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AN INVESTIGATION INTO ACCESSIBLE WEB NAVIGATION FOR THE BLIND PEOPLE

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ABSTRACT
Current screen-reader program used by the blind people to access the Internet inflicts navigation restrictions since the blind users can only perceive the content in serial mode. The serialized access using screen-reader program restricts the blind users from having the multi-dimensional effects required to fully understand the page layout. We believe that by accessing web pages using bi-modal interaction, a blind user would be able to perceive a two-dimensional perspective of a web page in his or her mental model. The purpose of this study is to investigate the differences in the mental models created by blind people from a two-dimensional web page using two different means: one using a screen-reader only and the other using a touch screen with audio feedback. Ten blind people and thirty sighted blindfolded participants participated in this study. This study employed within-subjects repeated measures experiments together with observations, verbal protocols and semi-structured questionnaires to achieve the objectives of the study. Besides, the influence of user's spatial ability on the user's performance was investigated using Tactual Performance Test (TPT). The study revealed that using touch screen with audio feedback; the blind people achieved more accurate orientation. However, the accuracy seems to be affected by page complexity. In addition, investigation of blind users' spatial ability on users' sense of position revealed that using touch screen with audio feedback, blind participants with lower spatial ability took longer time to locate information. Therefore, users' spatial ability plays an important determinant for the Web navigability using touch screen with audio feedback.

Keywords: web accessibility, two dimensional, mental model, non-visual navigation, touch screen with audio feedback.

INTRODUCTION

The Internet plays such a vital role in our daily life that it is important for everybody to be able to access the Internet regardless of one's disability or impairment. The disabled people should place themselves in line with the changes in technoloy so that they are not being excluded by progress and modernity.

Study by Hollier (2007) and Williamson (2000) found that people with vision disabilities has a strong desire to use computer and the Internet. For mild visually disabled people, the solutions are more conservative - they try to maximize the useful remaining vision (Chiang, 2005). The most popular assistive technology used by them to access the Internet is screen magnifier. On the other hand, severe visually disabled people especially the blind people require non-visual alternatives such as screen-reader programs, which include Job Access with Speech (JAWS), System Access, or Window-Eyes or Braille terminal to access the Internet. In general, a screen-reader program will get all the texts available on a computer screen and translated into sound by Text-to-Speech engine. To interact with the computer system, computer keyboard is the main input device used by the screen-reader users. The blind user can instruct the screen-reader program to speak out the content in specific manner using available keystrokes that will trigger specific functions. On the other hand, a Braille terminal, also known as Refreshable Braille display, is an electro-mechanical device for displaying Braille characters by raising dots through holes in a flat surface. However, it is worth to mention here that no more than 10% of blind people in the United States are literate to use Braille terminals as their primary reading medium (Seddon, 2005) mainly because it is cost-prohibitive (Wentz, 2011).

Research by Bigham *et al*. (2007) found that screen-reader users spent more time and needed more effort to perform a task on the Internet in comparison to their sighted counterparts. The screen-reader users displayed more investigative behavior than their sighted counterparts. The workload for moving back and forth is particularly tedious and time consuming (Takagi, 2007). Furthermore, without the contextual information provided by the layout, web pages can be hard to navigate, it is challenging for the screen-reader users to find the required information from the web pages (Jay, 2008).

The problem discussed above happens because the screen-reader program processes pages sequentially, from top left to bottom right of the page. Because of this, screen-reader users will have different mental model for accessing the two dimensional web pages as compared to the sighted users. The absence of the two dimensional information in the mental model of the screen-reader users is the key problem for them to use the Internet and to collaborate with their sighted counterparts effectively.

To get a two-dimensional perspective of a page, users with non-visual access have to utilize other senses. The sense of touch is a prevailing modality for interface design and plays an important role in assisting the blind people to develop a two dimensional perspective of a page (Kuber, 2007). Explosion of touch screen and gesture based consumer technologies motivated this study to explore the potential of these products. Some popular examples of touch screen technologies are Apple iPhone and Google's Android phones, desktop PCs such as HP Touch Smart, tablet computers such as the Apple iPad Air, Samsung Galaxy Tab S and Sony Xperia Z2.

We believe that by accessing web pages using a touch screen with audio feedback, a blind user would be able to gain a two-dimensional perspective of the web page in his or her mental model. If the mental model of the page contains two-dimensional information, it would help the blind user gain a better orientation of the web page and have a sense of position in the web page. This is important for the user to navigate the Web.

The remainder of the paper is structured as follows: Next section discusses the methodology to investigate the blind user's mental model when using a touch screen with audio feedback. The section titled Findings presents the result of the study. Finally, the last section presents the discussions and conclusions.

METHODOLOGY

Research in human-computer interaction (HCI) believes that it is the mental models that facilitate people to interact with complex computer systems (Zhang, 2007) (Staggers, 1993) (Li, 2005). Based on the model of Takagi *et al*. (2007) and data collection method for mental model studies as proposed by Sasse (Sasse, 1997), a conceptual framework as shown in Figure-1 is developed for the purpose of investigating how the touch screen with audio feedback enhances the blind people's overview and sense of position of a web page. The target population is blind people who are currently using screen-reader program as their assistive technology to access the Internet. A comparison that employs a quasi-experimental design is conducted to investigate the differences between screen-reader program and touch screen with audio feedback. Through experiments with objective and subjective measurements, the investigation on users' ability and preferences using touch screen with audio feedback is further conducted.

In order to investigate the effect of two dimensional perspectives on blind users' mental model, four types of data are needed as shown in Figure-1:

- Diagrammatic Representation - drawing, sketching or representation of functions, components and properties of the system
- Performance data - assesses user's ability to complete the task given, time taken to complete the tasks and number of errors produced
- Online protocols - record user's interaction with the system
- Verbal data - require users to verbalize their thought and feeling during the interaction with the system.

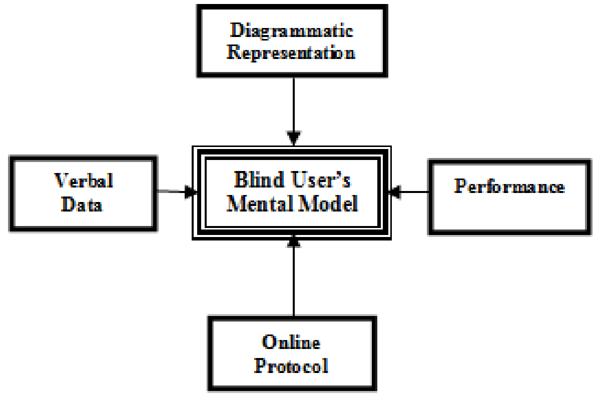

Figure-1. Conceptual Framework.

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This study utilized a mixed-method approach to evaluate the accessibility and usability of multi-modal environment for the blind people. This approach embeds the quantitative data with a traditional qualitative research design as proposed by Creswell (2010). The basis to adopt this research design is because relying on one single method seems insufficient to reveal inclusive answers. Therefore the combination of two methods offer more insights on the issues and provide a comprehensive view of multi-modal interaction using touch screen with audio feedback.

Based on the embedded mixed-methods design, the data was collected for both quantitative and qualitative studies. Quantitative data was collected from users' experiments with the intention of recording their performance on task completion and representing their visual imagination using diagrammatic representation. On the other hand, qualitative data was collected through observation, verbal protocol and semi-structured questionnaires to capture user's behavior, user's satisfaction and to observe their interactions with the system.

The research aim was addressed by conducting two experiments. The first experiment required participants to access the experimental pages using a touch screen display augmented with audio feedback. The second experiment required participants to access the

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experimental pages using a screen-reader program. A within-subject crossover experimental design was employed in this study. Each participant accessed the experimental pages using two different means: one using a touch screen with audio feedback and the other using a screen-reader only. The benefits of this experimental design are the elimination of between subject variance and also reducing the sample size needed for the experiment (Gavin, 2008) which is appropriate for this current study.

This project is assisted by a number of blind associations. Ten blind people participated in this experiment (3 females, 7 males). The number of participants is small, but compared to other related studies, the size of participants is reasonable. For instance, Takagi *et al*. reported that most experiments conducted with blind participants usually have only four to six people (Takagi, 2007). Some of the reasons of small number of blind participants include mobility problems and specific criteria needed for particular experiment. The researchers focused on recruiting blind people with some basic skill using a screen-reader program.

One drawback of crossover design is that the participant may gain preliminary experiences during the experiments (Cooper, 2003). These experiences known as learning effects occur when participants depend on familiarities gained in the first part of the study to indirectly improve their performance in the second part. To overcome the learning effect, this study randomly assigns the sequence in which the participants experiment web pages using the research apparatus. Half of the participants were asked to access the experimental pages using the screen-reader program first, then the touch screen with audio feedback. Half of the participants accessed the experimental pages in the opposite way. Moreover, the participants were asked to take a Tactual Performance Test (TPT) between the first and the second part of the study. The TPT test also served as a run-in period to reduce the learning effect.

As discussed in the previous publications (Abidin Xie, H., and Wong, K.W., 2012), the participants were asked to perform specific tasks. The study followed the experiment protocol as below:

a) Explanation about the study.
b) Consent to participate. All consents were given orally by the participant and audio-recorded for future reference.
c) The participants were trained on the procedure of the experiment using two training pages for about 10-15 minutes each. This is to make sure that any issues or doubt should be resolved before the real experiment started.
d) The experiment started by asking the participant to explore the experimental pages using JAWS screen-reader. There were altogether 6 experimental pages with different layout complexity used in the study.
e) After exploring each page, the participants were asked to briefly describe the page.
f) Then, the participants were asked to construct the layout of the Table using diagrammatic representation (Figure-2).
g) After the construction of diagrammatic representation, the participants were asked to answer a question.
h) Spatial Ability Test (TPT).
i) Repeat steps 4 - 7 above but now using touch screen display augmented with audio feedback. This study chose an Apple iPad as the experiment's apparatus. Voice Over program is available as screen-reading software for Apple iPad. The participants were trained on how to use the device prior to the real experiment.
j) Demographic survey.

Figure-2. Diagramatic Representation.

To investigate the influence of user's spatial ability on the user's performance, this study accessed user's spatial ability using Tactual Performance Test (TPT) (refer Figure-3), also known as Form Board Test and Seguin-Goddard Formboard (Strauss, 2006) (Hebben, 2002) (Spreen, 1991). The test consisted of ten holes of board with ten shapes of blocks, instruction manual and scoring form.

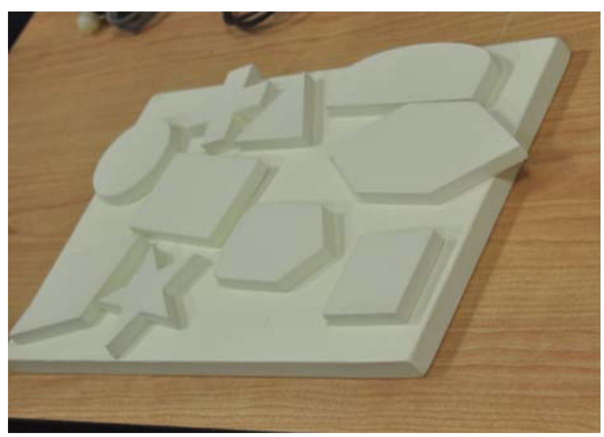

Figure-3. Tactual Performance Test kit.

The participant is presented with a block with holes and ten different blocks of shapes. The participant is instructed to insert the blocks as follows:

1. Using dominant hand only
2. Using non-dominant hand only
3. Using both hands

The blocks are placed in random order and a block should not be placed next to its matched hole. Participant's performance is reported in terms of total time to complete the insertion of 10 blocks for dominant, non-dominant and both hands. Stopwatch is used to clock the completion time and is recorded to the scoring form.

FINDINGS

The focus of this research is to investigate the mental model created by the blind people using touch screen with audio feedback. It discusses the results on the effect of using touching sense together with hearing sense to obtain the correct overview and sense of position of web pages, and the possible interaction effects between multi modal interaction and user's navigability.

Gaining overview

The first research question of this study was "How different are the orientations of a page obtained by the blind people when using touch screen with audio feedback as compared to screen-reader program only?" An indicator, which is the percentage of correct arrangements of diagrammatic representation, was used for measuring the orientation.

Experiments with 10 blind participants executing browsing task on 6 experimental pages showed that with touch screen with audio feedback, blind participants in this study constructed diagrammatic representation with significant accuracy. However this was only for simple web page layout. Although other pages except for unlinear layout showed better percentage of the correct arrangements of headings and cells using touch screen with audio feedback as compared to screen-reader program, the differences however were not statistically supported. One possibility for this outcome may be because the experiment was too short in terms of time for training for different types of layout. Moreover, only two types of layout were used in the training sessions (large region and complex unlinear layout), potentially resulting in a decrease in familiarity of different layouts.

From the result, this suggests that for better orientation using touch screen with audio feedback, simple layout should be used by the web designers.

Large region layout had recorded the highest accuracy by the blind users when using touch screen with audio feedback compared to other layouts. This particular layout reduced the quantity of information in the page so that it is easier for the blind people to scan the web page. This is consistent with other researches that claimed that a greater quantity of information is confusing and induces rapid scanning of the whole page (Borodin, 2007) (J. Mahmud, Borodin, Y., Ramakrishnan, I.V. and Das, D., 2007) (J. Mahmud, Borodin, Y. and Ramakrishnan, I.V., 2007). Furthermore, Miller's classic paper on The Magical Number Seven reported that only about seven (plus or minus two) pieces of information can be stored in short term memory at one time (Miller, 1956). Therefore, grouping the interrelated elements should be considered. By doing this, it could increase the amount of information to be retained in the blind users' memory (Balik, 2011).

Moreover, for small region layout, the "fat finger" symptom seems to be the main reason why the blind participants performed better using screen-reader program as compared to touch screen with audio feedback. For small region layout, the sequential access to the content seems more suitable and less confusing.

Complex unlinear layout had recorded the lowest accuracy by the blind users when using either screen-reader program or touch screen with audio feedback. This indicates that complex unlinear layout is difficult for the blind people and should be avoided by the web designers.

Data gathered from 30 sighted blindfolded participants showed that there are significant differences in orientation between screen-reader and touch screen with audio feedback. However, the significant differences are found only for complex unlinear layout, complex linear layout and simple layout. Statistical analysis found that the ability to use screen-reader program by the sighted blindfolded participants is poor, suggesting that their better orientation using touch-screen with audio feedback may be affected by their previous experiences on navigation in two dimensional perspectives. As suggested by Heller (1989), the blind people's visuo-spatial representations differ from sighted people's because the blind lack experience of external frame as reference cues. This includes knowledge of the horizontal and vertical that aids the construction of an object-centered representation (Rock, 1987).

Similar to the blind participants, the highest accuracy was recorded for large region layout by the sighted blindfolded participants. Sighted blindfolded outperformed blind participants on percentage of correct arrangement of diagrammatic representation for almost every layout, both using screen-reader program and touch screen with audio feedback. All sighted blindfolded participants utilized gliding gesture during exploration. It seems that the touch screen with audio feedback, with no direction constraints, allowed more accurate explorations, leading to higher scores of recognition. Although the touch screen with audio feedback does not offer any haptic feedback, the consistent position of the region on the tablet means those users can use kinesthetic sense (a sense pertaining to the position or movement of the body, the ability to know location and relative position) to communicate the layout of the page. Previous experience using mouse may facilitate the knowledge transfer for sighted blindfolded participants to understand and browse the layout Table more effectively.

Gaining detailed understanding of user's mental model may shed light on how to present information on the Web to make it accessible to different people and on how to create information structures that best support blind people's cognitive abilities. Most blind participants in this study had serial mental model of how information is organized on the Web. However, using touch screen with audio feedback, blind participants had vague two dimensional mental models and were unable to articulate that model similar to the one in sighted people's minds. The articulated models of two dimensional perspectives varied in complexity and some of them were not completely correct. Meanwhile, there were a few blind participants who had never considered the issue of information layout or could not articulate their thoughts in a spatial-based way. Training on using touch screen devices might be needed to help these blind participants gain a clearer picture of how information is organized on the Web. By constructing accurate two dimensional perspective of mental models, blind participants' tolerance of complex information layout on the Web could be improved, and they could be more comfortable with navigating the Web using touch screen with audio feedback and collaboration with their sighted counterpart might be possible.

Sense of Position

The second research question of this study was "How different the blind people locate the information when using touch screen with audio feedback as compared to screen-reader program only?" The second hypothesis of this study suggested that users utilizing two senses will have better sense of position of items on a web page. An indicator, which is the time taken to answer a question, was used for measuring the user's sense of position. The results from the blind participants for this hypothesis were not supported by the results. The results suggested that touch screen with audio feedback could not provide implicit location or position of information because the blind participants did not value the importance of spatial awareness.

The reason for this is not entirely clear, but it may well result from the unimportance of spatial awareness to the blind people. Few participants commented during the experiments that spatial awareness was not important and preferred to receive the information in serial order. This is possibly an effect of users' existing familiarity or current knowledge of the screen-reader program. Moreover existing users' mental models can either increase or decrease users' expectations of a system or technology (Carley, 1992) (Gentner, 1983) (Carroll, 1987).

Cattaneo *et al*. (2008) and (2010) believed that visual experience seems important to update spatial information efficiently. Although numerous studies have confirmed that congenitally blind people are able to generate visuospatial images, the performance however is lower as compared to sighted controls (Vecchi, 2001). Active visuospatial processes require modification and continuous update of mental representation (Vecchi, 2001). The results suggested that blind participants may have had prior knowledge of the screen-reader program and evaluated the multi-modal interaction in the experiments based on prior experience, thus skewing the results. This study also anticipated that the blind user's mental models are still new and continue to modify as discussed in (Norman, 1983) to get workable results.

Other than that, the reduction of confidence that the blind participants have when interacting with the environment without any haptic cues on the screen might be the other factor of poor performance. The smooth glass screen that the blind participants interact with is lacking of landmarks and requires pure spatial memory to support effective navigation (El-Glaly, 2013).

On the other hand, result from sighted blindfolded participants showed that there are significant differences in sense of position between the users of screen-reader program and the users of touch screen with audio feedback. Using touch screen with audio feedback, sighted blindfolded participants were able to locate the information statistically faster compared to screen-reader program. However, there is no significant difference found for small region layout. Some of the factors that might affect the results include familiarity with the task and the device used in the experiments, as well as the better mental strategies linked to male and young participants (Jonassen, 1996).

The inconsistency between these two groups could be attributed by different factors. The main factor could be attributed to the unfamiliarity of the blind users with the two dimensional navigation. The role of visual experience and the capacity to use visual imaginary strategies to cope with demanding tasks when interacting with multi modal system seem important as discussed previously. The use of touch screen with audio feedback with gliding gesture requires the rigorous coordination between horizontal and vertical scrolling. However, not all of the blind users appreciated this approach because they felt that the spatial information or default information distribution on a web page was not important. Since the majority of the blind users had never used a touch screen device with gliding gesture to access the Internet before, the mental model of a web page they have is still in serial order. It is envisaged that the blind participants would change their preferences if they are exposed to the touch screen device for a longer time.

Furthermore, blind participants are considerably slower at finding areas with specific information especially when involving values. Moreover there has been consistent evidence that blind people were able to construct and operate mental spatial imagery and pictorial imagery, but performed poorer than sighted people in demanding spatial tasks, such as mental rotation and scanning (Gottschling, 2006) (Heller, 1989) (Vanlierde, 2004). Previous researches on representation explanations emphasized that blind people and sighted people use different spatial representation formats (Zimler, 1983). For example, the most extreme version of the explanation proposed that the blind use "abstract semantic representations" whereas the sighted use analogue visuospatial representations (Zimler, 1983).

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Spatial ability effects

This study argues that blind participants with high level of spatial ability have more accurate orientation of a page and locate the information faster when using touch screen with audio feedback. Statistical results showed a positive correlation between users' spatial ability and time to locate information as predicted. However, an inconsistent correlation was found between users' spatial ability and correct percentage of diagrammatic representation. This may have been due to the fact that constructing diagrammatic representation is more difficult compared to finding a particular piece of information, especially when the blind participants were unfamiliar with the idea of diagrammatic representation.

Observation from video recording of navigation strategy, it seemed that people, who understood how the structure was semantically organized, developed good navigation strategies (Abidin Xie, H., and Wong, K.W., 2013). This resulted in faster and an increased number of successful searches. The diagram of the overall structure provides an indication of how subjects seemed to develop navigation strategies. Those who produced more detailed drawings, appear to perform better in the tasks given. However, the participant's memory may be influenced not only by information visualization but also by differences in individual ability and strategy.

Investigation using Pearson product-moment correlation coefficient found that blind participants' spatial ability plays an important determinant for web navigability using touch screen with audio feedback. This finding is consistent with other related work such as by Noordzij (2006) and McGookin (2008).

This finding also found that there is no consistent result on the relationship between blind people's spatial ability and correct overview of different experimental pages. The inconsistency of these findings might result from the fact that individuals with low spatial abilities have difficulties in constructing a visual mental model of the space, and they are more directed to the semantic content. Persons with impairment of visual-spatial abilities are often severely handicapped in terms of efficiency of functioning in a practical, everyday sense. The other reason might contribute from gender issue. Women reported higher levels of spatial anxiety, which is negatively related to the orientation way-finding strategy (Vecchi, 2001).

Noordzij *et al*. (2006) highlighted that the type of mental processing, either passive or active, might influence the construction of a spatial mental model. Passive processing refers to the maintenance and updating of visuospatial information in memory, whereas the active processing refers to the image generation and its organization. In tasks requiring passive processing of mental representations such as constructing the diagrammatic representation, the blind participants performed equally well using the screen-reader program and the touch-screen with audio feedback device. However, it is difficult for blind participants to perform tasks requiring active manipulation of visuospatial representations especially when trying to find a specific piece of information on the screen which is consistent with findings in (Vecchi, 2001) and (Noordzij, 2006). In this active visuospatial imagery task, blind participants performed at a lower level compared to sighted participants. Therefore, to improve the navigation performance of the blind people with low spatial ability, special tools should be provided to assist the exploration of web pages.

CONCLUSIONS

It seems clear that touch screen devices will become more and more common and essential to the everyday lives of Internet citizens. Therefore, ways must be found in which people with disabilities can participate equitably in the information economy. It is the responsibility of information providers and technologists to try in every way possible to assist this participation.

This study confirmed previous findings that the mental models of the screen-reader users are in a single column-like structure. However, expert and more experienced screen-reader users were able to imagine the layout in two-dimensional perspective although it was not 100% correct. Through a series of experiments, most blind participants agreed that touch screen with audio feedback is helpful in getting better orientation and better sense of position. However, lack of training in using touch screen devices and varied levels of their previous experience using screen-reader program contributed to the divergence of the comments. When accessing the web pages using touch screen with audio feedback, the size of the region plays an important role in assisting exploration process. If the size is too small, the users easily miss the neighborhood regions. Besides, page complexity seems to affect accuracy of overview.

This study also found that there is a significant interaction effect between a user's spatial ability and time to answer a question using touch screen with audio feedback, suggesting that a blind user's spatial ability has a potential moderating effect on his or her performance in using the touch screen with audio feedback.

Contrary to the screen reader program, which forces its user to access two-dimensional web content in a serial form, the touch screen with audio feedback has the potential to allow the blind user to access web content with two-dimensional perspective.

To support the use of touch screen devices by the blind people, researchers and designers need to work closely with the blind users. Most researchers and designers seem to prefer working with their own conceptualizations which we believe are not sufficient and accurate representations of how the blind users think and behave. Collaboration between the blind, rehabilitation and research communities is crucial. A collaborative design process is the best hope for developing good assistive devices. Designers of innovative devices must be ready to face a natural opposition to changes that go against conventional wisdom. Although input from the blind and rehabilitation communities is very important, going against accepted ideas may lead to interesting and valuable results. As a matter of fact, Braille's acceptance in the early stage was controversial and did not occur overnight.

Finally, on a practical level, designers could contribute to this process by grounding design models on users' models of tasks and the real world, and carefully engineering the system image to communicate that model. Systems developed in this manner are artifacts which would allow researchers to put the idea of conceptual design to test.

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