured on time taken, errors made and output accuracy by examining shapes, locations and sizes.

4.11.1 Time taken to complete a task 01 activities. Figure 10 strip chart demonstrates the range of times taken to draw instructed drawing images. The average time taken to draw a Diagram=5.19, SD =2.43 m:s; the mean the taken to draw an image=1.52, SD=1.10 m:s; and the mean time taken to draw a shape=0.56, SD=0.54 m: s . Some participants have taken longer than others, especially BVI participants reported higher variation of data based on their confidence and ability. Figure 10 illustrates the variation of data among different cohorts.

The average completion time of a shape-drawing task by BVI was 0.82s (SD=0.69s) and sighted was 0.31s (SD=0.11s). We found P value=0.046. The average completion time of an image-drawing task by BVI was 2.13s (SD=1.19s) and sighted was 0.92s (SD=0.58s). We found P value=0.012. The average completion time of a diagram-drawing task by BVI was 6.63s (SD=2.24s) and sighted was...
3.76s (SD=1.71s). We found $P$ value=0.005. The completion time difference between groups was statistically significant.

**Errors of Task 01 Trials**

![Bar chart showing errors made during Task 01 activities by BVI and sighted participants.]

Fig. 11. Errors made during task 01 activities by BVI and sighted participants.

Figure 11 visualises the errors made during Task 01, instructed drawing. Overall 15 errors were made where 8 errors out of 30 trials from the control (sighted) group and 7 errors out of 30 trials were from the experiment group. Errors were mainly due to forgetting commands and lack of prior system prior use knowledge. Figure 11 bar plot informs that the BVI participants are rigorous with their system learning and vigilant with system use. Sighted participants made 73% trials without errors and BVI participants made 76% trials without errors.

**Accuracy of Task 01 Trials**

![Bar chart showing accuracy of Task 01 activities by BVI and sighted participants.]

Fig. 12. Accuracy of task 01 activities by BVI and sighted participants.

Figure 12 demonstrates the accuracy of Task 01, instructed drawing. Accuracy was defined by the absolute difference between the produced shapes by participants and the given shape. We recorded accuracy into four categories. We recorded 100% accuracy for producing a given image with no difference; 90% accuracy for producing a given image with 1-2 errors; 80% accuracy for producing the given image with 3-4 errors; and 0% for not producing the image. We had two BVI individual
who failed to produce the given diagram due to their unfamiliarity with diagram drawings. Those two participants were below the age of 14. The plot bar demonstrates that the experiment group (BVI) shows close competence with control group when producing accurate images and majority of BVI participants (23/30 trials) completed images with 100% accuracy compared with (25/30) sighted participants. Accuracy was highly correlated with the difficulty of the task.

4.11.2 Finding of Task 01. BVI participants accurately produced the given shapes (shape, diagram and image) with 76% accuracy consuming less than a minute of average time to produce a given shape. Activity 03: diagram drawing activity reported to consume longer time (mean=5.19 m:s) as it was challenging due to multiple navigation steps across the screen, manipulation of multiple shapes in different zoom levels and from different starting points. Accuracy was defined by the absolute difference between the produced shape produced by participants and the given shape.

Supporting H1, errors made, accuracy and completion time were taken as indicators of the efficiency of the system. The above data demonstrates that sighted participants were the faster performers of instructed drawing. However BVI individuals were nearly as competent as sighted participants looking at accuracy of produced images and errors made. BVI users reported longer time to complete tasks than sighted participants due to multiple factors showing limited confidence, limited ability and limited computer use. We believe that SETUP09 improves the efficacy of academic and non-academic drawing activities especially of BVI users as opposed to not having access to such software at all.

4.12 Non-Instructed drawing: task 02
The performance was measure on time taken, errors made, output accuracy by examining shapes, locations and size. Participants were asked to draw a shape and an image of their choice with out giving any instruction. Their initial ideas were recorded to check accuracy of the task.

Figure 14 strip chart demonstrate the range of times taken for non-instructed drawings. Participants produced different types of images such as in 13 images of a stickman and a table are two examples. The average time taken to draw a shape of BVI users were mean=0.23, SD=0.38 m:s comparing to sighted users were recorded with the mean=0.37 and SD =0.38 m:s. The difference was not statistically significant during non-instructed shape drawing. The average completion time of an image-drawing task by BVI was 2.063s (SD=0.65 m: s) and sighted users reported the mean of 1.68 and SD=0.70 m:s the difference of two groups were not statistically significant. Overall BVI
participants performed statistically more closer to their sighted counterparts when instructions were not given.

Figure 15 visualises the errors made during Task 02, non-instructed drawing. Overall 9 errors were made where 5 errors out of 20 trials from the control (sighted) group and 4 errors out of 20 trials from Experiment group. Errors were mainly due to forgetting of commands and lack of prior system knowledge. Figure 7 bar plot informs that the BVI participant were more rigorous with their system learning and vigilant with system use. Sighted participants made 75% trials without errors and BVI participants made 80% trials without errors.

Figure 16 demonstrates that both sighted and BVI participants completed the planned/recorded drawing and stayed with the task until completion. Participants clearly enjoyed drawing shapes and images of their choice more than following instructions. They also had more practice of the system from task 01. There was a considerable difference between time taken drawing an instructed shape (mean=0.56 m:s) and a non-instructed shape (mean=0.23 m:s).

4.12.1 Finding of Task 02. BVI participants were asked to produced a shape and an image of their choice. They produced shapes and images with 100% accuracy with an average of 1.14 (m:s) whereas mean value of 1.02 (m:s) was recorded with sighted participants. The difference of two groups were not statistically significant. Accuracy was defined by the absolute difference between the shape produced by participants and their conceived shape at the start of the activity.
Supporting H2, accuracy and errors made were taken as indicators of SETUP09 system ability to build accurate mental images as conceived by BVI individuals. The above data demonstrates that sighted participants were the leading performers when it comes to speed of completion. However both groups reported 100% accuracy of manipulating their conceived mental images using SETUP09. In fact BVI participants (20%) has made less errors compared to their sighted (25%) counterpart.

4.13 Image recognition: task 03

The performance was measured on time taken to recognise and recognition accuracy by examining shapes, locations and sizes.
The average recognition time taken to recognise a shape task by BVI was 0.65s (SD=0.76s) and sighted was 0.44s (SD=0.25s). We found P value=0.43 between different groups. The average recognition time of an image recognition task by BVI was 0.76s (SD=0.53s) and sighted was 0.45s (SD=0.56s). The difference between groups was not statistically significant. We found P value=0.22 between groups. The average recognition time taken to recognise a diagram task by BVI was 2.14s (SD=0.87s) and sighted was 1.04s (SD=0.88s). We found P value=0.012. BVI participants were more efficient in identifying shapes and images than identifying diagrams produced by the system. The main reason being the unfamiliarity with Flowcharts and complexity of multiple shapes. Most BVI participants have never attempted to study or draw flowcharts due to the complexity of visual details. However most BVI participants managed to recognise individual shapes with high accuracy.

"Full Rec" symbolises participants’ ability to recognise all shapes and recognising the name of the image where "All Shapes Rec" symbolises participants ability to recognise all shapes without naming the image. "Some Shape Rec" symbolises participants ability to recognise some shapes presented in the image. The accuracy of 76% reported with full image recognition among BVI participants where as sighted participants reported with 90% accuracy. Overall only 20% trials were reported with only some shapes recognition. The differences in results were mainly due to the unfamiliarity of the conception of flowchart diagrams and limitation of knowledge due to age difference.

4.13.1 Finding of Task 03. Both groups recognised most of the art and shapes presented. BVI and sighted participants fully recognised system-produced shapes, images and diagrams with 76% accuracy and therefore no one was left with great difficulty. A few trials (20%) were made with partial recognition that was mainly the diagrams recognition activity. Overall they were taken less than a minute of average time to recognise a given shape and slightly longer time to recognise a diagram. Recognitions of diagrams were challenging due to the need knowledge of the concept of flowchart and multiple shapes on the screen. This knowledge can easily be gained by learning about flowcharts and use of flowchart tactile diagrams.

Supporting H3, accuracy and number of errors were taken as indicators to measure the ability to perceive system-produced tactile images. The above data demonstrates that sighted participants were the leading performers when it comes to time consumption. However both groups reported
over 76% of full recognition of system produced images. In fact all BVI and sighted participants continually recognised most image shapes (80%) of the presented image.

4.14 Drawing with and without a system

![Triangle on raised line paper](image1.png)  ![Triangle using SETUP09](image2.png)

Fig. 20. Draws of a triangle shape with and without a system

![Square on raised line paper](image3.png)  ![Square using SETUP09](image4.png)

Fig. 21. Draws of a square shape with and without a system

Figure 20 and 21 demonstrate totally blind individuals attempt to complete shapes of triangle and square. Blind participants used a marker pen on swell papers to draw the exact same shape (a triangle and a square). The time taken to complete the drawing by hand is comparatively less than using the system. However, it was evidenced that the images were not complete and less accurate.

4.15 The post SETUP09 questionnaire

The post SETUP09 questionnaire is reporting, alpha value as 0.74 of scale reliability with acceptable internal consistency, coefficient of reliability= -0.741, mean= 2.8 and SD=3.6. All participants who completed all 3 tasks successfully also completed post SETUP09 task questions. Level 1 signifies agreeing strongly and Level 7 signifies disagreeing strongly to questions asked. Five questions were posed at the end of 3 tasks. We asked all participants to give ratings for the five different
Subjective Data analysis of participants’ answers to post study questions

Figure 22: Subjective Data analysis of participants’ answers to post study questions

(a) A Survey plot of sighted group
(b) A Survey plot of BVI group

Figure 23: Subjective Data analysis of BVI and Sighted participants’ answers to post study questions

aspect of system SETUP09. (1) SETUP09 builds a Layout model in the participant’s mind (2) SETUP09 builds a navigation model in participant’s mind (3) SETUP09 is easy to use (4) SETUP09 is efficient (5) SETUP09 is supportive. Level 1 and two are repeatedly selected by majority of the participants throughout the questionnaire except the question about the supportiveness of the system. Participants suggested features such as auto text correction redo, undo options and better system feedback for error correction as some potential improvements. Both BVI and sighted participants picked similar ranks on above-mentioned five questions. The data suggests a slightly higher number of BVI users (12%) agreeing with system efficiency and ease of use than sighted participants (9%) where sighted participants were more keen on system supportive functionalities. However both user groups similarly agreed on system’s ability to build a navigation and layout model.

4.16 Discussion

An experiment was conducted to evaluate suitability of a command-driven drawing technique and virtual navigation system with BVI and blind-folded participants in the absence of established drawing and navigation methods for BVI computer users. The system SETUP09 was driven by set of compiler tokens for navigation and shapes manipulation. Tasks of instructed drawing, non-instructed drawing and image recognition were given to be performed using the SETUP09 system at the start. The performance of the participants improved significantly between learning and test stages. The results demonstrate that SETUP09 navigation and drawing technique is not only efficient among blind participants but also far more efficient among sighted participants. BVI participants took mean time of 1.47 (m: s) to draw a shape/image where sighted participants took mean time of 1.14 (m: s). Although we expected to see improved performance times of BVI individuals, it was evidenced that the low level of confidence, slowness of learning, low levels of computer literacy and efficiency impacted their ability with longer performance times. Hence the difference in performance levels is reported. On the other hand the sighted cohort was efficient, confident,
curious and able. We believe that increased training and learning time of the system technique and commands could produce equal or better performance with the BVI group. Even though instructed drawing shows significant difference between sight and BVI participants performance time, non-instructed drawing has no significant difference among group performance time. The results confirmed that totally blind individuals took slightly longer to complete the task than VI individuals and sighted individual completed the tasks faster than both blind and visually impaired individuals. However BVI participants made a small number of errors across all three tasks and demonstrated close competency when producing accurate results.

The post-experiment question validated strong agreement of the participants with regards to SETUP09’s ability to build a navigation and its layout model with levels 1, 2 and 3. More than 85% of the participants (Sight and BVI) picked level 1-3 for SETUP09 ability to build a navigation and layout model. Where as 85% picked levels 1 and 2 for system efficiency and 65% of the participants thought the system was supportive enough for the task specified. All of them took part in the questionnaire by giving detailed feedback on the choices and system improvements. Lots of BVI and sighted participants agreed that enough time for system familiarisation is the key to confidence and efficiency. Some participants didn’t like the system voice feedback feature as it added further delay in processing commands. Hence some suggested shorter sound feedback and auto corrective text. Few participants were unfamiliar with the Mac keyboard, which added some delay. Voice input commands would have added extra complexity of time delay with two-way feedback and confirmation messages. All participants were somewhat familiar with the keyboard and especially enjoyed hotkey commands for navigation. VI, low vision participants suggested the onscreen and printed text larger fonts and thickness of lines to identify variation of shapes. Diagrams were particularly difficult for sighted and blind participants due to unfamiliarity with the notion of DFD (data flow diagram) and FC (Flow chart). It was evidenced that the sighted cohort was much more competent in use of keyboard than their BVI counterparts.

In support of H1, H2 and H3, the results confirmed that BVI participants are showing competitive performance compared to sighted participants with high accuracy and fewer errors in all of the assigned tasks despite of the variance in completion time and recognition time which was expected. More than 76% of trials reported with 100% accuracy of given tasks 1-3 among BVI participants and more than of 76% trials were completed without errors. Almost all drawing activities were completed in 2.13 minutes or less, apart from the diagram drawing task, 85% of the participants strongly agreed that the system was efficient at building a navigation and layout model.

Task completion was a success for BVI individuals in the context of the lack of availability of a blind drawing system, and having never attempted to use a drawing tool for academic or general purpose. All BVI participants were highly determined to achieve the given tasks irrespective of time consideration. Some BVI participants had learning difficulties apart from visual impairment, which was a contributing factor in the reason for time taken to complete different task in finding efficiency. Overall BVI participants demonstrated their drive and motivation to manipulate graphics independently without any help of a support worker in everyday life. Our evaluation of SETUP09 shows similar accuracy and competency among BVI participants as with sighted participants when using navigation and drawing technique.

5 CONCLUSION

An experiment was conducted to evaluate the suitability of command driven drawing technique and virtual navigation system. The system was tested with BVI and sighted participants. Our basic observation of SETUP09 is that, it is a suitable and reliable platform, which helps to minimise the trials in effort, time, and resources to navigate on the screen and produce art. The results confirmed
that both BVI and sighted participants completed the trials with high accuracy and efficiency. The BVI participants managed to successfully complete most of the drawing tasks less than five minutes without the help of a support worker. However the degree of efficiency varies between participant groups. In general sighted participants were faster than BVI participants as we expected. Also we noted that visually impaired participants were faster than totally blind participants. Younger participants were the fastest among both BVI and sighted groups. Importantly BVI individuals made fewer of errors and showed high level of accuracy on a par with the sighted counterparts. We also studies the gap between the confidence and ability of technology and computer use among different groups and ages. There is a need for new and innovative assistive software for BVI users to overcome the impediment of fear of failure with the use of technology.

Although the sighted group performed faster than the experiment group, we observed that the SETUP09 system enables BVI users to move between screen locations and manipulate art with confidence, without any assistance of a support worker. The findings also reveal that there is no significant difference between art manipulation and image recognition using SETUP09 system among sighted and BVI participants with non instructed drawing, and that there is a high level of accuracy reaching a given location and manipulating art using the SETUP09 system compared to not reaching or completing a drawing task on the interface.

Many VI participants commented on the need for magnification as an add-on feature whereas totally blind individuals were keen on a quick feedback mechanism. All participants enjoyed formal drawing language (SETUP09) to communicate location, navigation and geometric information. The language is expandable, personalised and reusable. Future work will focus on extending easy command input mechanisms using braille, and speech. Even though speech is proven to be less accurate and time consuming [Sears et al. 2002], we hope that non-computer and braille users could benefit from it. Printing in 3D space needs 3D printers, which might not be practical for day to-day use, hence sonification can play a significant role to minimise system feedback time. Further investigation is required to explore BVI people’s potentially limited perception and conception of three-dimensional space. However, haptic validation using mobile phones or hyper braille could be made available.

The compass-based grid over-layer could also be used with many more general and practical applications as an easy navigation technique on the screen with everyday applications among sighted computer users. 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 a compass grid over-layer with keyboard keys or speech; to move cursor to a location on a webpage for software such as screen readers. The reading can initiate or resume from the newly selected grid mouse location; to find a location on a map using 3x3 compass-based grid over layer. The technique traces the navigation path and remembers to navigate back and forth. Compass-based navigation takes the cursor into intended screen location without having to rely on a tracker pad, mouse or visual perception.

Overall our results confirmed that SETUP09 2D drawing and navigation technique is reliable and efficient. It facilitates accurate mental models for BVI users. This research suggests a need for a thorough and quick feedback technique with sonification to help BVI individuals with feedback on location, size, shapes, and also a haptic technology for on-screen validation to improve the efficiency of scientific and non-scientific drawing in future.

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