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DEVELOPING AN EXTENSION TO AN EXISTING TACTILE AUTHENTICATION MECHANISM TO SUPPORT NON-VISUAL INTERACTION

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ABSTRACT
Authentication mechanisms are often developed without taking into account the needs of users with visual disabilities. In this paper, we describe an extension to an existing tactile authentication system, with the aim of supporting non-visual interaction. Tactile icons are presented in a timed sequence at one fixed point on the interface, reducing the need to navigate using a mouse. Findings from an evaluation with 16 blind and blindfolded participants revealed that tactile authentication sequences (termed: tactile passwords) could be recognized over a month-long period, with a 76.8% rate of accuracy on the first attempt to access the system. While the approach was found to address security concerns identified through literature (e.g. threats from third parties and hidden cameras), findings have indicated that usability was compromised to achieve accessibility. The study has provided insights for interface designers interested in developing inclusive authentication mechanisms using touch.

KEY WORDS
Accessibility, Accommodating People with Disabilities, Tactile Interfaces, User Authentication

1. Introduction

'Strong' alphanumeric passwords are recommended by organizations in order to enable users to access personal data securely. However, difficulties are often faced when recalling the many passwords which are needed for daily tasks. The memory burden imposed may unintentionally sway users toward less secure behavior [4]. To reduce the likelihood of making errors during the authentication process, practices such as writing down or sharing passwords, and reusing the same passwords for multiple systems, have become more common [1,4]. For individuals who are blind, additional challenges are encountered when accessing authentication mechanisms, which negatively impact the interaction experience. The difficulties are in part attributed to the following:

- The restrictions imposed by assistive technologies;
- The inappropriate design of authentication interfaces;
- The threat of attack from observers, hidden cameras, and keylogging software [28].

In this paper, we aim to address the barriers to access faced by individuals who are blind, through the development of an extension to an existing tactile authentication interface (A-TAS). Findings from an evaluation to determine the feasibility of the non-visual interface are also described.

1.1 Assistive Technologies

Screen reading solutions are often used by individuals who are blind, to translate visual content from the interface into an accessible format. However, the restrictions imposed by these applications can lead to levels of frustration among users [19]. Examples include difficulties navigating through content, as the user is required to move sequentially from object-to-object using keystrokes rather than interacting with a mouse. As a result, targeting items of interest on 'busy' interfaces can be a time-consuming process. The user may also have to negotiate extraneous information from menu bars or adverts, to locate the target, which can impact the subjective user experience.

The process of completing form fields (e.g. log-in pages) can also pose a challenge to users. To enter data into forms, the user must switch from 'reading' mode to 'edit' mode [31]. After entering data, the user may double-check that the data has been successfully entered in the box adjacent to the label, by changing modes once more. The switching process for every field in a form has been noted as an annoyance [31], adding to the cognitive burden faced with using a screen reader.

1.2 Interface Design

Subtle graphical cues, which are often presented by privacy and security tools [26], can also be difficult to access unless labeled appropriately. As many web applications use AJAX technologies to dynamically refresh content on a web site, updates can be difficult to identify using a screen reader. As a result, sites heavily dependent on asynchronous Javascript and XML (AJAX) are less likely to be visited by blind users [6]. According to Sauer et al. [26], timeouts and automatic refreshes coded into web applications, can cause the screen reader to lose its relative position within the web page, meaning that the user may be forced to repeat the task, after the time limit has expired.

1.3 Threats to Security

Attacks from third parties (e.g. shoulder surfers) remain a constant security threat for blind and sighted users alike. However, while sighted users may notice the presence of cameras recording password entry, these may go unnoticed by blind users [28]. Saxena and Watt [28] researchers suggest that spyware monitoring password entry, may be challenging to detect via a screen reader. If blind users have a negative view of online security, confidence in their ability to make appropriate decisions may be limited [26], with users relying on trusted sighted peers for support when accessing web authentication mechanisms.

1.4 Additional Factors

Auditory interfaces have been developed to address the challenges faced by blind users, when resolving CAPTCHAs [5, 26]). While these solutions are valuable, they rely on the user to wear headphones, to reduce the risk of third parties accessing secure data. However, during the interaction, environmental sounds may be attenuated or occluded, and observational attacks may still go unnoticed as the user may be engrossed within the task, so unaware of the environment around him/her.

1.5 The Need for an Accessible Solution

Although awareness is growing, surrounding the need to design for diverse users, interface designers often find themselves in a situation where they are forced to choose security goals over their conflicting access-oriented goals [15]. Individuals who are blind favor performing tasks independently, rather than relying on sighted users to aid them with computing interactions. A need has been identified for an accessible authentication solution, which addresses issues of security, memorability and accessibility.

Tactile interfaces have been designed to support blind users when interacting with graphical interfaces, by enabling users to 'visualize' information through their sense of touch. Research also suggests that tactile stimuli are known to be memorable over both short and long periods [11, 17], providing a discrete means of presenting information to the user. In this paper, we examine the feasibility of tactile stimuli presented within a timed sequence, to support the non-visual authentication process. The research described in this paper, represents the first step towards developing an authentication solution to support the needs of individuals who are blind.

2. Related Work

2.1 Accessible Authentication Interfaces

Authentication technologies have been adapted to provide a non-visual representation of content to aid blind consumers. For example, specific Automated Teller Machines (ATMs) offer the ability to use a headset in order to perceive voice guidance to use the interface[1]. Buttons with Braille labels are used to enter data and complete transactions. As an alternative to inaccessible numerical code generators (e.g. SecurID[2]) which are used to secure entry to online banking systems, the Xi-Sign 4500[3] device synthesizes text containing the user's one-time piece of secure information calculated by the user's banking card. The device reads back the transaction logs from the card so a user can audibly check the amounts charged to the card. While both solutions offer potential to individuals who are blind, they do not eliminate the issue of 'shoulder surfing', where observers may view and potentially recreate authentication information.

2.2 Tactile Authentication Interfaces

Research has shown that tactile technologies can play a significant role in the authentication process. Examples include the system developed by Deyle and Roth [10], where users where asked to use their sense of touch, to identify the status of pins (e.g. raised or lowered), and respond by selecting buttons to indicate their judgments. Entry to the system could be authorized depending on user performance. Bianchi et al. [3] have described the design of a haptic keyboard, which can be used to support the authentication process. Passwords are encoded as a sequence of randomized vibration patterns perceived underneath the fingertips. An evaluation of this system shows it outperforms previous interfaces which have used tactile feedback to obfuscate passwords. de Luca et al. [9] have developed a tactile authentication interface, which addresses the shoulder-surfing threat. Vibrations are presented via a mobile device, indicating to the trusted user whether he/she should enter the correct PIN digit or password character, or whether redundant information should be inputted instead. The user's password or PIN will appear to be different to the previous entry, making it more difficult for unauthorized individuals to recreate the authentication sequence [17].

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[1] Bank of America - http://www.bankofamerica.com/accessiblebanking
[2] RSA SecurID - http://www.rsa.com/node.aspx?id=1156
[3] Xiring - http://www.xiring.com/

2.3 Tactile Authentication System (TAS)

In an earlier study [17], we described the design of a web-based tactile authentication prototype (TAS), where the user is presented with pin-based feedback (e.g. similar to Braille characters) via a tactile mouse. The password is composed of a sequence of four tactile icons (tactons). The interface design is based on the PassFaces system [22], where the user is required to scan four on-screen grids. Each grid contains nine colored squares mapped to different tactons (Figure 1). The user is required to select one tacton from each grid, which corresponds to tactons within his/her pre-selected password, to successfully enter the system (Figure 2). As the position of tactons within each grid are randomized, the user is required to rely on his/her sense of touch to recognize his/her pre-selected cues from the wider range presented.

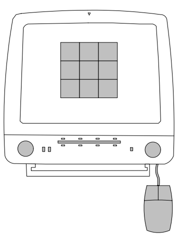

Figure 1. TAS system displaying grid of tactile stimuli

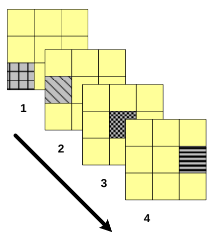

Figure 2. Example of authentication sequence to enter system

A usability study was conducted, where 16 sighted participants were asked to log-in to the system over a month-long period. While findings showed that low levels of error were experienced during the authentication process, distractions were faced when attempting to identify tactons, while moving the mouse around the interface [17]. As a result, task time was impacted, due to the complex tactual scanning process adopted (Figure 3).

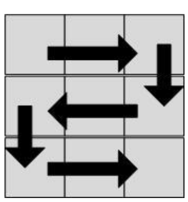

Figure 3. Participants moved sequentially from square-to-square to identify tactons corresponding to effects within their pre-selected tactile passwords.

One issue highlighted within the evaluation was the usage of the tactile mouse for both perceiving feedback and for navigating content on the page. The dual function served by the device, was thought to impact accessibility, particularly for individuals with visual and motor disabilities. Suggestions for improvement included presenting tactile feedback in sets of timed sequences at one fixed point on the interface. Keystrokes could be performed to navigate around the interface. In the research described in this paper, we aim to specifically address the needs of users with visual disabilities, by providing the structural and contextual information necessary to support interaction in the absence of visual cues.

2.4 Tactile Display Design

Tactile interfaces have been developed where information is presented both spatially and temporally to the user. Examples include the tactile belt developed by Srikulwong et al. [30], where tactons presented at points around the waist would indicate the direction for the user to navigate towards. Using a similar concept, van Erp and van Veen [33] developed tactile rhythms presented via a tactile matrix to provide an eyes-free method of informing the users of course changes while driving. The combination of spatially and temporally presented feedback provides a wide array of potential tactile mappings, which may aid interaction with an interface, by reducing the burden on the other senses.

Interface designers are aware of the challenges which can be faced when attempting to process temporally-presented tactile information over long periods of time. Examples include issues of fatigue or pain caused by actively perceiving feedback on the display. In terms of design guidance, research suggests that temporal intervals as small as 1.4ms can be resolved by users [34,16]. However, if stimuli are presented in succession, without a sufficient delay, changes can be difficult to detect, as identified by Gallace et al. [14]. Temporal resolution abilities vary amongst individuals, depending on location presented on the body, experience with tactile feedback, and other factors associated with age and disease identified by Brewster et al. [8].

In this paper, an extension to an existing tactile authentication interface is described. The interface aims to address users' perceptual capabilities, with the aim of improving the subjective experience for blind users when interacting with authentication mechanisms.

3. Study Design

The study aimed to examine the feasibility of using a set of tactons presented in a timed sequence to aid non-visual interaction. The study also offered the opportunity to identify differences in tactile perceptual performance between blind and sighted users, in the absence of visual cues.

3.1 Apparatus and Materials

A Tactile Authentication System, developed in our earlier study [17], was extended to address the needs of individuals who are blind (A-TAS). The VT Player device (Figure 4) interfaces with the web-based tactile authentication mechanism, presenting tactile feedback underneath the user's fingertips. The device consists of an optical mouse with two adjacent four-by-four matrices of pins on the top of the device. The pins can be raised or lowered, to provide a tactile representation of information on a graphical interface as the mouse is moved around it [25]. A set of raised pins can be arranged to form static patterns (Figure 5 – top), or alternatively can be designed to change state over time, providing dynamic cues (Figure 5 - bottom).

Figure 4. VT Player tactile mouse (Virtouch Ltd. [35]; Pietrzak et al. [24])

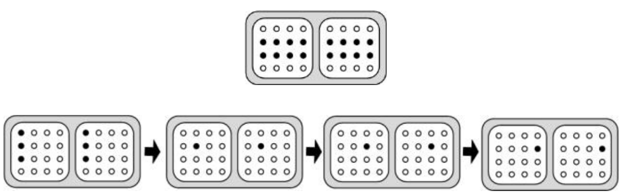

Figure 5. Static (top) and dynamic refreshable patterns (bottom) used within the system. Filled-in circles indicate raised pins.

A-TAS requires the user to interact with either keystrokes or a computer mouse to explore the interface using the non-dominant hand, while the VT Player device presents authentication information under the fingertips on the dominant hand. The VT Player is kept stationary at all points.

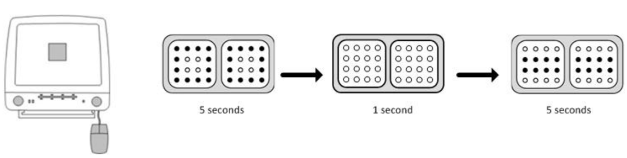

Figure 6. As the user hovers over one point on the graphical interface (gray square in center of screen), tactons are presented for five seconds, followed by a one second interval where no feedback is presented.

To access the system, the user identifies his/her name from a drop-down list. The names are presented using speech-based feedback from the Microsoft Speech SDK. In A-TAS, the user is presented with tactile feedback at one fixed point on the screen (not visible to the user, but marked by a gray-coloured square for purposes of this paper). A set of nine stimuli are presented in a timed sequence underneath the fingertips. Each tacton is played for a period of five seconds, followed by a one second gap interval where the pins are lowered. The next stimulus is then presented (Figure 6). These values were determined through our pilot studies, to ensure that participants were able to differentiate between each tacton presented [18]. Care was taken not to present tactons in quick succession, to reduce the risk of adding to the user's cognitive burden.

The user is asked to select one tacton from the sequence which corresponds to a tacton in his/her 'tactile password'. The mouse button is then selected. An auditory icon is then played to indicate that a new set of nine tactons are to be presented. The user must then use his/her sense of touch to identify the second tacton from his/her own tactile password. The user then repeats the process of identifying his/her preselected stimuli, until four tactons have been selected (Figure 7). If the four tactons selected correspond to the user's own tactile password, entry is granted to the system, indicated through auditory feedback. If an error has been made, the user is automatically redirected to the starting page, and can repeat the entry process.

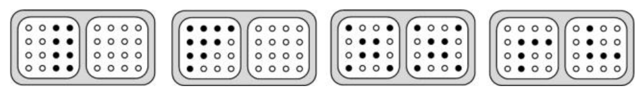

Figure 7. Tactile password consisting of four pre-selected tactile stimuli. Filled-in circles indicate raised pins.

Tactons are presented in a randomized order within each sequence of nine stimuli, meaning that each time users attempt to enter the system, they will have to locate their chosen stimulus through the sense of touch alone, rather than relying on the temporal position of tactile cues in each sequence. If an inaccurate attempt has been made, the user has two more chances to enter his/her tactile password. The user may abort the attempt, or reset the password by selecting buttons on the interface. Other instructions for usage of the interface are presented through speech-based cues.

3.2 Participants

Due to some of the difficulties faced with recruiting target users, fourteen fully-sighted volunteers (aged between 18-59) were selected, who would be blindfolded for all tasks. Two legally-blind participants (1 congenitally blind, 1 adventitiously blind), aged between 20 and 29 were also recruited. Both participants used screen readers to access graphical content on interfaces, due to their limited level of residual vision. The participant who was congenitally blind was able to read printed Braille. Both had experience of using a force-feedback mouse, one month prior to the study described in this paper. However, neither had previously interacted with a tactile mouse, or had used one prior for purposes of authentication.

3.3 Procedure

Participants were provided with fifteen minutes of initial training on the VT Player mouse, to expose them to a wide array of tactile stimuli and test basic recognition abilities. Tactile cues were presented to the dominant hand, while the computer mouse was placed in the non-dominant hand for purposes of navigation.

To enrol in the system, participants were asked to select four tactons, from a selection of thirty-six pin patterns. Tactons were presented consecutively, for five seconds each, with an interval of one second between cues, where all pins were lowered (Figure 6). Participants were then questioned on their reasons for selection of their tactile password. In order to commit the tactile password to memory, participants underwent a rehearsal phase, where they were presented with a sequence of tactile pin patterns from the original 36 tactons. They were asked to identify each of the four pre-selected tactons forming their tactile password. Participants were then asked to repeat this procedure ten times, to commit the tactile password to memory.

Participants were asked to log-in to the system every working day (Monday to Friday) for two weeks, and once at the end of the fourth week, following a procedure adapted from Valentine [32] and Brostoff and Sasse [7]. At all points, the time taken and number of errors made were logged using the system. After completion of the study, a questionnaire was presented to determine levels of perceived security when interacting with the interface and mental workload needed to interact with the system.

4. Results

4.1 Performance and Time Taken

Results presented in Table 1 show that all sixteen participants were able to enter A-TAS over the course of the four week trial. No tactile password resets were required, as entry could be made within the three attempt limit. From the total of 187 attempts to access the system, 76.8% of tactile passwords were accurately selected on the first attempt. By the second attempt, the rate of accurate entry had increased to 90.4%, with 100% accurately entered by the third attempt.

The highest levels of accurate entry on the first attempt, were recorded on Day 1 (88.2%) after rehearsal of the tactile password, and on Day 4 (100%). Findings suggested that levels declined most when there were longer periods between entry (e.g. the gap of the weekend (Day 5 to Day 8 -7.2%, and the 2-week gap between Day 12 and 28 (8.9%)). In a similar fashion, the average time taken to authenticate entry increased during these gaps (Day 5 to Day 8 - M: 9.5s, SD: 16.2s) and (Day 12 – Day 28 - M: 3.3s, SD: 33.0s). The longest average time taken to authenticate entry to the system was on Day 8 (M: 153.7s, SD: 48.8s), where one participant was noted to spend up to 239.0 seconds entering her password.

Table 1. Percentage of successful entries to the system by attempt

	First attempt (%)	**By the second attempt (%)**	**By the third attempt (%)**
Day 1	88.2	100.0	N/A
Day 2	81.3	81.3	100.0
Day 3	82.4	82.4	100.0
Day 4	100.0	N/A	N/A
Day 5	72.2	83.3	100.0
Day 8	65.0	85.0	100.0
Day 9	72.2	83.3	100.0
Day 10	61.1	83.3	100.0
Day 11	87.5	100.0	N/A
Day 12	86.7	100.0	N/A
Day 28	77.8	100.0	N/A

4.2 Usability, Security and Trust

Findings from the post-task questionnaire suggested that all sixteen participants expressed confidence in interacting with the tactile stimuli presented by the interface, and confidence in using the system without the assistance from a researcher. While eleven participants were satisfied with the ease of use of the system, seven agreed with the statement that minor levels of overload where experienced, due to the concentration required focusing on discerning between tactile cues over a long duration.

In terms of perceived security, all sixteen participants agreed with the statement that they felt more secure using tactile authentication compared to conventional alphanumeric passwords and PINs used at an ATM. However, when participants were asked to rate their levels of trust within the system, eleven out of sixteen were able to support the statement. Trust is discussed in more detail in Section 5.4.

5. Discussion

5.1 Rate of Recognition

Participants spent up to 45 minutes in training to use the system, setting up their tactile password and rehearsing it ten times in sequence. The period of training and rehearsal of information was influential to helping participant commit stimuli to memory, as lower levels of error were experienced in Day 1, and all participants were able to authenticate access by the second attempt, in contrast with Days 2-3 and 5-10). A comparison was conducted with findings from our earlier study [17] where users were required to tactually scan a set of four grids presented on the interface (TAS). TAS users were able to achieve stronger levels of accuracy on the first attempt to enter the system (92.9%), within a shorter period of time (M: 38.2s, SD: 15.1s), compared to A-TAS, where participants spent on average up to three times longer selecting a tactile password to enter the system (M: 135.2s, SD: 39.7s).

5.2 Password Selection Time

In terms of time taken, lower levels of deviation were experienced in Week 2 (23.7s), compared with Week 1 (46.9s). While the trend in deviation could in part be attributed to the randomized presentation of tactons within a timed sequence (i.e. pre-selected stimuli may appear sooner or later within the sequences presented), comments from four participants indicated that towards the beginning of the trial, time would be spent double-checking tactons presented via the tactile mouse. If a pre-selected tacton from the user's own tactile password was detected, they would prefer to spend time verifying the pattern, rather than haphazardly selecting the tacton, only to find out that it was incorrect. If the process took longer than the five second presentation limit for each pattern, they would have to wait until the pattern next appeared in the timed sequence, in-part contributing to the longer time spent entering tactile passwords in Week 1.

The time taken to select and enter tactile passwords was found to negatively impact the usability of the solution. Three participants brought up the issue of the need to perform online transactions within a short period of time, particularly due to the presence of timeouts on specific web sites. They were able to offer suggestions to expedite tactile password entry time. Examples included the customization of tacton presentation speed for more experienced users, or the use of a larger tactile display to make patterns easier, and therefore faster to differentiate between.

Research suggests that additional time may be taken by disabled users, when resolving information presented in a non-visual format. Bigham and Cavender [5] identified that blind participants spent almost five times longer than their sighted counterparts resolving auditory CAPTCHAs. Participants in the study reported by Sauer et al. [27] spent on average 65.64 seconds on each task. While task time is often used as an indicator of usability, this cannot be the sole definitive measure for a system's success, when the application is targeted to the needs of disabled users. The ability to perform tasks in their entirety, and strategies employed by users to solve technical challenges should also be considered, when determining the usability of an accessible solution.

5.3 Usability of the A-TAS Mechanism

A total of ten self-resets were logged by the system, six in Week 1 and four in Week 2. Six of these resets were performed by two blindfolded sighted participants, who were asked to suggest ways in which the solution could be better designed to support their needs. Participant #7 stated that he would often double-click the tactile mouse button instead of performing the single-click needed to select a tacton from the timed sequence. The result would be selecting two tactile patterns instead of the one he had meant to choose (e.g. one stimulus from one sequence, followed by another stimulus from a second sequence). Once the error was detected, he aborted each of the three attempts made.

Ten participants agreed with the statement that tactile stimuli were distinguishable from one another, and could be discerned using active tactile perception (i.e. continuously moving the fingers around the contactor pads). The six who did not support the statement, described issues when differentiating between dynamically-presented stimuli due to the short period of presentation of each tacton. This was evidenced by tactile password choices. Only seven participants had selected one or more dynamic tactons as part of their personal passwords, while the remainder opted for four static tactons. Analysis of the password choices revealed the three animated stimuli shown in Figure 8, were not selected in any of the participants' tactile passwords. As all three were presented in the third sequence of nine tactons presented via the system, it is possible due to a combination of similarity to one another, and spatial and temporal challenges processing cues, that participants believed that fewer errors would occur should a static tacton be selected instead.

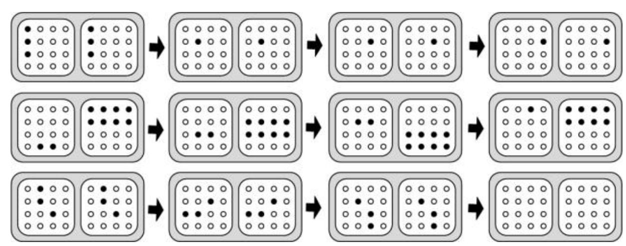

Figure 8. Three sets of dynamic cues which were not selected in participants' passwords.

5.4 Perceived Security and Trust

During the training process, participants were asked to describe the tactile password selected. The majority expressed difficulties verbalizing or drawing cues, resorting to making hand gestures or sounds to convey the stimuli selected. Descriptions tended to vary from participant-to-participant, even if similar cues had been selected to form a tactile password. Tactons were described in terms of objects or concepts which provided a sense of meaning to the individual user (i.e. pin pattern is car or cloud shaped). This was thought to offer a sense of assurance that even if they disclosed a password to a third party, the likelihood of it being replicated would be minimal.

In terms of perceived security from onlookers, participants suggested that as tactile cues were presented underneath the fingertips, observers would not be able to view and recreate stimuli. Furthermore, this would also address issues of hidden cameras recording entry.

Research suggests that alongside issues of security, trust is an important factor when interacting with online banking mechanisms (Nilsson et al. [21]). The researchers have identified a range of specific factors relating to interface design which can impact system usage (e.g. inadequate feedback and lack of control). In our study, eleven participants expressed greater levels of trust using tactile feedback to enter the authentication mechanism, compared to conventional alphanumeric passwords on an online system, or PINs at an ATM. Suggestions were made that the physical nature of the tactile device itself, combined with the tangible cues which could be perceived under the fingertips, contributed to the higher level of trust that was developed.

5.5 Performance of Blind vs Sighted Participants

Research suggests that recruiting individuals with disabilities to participate in user studies can be challenging. Sears and Hanson [29] suggest that reasons may be attributed to the limited number of representative users with the specific condition, and the practical difficulties of bringing individuals to a specific location for laboratory testing. As a result, blindfolded sighted users are often recruited for preliminary or exploratory studies, to examine the usability of non-visual interfaces (e.g. [12]).

In our study, we compared the performance of blind and blindfolded sighted participants, as we wanted to determine the feasibility of the A-TAS solution. The two blind participants opted to use the multi-device approach, rather than using keystrokes. They were on average found to achieve similar levels of accuracy on their first attempt to enter the system (81.8%) when compared with their sighted counterparts (78.4%). However, slightly more time was taken by blind participants to authenticate entry to the system (141.6s, SD: 53.8s) compared to sighted participants (M: 135.0s, SD: 38.7s). Performance time could have been influenced by the novelty of using two input/output devices to access the interface (i.e. mouse for navigation in non-dominant hand, and the VT Player in the dominant hand). Although a small sample size was selected, as variations between performance of both groups were limited, we judged these levels as comparable. The results have added to the body of research highlighting the practicalities of performing preliminary studies with non-representative users, if target users cannot be identified.

When asked to describe the benefits that the solution offered, the congenitally blind participant suggested that it would enable her to access personal information, without the need of a trusted sighted peer or a helpdesk attendant to assist her. The independence offered would enable her to access web sites which she was effectively barred from. She mentioned that currently, considerable time was spent checking the labels associated with form boxes on web-based authentication mechanisms, to ensure that the user name and password data were being entered in the correct boxes. While the tactile solution would not specifically address the labelling issue, it would allow her to focus on entering her tactile password, without the anxiety of wondering whether third parties were monitoring her data, as information would be presented underneath the fingertips, out of sight. The second participant, who had experienced sight in earlier life, suggested that the system design would enable both blind and sighted users to access data in a similar way. He appreciated the minimal use of headphones in the system. This was not due to worries over the attenuation of ambient sounds, but more so with the attention drawn to his disability by using headphones over a prolonged period in a public place.

Strategies to perceive tactile feedback were observed to vary among the blind participants. The congenitally blind participant opted to place the index finger from each hand on to the contactor pads on the mouse. In the post-task interview, she suggested that as she read Braille and processed raised paper diagrams using both hands, it was natural for her to use both index fingers for resolving tactile patterns. When asked whether her experience with Braille placed her at an advantage when using the system, she stated that towards the beginning of the trial, minor levels of confusion were experienced as she was expecting Braille, but resolving arbitrarily-designed tactile symbols instead. Similar to the blindfolded sighted users, the adventitiously blind participant opted retain one hand on the tactile mouse at all times. Post-task interviews revealed his worries about losing focus when navigating the interface, so keeping the non-dominant hand firmly on the ordinary computer mouse, enabled him to orientate position on the interface.

While our study did not specifically examine the user's ability to form a mental structural representation of interface layout, previous work has shown differences in mental structural representations between congenitally and adventitiously blind users. Afonso et al. [2] found that while spatial configurations could be conceptualized by both sighted and blind users when performing haptic exploration tasks, in contrast to the sighted and adventitiously blind groups, congenitally blind users were found to experience issues representing the concept of distance between objects. It has been acknowledged that in our study, sighted users may have been at an advantage to their blind counterparts, as they had experienced the spatially-distributed nature of web page content in the past. This may have influenced their navigation around the web pages for the task presented. However, the A-TAS interface was designed to minimize navigation where possible. All tactile information was presented within the center of the screen in sequence, allowing the user to remain in a fixed position to perceive and select the tactile stimuli.

Studies by Petrie and Kheir [23] have shown that certain usability problems are common among both sighted and blind groups when accessing web sites. The researchers suggest that different groups are affected by these problems differently, often amplified among individuals with disabilities. Findings from our study suggested that all users, regardless of level of sight, were affected by the tactual scanning time needed to explore cues. Theofanos and Redish [31] have suggested that in order to bridge the 'disability divide', blind users should play a more prominent role in the design and evaluation processes, to assess that assistive solutions match the needs of the target users. Metrics have also been proposed for evaluators to ensure consistency between accessibility and usability [13,20]. However, difficulties can be faced by designers when evaluating their systems against these criteria, as it may not be possible to design a 'one size fits all' solution for individuals with disabilities. Our solution has specifically examined needs of individuals who are blind.

5.5 Tactile Perception

Participants experienced confusion differentiating between specific stimuli, resulting in multiple attempts to be made to authenticate entry to the system. Figure 9 (left) shows all thirty two pins raised, forming the shape of two squares. This was confused with the eight pins forming the general outline of a square (Figure 9 – right). A post-task interview with the two participants who made this error suggested that they discerned between stimuli by examining the 'outline of objects', rather than exploring the interior. For other stimuli (e.g. Figure 10), confusion was caused as the patterns formed were similar in appearance, but presented at different locations on the contactor pads. Participants suggested that spatializing the position of pins presented via the mouse could be time-consuming, and anxieties over by-passing the five second display period of each tacton, prompted participants to select an incorrect tactile pattern.

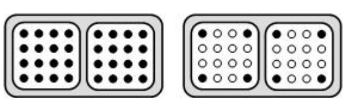

Figure 9. Confusion experienced between pattern composed of 32 raised pins (left), and pins with information presented at the edges

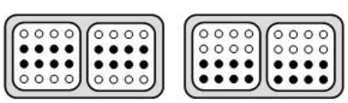

Figure 10. Confusion experienced between patterns

When asked in more detail about the challenges discerning between patterns, participants suggested problems were attributed to the proximity of pins to one another on each matrix, which could cause some pins to be blocked from tactile view. Comments were made about the limitations of the device, as only a fixed range of patterns could be presented due to the number of pins housed within each matrix. A longer interval period was recommended between presentation of each stimulus, as one way of improving recognition accuracy. However, this would impact the task time. In a study by Gallace et al. [14], participants were unable to reliably detect simple tactile pattern changes, when the interval between successive pattern presentations was atleast 800ms long. The authors have suggested that ramifications may be more severe in real world situations, such as noisy environments and instances the manipulation of perceptual load may be higher (e.g. when using an ATM in public). The results from our study highlight that care should be taken in the design of tactile cues to address human perceptual constraints. Tactile effects should be tested appropriately to ensure they are discernable from one another, under a range of contexts.

While tactile displays offer a discrete and affordable means of providing information to users, due to their compact size and power requirements [8], difficulties are known to be faced when using the hardware itself, and when resolving tactile cues presented by the displays. Findings from our study revealed that participants favored using the multi-device approach, as it enabled them to concentrate on the tactile cues presented using their dominant hand, yet allowed the flexibility to use the ordinary computer mouse for navigation or exploration around the interface. The multi-device approach could be used by both sighted and blind users. However, as many blind screen reader users are unfamiliar with using a mouse, a period of training may be needed to support their exploration of the interface.

6. Conclusions and Future Work

An extension has been developed for the Tactile Authentication System, to address the needs of blind users, through the presentation of timed-sequences of tactile cues at a fixed point on the interface. Findings have shown that tactile passwords could be committed to memory, and replicated over a four week period. The discrete presentation of tactons, enabled participants to feel that cues could be shielded from observers and hidden cameras. However, findings suggested that in order to achieve accessibility, usability was compromised. Our findings have provided insights for interface designers interested in developing inclusive authentication systems using touch-based feedback.

Future work will examine ways to improve selection time, through modifying the tacton presentation rate. We also aim to examine whether the tactile bandwidth can be widened through the use of larger tactile displays, and to study the impact of whether by manipulating the range of tactile patterns, security, memorability and usability are impacted.

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