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Investigation of dynamic three-dimensional tangible touchscreens: Usability and feasibility

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Investigation of dynamic three-dimensional tangible touchscreens: usability and feasibility

by

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Abstract

The ability for touchscreen controls to move from two physical dimensions to three dimensions may soon be possible. Though solutions exist for enhanced tactile touchscreen interaction using vibrotactile devices, no definitive commercial solution yet exists for providing real, physical shape to the virtual buttons on a touchscreen display. Of the many next steps in interface technology, this paper concentrates on the path leading to tangible, dynamic, touchscreen surfaces. An experiment was performed that explores the usage differences between a flat surface touchscreen and one augmented with raised surface controls. The results were mixed. The combination of tactile-visual modalities had a negative effect on task completion time when visual attention was focused on a single task (single target task time increased by 8% and the serial target task time increased by 6%). On the other hand, the dual modality had a positive effect on error rate when visual attention was divided between two tasks (the serial target error rate decreased by 50%). In addition to the experiment, this study also investigated the feasibility of creating a dynamic, three dimensional, tangible touchscreen. A new interface solution may be possible by inverting the traditional touchscreen architecture and integrating emerging technologies such as organic light emitting diode (OLED) displays and electrorheological fluid based tactile pins.

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1 Introduction

One of the great advantages of a touchscreen interface is the incredible amount of functionality that can be presented. Popular touchscreen smart phones are single platforms that can replace a cell phone, MP3 player, personal digital assistant (PDA), digital camera and more. The physical buttons that once controlled these individual features are replaced by virtual button interfaces on the touchscreen. What is gained in features however may be lost in feel. The rich visual content not only excludes those who are visually impaired but the lack of tactile cues means the touchscreen monopolizes visual attention. Perhaps it would be useful to merge the visual display with a dynamic tactile display -- a touchscreen with a three-dimensional (3D) tangible surface.

Nashel & Razzaque (2003) had a similar idea and presented a technique that used vibrotactile sensation to provide button location and activation cues on a mobile phone interface. Vibrotactile technology is a captivating solution that is gaining popularity as a tactile feedback solution, yet it requires sensing a touch before providing a tactile cue. This inherent feedback actuation of a vibrotactile device may not fully replace the benefits of a physical 3D surface.

An investigation of a dynamic 3D tangible touchscreen shows the idea is not well represented in literature or industry. The primary reason is the lack of a viable technical solution. Touchscreen architecture is rigid. Dynamic 3D surfaces are large and bulky. Also the benefits of such a device may not be obvious. Smooth surface touchscreens appear to be well received in the marketplace, for example the popular Apple iPhone as shown in Figure 1.

Figure 1: Apple iPhone (Apple iPhone, 2008)

This paper investigates the related research, usability and feasibility of a general purpose, dynamic 3D tangible touchscreen. A usability experiment with a simulated 3D touchscreen surface provides a first glance at this problem space and lays a foundation for further studies. In addition, requirements and a possible technical solution are proposed. The next section provides the perspective and context in which this idea was formed.

2 Background and Related Work

In an address to the Association of Computing Machinery (ACM), Roel Vertegaal aptly stated there must be a Moore's law equivalent for the growing number of computers per user (Vertegaal, 2003). Home computers, work computers, smart phones, and gaming systems are part of our modern tool/toy boxes. Also add the consumer machines with which we interact, such as grocery checkout kiosks, automatic teller machines, even gas station pumps. Each interface is most likely very different from the next. Joined by increasing functionality and variability caused by the original Moore's law, our routine machine interactions require increasingly more cognitive resources to process.

User interfaces that interact with multiple senses may help handle this interface overload. Multisensory, also called multimodal, interfaces are popular topics in recent human-machine studies and for good reason; there is growing physical evidence that our bodies are wired for this multi-input mode (Burke, et al., 2006; Fisher, Fels, MacLean, Munzner, & Rensink, 2004). Classical theory of neurological sensory processing favors a single modality model; it views the primary sensor areas in the cortex as unisensory (McGraw-Hill, 2004). In this model the primary somatosensory (sensory stimuli from the skin) cortex processes touch input, the primary visual cortex, vision and primary auditory cortex, hearing. It is thought that these inputs are handled separately and integrated into a complete picture by higher level neurological functions. Recent studies, however, suggest that these primary areas are actually multisensory; the other senses enhance the primary modality (Ghazanfar & Schroeder, 2006). For example, areas of the primary visual cortex are activated during tactile perception. It supports the idea that our visual processing is affected by somatosensory information. Perhaps the visual experience of a touchscreen interface may be improved by enhancing the tactile interaction.

2.1 Tangible and virtual controls

To help describe tactile interaction, this paper defines the term *control* as an object we use to manipulate and interact with our environment. Controls may be tangible objects such as door knobs, on/off buttons or a light switch. Tangible controls have primarily physical properties and typically maintain their manufactured shape and feel. Controls may also be virtual. They exist in computer memory, are viewed through a display and have visual and sometimes auditory properties. The play button on a PC's media player and the lighter/darker setting in a copier touchscreen are examples of virtual controls. The advantage of these virtual controls is the ability to change their shape, size, color, and behavior based on state or sensor values. This application of closed-loop control theory on virtual objects allows them to react appropriately within their environment. For example when a PC is busy performing an operation, the cursor changes from an arrow to a twirling hourglass and mouse selections are disabled.

2.2 Haptics, Tangible User Interfaces and the Virtual Continuum

Combine the closed-loop behavior of virtual controls with the tangible properties of the physical controls and you enter the growing world of haptics. Haptics is the study of tactile sensation. In practice it is the application of dynamic tactile sensation to controls. For example, steering wheel game controllers will shake if your virtual racecar drives over grass.

A related area of haptics is called tangible user interfaces. As defined by the Tangible Media Group at the Massachusetts Institute of Technology (MIT), these interfaces are the "physical embodiments of digital information" (Tangible Media Group, 2008). For example the metaDesk platform is a horizontal flat panel display that recognizes and responds to physical icon (phicon) movement on the surface (Ishii, 2002). Phicons, which may look like board game pieces, can be used to manipulate a map displayed on the surface or to play games that change the underlying display of the board.

To place haptics and tangible user interfaces in perspective, a simple visualization by Milgram, Takemura, Utsumi, & Kishino (1995) shown in Figure 2 illustrates the continuous scale of interfaces between reality (tangible controls) and virtual reality (virtual controls). Though Milgram et al. (1995) introduced the continuum and defined the terms for describing visual displays, these concepts have evolved to represent all variations in input and output interface development, including auditory and tactile modalities (Azuma, 2004).

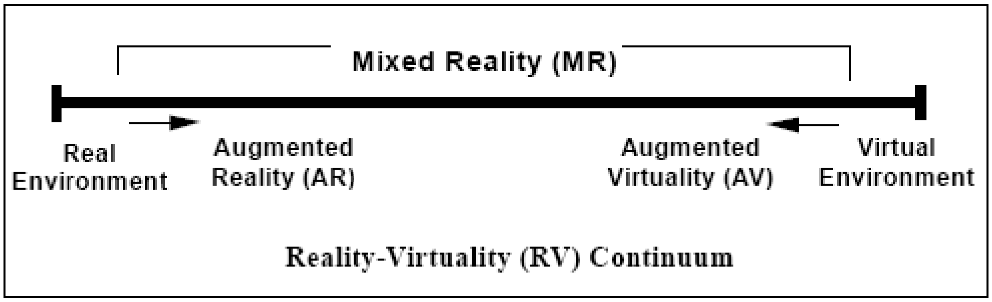

Figure 2: Reality-Virtuality Continuum (Milgram et al. 1995)

According to the model, augmented reality is where the virtual augments the real. Most of the work in this area is with digital enhancement of a real video signal. For example a TV broadcast of an American football game shows a computer generated first down line on the playing field. Further along the continuum, augmented virtuality is where real augments virtual objects. For example, cell phones with vibrotactile feedback will vibrate when a touchscreen button is selected (Merrett, 2007). The difference between these augmented terms is disappearing and the middle space merging reality and virtuality is more commonly called 'mixed reality.'

Single modality interfaces such as the purely visual TV first down line example populate the mixed reality area but there are new and interesting opportunities with the multimodal interfaces. For example a tactile-visual interface mentioned by Azuma (2007) uses hand gestures to manipulate the visual presentation of data in 3D space. Or a visual-auditory combination on a GPS device that provides both visual and oral directions. This paper concentrates on a tactile-visual interface -- enhancing the tactile modality of a touchscreen interface. We put this work in context by first discussing the development and maturity of the research performed in the three primary modalities evident in typical computer user interfaces.

2.3 Visual Modality

Of the three main interface modalities, visual output attributes of user interfaces has the most established and developed body of knowledge. Since 1995 the Institute of Electrical and Electronic Engineers (IEEE) has supported at least one forum dedicated to information visualization. Research of appropriate color usage, layout, and visual effects has evolved into commonly used practices that apply to all types of displays. For example, MacDonald (1999) explains that usage should consider color's positive and negative associations, text should be high contrast, and color choice is not as important as color consistency on all screens. More recent visualization research is centered on multimodal interfaces and how to integrate the modalities (e.g. Bouchet, Nigay, & Ganille, 2004; Ernst, 2005; Fisher et al., 2004; Massaro, 2004).

2.4 Auditory Modality

Audio enhancement of user interfaces, like the visual output modality, has a well developed technical foundation able to produce high quality and varied output. However the academic research and usability guidelines for the auditory modality are not as well established. One explanation is that sound typically plays a supporting role in multimodal devices. Brewster, Lumsden and colleagues in the Multimodal Interaction Group at the University of Glasgow, Scotland have an extensive body of work and comprehensive bibliography on sound and human computer interfaces (Brewster, 2008).

Interestingly some of the design issues for audio feedback, termed earcons, are similar to graphical guidelines. These include consistency across the user interface, avoid overloading the senses, and creating mappings that are simple and obvious (Lumsden, Brewster, Crease & Gray, 2002). Other guidelines are specific to the medium dealing with attributes such as timbre, tempo, accentuation and elongation. Building on these foundations of audio feedback, a significant area of research is dedicated to auditory interfaces for visually impaired users (Asakawa, Takagi, Ino, & Ifukube, 2002; Donker, Klante, & Gorny, 2002; Edwards & Mitsopoulos, 2005). Mynatt and Edwards (1992) introduced the term auditory user interface and proposed a graphical to audio mapping. This work is important because the popularity of graphical user interfaces (GUIs) has left out those that can not rely on visual sensory processing.

2.5 Tactile Modality

The visual and auditory modalities discussed are output mechanisms for typical computer user interfaces. A color change confirms a button selection. A short beep provides notification of a mistake. Touch has been primarily responsible for activation and manipulation. In the personal computing era, activation was dominated by indirect touch through keyboards and mice. Specifications are well developed and documented. Keyboards standards are defined by ISO/IEC 9241-4 for ergonomic requirements (ISO, 1998) and by ISO/IED 9995 for keyboard layouts (ISO, 2002). The mouse developed in the 1960s by Douglas Engelbart and popularized by the Apple Macintosh has been occasionally equipped with haptic feedback but is still primarily an x-y space pointing device (Dictionary of Multimedia and Internet Applications, 1999). As we move toward the ubiquitous computing era and more direct manipulation of controls, touch not only controls activation but also begins to enhance perception through feedback. As a result there is a growing interest in haptic and tangible user interfaces. Part of this growth includes improvements in touchscreen surfaces and touch sensing technology.

Smooth and durable surfaces appear to be one of the major touchscreen attributes in current systems. Early touchscreens used infrared touch sensing technology but among other problems suffered from parallax (Hartson & Hix, 1993). Today more accurate touch sensitive technologies such as resistive, capacitive, infrared, surface wave and, more recently, acoustic pulse recognition are available. These high precision, glossy surfaces present a smooth tactile feel but may not be the best interface solution for all situations or populations because of their lack of tactile cues.

Serving visually degraded situations such as multitasking environments, remote sensing or medical limitations, tactile enhancements of the smooth touchscreen surfaces are slowly entering the marketplace. Vibrotactile is the first commercially viable haptic feedback technology for touchscreens. Embedded piezo actuators shake the device which is felt directly by touch or indirectly with a stylus. Because research in this technology is addressing the same usability and feasibility issues as this thesis, there are a number of relevant studies.

Brewster, Chohan, & Brown (2007) studied laboratory and mobile environments of Personal Digital Assistants (PDAs) enhanced with vibrotactile feedback. The results showed that performance (# lines entered, total errors, corrections made) was improved in the laboratory test with vibrotactile feedback. Interestingly, the same positive laboratory results were not observed in a real-world environment but the qualitative responses showed that the subjects favored the tactile feedback.

Leung, MacLean, Bertelsen, & Saubhasik (2007) also studied vibrotactile feedback on a PDA and results were somewhat similar. The Leung experiment involved testing vibrotactile feedback with buttons, progress bars and scroll bars under varying levels of cognitive load. Performance measures included response time, task completion time, and accuracy. The vibrotactile feedback showed improvements with the scroll bar but many of the results were neutral. The increased levels of cognitive load showed no improvement with the vibrotactile feedback but again, in qualitative comments, the subjects preferred the tactile feedback.

The Brewster and Lueng studies both tested devices using stylus input. An interesting application by Poupyrev, Maruyama, & Rekimoto (2002) tested item selection from a list by tilting a handheld device – the variable vibrotactile feedback helped identify the item's location. Poupyrev's emphasis is somewhat different than the others in that it concentrates on a supportive, or as they call it, ambient channel of communication. In multimodal interface tests it is important to understand the supportive and destructive relationships of the different modalities.

Pin arrays are another solution for dynamic tactile feedback, though minimal research has paired them with touchscreens (Iwata, Yano, Nakaizumi, & Kawamura, 2001). Pin arrays may prove to be the best solution for creating 3D shapes with a touchscreen. Studies of these devices in context with other 3D shape ideas are reviewed in more detail in section 6.2 Solutions.

For any 3D shape device, a critical parameter is height. The control must be high enough to improve usability yet technically feasible. The human fingertip is quite adept at detecting small disruptions on a smooth surface. For example in analyzing the human mechanoreceptors for fine-surface texture recognition, Kawamura, Ohka, Miyaoka, & Mitsuya (1996) reported that an uneven surface of $3\mu m$ in amplitude is perceptible. The height of controls on actual three dimensional displays is much greater. The electronic Braille dot height standard is 0.8 mm (RNIB, 2007). Pin-based three dimensional tactile displays analyzed by Kammermeier and Schmidt (2002) show height ranges to 4*mm*. Table 1 summarizes the height ranges of these pin-based systems.

Table 1: Height Ranges of Pin-based 3D Tactile Displays

Device	Heights
TACTACT36, 6x6 tactile actuator array	0.5 – 1.6 mm
TACTACT4, 2x2 tactile actuator array	0 – 4 mm
BRUTUS, the Braille Module Actuator System	0.7 mm
VIRTOUCH Mouse	0 - ~1 mm

The height of controls in consumer products greatly varies with no single optimal setting across applications or even within the same application. A telling example, the Microsoft Windows Vista Hardware specification for a specialized control key defines over six variations of keyboard key styles, with no specific requirement for height (Windows Logo Program, 2007). A study of cell phone key height shows that heights of 0.3, 0.5 and 0.7*mm* are indistinguishable in performance tests yet the higher keys are considered more accessible (Tomioka, 2004). Based on these studies and the Braille specification, heights below 1*mm* is the space to be investigated.

2.6 Summary and Problem Definition

As our increasing knowledge of physical sensory processing continues to feed the development of haptic and tangible interfaces, usability studies are needed to ensure proper application and placement. This thesis investigated 3D tangible surfaces for touchscreens by addressing two questions.

1. Is the usability of a touchscreen surface improved with raised shapes augmenting the virtual controls?
2. Is it possible to create dynamic physical shapes on a touchscreen surface?

This study addressed the usability question by describing an experiment measuring performance, accuracy and user preference of a flat surface touchscreen versus a raised surface touchscreen. Feasibility is addressed by suggesting requirements for a dynamic 3D tangible touchscreen and reviewing key technologies that could support this type of interface.

3 Experimental Design

3.1 Objective

The purpose of this experiment was to understand the differences of performance and user preference between a flat surface and a raised surface touchscreen. Subjects performed simple target selection tests under single and dual tasking scenarios on a touchscreen platform. The test was designed to investigate a variety of typical touchscreen interactions.

3.2 Parameters

3.2.1 *Response Parameters*

Quantitative response parameters included time to complete a target selection task (task time) and target selection error rate. For a given task, a lower task time is associated with an easier to use interface. A higher error rate may be an indication of a hard to use or poorly designed interface.

Qualitative measures were results of a short questionnaire and debriefing session. The questionnaire consisted of three questions about tactile cues and this specific experimental setup. The questionnaire is shown in Appendix B. The debriefing session was an unstructured discussion about the test and the subject's opinion on tactile cues.

It was not the intent of this study to promote the importance of one measure over the other, rather to report the results of different measures. Importance may be application dependent. For example a low error rate may be very important when entering a Personal Identification Number (PIN) but less so when sending a text message.

3.2.2 *Control Parameters*

The control parameters selected for this experiment covered a typical range of basic interactions. The first and most critical was surface type with values of flat or raised. The second parameter was the number of targets to be selected with values of 1 target (single) or 5 targets (serial). The third control parameter was task type which varies between single task and dual task mode. Target and task type are explained further below.

3.3 Test Matrix

To understand a variety of touchscreen interactions, the experiment evaluated four application areas combining levels of target and task type. These segments are shown in Table 2 and further explained below.

Table 2: Task Target Mapping

	Single task	Dual task	
Single target	*flat vs. raised*	*flat vs. raised*	Feature selection, confirmation, cancel, interrupt
Serial target	*flat vs. raised*	*flat vs. raised*	Entering PINs, names, search terms
	Visually focused environments: office, industrial machines	Distracting environments: mobile devices, vehicle interfaces	**Applications**

3.3.1 Flat vs. Raised

The flat surface was the unmodified plane of the touchscreen. There was no physical or audible feedback when a button was selected. The raised surface was created by overlaying a thin transparent sheet enhanced with physical buttons that corresponded to the virtual buttons on the touchscreen display.

3.3.2 Single and Serial Target Selection

The highly configurable touchscreen GUI has a wide variety of control behaviors including menus, scrolling lists, sliders, radio buttons, menu selection, toggle, on/off, confirmation/cancellation, and text entry. This experiment limited the control interaction to single and serial target selection for two reasons. First, simple selection widgets are good candidates for applying shapes because of consistent button sizes, straight-forward actuation behavior and simple response behavior. Second, this interaction builds on previous touchscreen usability studies to provide consistency in user interface evaluation. Colle and Hiszem (2004) tested 1, 4 and 10 digit strings when investigating optimal touchscreen key size and spacing. Parhi, Karlson, & Bederson (2006) used the terms discrete and serial target selection in another study to understand optimal keysize for one-handed thumb use of small touchscreen devices. Their discrete target was one digit entry and the serial target was a four digit entry. Schedlbauer (2007) used a nine alphanumeric string entry to test keysize and spacing for touchpad and trackball performance and accuracy.

This study evaluated single (one target) and serial (five targets) selections. Single item selection simulates an alternative menu selection (Colle & Hiszem, 2004) or activating buttons, radio buttons and checkboxes (Parhi et al., 2006). Serial target selection simulates text entry (Parhi et al., 2006) and requires more planning and programming of motor sequences (Colle & Hiszem, 2004).

3.3.3 Single Task and Dual Task

In addition to variations in target selection, touchscreen applications are found in scenarios with a wide range of visual attention. Dedicated tasks such as an art museum kiosk or an ATM machine may command full visual attention. This study investigated this scenario to understand if a tactile modality improves usability in a predominately visual task. Towards the other end of the visual attention scale are interfaces in automobiles or mobile phone interfaces. The purpose of the second task was to periodically divert visual attention away from the touchscreen task. This mode attempted to simulate a distracting environment and provide an opportunity for the subject to rely more on his/her tactile sense for target selection.

3.4 Test Platform and Setup

3.4.1 Equipment

The equipment consisted of an Elo Touch Systems touchscreen monitor (AccuTouch Five-Wire Resistive) controlled by a Dell Latitude laptop. The Dell laptop (747 MHz CPU, 128 RAM) was running Windows XP and Java 6. The touchscreen was placed on a conference room or lab table and positioned at a 10 degree angle towards the participant. Participants sat in front of the tilted touchscreen display and interacted with it using their right hand. When multitasking, the second task was performed with their left hand. The setup is shown in Figure 3. The coin dish and grid paper were used for multitasking.

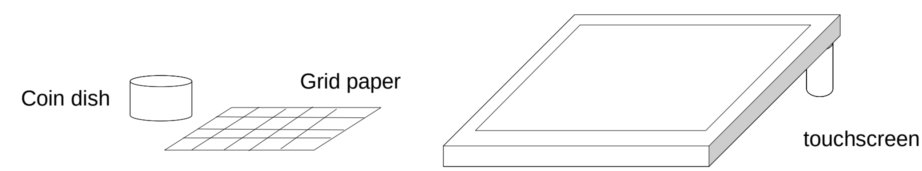

Figure 3: Touchscreen test set-up

The touchscreen interface was written in Java and consisted of five primary sections, as shown in Figure 4.

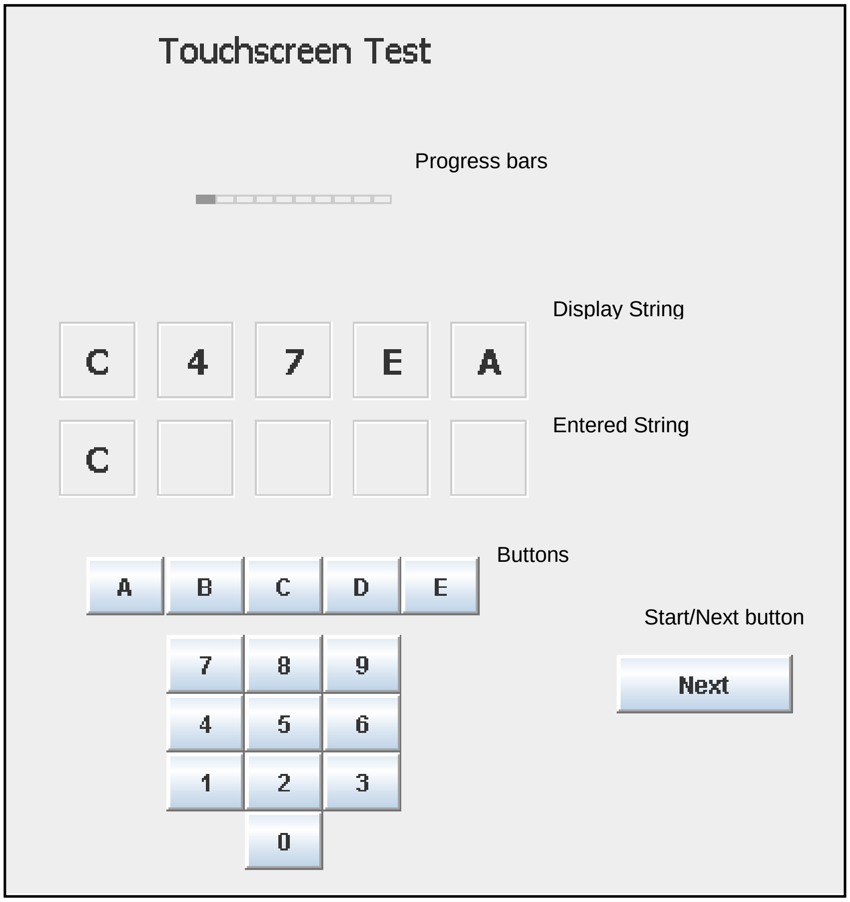

Figure 4: Touchscreen Test Interface

Progress bars are below the Touchscreen Test label. Figure 4 shows one sequence has been completed. Below the progress bars is a set of boxes that displays the characters to be entered. In Figure 4 the characters to be entered are C47EA. The next set of boxes below displays the characters entered by the subject. In Figure 4 character C was selected. The selection buttons consist of 15 alphanumeric characters A-E on the top row and 0-9 in a calculator layout. These virtual buttons measure 11x15*mm* (length x width). The last section is the Start/Next button, in Figure 4 the label is Next. This button measures 11x35*mm* (length x width). No visual or auditory feedback was provided when a button was pressed. Button activation occurred on release.

3.4.2 Overlay

The overlay design and implementation was obviously a critical factor in the experiment. The intent was to create simple tactile cues that may be technically feasible in a first generation surface. Requirements that guided the development of the overlay are listed in Table 3.

Table 3: Touchscreen Overlay Requirements

	Requirements
1.	The raised shape shall identify the virtual control space
2.	The raised shape shall minimize visual interference
3.	The raised shape shall either enhance or at least not detract from the existing flat surface control actuation,
4.	The raised shape shall be easy to identify by touch but not cause overly negative interference over the plane of the surface
5.	The raised surface heights should be less than 1*mm*

The raised surface was created by laying a standard overhead transparency sheet over the touchscreen. On the transparency were small, dome shaped buttons created by clear acrylic nail polish, as shown in Figure 5. As a result of this simple creation process, total control of button height could not be achieved. The average button diameter was 5.3*mm* (*sd* = 0.29) and the average height was 0.56*mm* (*sd*=0.03). Button dimensions were measured with a micrometer. This height was appropriate based on the requirement that button height shall be below 1*mm*.

Note the button labels were shifted to the left because the clear buttons had a slight magnifying effect. Many overlay/shape combinations were attempted to create a simple, smooth, yet noticeable button that would not interfere with the actuation mechanism of the touchscreen. The transparency/polish combination was the most practical solution for this experiment.

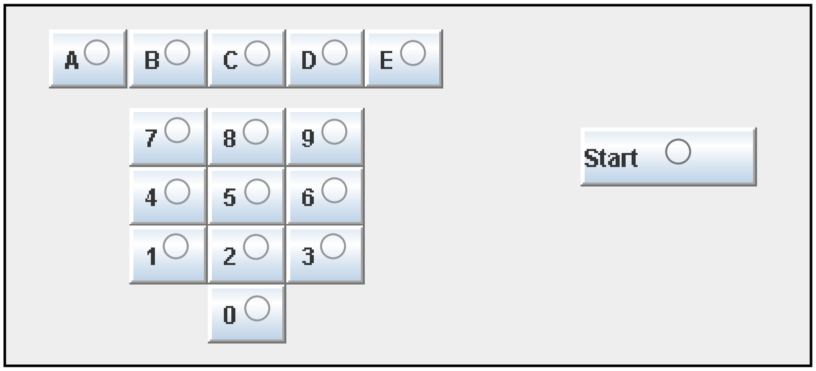

Figure 5: Shape Overlay

3.4.3 Dual Task Description

The second task for the dual task mode must be controlled by the left hand and it must be simple to perform and simple to verify. The task consisted of a cup of pennies and a sequentially numbered grid on an 8.5”x11” piece of paper (shown in Figure 3). The cup and paper were to the left of the touchscreen monitor. The subjects were instructed to pick-up one coin at a time using their left hand and place the coin heads-up in the grid, covering the next available sequential number. When describing this task the subject was told to “spend at least half your attention on this task.”

3.5 Subject Profile

Eighteen subjects (12 male, 6 female) from a software/engineering organization and students and faculty from the Rochester Institute of Technology (RIT) participated in this experiment. All participants were right-handed. The mean age was 31. Age information was recorded using six ranges, not specific values. Figure 6 shows the age ranges and distribution. Participation was voluntary and subjects were not compensated.

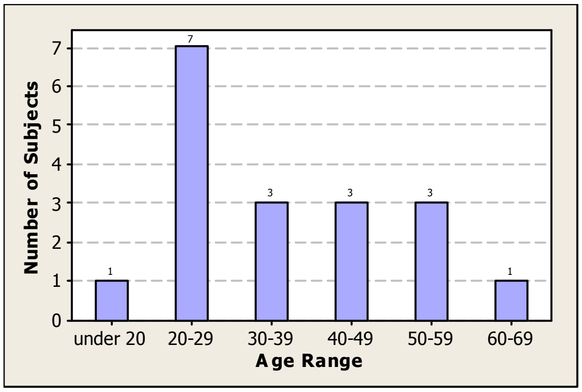

Figure 6: Test Subject Age Distribution

3.6 General Procedure

Upon arriving to the test location, the subjects read and signed the waiver/consent form, the tester described the setup, the subjects followed a simple training process and then performed the test. After the test the subjects answered a simple questionnaire and participated in a short debriefing. The procedure is listed below in Table 4. The entire procedure required about 30 minutes.

Table 4: Experimental Procedure

*The four trials were randomly ordered to eliminate a learning bias.

Order	Experimental Steps
1	Consent/Waiver Form
2	Training
3-6	Trial without shape overlay & single task*
3-6	Trial without shape overlay & dual task*
3-6	Trial with shape overlay & single task*
3-6	Trial with shape overlay & dual task*
7	Questionnaire and debriefing

The training consisted of single and serial target selection, using the touchscreen with and without the overlay, performing the coin task alone then finally performing the dual task with the coin and touchscreen tasks.

After the training session, the test was divided into four trials. For all combinations of experimental conditions, a trial consisted of 30 single target selections and then 10 serial target selections. The trial variations were a combination of flat (no overlay) vs. raised surface (overlay) and single tasking vs. dual tasking.

3.6.1 Single Target

The single target test required the subject to select Start, select the character displayed, select Next (which caused the next character to be displayed), select the next character displayed and so on for 30 selections. Each of the 15 alphanumeric characters was presented twice in random order. Requiring subjects to press the Next button between each target selection eliminated any movement time variation because the target selection always originated from the same point on the screen. Incorrect target selections were displayed and recorded but the subject was not allowed to backspace or correct.

Performance of the single target selection was measured in milliseconds from the release of the Start/Next button to the release of the selected button. Errors were recorded as binary values, 0 if no error (correct target selection) and 1 if error (incorrect target selection). The error rate for each segment and surface type (flat or raised) is measured as the total errors/total targets. For example, if 3 out of the 30 single target selections were incorrect, the error rate would be 3/30 or 10%.

3.6.2 Serial Target

The serial target test required the subject to select Start, then enter a sequence of five characters, select Next (which caused the next set of characters to be displayed), enter the next sequence and so on for 10 sequences. The ten serial sequences were randomly created then hard-coded in the software. Each sequence was fixed but the order in which they were presented was randomized for each trial.

Serial target selection performance was measured in milliseconds from the release of the Start/Next button to the release of the last button in a sequence. An error is defined as a sequence with one or more incorrect values. The analogy is entering a PIN number. If one or more of the PIN values is incorrect, then the whole PIN is incorrect. The error rate for each segment and surface type (flat or raised) was measured as the total incorrect sequences/total number of sequences. For example if two button selections in one sequence were incorrect, that one sequence would be incorrect. If no other errors were made and there were 10 total sequences, the error rate would be 1/10 or 10%.

4 Experimental Results

4.1 Overview

This section provides an overview of the experimental results. The following four sections provide detailed results for each application area. The last section reports the questionnaire results.

A tabular summary of task time and error rate is presented in Table 5.

Table 5: Summary of Task Time and Error Rate Measures

	Task Time (flat – raised)		Error Rate (flat – raised)	
	Mean difference	Paired sample *t*-test result	Mean difference	Paired sample *t*-test result
Single target, single task	-85 *ms*	$p = 0.000$	-0.7%	$p = 0.104$
Single target, dual task	116 *ms*	$p = 0.439$	-0.2%	$p = 0.826$
Serial target, single task	-273 *ms*	$p = 0.037$	-1.7%	$p = 0.331$
Serial target, dual task	-358 *ms*	$p = 0.381$	5.0%	$p = 0.035$

The task time columns show the mean difference in milliseconds between the flat and raised touchscreen surfaces and the *p*-value for the paired sample *t*-test. A negative task time difference indicates the flat surface task completion time was faster (lower) than the raised surface completion time. A graphical summary of task time is presented in Figure 7. The paired samples *t*-test was selected for the analysis because it accounts for the variation between subjects.

The error rate columns in Table 5 show the percentage difference between the flat and raised touchscreen surface and the p-value for the paired sample t-test. A negative error rate difference indicates the flat surface error rate was lower than the raised surface error rate. A graphical summary of the error rate is presented in Figure 8.

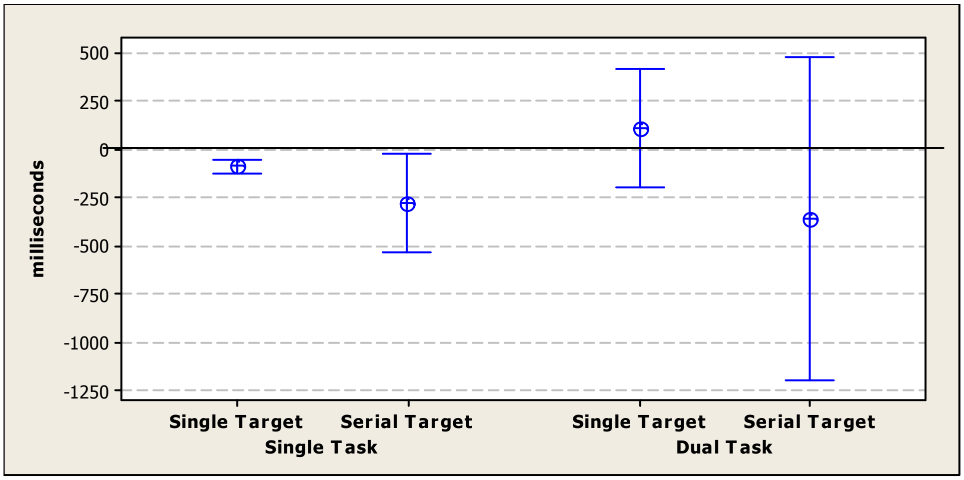

Figure 7: Graphical Summary of Task Time Mean Differences (95% CI)

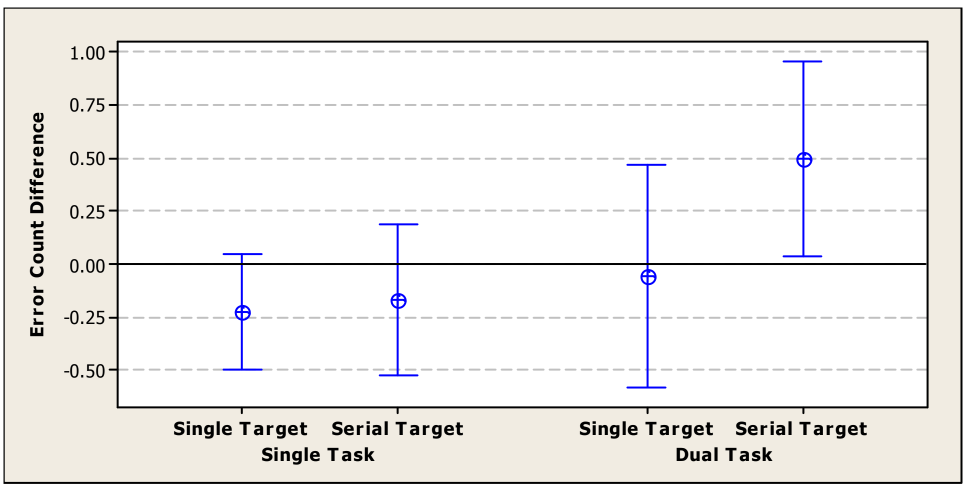

Figure 8: Graphical Summary of Error Rate Differences (95% CI)

4.2 Single Target Selection - Single Task

Figure 9 presents the task completion time differences between the surfaces for single target selection when performing a single task. The mean for single target selection time was 1062*ms* (*sd*=212) for the flat surface and 1147*ms* (*sd*=228) for the raised surface. The mean difference of time(*flat*) – time(*raised*) was -85*ms*. A paired samples *t*-test (H0: diff=0, H1: diff $\neq$ 0) indicated that the increase of the raised surface selection time was significant (*p*=0.000).

The scatter chart shows each subject's mean task completion time for the two surfaces and the time difference. Dots on the y=x line indicate no difference in task completion time between the two surfaces. Dots below the y=x line indicate the flat surface task completion time was faster. Dots above the y=x line indicate the raised surface task completion time was faster.

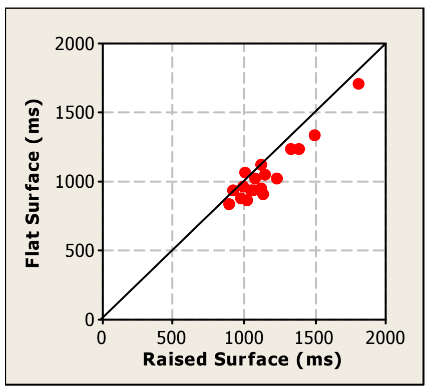

Figure 9: Task Time Scatter Chart – Single Target, Single Task

The single target error rate was 0.19% for the flat surface and 0.93% for the raised surface. A paired samples t-test (H0: diff=0, H1: diff $\neq$ 0) showed that the error rate difference between the surfaces was not statistically significant (p=0.104).

4.3 Single Target Selection - Dual Task

Figure 10 presents the task completion time differences between the surfaces for single target selection when performing dual tasks. The mean for single target selection time was 2283*ms* (*sd*=965) for the flat surface and 2167*ms* (*sd*=691) for the raised surface. The mean difference of time(*flat*) – time(*raised*) was 116*ms*. A paired samples *t*-test (H0: diff=0, H1: diff $\neq$ 0) shows that the decrease in time with the raised surface was not statistically significant (p=0.439).

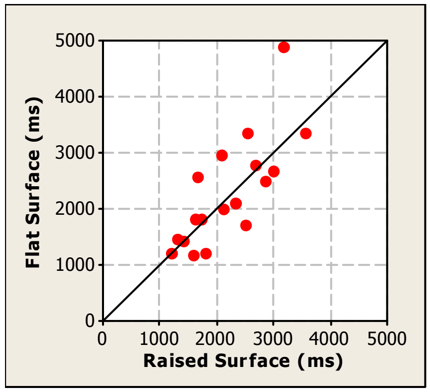

Figure 10: Task Time Scatter Chart- Single Target, Dual Task

The single target error rate was 0.74% for the flat surface and 0.93% for the raised surface. A paired samples *t*-test (H0: diff=0, H1: diff $\neq$ 0) shows the difference between the surfaces was not statistically significant (p=0.826).

4.4 Serial Target Selection - Single Task

Figure 11 presents the task completion time differences between the surfaces for serial target selection when performing a single task. The mean for single target selection time was 4641*ms* (*sd*=1425) for the flat surface and 4914*ms* (*sd*=1241) for the raised surface. The mean difference of time(*flat*) – time(*raised*) was -273*ms*. A paired samples *t*-test (H0: diff=0, H1: diff $\neq$ 0) showed that the increase in time with the raised surface was significant (p=0.037).

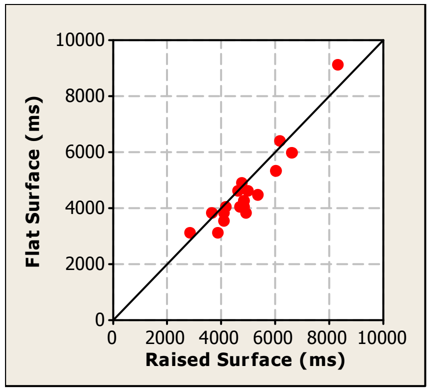

Figure 11: Task Time Scatter Chart – Serial Target, Single Task

The serial target selection error rate was 3.9% for the flat surface and 5.6% for the raised surface. A paired samples *t*-test (H0: diff=0, H1: diff $\neq$ 0) shows the error rate difference between the surfaces was not statistically significant (p=0.331).

4.5 Serial Target Selection – Dual Task

Figure 12 presents the task completion time differences between the surfaces for serial target selection when performing a single task. The mean for single target selection time was 7863*ms* (*sd* = 4423) for the flat surface and 8221*ms* (*sd* = 4078) for the raised surface. The mean difference of time(*flat*) – time(*raised*) was -358*ms*. A paired samples *t*-test (H0: diff=0, H1: diff $\neq$ 0) showed no statistically significant difference in task completion time between the flat and raised surface (p=0.381).

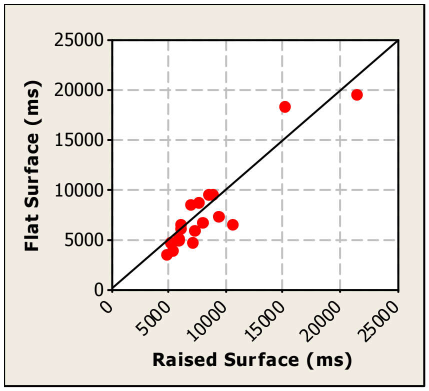

Figure 12: Task Time Scatter Chart – Serial Target, Dual Task

The serial target selection error rate when multitasking was 10% for the flat surface and 5% for the raised surface. A paired samples *t*-test (H0: diff=0, H1: diff $\neq$ 0) showed that the decreased error rate with the raised surface was significant (p=0.035).

4.6 Questionnaire

The three questions and their results are shown below. A histogram of each answer is displayed. The scale is 1 (strongly disagree), 2 (disagree), 3 (neutral), 4 (agree), 5 (strongly agree). The questionnaire is shown in Appendix B.

<u>Q1. I prefer a touchscreen with some type of tactile cues.</u>

Figure 13 shows the Likert scale responses to question 1. The mode is 4 (agree). Ten of eighteen subjects agreed that tactile cues on a touchscreen are preferable. The purpose of this question was to separate the specific experience of the touchscreen test from their general opinion of tactile cues. Generally people said they prefer interfaces with tactile cues. Interestingly one gentleman who owned an Apple iPhone certainly did not like the raised surface touchscreen. The iPhone is controlled exclusively through a touchscreen. Cell phone keypads were the most common interface mentioned in response to this question.

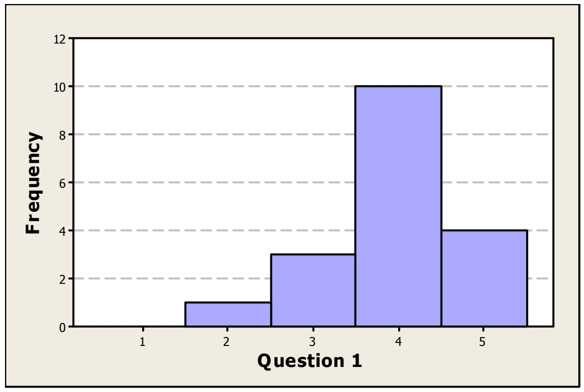

Figure 13: Question 1 Response Frequency Chart

<u>Q2. When multitasking, the raised buttons made the touchscreen easier to use</u>.

Figure 14 shows the Likert scale responses to question 2. The mode is 4 (agree). Eleven of eighteen subjects agreed that the tactile cues were helpful during the dual task trials. One purpose of questions 2 and 3 was to learn if there was a stronger opinion of tactile cues in the dual task trials. Since the responses to both questions are similar, the conclusion is the task mode did not affect tactile cue opinion in this experiment.

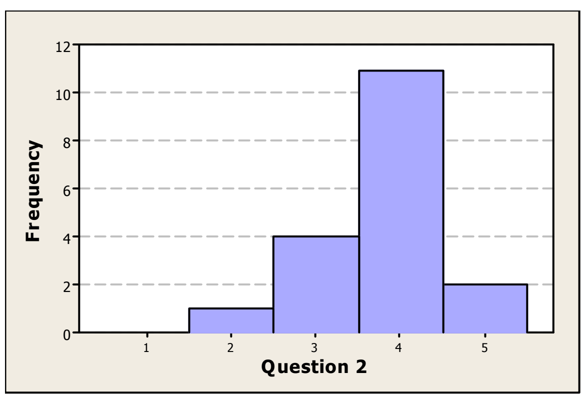

Figure 14: Question 2 Response Frequency Chart

Q3. Overall the raised buttons made the touchscreen easier to use.

Figure 15 shows the Likert scale responses to question 3. The mode is 4 (agree). Ten of eighteen subjects agreed that the tactile cues were helpful. Variation in responses can be caused by different interpretations of the questions. For this question, some subjects responded favorably because they liked the Start/Next tactile cue, but were not necessarily in favor of the keypad raised surfaces.

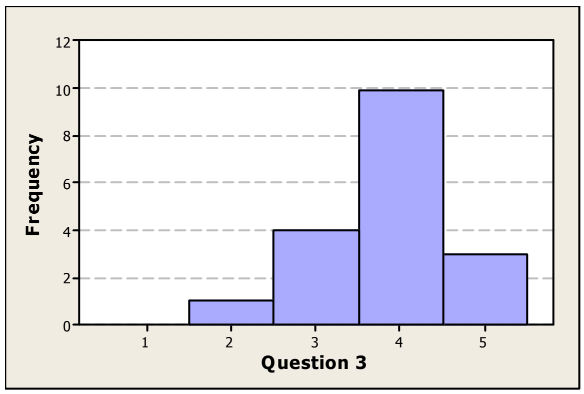

Figure 15: Question 3 Response Frequency Chart

5 Analysis and Discussion

5.1 Data Analysis and Test Summary

A summary of the experimental results using the application matrix is shown in Table 6. A value of *flat* means the flat surface performed better, *raised* means the raised surface performed better and *no difference* means there was no statistically significant difference between the surfaces.

Table 6: Experimental Results Summary

	Single Task		Dual Task	
	Task Time	Error rate	Task Time	Error rate
Single Target	*flat*	*no difference*	*no difference*	*no difference*
Serial Target	*flat*	*no difference*	*no difference*	*raised*

Dedicated, visually focused tasks, represented by the Single Task columns in Table 6 are completed faster on a flat surface for both single and serial target selections. Increasing the visual load, however, changes the relationship. For single and serial target selection, the dual task mode changed task time from an obviously flat surface advantage to no difference between the surfaces.

A similar trend between single task and dual task mode is observed for the serial target error rate. For the serial target selection, the flat surface error rate changed from 3.9% in single task mode to 10% in dual task mode. The raised surface error rate slightly improved from 5.6% in single task mode to 5% in dual task mode – a slight but opposite trend from the flat surface error rate. Notice that the raised surface error rate advantage in dual task mode is attributed to the poor performance of the flat surface.

Returning to the original question, is the usability of a touchscreen surface improved with physical shapes augmenting the virtual controls? Sometimes no – the flat surface performed better when visual attention is focused on this single task. Sometimes yes – the raised surface demonstrated higher accuracy compared to a flat surface when visual attention is divided. Maybe – the questions and debriefing show that raised navigation cues are important and that raised buttons may help locate isolated controls.

5.2 Test Comments/Limitations

Layout and test organization of the experiment were logical progressions from previous studies but this experimental combination of touchscreen and raised shape was something different. In this context, the Likert scale questions and debriefing were invaluable because they provided general feedback on this idea of tangible touchscreens and useful opinions on the specific experimental setup.

The topic of augmented touchscreen interfaces was a fairly new idea to the majority of the test subjects. Some were quite enthusiastic about the idea. One subject mentioned his decision to avoid upgrading to a touchscreen cell phone because he preferred the physical buttons.

Comments about the experiment were encouraged and a number of common responses were discovered. These comments and an explanation are listed in Table 7.

Table 7: Summary of Common Debriefing Comments

General Comment	Explanation
All buttons felt the same	The buttons for the numbers and letters had the same physical shape and size and were located closely in a group. There were no navigation markers therefore subjects relied more on visual identification
Start/Next key tactile cue was most helpful.	The start/next key was isolated on the right side of the interface and could be easily located using tactile sense.
Raised surface would be helpful if used frequently and was familiar with the layout.	An unfamiliar layout relies more on visual sense for button identification.
The raised buttons limited the selection area.	Though the touchscreen button actuation area never changed between the flat and raised surfaces, some subjects thought the smaller domed physical buttons on the overlay implied a smaller actuation area.
Magnification effect of the buttons on the overlay was distracting	The clear domed buttons on the overlay had a slight magnification effect and it was distracting to some of the subjects.

These comments helped identify the weaknesses of the experiment and may offer insight on why some areas of the test showed little or no difference. For example using the same button shape for all the keys means there was minimal navigational guidance for tactile selection. Without some type of variation the subject still relied on his/her visual sense for target selection. A subsequent experiment using raised shapes for only navigational cues may show greater differences between the flat and raised surfaces.

The raised button overlay was a simple solution to adding a 3D effect to the touchscreen controls. The dome shape was used because it had an effective yet somewhat non-intrusive tactile feel. Braille dot size overlays were too sharp and disruptive, though they may be helpful if used sparingly as tactile cues. The biggest problem with the implementation of the overlay was the magnifying effect of the see-through buttons and two people commented that it was a distraction.

Creating a multitasking, or more specifically a dual tasking, scenario was one of the main challenges of this experiment. Flight and vehicular interface research often benefit from expensive test instruments. Mobile applications can be evaluated *in situ*. One idea for the second task included hand-held video games but they were difficult to operate with one hand and demanded too much attention. The simple coin task developed for this experiment was easy to learn and easy to manage. During the training session the coin task performance was recorded for 30 seconds. Comparing this normalized single task rate (coins per minute) to their dual task rate showed that subjects were not ignoring or completely consumed with the coin task. It was a sufficient balance of attention between the touchscreen and coin tasks. In the future it may be interesting to use a dual task that forces an interruption of the touchscreen task.

Finally, the most obvious limitation of this experiment is the lack of a touch interface with the ability to dynamically form 3D shapes, however as described in section 6, such a device may be possible.

5.3 Discussion

The idea for this study grew from the frustration experienced by constant interaction with a copier/printer touchscreen. An incredible amount of machine functionality was controlled by small buttons displayed in crowded layouts. Maybe it would be possible to improve the interface by augmenting the virtual buttons with physical 3D shapes. In fact the original proposal assumed this touchscreen enhancement would result in positive improvements so the direction was to investigate different physical button heights. Reviewing current studies and existing technologies revealed that this augmentation idea is somewhat novel. Tactile displays are well studied (Benali-Khoudja, Hafez, Alexandre & Kheddar, 2004; Chouvardas, Miliou & Hatalis, 2007). Touchscreen GUI usability is also well represented in the literature (e.g. Forlines, Wigdor, Shen, & Balakrishnan, 2007; Huang & Lai, 2007; Plaisant & Schneiderman, 1992). It is the integration of tactile displays and touchscreens into tangible user interfaces that is a new area for consideration and investigation. Rather than assuming an augmented touchscreen is always a positive improvement, the focus changed to a simple comparison of augmented vs. non-augmented touchscreen surfaces.

The results of the experiment showed that the enhanced touchscreen is not always beneficial. In single task mode where visual attention was directed exclusively on the task, the experiment demonstrated that tactile enhancement decreased task completion time. With the increasing popularity of multimodal interfaces, this finding is an excellent reminder that some modality interactions may be negative. As for the dual task mode, the results agreed with Fisher et al. (2004) which stated that successful haptic feedback applies to tasks that are overloaded, complex or need manual control. Similar results were also found by Prewett et al. (2006) in a meta-analysis of studies that compare user performance of visual interfaces with visual-tactile and visual-auditory interfaces. They concluded that under single task conditions and a normal workload, visual-auditory interfaces were most effective. They also showed that visual-tactile interfaces were more effective under multiple task conditions with an increased workload.

Returning to the original impetus for this study, a 3D tactile enhancement to the copier/printer touchscreen interface may not improve usability since the machine usage may be considered a single task condition. Same with many kiosk interfaces – large screen kiosk applications normally command full visual attention and the tactile enhancement may interfere. Mobile applications such as smart phone interfaces are operated in multitasking environments and could benefit from this technology, though market barriers may be high due to saturation and maturity of existing devices. Vehicular interfaces may be the best application for market entry. Operating a vehicle is a multitasking activity and any feature that can improve safety yet provide a rich set of controls would be a huge benefit. There are many applications and conditions to consider and though the experiment covered a sizeable problem space, it is a narrow sample when compared to the incredible variability offered by manipulating visual and tactile parameters.

6 Technological Feasibility

Though the technological challenges are significant to bring a consumer grade three-dimensional touchscreen to the market, a number of developments may prove noteworthy. First however it is important to outline and frame the requirements that differ from a typical touchscreen. Common touchscreen architecture consists of a touch sensitive layer on top of a display layer. Adding dynamic, physical controls requires the interface plane to be flexible which may change the prevailing architecture.

6.1 Requirements

A simple functional structure diagram in Figure 16 shows the processor, interface and operator of a tactile enhanced touchscreen. The interface presents the operator with both visual and physical controls and the operator responds with tactile actuation. This actuation may be electrical, kinetic (force) or acoustic – depending on the touch sensitive technology used. On the processor side, the interface accepts instructions for presenting visual and physical controls and sends coordinates of the tactile actuation selected by the operator.

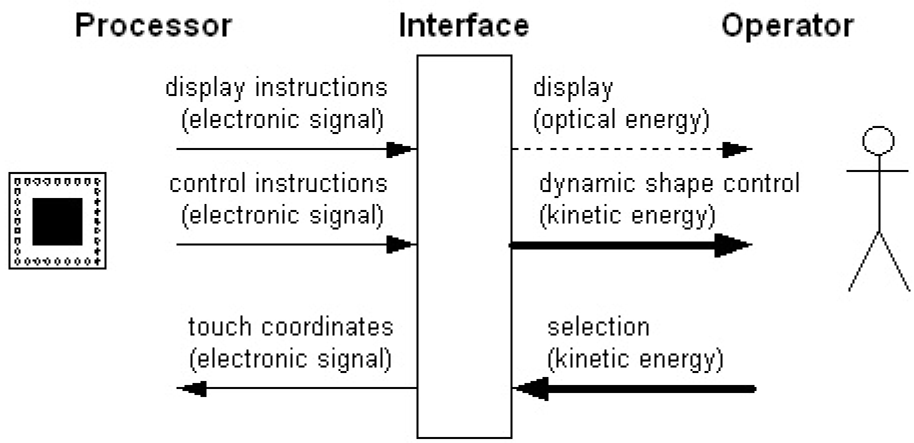

Figure 16: Three-dimensional Touchscreen Functional Structure Diagram

Inside the interface are four major components – skin, display, touch sensor, and three-dimensional control.

6.1.1 Skin

This is the protective outer layer and must be durable enough to handle environmental stresses, flexible enough to morph with the dynamic shapes and obviously must be transparent. In existing devices this function is often integrated in a single component with the touch sensor. Because the interface layers may no longer follow the traditional order, the skin function must be considered separately. The key challenge is to present a smooth, durable, protective surface that will stretch and contract with the dynamic surface changes.

6.1.2 Display

This layer presents visual information to the operator. Typical hardware controls use static labels but this closed loop device must present dynamic information. As for color and resolution, maximizing these properties makes an attractive interface but full color spectrum and high resolution may not be necessary for the typical target application. The most important requirement concerns the physical medium of the display. In existing touchscreens, the display is often the back layer with a transparent or semitransparent touch sensor overlay. Adding the shape controller means either a transparent shape controller above the display or a shape controller below a flexible, durable display. Most likely a flexible display on top is more realistic. Maximizing flexibility while still presenting dynamic information are the key challenges for the display function.

6.1.3 Touch Sensor

Sensor systems in current products include resistive, capacitive, acoustic and surface wave technologies (Elo TouchSystems, 2007; Quinnell, 1995). All rely on a disruption of a steady state in the layer above the display. With a shape controller, a disruption in the interface plane comes from both directions, one to create the shape, one to receive actuation. This is the key challenge in the touch sensor layer – to recognize an actuation from the touch and is either positioned or programmed to ignore a disruption from the shape controller.

6.1.4 Three-dimensional Shape Controller

Manipulation of a material to dynamically morph an object is a complex and as of yet unsolved commercial problem. The scene where an alien being appears human-like at one moment and then a pool of water in the next will probably stay in the realm of science fiction for a while. In the consideration of shape controllers for touchscreens, we limit the requirements to pushing towards positive values of z in the three-dimensional space. Even within this limitation there are many parameters to consider such as transition time, hardness, shape and height. Transition time should be minimized but more importantly it should be consistent and coordinated with the virtual object transition. Hardness probably has a minimal force value and will vary by application. As for height and shape, the greater the height and larger the shape, the more displacement of material means the greater energy required. The key challenge is to find the minimal dimensions of shape and height to provide a tactile benefit.

6.1.5 Physical Architecture

Using these requirements the suggested architecture inverts the traditional touchscreen architecture, as shown in Figure 17. The location of the touch sensitive layer depends on the technology used. The following sections describe relevant technology developments and select vertical markets which may foster applicable solutions.

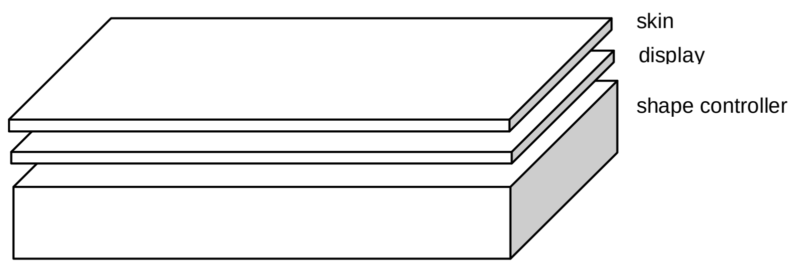

Figure 17: Inverted Touchscreen Architecture

6.2 Solutions

Developments that may address some of the more difficult requirements include advances in display technology, manipulation of rheological material to dynamically shape physical controls, touch sensing technology and the ability to manufacture in the sub-millimeter space.

6.2.1 Displays

Organic light emitting diode (OLED) technology produces brilliant, flexible displays that can be hosted on thin plastic sheets. A layer of organic material that glows when stimulated is sandwiched between anode and cathode layers. No bulky tubes of a cathode ray tube (CRT) or the required backlighting of a liquid crystal display (LCD), the OLED advantages include lower power consumption, superior display of hue, contrast and lightness, relatively easy to manufacture and as mentioned before, flexible. Sony Corporation has demonstrated a 0.3*mm* thick, full color 2.5 inch OLED display (Pink Tentacle, 2007). Flexibility and display quality are tradeoffs and currently the popular market favors the latter. One of the first commercially available flexible displays by Polymer Vision has a bending radius of 2 *cm* (BNet, 2004). Changes are fast in this technology and though durability and degradation of the organic material and flexibility of the host material are challenges, advances are sufficient for recent commercialization of OLED touchscreens (Samsung, 2007).

6.2.2 Shape Controlling Technologies

Poupyrev et al. (2002) suggested height becomes a pixel characteristic to accompany the color properties red, green and blue, creating the acronym RGBH. Treating height as a parameter at the pixel layer is an appropriate observation of the work in this field. Small pins in a grid, much like pixels, appear to be the medium of favor for forming shapes on a flat display. Many institutions and labs experiment with pin grids where 3D shapes are formed through the manipulation of density and individual control of pin height. Various pin actuation systems are based on shape memory alloys, servomotors and pneumatic hardware but no technology has delivered a clearly superior and viable solution (Wagner, Lederman & Howe, 2002; Moy, Wagner, & Fearing, 2000; Yeongmi, Oakley, & Ryu, 2006). Technologies using motors or other bulky control systems at this time require too much power and portability is limited.

A promising development described by Klein et al. (2005) uses the phase change of electrorheological fluids to power pin movement for a three-dimensional tactile surface. Electrorheological fluid is a material that changes viscosity based on the presence of an electrical charge. Rheology, the study of the deformation and flow of matter, is the basis for many types of so-called smart materials whose viscosity can be manipulated by external stressors. The advantage of managing viscosity is that motion and shape may be controlled without small moving parts or electromechanical systems. For example, magnetorheological fluids, which respond to magnetic field changes, replace valves and other mechanical parts in automotive suspension control systems (Delphi, 2007). Klein's medical three-dimensional surface project is to create a tactile display that simulates a patient's biological tissue, muscle and bone. The dynamic surface would restore the tactile sense lost by using an ultrasound system for elastographic analysis. The ER fluid for this display is silicone based Rheobay 3565 created by Bayer AG. Other chemical formulations such as liquid crystals and even water based cellulose ER fluids are under investigation to improve shear strength, decrease required voltage and minimize particle size (De Voider, Yoshida, Yolota, &

Reynaerts, 2006; Zhang, Winter & Stipanovic, 2005). Rheological fluids may be as promising a shape controlling technology as OLEDs is a display technology.

6.2.3 Touch Sensor

Rheological fluids may also provide a mechanism for sensing touch. By monitoring the change in current passing through the ER fluid, Liu, Davidson & Taylor (2005) showed that it is possible to sense the downward force of a touch. Another interesting possibility places the touch sensitive function in the display layer. Hudson (2004) uses the photo sensitive properties of an LED to demonstrate how an LED display can be used for touch-sensitive input. These examples and possible modification of the existing flat surface touch sensitive mechanisms are possible solutions to the modified touchscreen architecture.

6.2.4 Microsystems Manufacturing

Though rheological fluids may reduce the need for mechanical or electromechanical parts, the ability to manufacture in the sub-millimeter space is still very relevant. As with display pixels, the greater the pin density in a shape controller, the better the resolution. Even if pins are not part of the solution, any reduction in part size reduces space needed, power requirements, weight and material. To this end, developments in microelectromechanical systems (MEMS) technology are worth watching. MEMS are milli- and micrometer sized machines fabricated using techniques extended from integrated circuit manufacturing (Vittorio, 2001). Gears, switches, pumps, all types of mechanical and electrical components are etched and layered into systems that could fit on the head of a pin. One relevant research application uses MEMS microvalves to control air flow in pneumatic, dynamic Braille dots, creating a refreshable Braille display (Yobas, Durand, Skebe, Lisy & Huff, 2003). The near future of MEMS devices appears to be solving existing challenges by implementing the same designs, but on a smaller scale. Perhaps the largest potential, however, may be the applications that have yet to be imagined.

6.2.5 Solution Summary

In summary the second question in the problem definition was, is it possible to create dynamic physical shapes on a touchscreen surface? A promising first start may be possible by layering an OLED display over an ER fluid 3D surface and integrating a touch sensing system. Other solutions may be found through observation of different market segments.

6.3 Relevant Research and Applications

The market segment focus of this study is for ubiquitous, commercial applications however research and advances of relevant applications are found in many vertical segments. Though the current state of these developments is well documented, a few areas of interface innovation are worth noting (Benali-Khoudja et al., 2004; Chouvardas et al., 2007).

6.3.1 Gaming

Gaming is a leading outlet for interface innovation. On one hand it provides researchers and designers the opportunity to test and investigate creative technology applications; on the other hand it is a large, competitive market where novelty and technical excellence are basic requirements. A recent commercial success, the Nintendo Wii uses a haptic controller called the Wii-mote that senses gestures and provides vibrotactile feedback. The next innovation may come from Sony Corporation, another leading gaming console manufacturer. In 2006 Sony filed a patent for an electrorheologically controlled gaming controller (Sinclair, 2006). It is unclear where the cutting edge of console gaming will go but for more traditional gaming in the form of gambling, touchscreens are becoming more prevalent. Mechanical slot machines and table poker games are converted to touchscreen video games that also include customer services such as drink ordering, ticket purchasing and advertisements (Burke, 2004). These devices demonstrate that innovation may not always be in the form of a new physical gadget but in the inclusion of services and enterprise content. An extension of the casino scenario and possibly the best indicator of future gaming devices is the Microsoft Surface. Codenamed Microsoft Milan, this is a display that doubles as a table and includes features such as multitouch and gesture detection (Microsoft Surface, 2007). Microsoft and gaming may be leading the field in creating a new buzzword called surface computing.

6.3.2 Military

Military environments are sometimes at the extreme end of sensory overload and provide unique opportunities for advanced interface applications. An application of haptic technology to address extreme scenarios uses tactile actuators embedded in clothing. These actuators placed around the trunk, on the back, shoulders or arms can provide spatial and navigational cues, targeting information, alerts and commands (Jones, Lockyer & Piateski, 2006). Study of these wearable haptic devices provides valuable feedback about applicability of non-visual communication. For example, United States military soldiers in an obstacle course drill were able to favorably receive, interpret and accurately respond to commands delivered to tactile devices strapped around their waist (Pettitt, Redden, & Carstens, 2006). Brewster & Brown (2004) use the term tactons to describe these structured messages using groups of tactile actuators. This study of nonverbal communication is just one example of ideas and research evolving in the realm of sensory overloaded environments.

6.3.3 Medical

One area where interface innovation and medical advances intersect is surgical operations. For example the introduction of minimal invasive surgery which uses remotely controlled instruments may lessen the disruption to the patient however it also diminishes the tactile feedback needed by the surgeon. Surgeons rely on touch for identification and diagnosis. Healthy tissue is soft, tumors are hard. Remotely controlled instruments provide primarily visual feedback so the critical tactile information is lost. Research in this area, such as the three-dimensional surface by Klein et al. (2005) mentioned above, attempts to provide a tactile representation of a remote entity. Not only does this concept serve the medical community, it is also applied to remote robotic control, remote sensing of geological formations, and providing tactile representations for the visually impaired.

6.3.4 Visually Impaired Applications

Optacon was one of the first tactile assistive devices that captured the attention of users and developers. Introduced in the 1970s by Telesensory, this popular device used a lens module to capture text and translate it to a fingertip sized tactile pin array (Optacon, 2003). Unfortunately in the past thirty years advances in assistive tactile devices have not developed at the same rate as other touch related market segments. One explanation is that auditory devices such as text to speech systems appear to be a major focus for commercial development. Another explanation is the lack of technological solutions for tactile devices. Perhaps the value of this market segment is not in the advances that it generates, but with the potential to include a population previously unable to interact with mainstream interfaces. Of the population designated visually impaired, about 23% are totally blind (World Health Organization, 2008). This means 77% have some type of visual ability. Enhancing a touchscreen with tactile cues will open this medium to a greater number of users.

7 Future Work

To reach the goal of a viable product, further studies are needed both in usage tests and hardware development. The next set of usability tests should be based on the debriefing comments from the experiment. Rather than using the same shape for all buttons, vary the shapes to provide navigational cues. To diminish the learning curve problem of a physical layout, perhaps the layout should be something well known, such as a numeric keypad only configuration. Possibly the most important modification is using raised shapes to identify isolated selection areas. The raised Start/Next button received the most positive comments.

As for feasibility, eventually a prototype should be developed. This paper proposed using an OLED display on top of a pin array controlled by electrorheological fluid. There are many technical issues to investigate such as touch sensing technology, durability, synchronization, transition times, plus stretch and contraction of the OLED layer.

If we look beyond the near term and even beyond the first few iterations of touchscreens with dynamic 3D shape controllers, eventually we will vary layout, height, shape, size, feedback, texture and any other tactile effect. Add visual and audio variables and the combinatorial space explodes. Hard tooled surfaces may be replaced with dynamic surfaces. Keyboards would no longer be rigid, fixed layouts but customized to personal preference. Standards hopefully would emerge for form and function such that common 3D interface interactions will have consistent, look, feel and sound with the additional convenience of dynamic morphing. As a final point, the future of ubiquitous, general purpose commercial interfaces may be improved by augmented touchscreens, but the ideas presented in this study could also improve access to devices by people that have been left behind by the growth of primarily graphical interfaces.

8 Conclusion

This study introduced the raised surface touchscreen idea and addressed some fundamental issues such as appropriate usage and feasibility. Returning to our original two questions:

1. Is the usability of a touchscreen surface improved with raised shapes augmenting the virtual controls?

The experiment showed two significant results. The dual modality demonstrated a disruptive relationship when the task was predominately visual. The task time for both single and serial target selection was significantly faster when using flat surface touchscreens for visually focused tasks. The dual modality demonstrated a supportive relationship when the visual attention was divided. The error rate for serial target selection was significantly lower on the augmented touchscreens when performing dual tasks.

2. Is it possible to create dynamic physical shapes on a touchscreen surface?

This paper does not answer this question definitively, but provides ideas that show a solution may be possible. First general requirements were identified that demonstrate that the traditional architecture must be inverted to accommodate the shape controlling function. Addressing these requirements, a solution consisting of an OLED display on top of an electrorheological pin array was proposed. Finally the paper reviews a number of specialized application areas that may provide solutions to this general user interface challenge.

In conclusion, further research is needed in both usability and feasibility but many useful applications can be developed or improved with the introduction of dynamic, 3D tangible touchscreens.

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10 Appendix A: Task Time and Error Rates

Task Completion Times

Figure 18 shows the average completion task time for the single target selection. Interval bars are 95% confidence intervals.

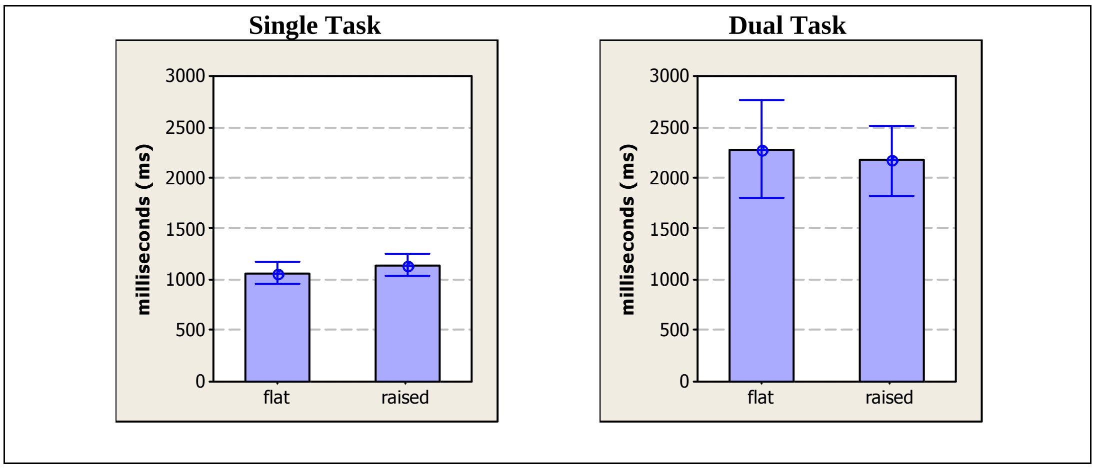

Figure 18: Single Target Selection Task Time

Figure 19 shows the average completion task time for the serial target selection. Interval bars are 95% confidence intervals.

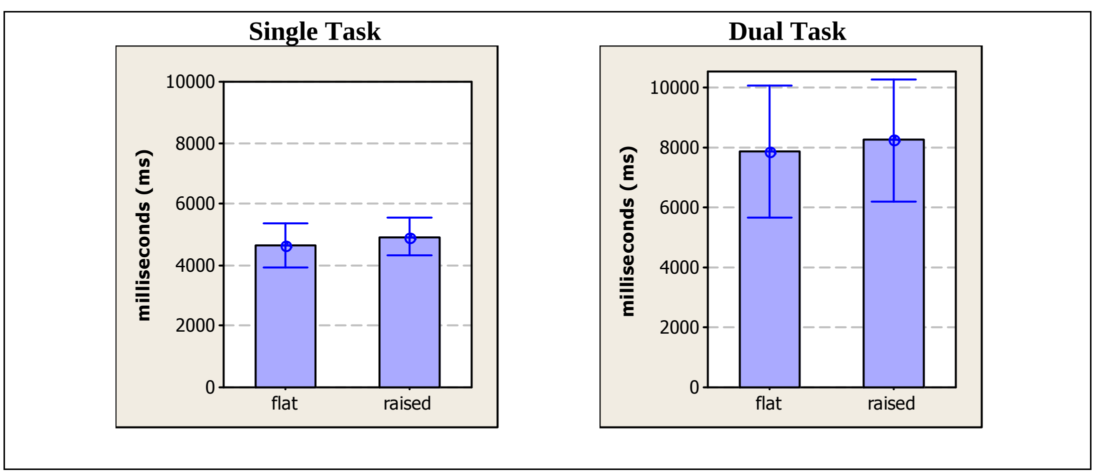

Figure 19: Serial Target Selection Task Time

Error Rates

Figure 20 shows the error rate for single target selection.

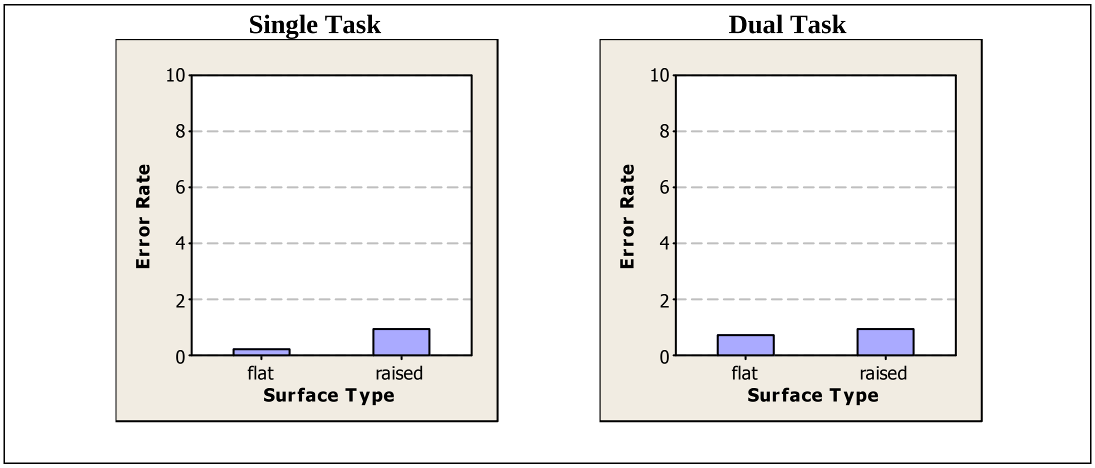

Figure 20: Single Target Selection Error Rate

Figure 21 shows the error rate for serial target selection.

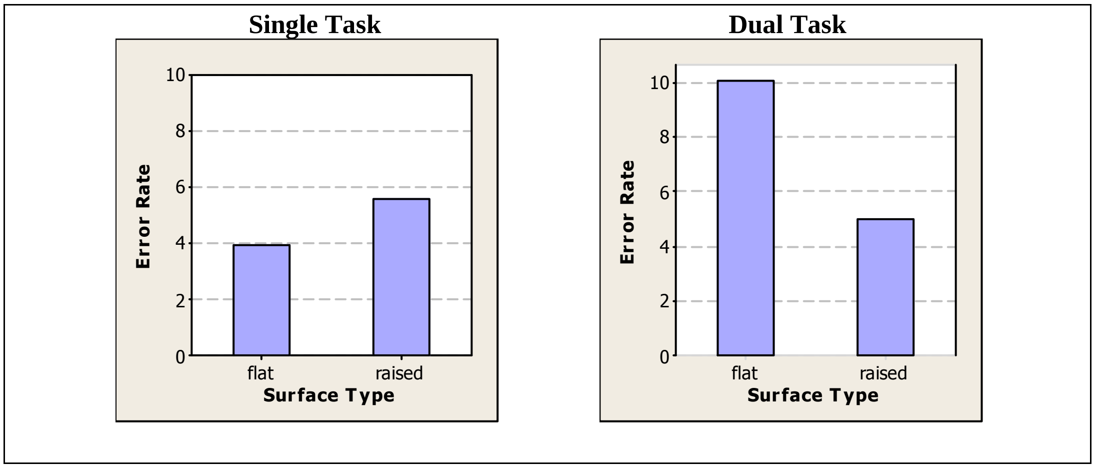

Figure 21: Serial Target Selection Error Rate

11 Appendix B: Questionnaire

Touchscreen Test Questions

Test ID: ______________

I prefer a touchscreen with some type of tactile cues.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

When multitasking, the raised buttons made the touchscreen easier to use.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

Overall the raised buttons made the touchscreen easier to use.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree