Multimodal Collaborative Handwriting Training for Visually-Impaired People

Beryl Plimmer[1], Andrew Crossan[2], Stephen A. Brewster[2], Rachel Blagojevic[1]

Department of Computer Science
University of Auckland, New Zealand
{beryl|rachel}@cs.auckland.ac.nz

Glasgow Interactive Systems Group,
Department of Computing Science
University of Glasgow, Glasgow, G12 8QQ, UK
{stephen|ac}@dcs.gla.ac.uk

ABSTRACT

"McSig" is a multimodal teaching and learning environment for visually-impaired students to learn character shapes, handwriting and signatures collaboratively with their teachers. It combines haptic and audio output to realize the teacher's pen input in parallel non-visual modalities. McSig is intended for teaching visually-impaired children how to handwrite characters (and from that signatures), something that is very difficult without visual feedback. We conducted an evaluation with eight visually-impaired children with a pre-test to assess their current skills with a set of character shapes, a training phase using McSig and then a post-test of the same character shapes to see if there were any improvements. The children could all use McSig and we saw significant improvements in the character shapes drawn, particularly by the completely blind children (many of whom could draw almost none of the characters before the test). In particular, the blind participants all expressed enjoyment and excitement about the system and using a computer to learn to handwrite.

Author Keywords

Multimodal interface design, visually-impaired users, haptic trajectory playback, signature training.

ACM Classification Keywords

H.5.2 [**User Interfaces**]: Haptic I/O.

INTRODUCTION

There are many situations throughout life where a signature is required; on legal documents, cheques or important letters, for example. In many cases, a signature is the final step needed to seal an agreement and without one no deal can be made. Most people learn to write as a child and take this ability for granted, so much so that signing a name takes little concentration. Proficiency in generating a consistent, visually appealing, verifiable signature is something we rarely think about. However, for children with a visual impairment learning this skill is very difficult. Yet, blind people also need to generate consistent signatures in the same way as their sighted counterparts.

After identifying the need for signature training, we engaged in some informal discussions with a number of visually-impaired adults. They told us their 'war stories' of learning to sign and the frustration of knowing that their signatures looked strange. One described her own signature as 'resembling the meanderings of an inebriated fly' (Figure 1). At the same time, we were sometimes surprised by the reactions of sighted people when explaining the project. The most common reaction was 'what do you mean blind people can't write?'. Many sighted people had not considered that it was very difficult for blind people to learn to write because of the complete lack of any feedback and with very little need to write in many everyday situations.

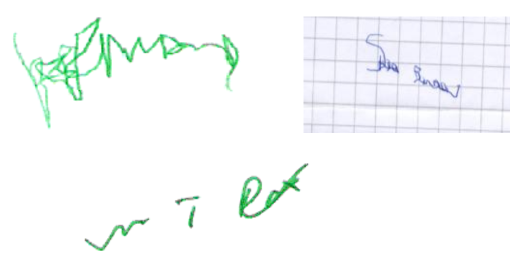


Figure 1: Example signatures from three visually-impaired people.

Until 20 years ago visually-impaired children in many developed countries went to specialist schools for the blind. However, integration is now common and children regularly attend their local school alongside sighted schoolmates. In specialist schools learning to sign their name was a part of the curriculum, but this has not followed into the integrated model of education.

Sighted children generally learn first to control a pen through drawing, scribbling and colouring. Eventually they are taught the letter shapes and learn to print each of the letters. As they grow older and more practiced, they de-

CHI 2008, April 5–10, 2008, Florence, Italy.

velop a handwriting style that will eventually lead to the creation of their signature. Blind children do not get the rich visual feedback that a sighted child gets while learning and the process is therefore far more difficult. A variety of techniques are used to teach blind children letter shapes. Raised letters (fridge magnets are popular) and stencils are used for exploring a static shape. Guided hand movement, with the teacher's hand over the student's, is used to form the letters. Hand-writing is often onto special plastic sheets over rubber drawing boards – this results in a raised line on the plastic along the pen path which the child can then feel to explore what has been drawn (called a Dutch drawing board). These techniques are clumsy and provide limited guidance and feedback to the learner. With the development of new technologies, we can start to address these problems in different ways and develop tools that provide better support for learning skills such as handwriting and signatures.

Some years ago the Optacon (Optical Tactile Converter) was a popular device for visually impaired people. It converted printed letters into an equivalent spatially distributed vibrotactile representation on the fingertip using a miniature handheld camera and tactile array to allow people to interactively explore and read documents. Learning to interpret these shapes by touch was difficult; nevertheless some users became fluent readers. Reading speeds with the Optacon are around 10 to 12 words per minute after an initial 9 day training period, reaching 30 to 50 after further training and experience [3]. In recent years this technology has been replaced by scanning, OCR (optical character recognition) and speech output. This further reduces the need for visually-impaired people to understand letter shapes and therefore teaching general writing skills is seen as less important. However, there are still situations when a signature is necessary so the knowledge of character shapes is still required.

In this paper we describe the development and evaluation of a computer-based collaborative teacher-student environment for training blind children to handwrite characters, eventually leading to complete signatures. It traces the design of the system, "McSig" (Multimodal collaborative Signature training system) from our initial ideas to the completion of the training environment, through iterative testing and refinement with blind adults that led to significant changes in the design of McSig. Finally, we describe a study carried out with blind children to test their acceptance of the technology and its usefulness as a handwriting training tool. Our goal with this project was to enrich guidance and feedback during writing thus making learning easier and more pleasurable. McSig combines pen-input models with haptic trajectory playback through force-feedback supported with auditory cues to provide a multimodal teaching and learning environment.

RELATED WORK

Braille and raised paper diagrams are the traditional tactile tools for allowing visually-impaired people to access graphical information. These are cheap and effective, however, they are static representations that take a lot of effort to create and alter. For these reasons, more and more information is now being presented through computers, with screen readers widely used to read documents or surf the Web. However, learning handwriting requires knowledge of the character shape as well as learning the motor skills required to generate the characters, which is best done through physical movements, practice and feedback. This is difficult to do using traditional tools or synthetic speech.

Creating a Drawing Non-Visually

There are examples of research systems designed to allow visually-impaired people to create diagrams and drawings themselves interactively. Work by Kurze [10] examined the development of an accessible interface for drawing. He describes an environment that combines swell paper – to create a physical line-based representation of the drawing – with a stylus and digitiser to provide positional information within an image to a computer. Verbal cues are used to label different lines on the image which can subsequently be read back by the computer as the user explores the drawing. This system allows a visually-impaired person to both create and explore a diagram, by exploiting the advantages of paper-based and computer-based technologies. The problem with this solution for handwriting is that it does not guide a user and help the drawing of a character; the user draws freehand and then can explore what was drawn. To create the right shapes a user needs some guidance and this requires a more dynamic interaction.

Rassmus-Gröhn *et al.* [12] similarly describe a drawing environment for visually-impaired people. Users interact with a PHANTOM force-feedback device (Sensable Technologies, www.sensable.com) to create shapes in positive or negative relief on a virtual surface. With this system, they were able to demonstrate how simple shapes could be recognised and also created by visually-impaired children. Again, the aim of this tool was to allow unconstrained drawing so it does not support the creation and re-tracing of correct character shapes, which have to be done very precisely to learn handwriting. This tool is more dynamic as the shapes are created virtually with the haptic device, but it does not support some key aspects of learning to handwrite.

Browsing Spatial Data Non-Visually

There are many systems that provide access to spatial information for visually-impaired people. TEDUB [9] allows people to browse technical diagrams using a range of input devices. A technical drawing from a source document (e.g. a bitmap) can be read in and parsed into a structured form and made accessible through haptic and audio feedback. Landau and Wells [11] similarly described the *Talking Tactile Tablet*, a hybrid system which combines a physical raised paper representation with a touch sensitive tablet for making diagrams accessible. Users can explore the raised paper representation as normal, but can also press down on an area of interest and hear information through speech about that particular area of the image. By using different pre-created raised paper diagrams that the tablet can distinguish, context-sensitive speech can be given to the user for multiple diagrams. Both of these examples can help in learning handwriting as children could be given tactile versions of the letter shapes to put on the tablet, but they do not provide tools to guide a user around a character to learn the motor skills needed to create accurate letter shapes.

Wall and Brewster [14] present a computer-based system for accessing bar charts that shares many features with a raised paper diagram. The user navigates around the image by moving a stylus over a standard graphics tablet representing the physical piece of raised paper. The user's non-dominant hand rests on a pin-array tactile display that provides a tactile representation of what is around the stylus tip. One immediate advantage of this system over a traditional raised paper representation is that it is computer-based; charts can be easily and quickly reloaded and could be dynamic. The system can take advantage of the computer-based representation to track the user's movements and provide further feedback to aid the user navigation through the environment. Yu and Brewster [16] describe a similar system to display bar graphs non-visually through a combination of force-feedback, non-speech and speech audio. They were able to demonstrate significant advantages of their multimodal graph system over traditional tactile diagram approaches. While these systems successfully allow people to browse data, they do not easily support the constrained exploration of a shape and guidance around it that would be needed to build a mental model of character shapes and develop the motor skills for controlling a pen.

Trajectory Playback for Teaching Shapes

The work in this paper takes inspiration from the literature on haptic training systems for sighted users. Force trajectory playback (where a user is guided along a path using forces generated by a haptic device) has been used to train users in simple manual tasks [15] and doctors to perform medical procedures [6]. There have been several examples of systems that use haptic guidance to train sighted users in Chinese or Japanese calligraphy [8, 13]. Other researchers have demonstrated experimentally that haptic guidance can be used to train users to move along a trajectory more accurately [7]. None of these studies, however, have been conducted with visually-impaired people, where the lack of visual feedback available to the learner will make the task more difficult. With this work our intention is for the teacher to use a tablet to create ink strokes and for these to be reflected on the haptic device for the visually-impaired student to feel in real-time.

The study described in this paper builds on results from previous work by Crossan and Brewster [4] that presented three studies examining trajectory playback as a method of transferring shape information to visually-impaired people. The first of those studies compared the performance of blind and sighted users in the task of recreating a trajectory felt through trajectory playback. As in the study described here, a PHANTOM force-feedback device was used to drag the participant's hand through the trajectory. Results showed that the task was significantly harder for the visually-impaired group than the sighted group, and within this group the task was most difficult for those who had been blind since birth. A second study aimed to compensate for this difference in performance by presenting multimodal playback of the trajectory. The pan and pitch of a tone were varied to display the user's current *x*, *y* position during the trajectory playback. The results demonstrated that users were significantly more successful in recreating the trajectory when they experienced haptic-audio playback rather than haptic playback alone. Finally, a small observational study was described where three sighted 'teachers' described a series of abstract drawings to three blind students, who had to recreate the drawings. Here the trajectory playback was employed to useful effect when verbal description of a shape was difficult. However, its usefulness was limited by the type of playback allowed by the interface. The playback trajectory had to be completely generated by the sighted user before it was played to the student at a constant speed. This removed the real-time aspect from the playback and hence made simultaneous verbal communication of the teachers' actions more difficult. The constant rate of the playback further restricted the teachers' expressiveness. For example, they could not slow down the playback for complex parts of the trajectory. From the results of this research we saw possibilities of an improved playback system that could potentially help students in learning to handwrite. We removed the limitations from our earlier system to allow real-time playback of the teachers' movements; teachers could then slow down their drawing for complex parts and also talk the student through a shape as they drew it.

THE McSig SYSTEM

We developed a multimodal, collaborative handwriting and signature training tool which we call McSig. The scenario envisaged for McSig is that a teacher and student will be working together in a shared environment, with the teacher guiding the student towards learning the letter shapes using words and actions. This is illustrated in Figure 3 and Figure 5 where the teacher (left) and student (right) can be seen sitting next to each other using McSig. Students interact with the PHANTOM Omni force-feedback device (from Sensable Technologies) by holding the end effector as they would a pen. To draw, they rest the tip of the PHANTOM pen on a surface, then hold down the button on the pen barrel and move the pen over the surface. After some initial testing, it quickly became clear that, as with sighted children, feedback is a key aspect of learning the shapes. To allow students to get feedback about the shapes that they draw, a Dutch drawing board was used as the surface (a standard drawing tool for visually-impaired people). When the pen is pressed down and moved over this type of material, the area of the board under the pen stroke is raised up from the surface creating a tangible line that can be felt by the user (with an outline scored on to the surface that can also be seen if the user has any sight). Further to this, voice output of both the teacher's and student's writing is generated by recognizing the characters using the Microsoft Windows handwriting recognition engine.

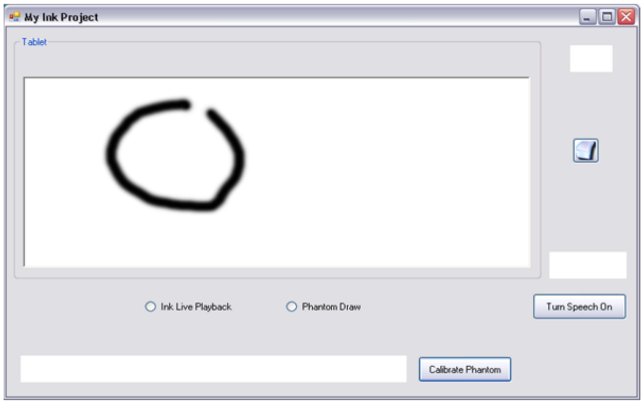


Figure 2: Screenshot of the teacher's display.

A screenshot of the teacher's display is shown in Figure 2. The white rectangular area represents the drawing space where the teachers can draw and also see the shapes drawn by students. They can choose between a collaborative training mode where the teacher works with the student to teach the letter shapes, and a free drawing mode, where the student can practice unaided. The teacher also has the option to turn the speech and sounds on or off if required.

Figure 3: The McSig system in use. The teacher (on the left) draws on a Tablet PC to create a shape and the student (on the right) can feel, explore and be moved around the shape.

The teacher can interact with the student in three ways. Firstly, verbal communication is important to allow the teacher to guide and explain concepts to the student. Secondly, the teacher has access to a Tablet PC and can interact with the student by drawing on the screen. As the teacher draws, his or her movements are echoed to the PHANTOM in real time and the student is dragged through the shape as it is drawn (we called this *Playback* mode). Finally, it is also possible for the teacher to create a stencil (*Stencil* mode) for the student to follow. The teacher draws a letter shape on the tablet which forms a virtual stencil in the student's drawing area. In this case, the student is first moved by the PHANTOM to the start of the letter shape. The pen is then constrained to the line drawn by the teacher, without the student being dragged through the shape as previously. This allows students to move through the letter shapes themselves with constraining forces to guide the movements. Initially, the constraining forces can be made strong such that the student is forced to follow the letter shape closely. As the student becomes more proficient at creating the letter shape, the constraining forces can be made weaker to provide less guidance eventually allowing students form the shapes by themselves.

Different characters are formed with either one stroke (like 'c', 'o', or 'e') or multiple strokes (like 't', 'f', or 'i'). To disambiguate between the situation where a character is formed by multiple strokes and the teacher is drawing multiple repetitions of the same character, we use a time-out. If the teacher forms a new stroke within one second, this is counted as a stroke from the same character. The time-out value was set through an iterative trial-and-error process.

Work from Crossan and Brewster [4] indicated that multimodal playback of a shape could help visually-impaired people to recreate the shape. Using the audio feedback from that previous study, we mapped the pitch of a sinusoidal tone to vertical movements, and audio pan to horizontal movements. The audio feedback was present when the teacher drew for the student. A high pitch indicated that the user's cursor was near the top of the drawing area, and a low pitch indicated it was near the bottom. Similarly with pan, as the teacher moved further left or right in the drawing area, the audio panned to the appropriate side. Distinct sounds were played at the start and at the end of the teacher's trajectory to clearly indicate to the student the beginning and end of the gesture.

Haptic Trajectory Playback

Haptic trajectory playback is not a trivial problem. The two main issues in creating an effective playback system are the stability of the algorithm and the safety of the user, particularly when some haptic devices can apply enough force to cause injury. Loss of control of the end effector is a particular problem when the user may not be able to see the device. In the our study, an implementation of a playback system based on the bead pathway developed by Amirabdollahian *et al.* [1] is combined with a PID Controller [2].

A proportional-integral-derivative (PID) controller is a standard algorithm from the control engineering literature [2]. The purpose of using the controller is to minimise the error between the current value of a system and a target value. In this case, we control forces sent to the force-feedback device in order to minimise the distance between the user's current cursor position and the target position on the trajectory. As the user's cursor approaches the target position and gets within a threshold distance, the target position is moved along the trajectory by a preset amount. This is repeated until the target position is the end point of the trajectory. By carefully tuning the parameters of the PID controller and the playback system, the user will be dragged through a close approximation of the trajectory in a smooth and stable manner.

The trajectory playback system used for McSig was based on an open source library that we had previously developed [5]. The preset PHANTOM Omni settings available in the library were used for the playback controller. Forces from the playback controller were capped at a maximum 3 Newtons for safety reasons.

Usability testing

A first informal usability test was conducted with one visually impaired adult early in McSig's development. When drawing with the PHANTOM she tried to feel the pen stroke on the surface with her other hand to explore the shape she had just drawn. This was not possible on the paper pad we were using, so we switched to a Dutch drawing board so that the strokes were raised above the surface and could be felt.

In a second formative study, four visually-impaired adults were recruited to test a further version of McSig: three were totally blind and one partially sighted. The usability test was modelled on the planned scenario of use that a visually-impaired child and his/her teacher would work together. They would start in Playback mode with the teacher drawing a letter on the tablet and use this mode until the student was confident with the basic shape. They would then move on to the Stencil mode and get the student to trace around the virtual stencil. Finally, the student would draw the letter unsupported and the teacher would perform a visual check to see how well it was drawn. Through this testing a number of refinements to the initial design were made:

- Participants preferred the Playback to Stencil mode, as it proved difficult to follow the shape of the letter in Stencil mode. The forces forming the groove of the stencil were strengthened and retested in order to provide a clearer path for the user. However, the letter shapes were still felt to be unclear;
- The audio playback cues were used more by some participants than others. Verbal feedback from the teacher during the playback was appreciated by the participants. The teacher would describe the movements as they were made and at the same time as a participant was feeling the shape of the character drawn;
- The character recognition was unreliable, frequently mis-recognising the characters. This severely affected the visually-impaired users' confidence so a button was provided for the teacher to turn it on or off (and the feature was not used for the final evaluation study);
- The PHANTOM Omni pen was not ideal for the task. The pen is larger than a normal pen and awkward to hold near the tip. Users were required to hold a button on the pen barrel as they drew, which meant that they held the pen further from the tip than was usual. Training in holding the pen was essential before the trials started.

The final design for the training tool can be seen in Figure 3 and Figure 5. Both show a teacher interacting with a visually-impaired student by drawing on the Tablet PC and having feedback echoed on the PHANTOM. The teacher and student sit next to each other to allow for easy verbal communication and to provide a similar frame of reference such that the teacher's left is the same as the student's.

EVALUATION

The aim of the evaluation was to assess the efficacy of McSig for improving visually-impaired children's handwriting performance. The physical setup is shown in Figure 3. The sessions were recorded using Morae™ (www.techsmith.com) and the time-stamped x, y and z coordinates of the PHANTOM when in Playback mode were recorded.

The task devised was based on introductory handwriting skill learning as our discussions with teachers suggested that visually-impaired children's handwriting skills vary from almost none to being able to produce an adequate signature. The evaluation test plan was evolved from our experiences with visually-impaired adults in the usability testing phase and discussion with teachers.

Participants were recruited through the local education centre for visually-impaired children in Auckland. In discussion with the teachers we set the following criteria for participant selection: over 10 years old and still at school; Braille reader; no other major disabilities. Drawing from the local population of 1.4 million, this gave us a potential participant pool of about 15 (visual impairment is a low-incident disability). Eight of these students participated in the study. As there was no consistency in their existing skills and with such small numbers we rely on qualitative analysis of the results.

Study

The first stage of the study allowed participants to familiarize themselves with the experimental set up. The key aims of this stage were to:

- Familiarize the children with the physical environment, allowing them to feel the Dutch drawing board, the PHANTOM and the computer;
- Get the children to establish their spatial orientation on the drawing board by outlining the limits of the space;
- Get the children to draw a circle, horizontal line and vertical line to familiarize them with the interface.

A letter set of 'o, c, a, d, e' was selected in discussion with the teachers as they were all variants of a circle and formed with a single stroke. We opted for simple, single stroke shapes as we wanted ones that were not too difficult for our young participants to draw. For each letter there was a pre-test, a training phase and a post-test (we did not pre-test 'o' as it was the same as the familiarization circle). All of a child's writing was with the PHANTOM Omni and drawing board. For each letter the child was asked if he/she new how to write the letter and if so, were invited to write it (pre-test phase). He/she was then shown how to write it by the teacher (in this case, one of the experimenters) writing the letter on the Tablet PC with the movement echoed by the PHANTOM. The number of repeats of training strokes depended on the child's confidence (training phase). When the child was ready we re-tested (post-test phase). If the child could not form the letter correctly he/she was re-trained and re-tested. A session ran for a maximum of 20 minutes, stopping earlier if all the letters were completed (which only happened with the partially-sighted group).

Figure 5: A partially sighted participant using the PHANTOM – note only one hand in use.

Results

Of the eight participants three had a small amount of useful vision. These partially-sighted students used both Braille and super-enlarged print. They all had deteriorating eye conditions and had learned to write when their eyesight was better, but did not write now as they could not see what they had written. Of the five totally blind students one had lost her sight at three years old, the others had been blind since birth. The results were quite different for the two groups so they are presented separately.

Partially sighted participants

The participants with partial sight quickly familiarised themselves with the devices and drawing space. They could all form the circle, horizontal and vertical lines without difficultly. One participant formed all the pre-test letters correctly. Both of the others formed the 'd' by starting at the top and created a letter than looked more like a mirror image '6' (Figure 4). One of them also formed a visually correct 'e' but formed it in the opposite direction to normal.

Figure 4: Pre- and post-training 'd' by a partially sighted student (red dot is the start point of the pre-training stroke).

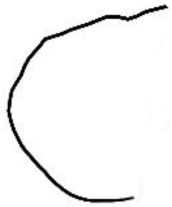
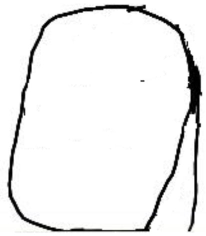
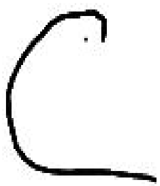
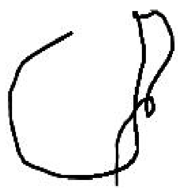
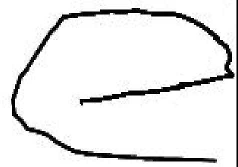
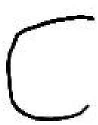
These participants interacted with the drawing space in a very similar manner to a sighted user except that they often had their eyes very close to the surface so that they could see the lines drawn on the drawing board (Figure 5); they did not feel the tactile letters. It was very quick to retrain the partially sighted users to form letters correctly. We completed the study with all of these students within 20 minutes. These participants made very few comments about the system. Their general attitude was that they already knew how to write and they simply followed our instructions

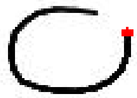
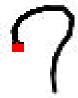
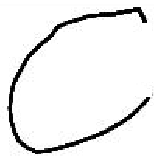
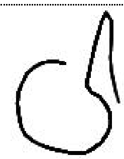
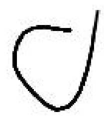
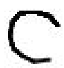
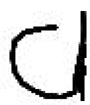
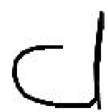
Blind Participants

The familiarization and spatial orientation processes took considerably longer with the blind participants as they needed to explore by touch the different devices and trace around the drawing space at least twice to gain orientation. They also interacted with the drawing space quite differently. Typically they used both hands, one to hold the pen and the other to retain their orientation within the space and feel the tactile marks made by the pen (Figure 6). One of these participants used so much pressure that the pen could not move over the surface and another did not use enough pressure to get a tactile line. We taught them to use the appropriate amount of pressure before continuing with the study. All but one participant completed the basic circle and vertical and horizontal lines without difficultly. Table 1 shows the pre- and post-test letters for each of the blind participants along with their age and roughly in order of worst to best performance. All of the participants had no concept of the shape of some letters: when we asked to draw the letter in the pre-test they often said something like 'I don't know how to do that one'; we have marked these cells in the table 'unable to do'.

Figure 6: A totally blind participant using the PHANTOM – note the non-writing hand used to feel the tactile line that has been drawn on the drawing board.

Table 1: Pre- and post-test letters drawn by the totally blind participants.

“Mae” Age 14	**o**	**c**	**a**	**d**	**e**
Pre-test		Unable to do	Unable to do	Out of time	Out of time
Post-test				Out of time	Out of time
“Sue” Age 19	**o**	**c**	**a**	**d**	**e**
Pre-test	No data		Unable to do	Skipped	Unable to do
Post-test	No data			Skipped	
“Tam” Age 13	**o**	**c**	**a**	**d**	**e**
Pre-test		Unable to do	 In his name	Unable to do	Out of time
Post-test					Out of time

“Nik” Age 11	o	c	a	d	e
Pre-test		 Formed backwards		Unable to do	Out of time
Post-test					Out of time
“Ann” Age 17	**o**	**c**	**a**	**d**	**e**
Pre-test		Unable to do	 In name		Unable to do
Post-test					

There was a considerable difference in the existing skills of the blind participants. The worst, “Mae”, could not create a reasonable pre-test circle/‘o’ and had no knowledge of any of the letters. Her fine spatial orientation and skills were very poor. We did two rounds of training with the ‘c’ before she felt that she could remember the shape and three rounds with the ‘a’, the third round was at the 20 minute time limit and at the limit of her concentration. In contrast, “Ann”, the best of the blind participants could form an accurate ‘o’ and ‘a’ and quickly learnt the other letters. She also scaled the letters accurately; while the training letters created on the PHANTOM were large, about 6cm high, she drew her letters at about 1cm in the tests. All of the blind participants had a very limited knowledge of letters and had only been taught letters in their names – hence the better knowledge of ‘a’ by “Tam” and “Ann”.

The results in Table 1 show some significant improvements in writing performance. “Mae” was unable to draw any of the letters successfully in the pre-test but was able to draw a recognisable ‘o’, ‘c’ and ‘a’ at the end. “Sue” also improved significantly, able to do a recognisable ‘c’, ‘a’ and ‘e’ after the test. “Ann” was able to do a good version of all of our letters after the test. These results suggest that McSig was able to help the participants learn to draw the letters successfully.

The blind participants all expressed enjoyment and excitement about the experience. Within the first few minutes, unprompted, they would make comments like “cool”, “fantastic”, “this is neat”. “Tam” said “I like how I learnt it from the computer, after the computer did it lots of times I could do it!”. This suggests that McSig may be a motivating way for them to learn to handwrite, giving them active guidance for learning and dynamic, direct feedback on how they are doing. The blind participants response was very different to the partially sighted participants who were politely interested but not captivated..

DISCUSSION AND CONCLUSIONS

The results of our study are promising, showing that McSig could help visually impaired and particularly blind children to learn to make better character shapes. This is important as handwriting is a very difficult skill for a blind child to learn, but being able to handwrite your own name or signature is an important skill for life.

It took us some time to understand why the virtual stencil did not work. We believe it was because visually-impaired people use two hands to write, one holding the pen and the other for spatial orientation on the paper. The stencil was virtual, only discernible from the hand holding the PHANTOM. To solve this we could use a second PHANTOM for the other hand, but two such devices in a small area is problematic due to clashes between the armatures. An alternative would be to use a large tactile pin array instead of the drawing board. The pins could be raised in the areas where the user drew. At this time such devices are still only research prototypes and are not commercially available at any reasonable cost. We are currently investigating other options as we still believe there are many benefits to having a stencil that can be explored.

The partially-sighted students had a reasonable knowledge of letter shapes before our study. However, they did produce some letters in mirror image and form other letters incorrectly. We were intrigued by the incorrect formation hypothesising that it could be because they had been taught incorrectly or that their poor vision meant they did not pick up the subtleties of letter shapes. We discussed the cause of miss-formed letters with their teachers but they had no better ideas. With the software we could quickly re-train these students to form letters correctly.

The blind students all made significant progress in their writing skills during their short training session. Existing writing competence did not appear to have any association with age or general academic performance. The evaluation study reinforced the difficulty, for visually-impaired children, of learning to write. Even the most basic skills, such as how much pressure to exert, must be specifically learnt. Our discussions with the participants and teachers suggested that it was dependent on the interest of students, their parents or individual teaching assistants as some saw learning a signature as a higher priority than others (students in integrated schools have a teaching assistant with them for many hours a week). McSig could perhaps make it easier for the teachers (or even parents) to teach handwriting as it appeared to be motivating for the students.

None of the blind participants knew all of the letters in the training set, with knowledge focused on letters in their own names. The least competent writer, “Mae”, improved her spatial orientation, adjusted her pen pressure and mastered a basic circle. She required significant training to be able to create the ‘o, c, a’ and these were very large and jerky, but she was unable to write them at all before the training. Of the three middle performing students, in the pre-test we noted two miss-formed letters, one reversed ‘c’ (“Sue”) and the other miss-formed ‘c’ and had an inaccurate idea of ‘a’ (“Nik”). These students corrected misunderstandings and learned the basic shape and formation of one or two letters they did not know before the study. Student “Ann” with the best existing skills could form an appropriate ‘o’ and ‘a’ and a reasonable ‘d’. The training did not significantly change her performance of the ‘o’ and ‘a’, but she did learn ‘c’ and ‘e’ and improved her ‘d’. The most interesting aspect of this student’s performance was that she could scale the examples to an appropriate size for handwriting. While scaling is trivial for sighted people, it is not obvious for visually-impaired people due to the lack of feedback.

The evaluation study considered only a small set of single stroke letters, due to the skills of our participants. McSig supports multi-stroke letters and multiple letters. Even finer spatial orientation is required to create some multi-stroke letters, for example ‘K’ requires careful positioning to connect the two strokes. Likewise the spacing between letters and words is critical to the visual appearance of words and sentences. These could all be taught with McSig, although in the current implementation the workspace is much smaller than the A4 drawing pad due to the working drawing area of the PHANTOM Omni. A larger PHANTOM Premium could be used if needed. Cursive handwriting is also possible. The teacher can write ‘joined up’ and the student can then feel the lines in the same way as single characters. This would then allow children to move from printing single characters to cursive writing as their skills developed. This would then be the stepping stone to the creation of a signature. The teacher or student could create a signature that the student could then practice until confident that it was consistent and visually appealing. If the stencil mode could be improved the student could then return to the system to practice the signature over time to keep it consistent. Our future work will include a longitudinal study to gauge the retention of leaning over time and to teach a specific individual signature to participants.

We have considered setting up a self-training mode so that students could practice by themselves. It may be possible to do this by providing a library of example characters and voice input commands to navigate the library and start each example. Using the keyboard for these commands would not work as the student would need to remove at least one hand from the drawing pad, locate the appropriate key and then reposition the hand on the drawing pad. Voice input commands could replace the keyboard so that this repositioning was not required: however, reliable voice recognition would be required. Providing appropriately supportive feedback could be more difficult. Character recognition techniques could be used to compare the student’s stroke shapes with the training shapes and score the closeness of match: however, character recognition provided unreliable in our usability tests because it relies on size and the context of a character within a word. We would need to develop more general recognisers along the lines of those discussed in [4].

These techniques and the software could be applied to other two-dimensional drawing tasks. The teachers of visually-impaired students were particularly keen to try it for geometry. These teachers currently spend much time making two-dimensional drawings of simple geometric figures such as triangles to help their students. While general mathematics teachers often use three-dimensional blocks to demonstrate geometry, the teachers of visually-impaired students involved in this study told us that when 3D blocks are used to represent a 2D figure it confuses the students. They suggested that McSig may be useful to help students construct a better understanding of 2D geometric principles.

There are also possibilities for multimodal guidance outside of applications for visually impaired people. Being able to guide in real time would be useful for training medical procedures involving touch or where other, subtle touch-based skills need to be learned. In the medical domain an expert doctor could teach a medical student to perform an examination such as palpation by making the movements required and having them echoed to students in real time so that they can feel how to move and what pressures to apply.

In conclusion, it is possible for visually-impaired people to handwrite a consistent signature, but it is extremely difficult for them to learn to make a visually 'normal' signature. The learning task is both difficult and not very fulfilling because of the lack of feedback. McSig takes an innovative approach combining force-feedback guidance and audio cues with a physical tactile rendering of the pen strokes to enrich the interaction experience. By allowing a student and teacher to work together in real time with haptic guidance we have shown that it is possible to improve children's handwriting performance after a short 20 minute session with our system. All the blind participants in our study learned at least two new letters and the blind students in particular enjoyed the experience. This suggests that multimodal support for learning handwriting is feasible and that this could lead to the easier learning of signatures, which are important for everyday life.

ACKNOWLEDGEMENTS

This work was funded by the University of Auckland Research Fund, EU/IST eInclusion project MICOLE (IST-2003-511592 STP) and EPSRC Advanced Research Fellowship GR/S53244. We wish to thank the adult participants who gave their time and expertise for the usability study and the teachers, parents and students who participated in the evaluation study.

REFERENCES

1. Amirabdollahian, F., Loureiro, R. and Harwin, W., Minimum Jerk Trajectory Control for Rehabilitation and Haptic Applications. In *Proceedings of the IEEE International Conference on Robotics & Automation*, (Washington DC, 2002), 3380-3385.
2. Astrom, K.J. and Hagglund, T. *PID Controllers*. International Society for Measurement and Control, Research Triangle Park, N.C., 1995.
3. Craig, J.C. and Sherrick, C.E. Dynamic Tactile Displays. In Schiff, W. and Foulke, E. eds. *Tactual Perception: A Sourcebook*, Cambridge University Press, Cambridge, 1982, 209-233.
4. Crossan, A. and Brewster, S. Multimodal Trajectory Playback for Teaching Shape Information and Trajectories to Visually Impaired Computer Users. *Transactions on Accessible Computing*, 2008.
5. Crossan, A., Williamson, J. and Brewster, S., A General Purpose Control-Based Playback for Force Feedback Systems. In *Proceedings of Eurohaptics 2006* (Paris, France, 2006).
6. Dang, T., Annaswamy, T.M. and Srinivasan, M.A., Development and Evaluation of an Epidural Injection Simulator with Force Feedback for Medical Training. In *Proceedings of Medicine Meets Virtual Reality*, (USA, 2001), IOS Press, 97-102.
7. Feygin, D., Keehner, M. and Tendick, F., Haptic Guidance: Experimental Evaluation of a Haptic Training Method for a Perceptual Motor Skill. In *Haptic Interfaces for Virtual Environment and Teleoperator Systems*, (Florida, 2002), IEEE Computer Society, 40-47.
8. Henmi, K. and Yoshikawa, T., Virtual lesson and its application to virtual calligraphy system. In *Proceedings of IEEE International Conference on Robotics and Automation*, (1998), 1275–1280.
9. Horstmann, M., Hagen, C., King, A., Dijkstra, S., Crombie, D., Evans, G., Ioannidis, G.T., Blenkhorn, P., Herzog, O. and Schlieder, C., TeDUB : Automatic interpretation and presentation of technical diagrams for blind people. In *Proceedings of Conference and Workshop on Assistive Technologies for Vision and Hearing Impairment - CVHI'2004, EURO-ASSIST-VHI-2 : Accessibility, Mobility and Social Integration*, (Granada, Spain, 2004).
10. Kurze, M., TDraw: A Computer-based Tactile Drawing Tool for Blind People. In *Proceedings of ACM ASSETS '96* (Vancouver, Canada, 1996), 131-138.
11. Landua, S. and Wells, L., Merging Tactile Sensory Input and Audio Data by Means of the Talking Tactile Tablet. In Proceedings of *Eurohaptics 2003*, (Dublin, Ireland, 2003), 414-418.
12. Rassmus-Gröhn, K., Magnusson, C. and Eftring, H., User evaluations of a virtual haptic-audio line drawing prototype. In *Proceedings of Haptic and Audio Interaction Design (HAID2006)*, (University of Glasgow, UK, 2006), LNCS vol 4129, 81-91.
13. Teo, C., Burdet, E. and Lim, H., A Robotic Teacher of Chinese Handwriting. In *Proceedings of the Symposium for Haptic Interfaces for Virtual Environment and Teleoperator Systems*, (2002), 335-341.
14. Wall, S. and Brewster, S., Feeling what you hear: tactile feedback for navigation of audio graphs. In *Proceedings of ACM CHI 2006*, (Montreal, Canada, 2006), ACM Press Addison-Wesley, 1123-1132.
15. Yokokohji, Y., Hollis, R.L., Kanade, T., Henmi, K. and Yoshikawa, T., Toward Machine Mediated Training of Motor Skills -Skill Transfer from Human to Human via Virtual Environment. In *Proceedings of RO-MAN*, (Japan, 1996), 32-37.
16. Yu, W. and Brewster, S.A. Evaluation of Multimodal Graphs for Blind People. *Journal of Universal Access in the Information Society, 2* (2). 105-124.