

ABSTRACT

MENDAT, CHRISTINA COSTANZO. Measuring age differences in the effectiveness of tactile cues in cellular phones. (Under the direction of CHRISTOPHER B. MAYHORN and DONALD H. MERSHON).

The trend of technology miniaturization has permeated the cellular phone industry and resulted in technology that has not only become smaller in terms of size, but slimmer resulting in flat-smooth keypads. Even though this trend has affected the majority of cell phone designs currently on the market, little to no research has examined the effects of this type of design on older adults.

The current study is comprised of four experiments designed to examine the effects of keypad surface on dialing performance as well as to identify aids that may enhance dialing performance. The first study examined differences in dialing performance between keypads with raised-rubber keys and flat-smooth keys as a function of age (i.e., younger versus older adults). The results revealed that both younger and older adults performed significantly better in terms of dialing accuracy and dialing time with the raised-rubber keypad.

The second study examined discrimination performance between various tactile cues. The findings from this experiment revealed that two tactile cues were readily discriminable for both age groups. These same discriminable tactile cues were then placed on existing raised-rubber keypads (in specific arrangements) to comprise the stimuli for Experiment 3. The findings from Experiment 3 revealed that only one of the four tactile cue arrangements significantly affected dialing performance.

In Experiment 4, however, the tactile cues that were not found to enhance dialing performance with the raised-rubber keypad were shown to enhance dialing performance with a flat-smooth keypad.

The results from this four-part study revealed that both younger and older adults performed significantly better in terms of dialing accuracy and dialing time with the raised-rubber keypad. Although the addition of tactile cues on the raised-rubber keypad did not significantly affect dialing performance, the addition of tactile cues on the flat-smooth keypad did significantly affect dialing performance.

These findings demonstrate that if future cellular keypad designs are flat and smooth in nature, the addition of tactile cues in specific locations can match dialing performance to that of the performance with the raised-rubber keypad. If tactile cues are not added to these types of keypad surfaces, however, these findings demonstrate how the trend of miniaturization and smooth keypads may potentially alienate the largest growing population in the U.S. (i.e., older adults) with respect to usability.

**MEASURING AGE DIFFERENCES IN THE EFFECTIVENESS OF TACTILE
CUES IN CELLULAR PHONES**

by

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DEDICATION

I would like to dedicate this work to the two loves of my life:

my husband Matthew and my son

Carter Burkes Mendat born on September 20, 2005.

BIOGRAPHY

Christina Costanzo Mendat was born June 24, 1976 to parents, Mary and Salvatore Costanzo. Raised in a rural town in eastern North Carolina, Christina learned an appreciation for southern hospitality. Also being raised in a Sicilian family, Christina formed a love for her heritage. Some may find this an interesting combination to say the least, but to Christina; this “interesting” combination of cultures made her who she is today.

There was never a doubt that Christina would pursue an advanced degree. Ever since she was a young girl, she loved going to school. Even when sick, she wanted to go to school. This passion for learning continues today even after having completed the requirements for the PhD.

Christina, now, has a family of her own and plans to continue the tradition of learning about various cultures and learning in general. She plans to work in her degree area of human factors psychology and continue taking courses in various areas as well as teaching courses in Cognition.

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Measuring Age Differences in the Effectiveness of Tactile Cues in Cellular Phones

The older adult segment of the population is growing at an unprecedented rate. Recent statistics predict that by the year 2025, there will be approximately 82 million individuals in the United States over the age of sixty (U.S. Census, 2001). This increased lifespan is accompanied by a number of well-documented cognitive declines including working memory (Craik, Morris, & Gick, 1989), spatial ability (Salthouse, 1996), and text comprehension (Harris, Rogers, & Qualls, 1998). Accompanying these cognitive declines are well-documented perceptual declines such as visual degradations associated with aging. For instance, the range in visual accommodation decreases so much by the age of 60 that little accommodative reserve remains, much less light reaches the retina, and contrast requirements can also increase. Older adults also experience declines in perceiving high frequency sounds, discriminating between pitches and localizing different sounds (Kline & Scialfa, 1997).

In addition to the major sensory declines in vision and hearing, there are age-related sensory declines associated with tactile ability. (This paper will use the terms tactile, taction, and haptics interchangeably.) Little research has focused on these age-related changes in tactile ability other than one study which reported that tactile thresholds increase with age (Thornbury & Mistretta, 1981) and another more recent report that the tactile acuity of adults diminishes by one-percent each year after the age of 20 (Stevens & Patterson, 1995).

Haptic Research

Since E. H. Weber's discovery of the two-point threshold, a great deal of research has been conducted in the domain of "haptics." The literature in this area of research is quite broad and covers a number of aspects of the tactile sense including pain, tactile discrimination, reading

by touch, gap detection, and the mechanoreceptors (the underlying mechanisms of touch). The proposed research is designed to focus on tactile discrimination of keypad surfaces and cues.

Prior work suggests that tactile information such as textured surfaces (e.g., sandpaper, waterstones, emery cloth, Braille, etc.) can be readily discriminable during times when the visual modality is not in use (Heller, 1982; 1989). Additionally, participants who are limited to examining surfaces tactually perform comparably to those using the visual modality in texture discrimination tasks. In one study (Heller, 1982), three experiments used relative smoothness judgments to analyze the various effects of multi-modal information (i.e., vision, haptic, or both) on texture perception of aluminum-oxide abrasive papers. The grit values used in each of the experiments were 80, 100, 120, 150, 180, 220, 240, 280, 320, and 400. The grit value 80 represented the roughest texture while the grit value 400 represented the smoothest texture within the set. Findings from all three experiments revealed that participants performed comparably in the haptic and visual conditions, and that in the bimodal condition (haptic + visual information), the haptic modality was most responsible for the judgment of texture.

In a similar study, Heller (1989) examined the difference in texture perception between blind and sighted adults. Results revealed that the sense of touch was just as capable as vision in discriminating between smooth- and rough-textured surfaces. Moreover, in a similar study that used aluminum-oxide abrasive papers and Japanese sharpening stones as stimulus materials, Mendat (2002) found that participants in vision and haptic conditions performed comparably in the discrimination of smooth and rough textures.

“Gratings” have sometimes been used as stimuli in texture research. A grating is an etched surface with a series of grooves and ridges parallel to one another creating a textured surface. For example, one study utilized eight different aluminum-alloy grated plates (Lederman,

1981). Each plate was 14.0 x 11.4 x .5 cm in surface area with groove widths that varied from .250 mm to 1 mm, in increments of .125 mm. Using a magnitude-estimation paradigm, participants were asked to assign values to each grated surface based on roughness. Findings revealed that roughness estimates increased as fingertip force increased and as groove width increased, resulting in greater skin indentation.

By using an innovative technique to develop gratings, Morley, Goodwin, and Darian-Smith (1983) also examined the discriminability of different gratings varying in groove width. Using the technique of ultraviolet light polymerization, nylon surfaces were prepared to make gratings with groove widths that could vary in width at the micron (μ) level. The standard comparisons in this experiment were 770 μ and 1002 μ . For the 770 μ standard, there were 20 comparison values. For the 1002 μ standard, there were 18 comparison values. Participants were asked to feel, with their three middle fingers, three surfaces and indicate which of the three surfaces was different from the other two. Results indicated that humans could discriminate between two gratings, which differ in period order by 5% (45 μ).

Spatial discrimination is another task that is used to assess tactile ability. Grant, Thiagarajah, and Sathian (2000) examined the difference between blind and sighted adults in the spatial discrimination of raised dots and grated textures. In the first experiment, participants reported whether a raised dot, within an array of dots, was offset to the right or left. For early trials, sighted adults did not perform as well as blind adults, which may be attributed to the latter population's familiarity with Braille. Their second experiment examined the difference in performance of blind and sighted adults in a grating-discrimination task. The grating stimuli had a constant groove width of 1.0 mm, with ridge widths that varied in value from 0.05-1.45 mm. In this task, participants reported whether a comparison grating stimulus was the same as or

different from the standard stimulus. It was found that both groups performed comparably on the grating-discrimination task, leading to the conclusion that previous experience with tactile stimuli (i.e., Braille) did not enhance such performance.

In addition to the finding that individuals are able to readily discriminate various textures from one another, other research has shown that participants can generate representative images based on a stimulus' texture and spatial pattern. In other words, individuals are able to generate a visual image of a stimulus based on its texture and spatial pattern (Sathian, 1989). Given these several findings, one goal of the proposed research is to determine how performance on these haptic discrimination tasks varies with age. Insight derived from such an investigation should be informative for designing technology to meet the specialized needs of older adults.

Older Adults and Technology

Despite the many genuine sensory and cognitive declines that are associated with aging, as well as the associated stereotypes (Butler, 1995), sustaining a healthy life and maintaining independence is important to older adults (Mynatt & Rogers, 2002). Many technologies, both available and in development, promise to fulfill these needs and contrary to popular belief, older adults do want to learn how to use different technological devices available to them (Rogers, Mayhorn, & Fisk, 2004). To that end, recent research has revealed that adults over the age of 65 are joining the “wired” world faster than any other group (Adler, 2002). In a recent study (Mayhorn, Stronge, McLaughlin, & Rogers, 2004), older adults expressed an interest in using computers to obtain information. With the advent of the Internet, increasingly more individuals are using it as a way to access various types of information as well as using it for a mode of communication.

One well-researched area in the field of aging and technology is that of computer skill acquisition. A number of studies have examined the difference in performance between younger and older adults on web-based tasks. For instance, past research has revealed that older adults have difficulties with highly spatial computer-based tasks such as navigating through a website (Kelley & Charness, 1995). Another related study (Mead, Spaulding, Sit, & Walker, 1997) revealed a number of performance differences on a web-based task between older and younger users. One of these differences was that older participants had difficulty with tasks that require more than 3 clicks. Additionally, they found that older participants had difficulty remembering previous steps in the navigational procedure.

A more recent pervasive trend is in portable computing and miniature devices. In a study that examined the use of various input devices with Personal Digital Assistants (PDAs). Wright, Bartram, Rogers, et al. (2000) examined performance between older and younger adults utilizing either small keyboard devices or touch-screens. The authors found that while younger adults performed more quickly than older adults with the touch screen devices, an overwhelming 88% of the participants (including the younger participants) preferred using the small built-in keyboard. While younger adults were faster than the older participants, the two groups performed comparably in terms of accuracy. Yet another study (Mayhorn, Lanzolla, Wogalter, & Watson, 2005) examined skill acquisition with PDA-based medication-adherence software by young and older adults. The results revealed that older adults took longer to learn to use the software and made more errors than younger adults; however, age-related differences in performance decreased with practice over time. Although these studies may illustrate how older adults may take longer to learn to use various technological devices, they also illustrate that given time, older adults can become proficient with such technologies.

Input Devices

While desktop computers and PDAs vary considerably in terms of functional complexity, they share a variety of input devices, which have been well researched. The following section presents findings from studies that have examined the use of input devices by older adults. Two main input devices that have been studied with respect to navigating the user interface of a desktop computer are the mouse and the trackball. Research has found that, in general, older adults perform much better with the trackball input device than with the mouse (Chapparo, Bohan, Fernandez, Kattel, & Choi, 1999; Charness, Bosman, & Elliot, 1995). Additionally, Charness et al. (1995) conducted a study examining the usability of the light pen input device, which revealed that older adults found the light pen to be more manageable than the computer mouse.

Both Charness (1995) and Chaparro et al. (1999) found that older adults perform more slowly than younger adults on computer-based tasks, but that they perform better with the trackball and light pen input devices than with the traditional computer mouse. They speculated that older adults' difficulty with computer-based mouse tasks might be a function of age-related motor declines. Examining the components of mouse control, Smith, Sharit, and Czaja (1999) had participants engage in four different tasks: pointing, clicking, double clicking, and dragging. Findings revealed that older adults had longer movement times, more submovements and more errors than younger adults for clicking and double-clicking tasks.

One element not addressed in the previous studies that may affect older adults' performance is that of feedback. Contrary to the findings of the previously mentioned studies on computer input devices, Walker, Millians, and Worden (1996) found that the functionality of a computer mouse can be adjusted to compensate for age-related declines in movement control.

Specifically, the authors found that changing the gain setting of the mouse allowed older adults to perform quite well during mouse-based tasks. Gain setting refers to the sensitivity of the mouse to movement initiated by the user, which is simultaneously represented on the computer screen. This sensitivity can be changed to be more and/or less sensitive to movement from the user based on an individual's comfort level. This finding demonstrated that feedback may be an important component in using input devices.

Further evidence that older adults benefit from multi-modal feedback comes from a study that investigated a drag-and-drop computer task that utilized a vibratory computer mouse (Jacko et al., 2004). In this experiment, individuals were instructed to select a file icon and drag it to the designated folder icon. The different feedback modalities were auditory (a suction-cup sound which indicated the file had been dropped), visual (the target folder file would be highlighted) and haptic (a mechanical vibration when the two icons were correctly positioned). Seven feedback conditions were developed, including one unimodal condition for each separate modality, three bimodal conditions, and one trimodal condition. Of most interest to the present study, are the results involving the haptic feedback. The findings revealed that the device was most efficient when it included the vibration haptic feedback.

While these findings regarding the additive effects of different modes of feedback are informative, another aspect of feedback that has been investigated is the use of multiple cues within a modality. In a study by Kirkpatrick and Douglas (2001) on shape perception, participants haptically examined five shapes that differed in terms of tactile points (i.e., cues within a surface which the authors described as curvatures). The authors interpreted the results by suggesting that more tactile cues increased haptic discrimination accuracy by two- to three-fold, relative to baseline performance. Contrary to these findings, another study (Oakley,

Brewster, & Gray, 2001) indicated that multiple tactile cues may not be as beneficial as previously suggested. Oakley et al. (2001) conducted a study examining the use of haptic icons in a computer menu-selection task. While participants were able to discriminate haptic icons from one another, results indicated that an abundance of cues can be confusing to users and that haptic stimuli should be designed carefully to avoid this confusion.

Although the inclusion of various forms of feedback represents one type of assistance that technology designers might provide to benefit older adults, other aspects of the device interface might be equally important. For instance, spatial arrangement has been widely investigated in the ergonomics literature as a means to improve the usability of visual displays, manual controls, and keyboard arrangement (Sanders & McCormick, 1993). Spatial arrangement refers to the location of various elements in a display or stimulus. Of particular interest in the present study is the spatial arrangement of tactile cues, because it has been suggested that various features (e.g., borders, colors, raised-tactile features) can be manipulated to clarify the relationship of components (Sanders & McCormick, 1993). Research in this area, however, is limited and should be extended.

Older Adults and Cellular Phones

Up to this point, discussion has focused on the trends in miniaturization, tactile abilities, and the utility of various input devices. One area that is affected by all of these aspects is cellular phone research. Estimates indicate that there are approximately 180 million cellular phones in use in the U.S. (McFarland, 2002) with approximately 62% of Americans owning a cellular phone. Coupled with the increase in cellular phone usage has been the change in the demographics of the typical cellular phone user from the middle-aged businessperson to the young and elderly (Goodman et al., 1997). A cellular phone research group (textually.org, 2004)

has reported that 39% of older adults (65 and older) report using cellular phones, but that this same population only accounts for 15% of overall cellular phone ownership.

While cellular phones provide the convenience of dialing and talking from any location, this same technology can be used in emergency situations to summon help. With the increased access to cellular phones, older adults can use this technology as an avenue for safety and independence. However, there have been no studies to date, which have investigated older adults' usage of cellular phones in terms of dialing or preference. This lack of research has great implications for older adults and their use of cellular phones in that the ability to use this technology depends on the usability.

Cellular Phone Research and Haptics

Much research on cellular phones has focused on the use of cellular phones while driving (Goodman, Tijerina, Bents, & Wierwille, 1999; Parkes, 1993). For example, Wogalter and Mayhorn (2005) found that the perceived risk of concurrently driving and using a cellular phone varied by phone ownership, such that owners were less likely than non-owners to report the negative impact of cellular phone use. Some of the research with cellular phones also includes open road studies (Reed & Green, 1999), as well as stimulator studies (Reed & Green, 1999; Strayer & Johnson, 2001).

Few studies, however, have focused on the characteristics of cellular phones that consumers find important (Mendat, Bell, & Wogalter, 2004; Yun et al., 2001) and even fewer studies have examined the effects that specific tactile characteristics have on dialing performance (Mendat et al., 2004). Although one study (Bubb-Lewis & Blanchard, 2002) found that individuals prefer smaller models of cellular phones when considering portability, when the participants considered usability and comfort, they preferred more traditional sizes of phones.

In a recent study conducted by Mendat, et al. (2004), a questionnaire administered to 289 individuals revealed that individuals believe that tactile cues benefit cellular phone usability. For instance, participants reported that they would be willing to pay more for cellular phones that would allow them to locate the buttons by touch. They also reported that it would be helpful to have tactile cues available to them in situations of low-lighting and/or limited vision. While the first part of the Mendat et al. (2004) study focused on consumer perception, the second part examined empirically the effectiveness of tactile cues in a dialing task.

Eight individuals ranging in age from 24-33 years ($M = 26$, $SD = 2.9$) participated in the second part of the study. Two Motorola StarTAC flip-top cellular phones were used as the stimuli with the only difference between the two phones being the textural differences of the keys (soft-rubber versus smooth-plastic). Ten fictitious phone numbers, each composed of 7 digits, were printed onto labels and affixed to index cards, which were used for stimulus presentation during the experiment.

A repeated-measures ANOVA was used to analyze the mean number of errors for dialing with the smooth-plastic key phone and the soft-rubber key phone. The cellular phone with soft-rubber keys produced a lower mean number of errors ($M = 0.84$, $SD = .58$) than did the other cellular phone ($M = 1.8$, $SD = .48$) with the smooth plastic surfaces, $F(1, 14) = 12.56$; $p < .0036$.

Results from another study that investigated the usability of tactile cues indicated that raised-dome cues were more effectively discriminated than embossed line cues (Roe, Muto, & Blake, 1984). This study was designed to assess the performance of key localization. A membrane keypad refers to a keypad which has a layer over the keys, resulting in key indiscriminability. Participants received one of two tactile feedback types or cues including either: a 1) a raised-numeric line; or 2) a raised-dome. Each of these cue-types was located atop

the existing keys on the interface. The findings from this study revealed that participants performed significantly better in the raised-dome condition than in the raised-numeric line condition. While these results are interesting in terms of the effectiveness of various tactile cue types, the location or arrangement of tactile cues was not manipulated.

To date, it appears that only two studies have investigated any aspect of spatial arrangement of tactile cues on cellular phones. Lorichio and Lewis (1991) studied lateral key pitch which refers to the center-to-center key spacing between keys. In this study, the authors examined the preferences between standard keypad sizes and the reduced keypad sizes found in cellular phones. Results indicated that individuals preferred phones with greater key spacing than phones with smaller key spacing. Another study examining lateral key pitch (Mooney, Nussbaum, & Smith-Jackson, 2002) employed a dialing task with cellular phones that differed in lateral key pitch. Of particular interest in their study were the effects of various lateral key pitches (10 mm, 11 mm, 12 mm, and 13 mm) on dialing performance for disabled versus non-disabled individuals. The disabilities included: visual impairments (legal blindness and total blindness) and upper extremity disabilities (severe and minor). The authors found a significant effect of lateral key pitch in each of the measures, including dialing time, errors, and preference. Participants were able to dial faster and produced fewer errors when using phones with the 11 mm and 12 mm lateral key pitch spacing.

Whether these spatial arrangement findings generalize to older adults is an empirical question that needs to be addressed. Thus, another goal of the current study is to investigate the potential usability benefits that older adults might receive with the manipulation of spatial arrangement. In the present work, spatial arrangement will refer to the physical placement of tactile cues on the numeric keypads of the cellular phone interface.

Research Premise

With the increased access to cellular phones, older adults may choose to use these devices as an avenue for safety and independence. For example, these phones can provide older adults with quick access to help such as 911, a friend or relative. In a recent study (Mayhorn, Lanzolla, Wogalter, & Watson, 2005), older adults suggested including an emergency 911 feature in future designs of handheld devices. However, the ability to use this technology is contingent on the usability of the technology. The previous studies' findings illustrate the importance of key characteristics in the usability of cellular phones.

Although many cellular phones now come equipped with added features such as backlighting and larger screen displays, these features can be difficult to utilize in situations where visual attention is reduced and/or visual acuity is less than optimal, as is often the case with older adults. Given the trend towards miniaturization, even though there may be larger screen displays, the resulting tactile interface is small, making the keys more difficult to discriminate (Goodman, Tijerina, Bents, & Wierwille, 1999). Thus, populations with reduced tactile acuity and motor control may be differentially affected by these usability issues.

Freides (1974) has pointed out that individuals rely on whichever sense is more adept for a given stimulus. In the case of cellular phones, this is touch. However, a lack of research which clearly defines tactile abilities and limitations (Kroemer, 1997) demonstrates the need to address the human factors/ergonomics of the interface (Nam, Kim, Smith-Jackson, & Nussbaum, 2003). Past studies have illustrated that older adults do want to use technologies available to them for both independence and convenience. Thus, it is imperative to identify those characteristics of cellular keypads that may improve their usability (Oyama, Ohwa, & Noro, 2003).

Both Mendat et al. (2004) and Norman and Raines (2002) have proposed that textural cues may enhance dialing performance. While the Mendat et al. (2004) study revealed that rubber keys may enhance dialing performance, there were a number of limitations which the present study will address, including: 1) sample size; 2) age range; and 3) number of trials. The proposed research should further evaluate whether small tactile cues can improve performance on a dialing task for both younger and older adults and whether various spatial arrangements of the tactile cues can affect dialing performance.

Research Hypotheses

Based on the study objectives and the research reviewed, eight hypotheses were developed:

First, similar to the Mendat et al. study (2004), participants will perform better in the raised-rubber key condition than in the flat-smooth key condition. This effect would also be consistent with the findings of Lederman's study (1981), which were interpreted as showing that deformation of the skin enhances tactile perception.

Second, due to the decrease in tactile acuity over time (Stevens & Patterson, 1995), younger adults will perform better than the older adults in terms of (a) response time, and (b) errors produced, regardless of key-type (raised-rubber or flat-smooth).

Third, participants will have (a) faster response times and (b) higher discrimination accuracy for pairs of keys that have one key with a tactile cue (raised dot, raised line or textured key) paired with a blank key than they will for key pairs that have one tactile cue compared to another tactile cue and/or itself. According to research by Sathian (1989) individuals are able to detect a single dot as small as 15 μ on a smooth surface.

Fourth, participants will perform better with key pairs, which have a more textured tactile cue (i.e., a raised line or abraded key) compared to a single raised dot. Heller (1989) has noted that rough textures can be as readily identified by touch as by vision and in a study that examined differences in performance between blind and sighted adults, Grant, Thiagarajah, and Sathian (2000) found that sighted individuals did not perform as well with dot patterns as did blind individuals, although they performed comparably with grating-type stimuli.

Fifth, younger adults will have (a) faster response times (Walker, Philbin, & Fisk, 1997) and (b) higher number of correct responses than older adults for all cue types, when required to discriminate whether pairs of tactile cues are the same or different. Three different tactile cues will be compared including a raised dot, raised line, and textured key.

Sixth, it is expected that both age groups will perform better with a single location cue (a tactile cue only on the 5 key) on the raised-rubber keypad than with a raised-rubber keypad having tactile cues located on the 1, 3, 5, 7, and 9 keys (a multiple-location cue condition). A recent study found that multiple tactile cues may not necessarily benefit haptic performance (Oakley, Brewster & Gray, 2001).

Seventh, the older adults will not perform as well with the multiple tactile cues in the soft-rubber key condition as they will in the smooth key condition which may be due in part to the better discriminability of tactile cues on a smooth surface (LaMotte & Whitehouse, 1986) than a raised-rubber surface.

Eighth, in the smooth key condition, both age groups will perform better with tactile location cues on the 1, 3, 5, 7, and 9 keys (multiple location condition) than in the single location condition. In a study on shape recognition, Kirkpatrick and Douglas (2001) found that multiple tactile points could enhance shape recognition, which might generalize to keypad interfaces.

Experiment 1

This experiment is a replication and extension of an earlier study by Mendat et al. (2004) to further support the contention that individuals perform better if keys have more tactile features (such as a soft-rubber surface). This experiment expands upon the previous study by including older adults. It was expected that older adults would benefit from the more discriminable key-type.

Method

Participant

A total of 32 individuals took part in this experiment. By signing up electronically, 16 college student volunteers (aged 18-20 years, $M = 18.5$ years, $SD = .73$) earned partial research credit for their introductory psychology course. Each of these participants reported having used a cellular phone prior to the study. The other 16 volunteer participants (aged 62-83 years, $M = 71.4$, $SD = 4.63$) were recruited from a database of senior citizens from the Raleigh-Durham area. Each of these individuals had expressed, during earlier “human factors and aging” research conducted at NCSU, his/her interest in volunteering for subsequent studies. Based on self-reports, each of the older participants reported being a healthy self-sufficient adult, living an active life, who had used a cellular phone prior to the study. All participants were right-handed. Due to one of the older adult’s participants limited hand mobility, the data associated with this individual was not included in the final dataset and another participant was recruited to replace the data.

Before the start of the experiment, participants were administered both the Digit Symbol Substitution task (a perceptual speed task) and the Shipley Vocabulary task (a measure of crystallized intelligence) to ensure that the older and younger participants were representative

samples. The results from these tasks were consistent with findings from previous cognitive aging research on these measures. As predicted, younger adults ($M = 68.8$, $SD = 1.06$) performed significantly higher on the perceptual speed task than the older adults ($M = 50.6$, $SD = 2.03$), $t(30) = 5.14$, $p < .001$. The opposite effect was found for the vocabulary task where older adults ($M = 35.5$, $SD = 3.54$) performed significantly better than the younger adults ($M = 29.0$, $SD = 3.62$), $t(30) = 5.13$, $p < .001$. Two anthropometric measures of the thumb were also taken by the experimenter. The experimenter used a string and ruler to make these measurements. On average, participants had a thumb circumference of 7.2 cm and a distal pad length of 4.8 cm. No significant difference in thumb size was found as a function of age, $t(15) = 2.13$, $p = .82$.

Experimental Design

Consistent with Table 1, a 2 (age – older or younger) X 2 (key type – raised-rubber or flat-smooth) mixed factorial design was employed with key type varied within and age used as a grouping variable. The dependent measures in this experiment were: 1) number of correct number sequences dialed, 2) number of correct key presses averaged across all sequences (correct and incorrect), 3) dialing time, and 4) dialing errors. The maximum number of entries in each condition was 20. The types of errors were examined to determine if there were a significant difference in the number of omissions, wrong actions, and “navigation” errors.

Any instance in which a participant failed to dial one or more numbers present in the 10-digit number was considered an error of omission. A wrong action error was recorded if an individual entered one or more incorrect numbers in the 10-digit number. In addition, a navigation error was recorded if a person pressed one of the navigational keys as opposed to the number keys. Thus, three different types of errors were tracked during this experiment.

Stimuli and Apparatus

Each participant was asked to complete a demographics questionnaire and cell phone usage questionnaire (see Appendix A) before the experimental session. The demographic questionnaire administered to participants was used to assess their levels of experience with cellular phones (see Appendix B). In addition to the aforementioned questionnaires, each individual was administered the Shipley Vocabulary Test (Shipley, 1986) and the Digit Symbol Substitution Task (Wechsler, 1997).

Two cellular phones were used in this experiment. The cellular phones were identical in spatial arrangement and differed only in terms of keypad surface, such that one keypad had smooth-plastic flat keys (Kyocera Model 5135), level with the phone casing, and the other had soft-rubber raised keys (Kyocera Model 2119), raised from the phone casing. In an effort to compare the phones solely on the textural differences of the keys, the “home” key indicators (sometimes found on cellular phone and calculator keypads on or near the # 5 key) were removed from both cellular phones (see Appendix C for images and specifics of the phones). The phones were not in service, but the phones were charged so that numbers entered into the keypad would register on the visual display (phone interface). A large wooden box with a curtain served to preclude vision. A cushioned armrest was placed in the apparatus so individuals did not experience any discomfort during the dialing task.

The SuperLab™ Program (Abboud & Sugar, 1997) was used to record dialing times with an accompanying response pad operated by the experimenter. While this procedure may include some experimenter error, having participants dial the phone numbers and record response times would introduce still larger error, due to the motor requirements of the task. Given that the

SuperLab™ software program allows for an accuracy of +/- 1 millisecond, experimenter error should be constant across experimental conditions and age groups. Additionally, a single experimenter ran an entire session making any error less significant. Each trial block consisted of ten 10-digit phone numbers (Appendix D). For each phone, individuals participated in two blocks of trials. The phone numbers and trial blocks were counterbalanced with a Latin-square procedure.

Procedure

Before the main experimental session began, participants were asked to read and sign a consent form (Appendix E) as well as to complete the questionnaires and the two abilities tests. Once these tasks were completed, the experimenter read aloud the instructions (Appendix F) for the experiment and took two thumb measurements. The participants were then asked if they had any questions regarding the experiment. After any questions had been answered, the experimenter asked the participant to wipe his/her dialing hand with a cleansing wipe. This procedure was followed to control for possible residue buildup and potential interference with fingertip sensitivity.

The participant placed his/her right hand through the curtain, resting the forearm in a comfortable position on a cushion. After a short period during which participants were allowed to familiarize themselves with the feel of the keypad, the experimental session began. Participants were not allowed to visually inspect the phone during the experiment. Each individual faced a computer monitor, which displayed the 10-digit phone numbers to dial. Once a number was displayed on the monitor, the program automatically started to record the dialing time. When the participant had completed dialing, he/she reported completion by saying aloud

“done” and the experimenter pressed a key, which stopped the clock. The experimenter then removed the telephone from the participant and logged the number dialed.

The phone was then placed back into the participant’s hand and the computer monitor displayed the second number. The session was repeated in this manner for all numbers until the participant had dialed twenty phone numbers with each phone. After dialing the twenty numbers with the first phone, each participant received a 3-minute break. At the conclusion of the break, the second half of the experiment commenced.

Upon the completion of the dialing task, each individual was asked a few questions, including if they noticed any differences in the two phones during the experiment. They also were asked to indicate their level of confidence that they dialed accurately with each of the phones. Finally, each participant was debriefed, shown the cellular phones, and told the purpose of the experiment.

Results

Four 2 (age – younger or older) X 2 (keypad – raised-rubber or flat-smooth) mixed factorial analyses of variance were applied to the data for the following four dependent variables: correct sequences, keys correct, dialing time and dialing errors (errors analyzed included: navigation errors, wrong numbers, and omission errors) with cell phone as the within-variable and age group as the between-variable. An alpha level of .05 was used for all statistical tests. The following section is divided into four parts. The first part will discuss the results on the measures of accuracy. The second section presents the results on the dependent measure of inspection time. The third section will discuss the results for the various measures of error. The final section presents the results for participant confidence ratings.

Initially, a covariate design was to be employed in the data analyses to control for any effect of pre-existing cell phone experience on dialing performance. Upon conducting the analyses with level of cell phone experience treated as the covariate, however, the statistics revealed a significant interaction between age and level of experience with cell phones. Younger adults had much more experience with cell phones than did older adults. One of the assumptions when using a covariate in an analysis of variance is that it (the covariate) should be independent of the other independent variables (Aiken & West, 1991). Therefore, if the covariate had been included in this model, it would violate the assumption of a covariate model as well as potentially underestimating the effect size of the other factors.

Accuracy

As mentioned previously, two main types of accuracy were analyzed in this experiment: correct sequences and keys correct. The first accuracy measurement discussed in this section is the correct number of sequences for each of the phones. The second is the correct number of individual key presses.

Correct Sequences. Each participant dialed twenty 10-digit telephone numbers with both cell phones. Thus, each participant could reach a maximum accuracy of 20 for each cell phone. The analysis of variance revealed a main effect for cell phone $F(1, 30) = 41.12$, a main effect for age group $F(1, 30) = 13.48$, and a significant interaction of cell phone and age group $F(1, 30) = 4.40$. The main effect of cell phone indicated that all participants, regardless of age group, were more accurate in terms of the correct number of sequences when they used keypads with raised-rubber keys. The main effect of age group indicated that younger adults were more accurate than older adults during the dialing task. The interaction revealed there was a greater difference in correct sequences dialed between keypads for older adults than there was for younger adults.

Table 1 presents the means for correct sequences for each condition. The ANOVA summary table is presented in Table 2.

Correct Key Presses. The second dependent measure of accuracy analyzed in this experiment was keys correct (correct number of key presses within a sequence). Each number dialed was comprised of 10 digits, yielding a maximum of 10 key presses correct. The analysis of variance revealed results similar to the correct sequence data in that there was a main effect

Table 1.

Table of Means for Correct Sequences – Experiment 1

<u>Keypad Type</u>	<u>Age Group</u>		<u>Est. Marginal Means</u>
	<u>Younger</u>	<u>Older</u>	
Raised Rubber	11.13 (5.51)	4.69 (6.32)	7.91 (1.05)
Smooth Flat	2.00 (2.83)	.06 (.25)	1.03 (.36)
Est. Marginal Means	6.77 (6.32)	2.39 (5.07)	

Note. Values in parentheses are standard deviations.

Table 2.

Analysis of Variance for Correct Sequences – Experiment 1

Source	DF	F	Pr>F
Cell Phone	1	41.12	.001*
Age Group	1	13.48	.001*
Cell Phone X Age	1	4.40	.044*
Error (cell)	30		
Error	30		

Note. Values with asterisks are significant at the .05 level.

for cell phone $F(1, 30) = 76.08$, and for age group $F(1, 30) = 25.86$, as well as a significant interaction of cell phone and age group $F(1, 30) = 4.08$. Consistent with the results of correct sequences, these results indicate that regardless of age individuals had a higher number of correct key presses when using the raised-rubber keypad than the flat-smooth keypad and that the younger adults were generally more accurate than the older adults. In addition, the interaction revealed that there was a greater difference in correct key presses between keypads for older adults than there was for younger adults. Table 3 presents the means for correct sequences for each condition. The ANOVA summary table is presented in Table 4.

Table 3.

Table of Means for Correct Key Presses within a Sequence – Experiment 1

<u>Keypad Type</u>	<u>Age Group</u>		<u>Est. Marginal Means</u>
	<u>Younger</u>	<u>Older</u>	
Raised Rubber	8.60 (1.90)	6.67 (2.41)	7.67 (.38)
Smooth Flat	5.54 (2.15)	1.85 (1.56)	3.69 (.33)
Est. Marginal Means	7.07 (2.53)	4.31 (3.18)	

Note. Values in parentheses are standard deviations.

Table 4.

Analysis of Variance for Keys Correct in a Sequence – Experiment 1

Source	DF	F	Pr>F
Cell Phone	1	76.08	.001*
Age Group	1	25.86	.05*
Cell Phone X Age	1	4.08	.001*
Error (cell)	30		
Error	30		

Note. Values with asterisks are significant at the .05 level.

Dialing Time

To test for any significant differences in dialing performance as a function of age and/or cell phone keypad type, an analysis of variance was applied to the dependent measure of dialing time. This analysis revealed a significant main effect for age group $F(1, 30) = 18.69$, but not for cell phone. No significant interaction was found. This finding demonstrates simply that younger adults dialed the keypads significantly faster than the older adults. See Table 5 for the means of each condition. The ANOVA summary table is presented in Table 6.

Table 5.

Table of Means for Dialing Time (in seconds) – Experiment 1

<u>Key Type</u>	<u>Age Group</u>	
	<u>Younger</u>	<u>Older</u>
Raised Rubber	15.93 (6.85)	34.16 (11.86)
Smooth Flat	22.56 (10.02)	36.04 (17.32)

Note. Values in parentheses are standard deviations.

Table 6.

Analysis of Variance for Dialing Time – Experiment 1

Source	DF	F	Pr>F
Cell Phone	1	3.68	.065
Age Group	1	18.69	.001*
Cell Phone X Age	1	1.15	.293
Error	30		
Error (cell)	30		

Note. Values with asterisks are significant at the .05 level.

Error-Types

To assess the types of errors made by participants and the types of errors that may be more likely with particular phone types, analyses were conducted on three main types of errors: omissions, wrong actions, and navigation errors. The following section presents the results from each of these analyses respectively. Tables of means of ANOVA summary tables for each of the following error analyses are presented in Appendix G.

Omission Errors. An omission error was considered as any instance in which a participant failed to press the correct number in the number sequence provided. Similar to the other analyses employed thus far, an analysis of variance was applied to the omission data. This analysis revealed significant effects for cell phone $F(1, 30) = 11.85$, age group $F(1, 30) = 8.08$, and a significant interaction $F(1, 30) = 7.22$ of the two. These results indicate that both age groups committed fewer omissions errors with the raised-rubber keypad than with the flat-smooth keypad and that older adults committed more such errors, overall, than younger adults. Furthermore, there was a much larger difference in the occurrence of omission errors between types of keypads for older adults than there was for younger adults.

Wrong Action Errors. A wrong action was considered as any instance in which a participant dialed a number not consistent with the sequence of numbers in the phone number. An analysis of variance was applied to these data and a significant main effect was found for cell phone $F(1, 30) = 29.80$ and age group $F(1, 30) = 4.35$. This result revealed that both age groups committed significantly more wrong-action errors with the flat-smooth keypad and that older adults committed significantly more wrong-action errors than their younger adult counterparts. No significant interaction was found.

Navigation Errors. A navigation error was considered as any instance in which a participant pressed a navigational key during the number sequence. Some examples of navigational keys include: “Send,” “End,” “Scroll Up,” and “Scroll Down” keys. An analysis of variance was applied to these navigation-error data and revealed a significant main effect of cell phone, $F(1, 30) = 22.92$, age group, $F(1, 30) = 26.61$, and a significant interaction, $F(1, 30) = 18.63$. This result indicates that both age groups committed significantly more navigation errors with the flat-smooth keypad and that older adults committed significantly more navigation errors than younger adults. Furthermore, the difference in number of navigation errors committed between keypads was greater for older adults than for younger ones.

Confidence Ratings Analysis

To assess changes in participant confidence over time, each individual was asked for his/her level of confidence in dialing a cell phone before and after the dialing task. Analyses of the confidence ratings at these two points in time were conducted in an effort to reveal whether experience with the dialing task would affect a change in confidence.

A 2 (age – younger or older) X 2 (confidence rating – pre-task or post-task) analysis of variance was conducted on the confidence-rating data. The main effect of age was not significant nor was the interaction. However, the main effect of time was significant such that, overall, participants felt significantly more confident ($M = 3.53$, $SD = .76$) before the actual dialing task than after participating in the task ($M = 2.81$, $SD = .55$), $F(1, 30) = 29.71$.

Discussion

With respect to accuracy, the results from this experiment demonstrated that both age groups performed significantly better with the raised-rubber keypad than with the flat-smooth keypad. In addition, it was found that younger adults performed significantly better with both

cell phones as compared to the older adult participants; however, younger adults' performance with the raised-rubber keypad surface was significantly higher than with the flat-smooth keypad surface. Each of these findings was consistent with Hypothesis 1 of this study.

For dialing time, the findings were consistent with Hypothesis 2a such that younger adults had faster dialing times with both keypad surfaces than did the older adult participants. There were no differences in dialing time as a function of the keypad surface.

Hypothesis 2b of this study predicted that younger adults would produce fewer errors with both keypad surfaces as well. This hypothesis was confirmed for each of the errors recorded here, which include omission errors, wrong-action errors, and navigation errors. With respect to omission errors, the results suggest that not only did younger adults produce fewer errors overall but that the type of phone also interacted with this effect. Younger adults, in general, had very few errors with either the raised-rubber keypad or flat-smooth keypad. Of interest was the finding that older adults committed as many errors with the raised-rubber keypad as did younger adults with the flat-smooth keypad. The older adults' performance with the flat keypad surface had the highest omission error rates across all of the conditions as well.

Hypothesis 2b of this study was again confirmed with the wrong-action error data. The results indicated that, overall, younger adults committed significantly fewer wrong-action errors with both keypad surfaces than older adults. Hypothesis 1 was also confirmed with the wrong-action error data in that both age groups committed fewer errors with the raised-rubber keypad surface than with the flat-smooth keypad surface.

The final error data that were analyzed involved navigation errors. The same trend found with the omission-error data was evident with the navigation data. Navigation errors were affected by both the cell phone type and the age of the participant. Another finding was that older

adults committed significantly more navigation errors with the flat-smooth keypad surface than any of the other conditions. Consistent with the other error data, younger participants committed significantly fewer navigation errors with both phones than did the older participants. Furthermore, older adults were at a greater advantage with the raised-rubber keypad than younger adults in that they committed fewer navigation errors with the raised-rubber keypad than with the flat-smooth keypad.

Quite apparent from the aforementioned findings is that participants, overall, performed significantly better on all dependent measures with the raised-rubber keypad surface than with the flat-smooth keypad surface. This finding was consistent for both types of accuracy, dialing time, and the various types of errors. These results demonstrate that the flat-smooth keypad surface is not an optimal one and that other keypad surfaces should be implemented in phone design.

Experiment 2

Experiment 1 revealed that the raised-rubber keypad surface was the better keypad to be used for dialing by both younger and older adults. One potential reason for this finding could be that the more “texturalized” nature of the rubber surface allowed for greater haptic discriminability between the keys on the keypad. The present experiment was designed to investigate the haptic discriminability of particular tactile cues. More specifically, this experiment examined the discriminability of raised dots, raised lines, and a more textured surface (grating-type cue) using a same-different task in which participants were required to discriminate between pairs of tactile cues.

Method

Participants

As in Experiment 1, a total of 32 individuals took part in this experiment. By signing up electronically, 16 college student volunteers (aged 18-25 years, $M = 19$ years, $SD = 1.67$) earned partial research credit for their introductory psychology course. Each of these participants reported having used a cellular phone prior to the study. The other 16 volunteer participants (aged 60-74 years, $M = 64$, $SD = 3.97$) were recruited from a database of senior citizens from the Raleigh-Durham area. Each of these individuals had expressed, during an earlier experiment on aging not related to cell phones, his/her interest in volunteering for subsequent studies. Based on self-reports, each of the older participants reported being a healthy self-sufficient adult, living an active life, who had used a cellular phone prior to the study. All participants were right-handed.











As in Experiment 1, participants were administered both the Digit Symbol Substitution Task (a perceptual speed task) and the Shipley Vocabulary Task (a measure of crystallized intelligence). These results were consistent with findings from previous cognitive aging research and the findings from Experiment 1. As predicted, younger adults performed significantly higher on the perceptual speed task ($M = 68.7$, $SD = 10.86$) than did the older adults ($M = 58.7$, $SD = 8.18$), $t(29) = 2.87$; $p = .008$. The opposite effect was found for the vocabulary task where older adults ($M = 35.6$, $SD = 3.56$) performed significantly better than the younger adults ($M = 29.8$, $SD = 3.60$), $t(29) = -4.50$; $p < .001$. Two anthropometric measures of the thumb were also taken by the experimenter. On average, participants had a thumb circumference of 7.5 cm and a distal pad length of 5.0 cm. No significant difference in thumb size was found as a function of age, $t(15) = 2.13$, $p = .33$.

Experimental design

Ten stimulus pairs were broken down into three different pair-type categories: cue to no cue, cue to different cue, and a pair with the same characteristics. Analyses were conducted on both the stimulus pairs individually and the pair-type categories. Both of these analyses were consistent in their results. Thus, for parsimony's sake a 2 (age – older vs. younger) X 3 (pair-type – cue to no cue, cue to different cue, or same pair) mixed factorial design was employed, with cue type varied within and age used as a grouping variable. The two dependent measures in this experiment were average number of correct responses for pair-types on a same-different task as well as the average inspection time for each pair-type (see Table 7 for more detail on the stimulus pair-types).

Table 7.

Ten Stimulus Conditions Investigated

Pair	Pair Description	Age Group		Stimulus Depiction
A.	Raised Dot – Raised Dot	Young	Older	
B.	Raised Dot – Raised Line	Young	Older	
C.	Raised Dot – Texture	Young	Older	
D.	Raised Dot – No Cue	Young	Older	
E.	Raised Line – Raised Line	Young	Older	
F.	Raised Line – Texture	Young	Older	
G.	Raised Line – No Cue	Young	Older	
H.	Texture – Texture	Young	Older	
I.	Texture – No Cue	Young	Older	
J.	No Cue – No Cue	Young	Older	

Stimuli and Apparatus

Ten prototypes with two keys each, developed with SolidWorks® 3D CAD software, were used in this experiment (see Appendix H for description of stimulus development). Prototypes varied as to which cues were presented (see Table 7). The dimensions of the raised dots, used in some stimulus pairs, were .69 mm in dot height and 1.80 mm in dot diameter. Those stimulus pairs which had a raised line were of the dimensions .69 mm in line height and 5.08 mm in line width. The textured cue used in this study was a grating-type cue with the following dimensions: .69 mm ridge height, 1.15 mm groove width, .75 mm ridge width, and 4 mm overall width. A large wooden box with a curtain prevented viewing the stimuli and a cushion was placed in the apparatus, so individuals did not experience any discomfort during the same-different task.

Procedure

Upon entering the laboratory, participants were asked to read and sign an informed consent form (see Appendix I). As in Experiment 1, each individual also was administered the abilities tests. After the two ability tests were completed, each participant completed the cell phone usage questionnaire (see Appendix J) and demographic questionnaire. The experimenter read aloud the instructions for the experiment (see Appendix K). These instructions asked participants to haptically determine with the thumb (examination by the thumb is consistent with the phone dialing tasks in the other experiments) whether the two keys presented at any given time were the same or different. To indicate their answers, participants were asked to say either “same” or “different” out loud to the experimenter.

Each participant was then asked if he or she had any questions regarding the experiment. After all the questions had been answered, the experimenter asked each participant to wipe

his/her preferred hand with a cleansing wipe to control for possible residue buildup and any related decreases in fingertip sensitivity.

Each individual was provided a brief practice period with the same/different task before starting the experiment. This was done, because the two comparison keys were mounted on an alternative surface (i.e., a wooden block). Affixed to the wooden block were two keys in the same general area that the 5 and 6 key would be located on a keypad. Each individual was to haptically examine both keys with his or her thumb and report whether the two keys were the same or different. Participants were told to take the time necessary to develop an informed opinion. However, the experimenter recorded total inspection time with the SuperLab™ computer software program, similar to the recording of dialing time in Experiment 1. Participants received a 2-minute rest break at the halfway point of the experiment. Once the second half was completed, the experimenter answered any questions, debriefed the participant by showing the cellular phones, and described the purpose of the experiment.

Results

A series of 2 (age – younger or older) X 3 (pair type – same, cue to cue, or cue to no cue) mixed factorial analyses of variance, with pair-type as the within variable and age group as the between variable, were applied to the data on the average number of correct responses for each pair-type, as well as on the average inspection time for each pair-type. An alpha level of .05 was used for all statistical tests. A Scheffé test was conducted when multiple comparisons were indicated. This result section is divided into two sub-sections. The first sub-section discusses the accuracy with which participants judged the pair-types while the second sub-section presents the results on inspection time.

Pair-Types Correct

To assess which types of tactile cues were more discriminable, an analysis of variance was conducted on the mean correct score for each pair-type. This analysis revealed a significant main effect for both pair-type, $F(2, 60) = 12.36$ and age group, $F(1, 30) = 6.76$. No significant interaction was found. These results indicate that both age groups were more accurate in discriminating between different cues than in judging that a pair of stimuli was the same. Participants also were more accurate in discriminating between a cue and the absence of a cue than in comparing stimuli with different cue pairs. Consistent with previous findings in this study, younger adults were more accurate in discriminating the pairs, overall, than were the older adults. Table 8 presents the means for pair-types correct for each condition. The ANOVA summary table is presented in Table 9.

Table 8.

Table of Means for Pair-types Correct— Experiment 2

<u>Pair Type</u>	<u>Age Group</u>		<u>Est. Marginal Means</u>
	<u>Younger</u>	<u>Older</u>	
Same Pair	2.91 (.62)	2.25 (.65)	2.58 (.11)
Cue to Different Cue	2.73 (1.03)	2.75 (.87)	2.74 (.17)
Cue to No Cue	3.67 (.37)	3.25 (.67)	3.47 (.10)

Note. The average maximum correct score for each pair-type is 4.

Table 9.**Analysis of Variance for Pair-Types Correct – Experiment 2**

Source	DF	F	Pr>F
Pair-Type	2	37.66	.001*
Age Group	1	6.76	.014*
Pair-Type X Age Group	2	.57	.457
Error	30		
Error (pair-type)	60		

Note. Values with asterisks are significant at the .05 level.

Stimulus Pair Analyses

Additional descriptive analyses were conducted to identify which stimulus pairs were most often judged correctly by participants. These analyses revealed that participants had the highest means for the following stimulus pairs: Raised Dot – Texture, Raised Dot – No Cue, and Texture – No Cue.

Table 10.**Means and Standard Deviations for Stimulus Pairs– Experiment 2**

Pair	Pair Description	Mean Correct Comparisons	Std. Deviation
A	Dot – Dot	2.19	1.23
B	Dot – Line	2.41	1.32
C	Dot – Texture	3.31	1.09
D	Dot – No Cue	3.78	.61
E	Line – Line	1.97	1.23
F	Line – Texture	2.50	1.29
G	Line – No Cue	3.28	.85
H	Texture – Texture	2.88	1.16
I	Texture – No Cue	3.34	.97
J	No Cue – No Cue	3.28	.92

Note. Maximum correct for each pair-type is 4. Values in bold represent those stimulus pairs with the highest correct judgments.

Inspection Time

Inspection time was also a variable of interest in this experiment. It was desirable to assess whether certain tactile cues are more quickly discriminated than other tactile cues. Also of interest was to ascertain whether inspection time was differentially affected by age of the participant, as well as by the presence or absence of a tactile cue. Similar to the pair-type correct data, a significant main effect of time was found for pair-type, $F(2, 60) = 28.32$ and age group, $F(1, 30) = 10.51$, with no significant interaction. These results reveal that the cue to blank stimulus pair condition took the shortest amount of time as compared to other conditions. Participants also took longer to discriminate same-pair stimuli as compared to keys with different pairs of cues. Again, older adults took significantly longer to inspect all stimulus pairs than younger adults. Table 11 presents the means for pair-types correct for each condition. The ANOVA summary table is presented in Table 12.

Table 11.

Table of Means for Inspection Time per Sequence (in sec) – Experiment 2

<u>Cell Phone</u>	Age Group	
	<u>Younger</u>	<u>Older</u>
Same Pair	7.2 (3.97)	10.4 (3.86)
Cue to Different Cue	6.0 (2.49)	9.6 (3.49)
Cue to No Cue	4.3 (1.68)	7.5 (2.93)

Note. Values in parentheses are standard deviations.

Table 12.**Analysis of Variance for Inspection Time – Experiment 2**

Source	DF	F	Significance
Pair Type	1	28.32	.001*
Age Group	1	10.51	.003*
Pair Type X Age Group	1	.23	.796
Error	30		
Error (pairtype)	60		

Note. Values with asterisks are significant at the .05 level.

Discussion

The purpose of Experiment 2 was to identify which tactile cues might be more discriminable from other tactile cues. In addition, it was of interest to identify whether the age of participants had an effect on this type of discrimination. As predicted by Hypothesis 5b, the results indicated that younger adults were more accurate overall at discriminating between pairs of tactile cues than older adults. It was also predicted by Hypothesis 3b that there would be a main effect of pair-type, such that both age groups are more accurate for pairs where one key has a tactile cue and the other does not. This hypothesis was also supported.

The effects found for accuracy were also found for inspection time. For instance, consistent with Hypothesis 5a, younger adults had significantly faster inspection times for all pair-types. In addition, both age groups were significantly faster with pair-types that had one cue present and one cue absent (Hypothesis 3a) than with pairs in which a cue was to be distinguished from no cue.

Also of interest to this study was which specific tactile cues were more discriminable. It was anticipated that the raised line and the textured cue would yield higher correct responses and

faster response times than the raised dot cue, when each was compared to a no-cue key. This result, which would not have supported Hypothesis 4, was only partially obtained in that the texture cue was readily discriminable by participants whereas the raised line was not readily discriminated. The raised line cue ($M = 3.28$, $SD = .85$) and textured cue ($M = 3.34$, $SD = .97$) were readily discriminated when they were paired with a no-cue key. However, the single-raised dot key ($M = 3.78$, $SD = .61$) compared to a no-cue key was detected the most accurately of all.

The findings from Experiment 2 reveal that participants of both age groups can readily discriminate between pairs of keys when one has a tactile cue and one key does not. Participants also perform quite well when discriminating two keys with differing tactile cues. The two cues that were most readily discriminated were the raised-dot cue and the textured cue. An area not investigated by Experiment 2, however, is the localization of such tactile cues on the keypad surface. Experiment 3 was designed to investigate this spatial arrangement variable by examining the performance of young and older adults during a dialing task that utilized cell phones outfitted with prototype tactile cues. The discriminability results from Experiment 2 were used to direct the design of these prototype tactile cues to supplement existing cell phone interfaces.

Experiment 3

The findings from Experiment 1 demonstrated that participants of both age groups performed substantially better with the raised-rubber keypad as compared to their performance with the flat-smooth keypad. Although participants performed significantly better with raised-rubber keypad, dialing performance still was not optimal.

The results from Experiment 2 revealed that cue to no cue “pairs” were more reliably discriminated, followed by cue to cue “pairs.” Same “pairs” were found to be less discriminable

for both age groups. Further analyses indicated that two tactile cues were the most discriminable, in terms of accuracy and inspection time, from each other and from a key with no tactile cue available: the raised dot and the textured key. The raised line, in Experiment 2, was not found to be readily discriminable from other cues and thus, will not be considered further.

Another variable of interest was the spatial arrangement of the tactile cues. Current cellular phone keypads typically have one (if any) tactile cue located on the key in the 5 position. However, this tactile cue can vary in shape, size and/or orientation. Thus, one goal of this study was to examine the effect of spatial arrangement of tactile cues on the keypad. Because this variable has not been examined in the literature, this manipulation was largely exploratory and should supplement findings from the previous experiments.

The purpose of Experiment 3 was to synthesize the aforementioned results from Experiments 1 and 2 by examining the effectiveness of tactile cues (raised dot and textured) strategically located in various spatial arrangements on an existing key-type (raised-rubber) which was found to be an effective keypad surface for dialing. By adding tactile cues to the existing raised-rubber keypad surface in different locations on the keypad, the goal was to identify if the addition of additional cues would further aid in dialing performance.

Method

Participants

A total of 28 individuals took part in this experiment. By signing up electronically, 14 college student volunteers (aged 18-23 years, $M = 19.4$ years, $SD = 1.65$) earned partial research credit for their introductory psychology course. Each of these participants reported having used a cellular phone prior to the study. The other 14 volunteer participants (aged 62-78 years, $M = 70.1$, $SD = 4.32$) were recruited from a database of senior citizens from the Raleigh-Durham

area. Each of these individuals had expressed, during an earlier experiment, his/her interest in volunteering for subsequent studies. Based on self-reports, each of the older participants reported being a healthy self-sufficient adult, living an active life, who had used a cellular phone prior to the study. All participants were right-handed. The data from one older adult was excluded and replaced with another individual due to that individual's participation in an earlier study.

Participants were administered both the Digit Symbol Substitution Task (a perceptual speed task) and the Shipley Vocabulary Task (a measure of crystallized intelligence). These results were consistent with findings from previous cognitive-aging research and the findings from Experiments 1 and 2. As predicted, younger adults ($M = 64.5$, $SD = 10.5$) performed significantly higher on the perceptual speed task than the older adults ($M = 45.9$, $SD = 5.47$); $t(13) = 2.11$, $p < .001$. The opposite effect was found for the vocabulary task where older adults ($M = 34.4$, $SD = 4.11$) performed significantly better than the younger adults ($M = 28.4$, $SD = 4.18$); $t(13) = -3.83$, $p = .002$. Two anthropometric measures of the thumb were also taken by the experimenter. On average, participants had a thumb circumference of 7.1 cm and a distal pad length of 4.6 cm. No significant difference in thumb size was found as a function of age.

Experimental Design

Consistent with Table 14, a 2 (age – older or younger) X 5 (cell phone keypad – A, B, C, D or E) mixed-factorial design was employed with cell phone keypad varied within and age used as a grouping variable. The cell phone keypads consisted of varying tactile cues and varying spatial layout. The dependent measures in this experiment were: 1) number of correct sequences dialed, 2) number of correct key presses averaged across all sequences (correct and incorrect), 3) dialing time, and 4) dialing errors. The maximum number of entries in each condition was 10. The types of errors were examined to determine if there was a significant difference in the

number of omissions, wrong actions, and navigation errors depending on the type of cell phone keypad used. A large wooden box with a curtain served to block vision and a cushioned armrest minimized discomfort.

Stimuli and Apparatus

Five different cellular phones were used as stimuli in this experiment. All five of the phones (Nokia Model 5190 – see Appendix L for image and description) had raised-rubber keys with various types and spatial layout of tactile cues (see Table 14). The various spatial arrangements were based on current cell phone designs (i.e., tactile cue on 5 key) and on anecdotal evidence from Experiment 1 where it was observed that many individuals utilized the 1 and 5 key to orient themselves on the keypad. Additionally, some individuals would localize the 5 key and then work the diagonals to the 1, 3, 7, and 9 keys for further localization. These types of cues used in this experiment were derived from the findings of Experiment 2 which indicated that participants were most readily able to discriminate the raised dot and textured cue. Experiment 2 also revealed that participants were best able to discriminate a key with a cue from a key without a cue. As a result, five forms of spatial arrangement and tactile cues were developed.

The first cell phone, (i.e., Cell Phone A) had a raised dot on the key in the five position. This cue and arrangement were chosen to be consistent with the current cellular phone keypads on the market. Cell Phone B had a textured cue in the five position. This cue and arrangement were chosen to be consistent with current cellular phone keypads but with the addition of a novel cue.

Cell Phone C had a raised dot in the five position and a textured cue in the 1, 3, 7, and 9 key positions. The dot was placed on the 5-key to be consistent with current keypads while the

texture cue was placed on the peripheral keys. Dots were not placed on the peripheral keys due to potential confusion of the keys given their past experience with a dot on the 5-key (i.e., participants may have located a dot-key and assumed it was a five given their past experience).

Cell Phone D had a raised dot in the five position and a textured cue in the one position. During Experiment 1, the experimenter observed that older adults made many navigation errors. By placing a textured cue in the one position, it was hoped that the threshold between the number and navigation keys would be more apparent to participants.

The final cell phone was a control that had no tactile cues. Stereolithography was not used to develop the keypads in this experiment (as in Experiment 2), due to the high cost of developing each individual keypad. Thus, each of the keypad stimuli were made by affixing tactile cues with specific dimensions used in Experiment 2 to existing raised-rubber keypads. As in Experiment 1, the phones were not in service, but were charged, so that numbers entered into the keypad would register on the visual display.

The SuperLab™ Program (Abboud & Sugar, 1997) was used to record dialing times with an accompanying response pad operated by the experimenter. Each trial block consisted of ten 10-digit phone numbers (see Appendix M). For each phone, individuals participated in one block. The phone numbers and trial blocks were counterbalanced with a Latin-square procedure.

Procedure

The experimental dialing task was identical to that used in Experiment 1. The only deviation in experimental procedure was the inclusion of a cell phone opinion survey which was administered after the demographic questionnaire (see Table 14). Items from this survey were used to query individuals about how they used their cellular phones and whether they believed tactile cues to be an important addition to the cell phone interface. Participants were asked to rate

how much they agreed with each statement presented to them using a 9-point agreement scale with the following numerical anchors and wording: (0) not at all agree; (2) somewhat agree; (4) agree; (6) very much agree; and (8) extremely agree. A previous study (Mendat, Bell, and Wogalter, 2004) used this same opinion survey and scale with 289 participants.

Table 13.

Experimental conditions in Experiment 3

Phone	Cue-type	Location	Age Group	Diagram
A	Raised dot	5	Young Older	
B	Textured	5	Young Older	
C	Raised Dot Textured	5 1, 3, 7, 9	Young Older	
D	Raised Dot Textured	5 1	Young Older	
E	No Cues	No Cues	Young Older	

A number of t-tests were conducted to determine whether age group differences in opinion were present. The results revealed that for most items age groups had comparable agreement ratings. There were two items, however, that younger and older adults rated significantly differently. Older adults ($M = 3.71$, $SD = .91$) reported they were much more likely than young adults ($M = 2.64$, $SD = 1.08$) to look at the keypad prior to pressing keys during cell phone menu navigation, $t(26) = -2.83$, $p = .009$. When dialing their phones in low-lighting conditions, younger adults ($M = 2.57$, $SD = .76$) rated their dialing success rate at higher level than that reported by older adults ($M = 1.86$, $SD = .77$); $t(26) = 2.41$, $p = .02$.

Table 14.

Opinion Survey Items (0-8 point agreement scale) – Experiment 3

Statement	Younger	Older
*a. When I navigate menus of a cellular phone, I am likely to look at the buttons to locate them before pressing them.	3.29 (2.16)	5.43 (1.83)
b. It would be helpful to have button features to help locate them by touch or feel them in situations where you are not looking at the phone.	4.57 (1.83)	4.29 (1.07)
*c. When I am not able to see the buttons on a cellular phone, for example because of low lighting conditions, I am almost always successful in navigating and dialing.	3.14 (1.51)	1.71 (1.54)
d. When I make a phone call on a cellular phone, I always look at the actual buttons to locate and dial them.	3.43 (2.28)	5.00 (1.88)
e. I would consider buying a phone with features that allow the buttons to be identified by touch or feel.	3.71 (1.73)	3.57 (.85)
f. I would be willing to pay more for a feature that allows the buttons to be located by touch or feel.	2.00 (2.22)	1.86 (1.46)

Note. Values in parentheses are standard deviations. Asterisks denote those survey items which age groups differed significantly at the .05 level.

Results

A series of 2 (age – younger or older) X 5 (cell phone keypad – A, B, C, D, or E) mixed factorial analyses of variance were applied to the data for the following four dependent variables: correct sequences, keys correct, dialing time and dialing errors (errors analyzed included: navigation errors, wrong numbers, and omission errors) with cell phone as the within-variable and age group as the between-variable. An alpha level of .05 was used for all statistical tests. A Scheffé test was conducted when multiple comparisons were indicated. The following section is divided into three parts. The first part will discuss the results on the dependent measures of accuracy. The second part presents the results on the dependent measure of inspection time. The final part will discuss the results on the various dependent measures of error.

Accuracy

Correct Sequences. Each participant dialed ten 10-digit telephone numbers with each of the five cell phones. Thus, each participant could reach a maximum accuracy of 10 for each cell phone. The analysis of variance revealed a main effect for cell phone, $F(4, 104) = 6.13$ and a main effect for age group, $F(1, 26) = 35.12$. These findings revealed that younger adults were

Table 15.

Table of Means for Correct Sequences – Experiment 3

<u>Cell Phone Keypad</u>	<u>Age Group</u>		<u>Est. Marginal Means</u>
	<u>Younger</u>	<u>Older</u>	
Cell Phone A	5.57 (3.59)	1.93 (2.95)	3.75 (.62)
Cell Phone B	6.86 (2.32)	2.71 (3.43)	4.79 (.55)
Cell Phone C	6.14 (2.28)	.43 (.76)	3.29 (.32)
Cell Phone D	6.00 (2.60)	1.64 (2.31)	3.82 (.46)
Cell Phone E	8.07 (1.54)	3.07 (3.71)	5.57 (.54)
Est. Marginal Means	6.53 (2.63)	1.96 (2.90)	

Note. Values in parentheses are standard deviations.

substantially more accurate with all the keypads, as compared to older adults. In addition, the results revealed that across both age groups, individuals were significantly more accurate with Cell Phones E (i.e., control) and B (i.e., single textured cue) than with any other phone (see Table 18). No significant interaction between age and cell phone was found. Table 15 presents the means for correct sequences for each condition. The ANOVA summary table is presented in Table 16.

Table 16.

Analysis of Variance for Correct Sequences – Experiment 3

Source	DF	F	Pr>F
Cell Phone	4	6.13	.001*
Age Group	1	35.12	.001*
Cell Phone X Age	4	1.72	.20
Error	26		

Note. Values with asterisks are significant at the .05 level.

Table 17.

Pairwise-Comparisons of Keypads for Correct Sequences

Keypad Comparison	Mean Difference	t	Pr>F
Keypad A – Keypad B	-1.04	-2.17	.04*
Keypad A – Keypad C	.46	.72	.47
Keypad A – Keypad D	-.07	-.14	.89
Keypad A – Keypad E	-1.82	-3.27	.00*
Keypad B – Keypad C	1.50	2.39	.02*
Keypad B – Keypad D	.96	2.50	.02*
Keypad B – Keypad E	-.79	-1.97	.06
Keypad C – Keypad D	-.54	-.96	.35
Keypad C – Keypad E	-2.29	-4.00	.00*
Keypad D – Keypad E	-1.75	-3.55	.00*

Correct Key Presses. The second measure of accuracy analyzed in this experiment was the number of correct key presses within a sequence. Each number dialed was comprised of 10 digits, yielding a maximum of 10 key presses to evaluate. The analysis of variance revealed results similar to the correct-sequence data. A main effect for cell phone, $F(4, 104) = 4.88$ and a main effect for age group, $F(1, 26) = 27.08$ were found. A significant interaction of cell phone and age group was not found. These results are comparable to those with the correct-sequence results, which indicated that individuals in both age groups were significantly more accurate with Cell Phones E (i.e., control) and B (i.e., single textured cue) than with any other phone. Table 18 presents the means for correct sequences for each condition. The ANOVA summary table is presented in Table 19.

Table 18.

Table of Means for Correct Key Presses within a Sequence— Experiment 3

<u>Cell Phone Keypad</u>	<u>Age Group</u>		<u>Est. Marginal Means</u>
	<u>Younger</u>	<u>Older</u>	
Cell Phone A	8.14 (2.24)	5.19 (3.27)	6.67 (.53)
Cell Phone B	9.35 (.60)	6.08 (2.97)	7.71 (.40)
Cell Phone C	9.35 (.53)	5.14 (2.06)	7.25 (.20)
Cell Phone D	9.06 (1.01)	5.54 (2.92)	7.30 (.41)
Cell Phone E	9.68 (.26)	6.79 (2.43)	8.24 (.33)
Est. Marginal Means	9.12 (1.24)	5.75 (2.75)	

Note. Values in parentheses are standard deviations.

Table 19.**Analysis of Variance for Keys Correct in a Sequence– Experiment 3**

Source	DF	F	Pr>F
Cell Phone	4	4.88	.00*
Age Group	1	27.08	.00*
Cell Phone X Age	4	1.03	.40
Error	26		

Note. Values with asterisks are significant at the .05 level.

Dialing Time

To test for any significant differences in dialing performance as a function of age and/or cell phone keypad type, an analysis of variance was applied to the dependent measure of dialing time. This analysis revealed a significant main effect for age group, $F(1, 26) = 18.69$, but not for cell phone. Older adults took significantly more time to dial the phone than did younger adults. No significant interaction was found. See Table 20 for the means of each condition. The ANOVA summary table is presented in Table 21.

Table 20.**Table of Means for Dialing Time (in seconds) – Experiment 3**

<u>Key Type</u>	<u>Age Group</u>	
	<u>Younger</u>	<u>Older</u>
Cell Phone A	15.84 (4.18)	35.73 (7.84)
Cell Phone B	14.79 (4.75)	32.61 (9.13)
Cell Phone C	18.46 (11.59)	34.86 (11.47)
Cell Phone D	17.56 (7.37)	36.20 (10.35)
Cell Phone E	15.13 (6.57)	32.76 (8.10)

Note. Values in parentheses are standard deviations.

Table 21.**Analysis of Variance for Dialing Time – Experiment 3**

Source	DF	F	Pr>F
Cell Phone	4	2.07	.09
Age Group	1	47.73	.00*
Cell Phone X Age	4	.39	.82
Error	26		
Error (cell)	104		

Note. Values with asterisks are significant at the .05 level.

Error-Types

As in Experiment 1, a series of 2 (age – younger or older) X 5 (cell phone keypad – A, B, C, D, or E) planned analyses were conducted on three main types of dialing errors: omissions, wrong actions, and navigation errors. A Scheffé test was conducted when multiple comparisons were indicated. The following section presents the results from each of these analyses (see Appendix O for summary tables).

Omission Errors. This analysis revealed no significant differences in omission errors for age group or cell phone at the .05 level. Age group did approach significance with a p-value of .10.

Wrong Action Errors. This analysis revealed a significant main effect for cell phone, $F(4,104) = 3.99$ and age group, $F(1,26) = 30.23$. No significant interaction was found. These results indicate that older adults committed more wrong action errors than older adults and that participants of both age groups committed significantly fewer errors with Cell Phone E (i.e., control) than with the other phones.

Navigation Errors. This analysis of variance revealed a significant effect of age group, $F(1, 26) = 10.44$. Older adults committed significantly more navigational errors than younger

adults, whereas performance of younger adults was almost perfect. Although this analysis revealed neither a significant effect of cell phone nor a significant interaction of the two (at the .05 level); both of these effects did approach significance.

Confidence Ratings Analysis

As in Experiment 1, participants rated their confidence with dialing the cell phone before and after completion of the dialing task. A 2 (age – younger or older) X 2 (confidence rating – pre-task or post-task) analysis of variance revealed no main effects of age or time and no interaction. Participants did not differ significantly in their confidence ratings from before ($M = 2.89$, $SD = .92$) the dialing tasks to after them ($M = 2.64$, $SD = .91$). This effect was different than that found in Experiment 1. In Experiment 1 both age groups rated their confidence level significantly higher before the dialing task than afterward. In Experiment 3, however, both age groups rated their confidence level as being similar before and after the dialing task. This finding could be due, at least in part, to the instructions given participants in that they were notified that they would be working with keypads that might differ by feel. This instruction deviated from Experiment 1 and may have deflated the initial confidence rating, because participants knew they could be working with an unfamiliar sort of phone.

Discussion

Similar to Experiment 1, younger adults were expected to have faster dialing times and a lower number of errors than older adults. This result was found, consistent with Hypothesis 5. The results also revealed, as expected, that participants (both older and younger adults) performed better in the single-location tactile cue (home key) condition than in the five-key location (1, 3, 5, 7, and 9) condition, supporting Hypothesis 6.

The findings from this study suggest that cell phones with a raised-rubber keypad surface can be sufficient in aiding dialing performance. The addition of tactile cues appeared to actually

decrease dialing performance with the respective multiple-location tactile cue phones. This could be due to an overload of tactile features, thereby confusing participants similar to the outcome described in Oakley et al. (2001), where participants became confused and less sensitive in terms of tactile discriminability when exposed to multiple tactile cues. Such a tactile-cue overload would also be consistent with research investigating multi-sensory cues. One recent study, for example, reported that high visual cue conditions resulted in slower performance and more errors in a target acquisition task (Pierno, Caria, Glover, & Castiello, 2005).

One limitation of this experiment was the use of only one keypad surface, the raised-rubber keypad. A full factorial design (i.e., employing both raised-rubber and flat-smooth keypads) was not practical given the reports of fatigue from older adults during Experiment 1. In addition, the resources were not available to allow the analysis of five flat-smooth phones.

Experiment 1 illustrated that participants of both age groups performed significantly better with the raised-rubber keypad. The purpose of Experiment 3, on the other hand, was to identify whether additional tactile cues could further enhance this performance. Although the results did not fully support this idea, they did reveal that a single tactile cue on the 5 key was more effective than multiple tactile cues. Due to this finding, it was of interest to conduct a fourth experiment to see if this same trend revealed itself with a flat-smooth surface keypad and/or if a multiple-cue condition may be more effective with the flat-smooth keypad than with the raised-rubber keypad.

Experiment 4

The results from Experiment 3 revealed that the additional tactile cues on an existing raised-rubber keypad did not significantly enhance dialing performance. Specifically, participants performed significantly better with the raised-rubber keypad with no tactile cues

than the other keypads. However, participants performed even better with the raised-rubber keypad if it had one textured-tactile cue located on the 5 key. Experiment 4 (a smaller-scale experiment) was designed to assess whether similar results would be found for a phone having a smooth-flat keypad surface. It was anticipated that additional tactile cues might be more beneficial when added to a smooth-flat keypad surface than when added to a raised-rubber keypad surface.

Method

Participants

A total of 20 individuals took part in this experiment. Ten college student volunteers (aged 18-23 years, $M = 19.8$ years, $SD = 1.75$) and ten volunteer participants (aged 60-71 years, $M = 66.20$, $SD = 3.99$) participated in this experiment. All of the participant criteria were identical to those in the other three experiments.

Participants were administered both the Digit Symbol Substitution Task (a perceptual speed task) and the Shipley Vocabulary Task (a measure of crystallized intelligence). These results were consistent with findings from previous cognitive aging research and the findings from each of the previous experiments where younger adults ($M = 69.9$, $SD = 7.61$) performed significantly higher on the perceptual speed task than the older adults ($M = 51.7$, $SD = 8.06$); $t(9) = 2.26$, $p < .001$. The opposite effect was found for the vocabulary task where older adults ($M = 36.20$, $SD = 1.99$) performed significantly better than the younger adults ($M = 28.80$, $SD = 3.36$); $t(9) = 6.74$, $p = .001$. On average, participants had a thumb circumference of 7.1 cm, and a distal pad length of 4.3 cm. No significant difference in thumb size was found as a function of age, $t(9) = 2.26$, $p = .53$.

Experimental Design

Consistent with Table 23, a 2 (age – older or younger) X 3 (cell phone keypad – A, B, C) mixed factorial design was employed with cell phone keypad varied within and age used as a grouping variable. The dependent measures in this experiment were: 1) number of correct sequences dialed and 2) number of correct key presses, averaged across all sequences (correct and incorrect), and 3) dialing errors (errors analyzed included: navigation errors, wrong numbers, and omission errors). The maximum number of entries in each condition was 10.

Stimuli and Apparatus

Three different cellular phones, of the same model, were used as stimuli in this experiment. All three of the phones (Kyocera Model 5135) had smooth-flat keys with no tactile cue, one tactile cue, or multiple tactile cues (see Table 22). The types of cues used in this experiment were derived from the findings of Experiment 2 which indicated that participants were most readily able to discriminate the raised dot and textured cue. The combination of tactile cue types and locations were determined from the findings of Experiment 3 which revealed that participants performed well with a single-tactile cue located on the five, whereas they did not perform as well with the multiple-location cue condition. The cellular phone keypads were of an existing smooth-flat model that was modified by the addition of a tactile cue or cues (similar to what was done for the stimuli in Experiment 3). As in the previous experiments, SuperLab was used to record dialing times and was operated by the experimenter.

The purpose of this experiment was to identify whether a multiple location cue condition may be advantageous with a smooth-flat keypad surface even though it was not found to be advantageous with a raised-rubber keypad surface. Similar to each of the previous experiments, a

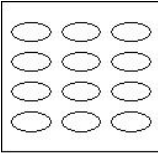
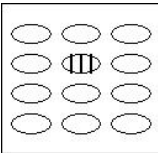
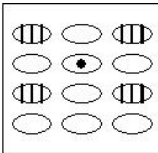
control condition with no tactile cues was included in this experiment. The same experimental procedure was used in this experiment as was used in Experiments 1 and 3. The only difference was the number of cellular phones dialed.

Procedure

The experimental dialing task was identical to that used in Experiments 1 and 3. As in Experiment 3, each participant was administered a cell phone opinion survey (see Table 23) in addition to the demographic questionnaire, cell phone usage questionnaire (see Appendix P) and the two cognitive abilities tests. This survey was administered during this experiment to

Table 22.

Experimental conditions in Experiment 4

Phone	Cue-type	Location	Age Group	Diagram
A	No Cues	No Cues	Younger Older	
B	Textured	5	Younger Older	
C	Raised Dot Textured	5 1,3,7,9	Younger Older	

identify whether the same trends in answers would be apparent in the new sample. For example, would older adults continue to rate tactile features as more important than younger adults. The findings in this experiment were different from those in Experiment 3 in that previously age groups only differed significantly on two survey items, whereas in this experiment the two age groups differed significantly on every opinion survey item (at a .05 alpha level). Although the reason for the inconsistency of these results is not apparent, differences in responses may be due to demographic differences across the samples. For instance, mean age of the older adult participants varied between Experiment 3 ($M = 70.1$, $SD = 4.32$) and Experiment 4 ($M = 66.2$, $SD = 3.99$). In addition, findings from the cell phone usage questionnaire revealed that 40% of the older adults in Experiment 4 reported using a cell phone at least once a day, whereas in Experiment 3, only 7% of participants reported using a cell phone at least once a day. Thus, differences in the cell phone survey may be due to these changes in demographic variables across experiments. In Experiment 3, as in the current experiment, t-tests were conducted to assess whether individuals differed significantly on their responses to the cell phone opinion survey items as a function of age. The results revealed that older adults were significantly more likely to look at the keypad prior to pressing keys during cell phone menu navigation than younger adults. When dialing their phones in low-lighting conditions, younger adults reported a significantly higher level of dialing success than older adults. In the current experiment, however, these results were not found. Although the reason for this inconsistency of results is not apparent, one reason may be due to the smaller number of participants and related sampling bias.

Results

A series of 2 (age – younger or older) X 3 (cell phone keypad – A, B, C) mixed-factorial analysis of variance were applied to the data for the dependent variables: correct sequences, keys

correct, and dialing time, with cell phone as the within-variable and age group as the between-variable. An alpha level of .05 was used for all statistical tests. A Scheffé test was conducted when multiple comparisons were indicated. The following section is divided into two parts. The first part will discuss the results of the measures of accuracy and the second the results on inspection time.

Accuracy

Correct Sequences. Each participant dialed ten 10-digit telephone numbers with each of the three cell phones. Participants could reach a maximum accuracy of 10 for each cell phone. The analysis of variance revealed a main effect for cell phone, $F(2, 36) = 18.23$, and a

Table 23.

Opinion Survey Items (0-8 point agreement scale) – Experiment 4

Statement	Younger	Older
*a. When I navigate menus of a cellular phone, I am likely to look at the buttons to locate them before pressing them.	3.80 (1.48)	6.80 (1.40)
*b. It would be helpful to have button features to help locate them by touch or feel them in situations where you are not looking at the phone.	4.80 (1.40)	6.20 (1.13)
*c. When I am not able to see the buttons on a cellular phone, for example because of low lighting conditions, I am almost always successful in navigating and dialing.	4.80 (2.15)	1.80 (1.75)
*d. When I make a phone call on a cellular phone, I always look at the actual buttons to locate and dial them.	2.80 (1.69)	6.00 (2.11)
*e. I would consider buying a phone with features that allow the buttons to be identified by touch or feel.	3.40 (.97)	6.20 (1.75)
*f. I would be willing to pay more for a feature that allows the buttons to be located by touch or feel.	1.20 (1.03)	4.80 (2.70)

Note. Values in parentheses are standard deviations. Asterisks denote those survey items which age groups differed significantly at the .05 level.

main effect for age group, $F(1, 18) = 44.37$. A significant interaction between age and cell phone was also found, $F(2, 36) = 18.23$. Overall, the low level of accuracy for all of the phones is consistent with the flat-smooth keypad condition from Experiment 1 where participants performed significantly worse with such phones than with the raised-rubber phone. Also consistent with previous findings, is the result of younger adults performing significantly better with all of the keypads as compared to older adults. In fact, none of the older adults performed a correct sequence with any of the phones. The significant interaction revealed that younger adults performed substantially better with Cell Phone B (tactile cue on 5 key) and Cell Phone C (multiple-cue keypad) than with the smooth-flat control phone. Table 24 presents the means for correct sequences for each condition. The ANOVA summary table is presented in Table 25.

Table 24.

Table of Means for Correct Sequences – Experiment 4

<u>Cell Phone Keypad</u>	<u>Age Group</u>		<u>Est. Marginal Means</u>
	<u>Younger</u>	<u>Older</u>	
Cell Phone A	.00 (.00)	.00 (.00)	.00 (.00)
Cell Phone B	3.80 (2.10)	.00 (.00)	1.90 (.33)
Cell Phone C	3.50 (2.12)	.00 (.00)	1.75 (.34)
Est. Marginal Means	2.43 (2.41)	.00 (.00)	

Note. Values in parentheses are standard deviations.

Correct Key Presses. The second dependent measure of accuracy analyzed in this experiment was number of correct key presses within a sequence. Each number dialed was comprised of 10 digits, yielding a maximum of 10 key presses correct. The analysis of variance revealed results similar to the correct-sequence data. There was a main effect for cell phone, $F(2, 36) = 20.37$, and a main effect for age group, $F(1, 18) = 113.35$. However, a significant

interaction of cell phone and age group was not found. These results indicate that participants were significantly more accurate with Cell Phone C (i.e., the multiple-cue condition) than with the other two phones. Again, older adults committed significantly more errors, overall, than did younger participants. Table 26 presents the means for correct key presses for each condition. The ANOVA summary table is presented in Table 27.

Table 25.

Analysis of Variance for Correct Sequences – Experiment 4

Source	DF	F	Pr>F
Cell Phone	2	18.23	.00*
Age Group	1	44.37	.00*
Cell Phone X Age	2	18.23	.00*
Error	18		
Error (cell)	36		

Note. Values with asterisks are significant at the .05 level.

Table 26.

Table of Means for Correct Key Presses within a Sequence – Experiment 4

<u>Cell Phone Keypad</u>	<u>Age Group</u>		<u>Est. Marginal Means</u>
	<u>Younger</u>	<u>Older</u>	
Cell Phone A	6.11 (1.05)	1.20 (1.29)	3.66 (.26)
Cell Phone B	7.18 (1.31)	1.39 (1.31)	4.28 (.28)
Cell Phone C	8.39 (1.58)	3.92 (2.17)	6.15 (.42)
Est. Marginal Means	7.23 (1.59)	2.17 (2.03)	

Note. Values in parentheses are standard deviations.

Table 27.**Analysis of Variance for Keys Correct in a Sequence – Experiment 4**

Source	DF	F	Pr>F
Cell Phone	2	20.37	.000*
Age Group	1	113.35	.000*
Cell Phone X Age	2	1.36	.27
Error	18		
Error (cell)	36		

Note. Values with asterisks are significant at the .05 level.

Dialing Time

As in the previous experiments, an analysis of variance was applied to the dependent measure of dialing time. This analysis revealed a significant main effect for cell phone $F(2, 36) = 10.82$ and for age group $F(1, 18) = 75.86$. These results reveal that participants, in general, took more time dialing while using Cell Phone B (i.e., single-location cue keypad) than the other two phones and Cell Phone A (i.e., control) took the least amount of time to dial. In addition, older adults took significantly longer to dial all of the phones as compared to younger adults. No significant interaction was found. See Table 28 for the means of each condition. The ANOVA summary table is presented in Table 29.

Error-Types

As in Experiments 1 and 3, a series of planned analyses were conducted on three main types of dialing errors: omissions, wrong actions, and navigation errors. A 2 (age – younger or older) X 5 (cell phone keypad – A, B, or C) was applied to each of the dependent measures. A Scheffé test was conducted when multiple comparisons were indicated. The following section

presents the results from each of these analyses respectively (see Appendix Q for summary tables).

Table 28.

Table of Means for Dialing Time (in sec) – Experiment 4

<u>Key Type</u>	<u>Age Group</u>	
	<u>Younger</u>	<u>Older</u>
Cell Phone A	10.96 (2.11)	32.66 (2.11)
Cell Phone B	18.38 (2.55)	38.51 (2.55)
Cell Phone C	11.24 (1.81)	37.01 (1.82)

Note. Values in parentheses are standard deviations.

Table 29.

Analysis of Variance for Dialing Time – Experiment 4

Source	DF	F	Pr>F
Cell Phone	2	10.82	.00*
Age Group	1	75.86	.00*
Cell Phone X Age	2	2.03	.15
Error	18		
Error (cell)	36		

Note. Values with asterisks are significant at the .05 level.

Omission Errors. This analysis revealed a significant main effect of cell phone keypad where both age groups committed fewer omission errors with Cell Phone C (i.e., 1, 3, 5, 7, 9 multiple-location cue condition) and Cell Phone B (i.e., 1 and 5 multiple-location cue condition) as compared to the control phone keypad, $F(2, 36) = 4.15, p = .02$. A significant main effect of age was also found. Older adults made significantly more omission errors as compared to the

younger adult participants, $F(1, 18) = 9.27, p = .007$. No significant interaction was found for this dependent measure.

Wrong Action Errors. This analysis revealed a significant main effect for cell phone, $F(2, 36) = 4.00, p = .03$, and age group, $F(1, 18) = 17.57, p = .001$. No significant interaction was found. These results indicate that participants committed significantly fewer errors with Cell Phone C (i.e., 1, 3, 5, 7, 9 multiple-location cue condition) than with Cell Phone B (i.e., 1 and 5 multiple-location cue condition). There was no significant difference in performance between Cell Phone A (i.e., control) and the other two phones. These results demonstrate that although participants performed comparably with Cell Phone B and Cell Phone C, with respect to omission errors, their performance differed between the two with respect to wrong-action errors.

Navigation Errors. This analysis revealed a significant main effect for cell phone, $F(2, 36) = 5.71, p = .007$, and for age group, $F(1, 18) = 110.92, p < .001$ such that age groups committed less navigation errors for the multiple-location cue keypads than with the control keypad. In addition, younger adults committed less navigation errors overall than did the older adults. Although this analysis did not reveal a significant interaction of the two at the .05 level, the interaction did approach significance suggesting that older adult performance may have had a greater difference in navigation errors between keypads than did younger adults.

Discussion

Findings from Experiment 4 revealed a different pattern of results from Experiment 3 when tactile cue and spatial arrangement were considered for smooth-flat rather than raised-rubber keypad designs. When these variables were investigated with smooth-flat keypads, the data provided support for Hypotheses 7 and 8. Hypothesis 7 predicted that both age groups would perform better with the 1, 3, 5, 7, 9 multiple-cue condition than with the single-cue

condition. The latter hypothesis predicted that older adults would not perform as well with the multiple-location cue condition with the raised-rubber key condition, as they would with the multiple-location cue in the smooth-flat keypad condition. This effect was not only found with older adults, but with younger adults as well. In general, participants' dialing performance was positively affected by the addition of multiple tactile cues on the smooth-flat keys. This was not the case in Experiment 3, when participants dialed raised-rubber keypad surfaces with the same multiple tactile cues affixed to the keys.

These findings illustrate that if cell phone manufacturers continue to develop smooth-flat keypad designs, users will be benefited by the addition of tactile cues and/or features. Even the addition of one prominent tactile cue, such as the textured cue used in this study, can enhance dialing performance as compared to a smooth-flat surface keypad with no tactile cue or a tactile cue which cannot be discriminated effectively by users.

General Discussion

The current trend in cellular phone design is that of miniaturization (Goodman et al., 1997). A concomitant trend is that of cellular phone thickness. New designs are being developed with smooth-flat keypad designs (i.e., keys flush with the phone casing), because such designs allow phones to be slimmer (Oyama & Shiramatsu, 2002). The current study provided data from four experiments to support several general findings. For instance, older adults did not perform as well as younger adults, and both age groups performed more poorly, with the flat-smooth keypads. Furthermore, younger adults completed the dialing tasks more quickly and committed fewer errors than older adults. Each experiment provided a number of specific results which are summarized below.

In Experiment 1, differences in dialing performance were investigated as a function of a raised-rubber keypad surface and a flat-smooth surface. The results revealed that the raised-rubber keypad yielded significantly better dialing performance than the flat-smooth phone and that older adults were at a relatively greater disadvantage when using the flat-smooth keypad.

The goal of Experiment 2 was to identify tactile cues that may be readily discriminable from one another. Findings from this study indicated that the raised dot and the textured cue stimuli were most readily discriminable from each other for both age groups.

Experiment 3 was designed to synthesize the findings from the previous two experiments by developing keypad prototypes with various tactile cues and spatial arrangements. One finding of this study revealed that although tactile features, such as raised-rubber keypads, can aid in dialing performance, an abundance of tactile features can actually impair performance. For example, a raised-rubber keypad with one additional tactile cue (feature) located on the 5 key position will yield better dialing performance than the same keypad with multiple tactile cues at various locations in the keypad. This finding is consistent with research in the visual modality which indicates that high levels of visual cues can cause perceptual impairments (Pierno et al., 2005). Furthermore, a raised-rubber keypad with no additional tactile cues will also yield better dialing performance than a multiple-cue keypad. The findings with the multiple-cue keypad suggest that participants become confused with the additional tactile features, causing them to have difficulty in locating the positions of the keys.

Lastly, Experiment 4 was developed to identify whether the findings from Experiment 3 could be generalized to flat-smooth keypads. The opposite effect was found, however. Participants' dialing performance improved in the multiple-cue condition (The opposite had been found for this same condition in Experiment 3 with the raised-rubber keypad). This finding may

be due, at least in part, to the haptic resemblance of the tactile cues to that of raised keys (similar to a raised-rubber keypad).

Dialing Style

In general, younger adult participants were more accurate in dialing, committed fewer errors, and had faster dialing times than older adults. In addition to these quantitative differences, a number of differences were noted anecdotally by the experimenter during the final two experiments. One of the most pronounced differences was the difference in dialing style and/or strategy between the two age groups.

As can be inferred from the dialing time data, younger adults did not hesitate a great deal, if at all, before commencing the dialing task. The majority of the older adults (approximately 85% based on observations documented by the experimenter) would locate a starting point (i.e., the 1 or 5 position) and return to that key before dialing each subsequent number in the sequence. By contrast, younger adults (approximately 90%) would not repeatedly return or reorient themselves to that “home” key during dialing. These observations are consistent with previous research investigating website navigation which reported that older adults have difficulty in remembering previous navigational steps when engaged in a website search activity (Mead, Spaulding, Sit, & Walker, 1997). The majority of older adults, however, employed one of two main dialing strategies. For our purposes, one of these strategies will be called the “home” strategy and the other will be called the “count-off” strategy.

By using the “home” strategy, older adults would repeatedly return to a “home” key during the dialing of a number sequence. For example, an older adult would dial two of the ten numbers in a sequence and then return to the “home” (i.e., 0 or 5 position) position before dialing

the third number and so on. It was typical for an older adult participant to return to that “home” position multiple times in the dialing of a single number sequence.

In using the “count-off” strategy, older adult participants would verbally count off the numbers while simultaneously feeling them and only press the number when they had counted off to the appropriate number. For example, a participant using this strategy would start at what they believed to be the “1” position and count off each number until they reached what they perceived to be the “7” position.

It appeared, during testing, that the younger adults felt much more confident in their spatial abilities than the older adults (Pak, 2001). This finding is consistent with the noted normative decline in spatial ability as a function of age (Craik & Salthouse, 2002; Salthouse, 1992). This observation coupled with the differences in dialing time (which may be due, at least in part, to the differences in dialing “strategy”) between the two age groups may provide some insight as to why older adults took longer to dial the number sequences. The increase in dialing time for older adults may not be just a product of slowing related to aging, but may also be a product of the chosen compensatory strategy used while dialing (Walker, Millians, & Worden, 1996; Walker, Philbin, & Fisk, 1997; Salthouse, 1992). This finding may help other researchers understand differences in performance with other systems and devices as well.

General Limitations

There are, of course, also a number of limitations that should be addressed. One limitation could be considered the “blind-dialing” experimental procedure in which participants were not allowed to see the phone while dialing. As revealed in the cell phone opinion survey, most participants reported looking at their keypad interface while dialing. However, it was the goal of this study to identify design methods for cell phone keypads that capitalize on tactile

features. Had vision been allowed in this study, it would have been difficult to parse out the effects of various tactile features from being able to see the phone. In addition to the lack of vision during the dialing task, the lack of auditory feedback may also have been problematic. Auditory feedback was not provided, however, so that this study could ensure the effects found were due to the tactile feedback manipulations (i.e., raised-rubber key or tactile cues) rather than the effects of another non-controlled modality. In summary, this study focused on taction, which was best investigated by controlling for the other senses.

Another limitation of this study could also be the age groups recruited. This study did not include any middle-aged adults. The reasoning for this exclusion was to better identify the differences in performance between extreme populations. Furthermore, it was the purpose of this study to identify techniques to optimize designs which meet the needs of older adults. Arguably, any design features that enhance older-adult dialing performance should benefit other age groups as well (Nayak, 1995; Vanderheiden, 1997).

It was found early in the study that older adults became fatigued more quickly during the dialing tasks than did younger adults. For example, in Experiment 1, participants dialed 20 numbers with two phones, yielding a grand total of 40 numbers to be dialed. The majority of older adult participants reported being fatigued with the task at the mid-point of the experiment (this was not found with younger adults). Thus, the design of subsequent experiments was constrained in an effort to limit fatigue by being conservative in terms of the total trials. Although a number of significant effects were found and the majority of the research hypotheses were confirmed, the power of some of the analyses were not as high as they might have been with the inclusion of more number sequences per condition.

Cellular phone experience was also a limitation in this study. Older adults in general had very little previous experience with cellular phones whereas younger adults, in general, use cellular phones multiple times a day. Initially, the planned analysis was to treat level of experience as a covariate in an attempt to control for differences in level of experience. The analyses revealed, however, that using level of experience as a covariate was not statistically sound in that the level of experience interacted with the other independent variables - a violation of the assumptions for such an analysis (Aiken & West, 1991). To control for this variable, future research should specifically recruit older adult participants with different levels of cellular phone experience. The same would be desirable for younger adults. Recruiting in this manner would allow for the analyses to control for this difference in experience. One final limitation of this study, with respect to recruiting, was the use of convenience and snowball sampling. Specifically, older adults were recruited from an existing database of individuals who had indicated an interest in participating in research studies. Younger adults were recruited from the introductory psychology courses. Future research could benefit from a more “random” selection process.

Design Recommendations

Although this research has a number of potential methodological shortcomings, as discussed earlier, the results are informative and may be used as design recommendations for cellular phone manufacturers. Given the results of Experiment 1, designers might further develop raised-rubber keypads to reduce error. Unfortunately, current cellular phone designs seem to increasingly rely on the use of flat-smooth keys. Although, raised-rubber keypads were found to be the most usable for both age groups, other findings indicate other design recommendations to be considered.

The findings from Experiment 2 suggest that designers might incorporate specific tactile cues that are most discriminable from one another. Designing cellular phone keys with the dimensions and characteristics from this study may allow the keys to be more discriminable when dialing and/or navigating.

If incorporating tactile cues on raised-rubber keys, findings from Experiment 3 suggest that the spatial arrangement of these cues are important. Multiple tactile cues may not always improve the usability of a phone. Rather, a single tactile cue such as the raised dot or raised texture cue on the 5-key would yield better dialing performance than a keypad with multiple tactile cues. On the other hand, the findings from Experiment 4 suggest that tactile cues located in the 1, 3, 5, 7, & 9 key positions do yield better dialing performance when incorporated on a flat-smooth type of keypad.

The aforementioned design recommendations are based on the quantitative results from this study. In addition, qualitative observations revealed a number of findings. For instance, the qualitative results of search patterns and differences in spatial abilities suggest that it would be desirable for flat-smooth cellular phone keypads to have at least one “home” tactile cue or ideally, multiple tactile cues. To alleviate any confusion with respect to past experience, one suggestion is to use the raised dot cue only in the 5-key position. When using a multiple cue keypad (such as in a flat-smooth keypad), the findings from this study support the use of textured tactile cues on the peripheral keys. The major finding of this study specifically is that tactile cues are important, but that their advantage can vary depending on the type of keypad. Thus, it is important to take into account the type of keypad surface before identifying what tactile cues to be included.

Future Directions

It is obvious that there are many features of cellular phone that can and should be investigated. This study focused solely on the presence of tactile cues and the spatial arrangement of the cell phone interface with the reasoning that many older adults experience sensory decline resulting in reliance on multi-modal redundancy. Additionally, there has been little known research that has investigated characteristics of the tactile interface (Mooney et al., 2002) and even less research that has investigated this aspect of the tactile interface and/or how to better design for the visually-impaired population in general.

As mentioned previously, one limitation of this study was in the use of a sole modality (i.e., touch) when dialing. Future research could include manipulations of other modalities such as vision and audition. With respect to vision, one could vary the intensity of the keypad backlighting to identify an “ideal” luminance level for dialing (Pollard & Cooper, 1984). Regarding the auditory modality, one could vary the volume of the auditory feedback provided to the user while dialing (Pollard & Cooper, 1984). One could also vary the tones of the keys and/or evaluate the use of synthesized speech to indicate a key press (Howell & Powell, 1987). Each of these studies could be conducted separately or in conjunction with one another to further identify ways in which cellular phone keypad design can be optimized.

With respect to the haptic modality, the current research represents an initial set of experiments which could be expanded to include a number of other factors. For instance, it would also be desirable to examine the effects of key shapes (Breinholt, & Krueger, 1996), height of keys, lateral key pitch, and overall size of the keypad on dialing performance (Oyama, Ohwa, & Noro, 2003). It would also be of interest to examine the effects of key convexity, concavity, contiguity, and alternate arrangement of keys on dialing performance. While a

number of design features remain to be investigated, the current set of experiments served as a suitable introduction to the research area.

Conclusions

Currently, most manufacturers utilize cellular phone designs including keypads that are flat, smooth, and level with the phone casing. In addition, these cellular phones tend to be very small and compact with documented usability issues reported by older adults (Davenport, Helal, Kemp, Mann, & Tomita, 2003). The development of these new and sleek cellular phones seems to be guided by aesthetics and marketing rather than functionality and/or usability. Given this information, it is important for human factors professionals to investigate the usability of such devices (Smith-Jackson, Nussbaum, & Mooney, 2003). Furthermore, past research has identified the usefulness and need for usability analyses that target various audiences to allow for better design (Gould, & Lewis, 1985; Taylor & Bonner, 1989).

This study addressed the usability of two keypad types (i.e., raised-rubber keys and flat-smooth keys) as well as the functionality of various tactile cues filling a substantial gap in the literature on cellular phones and haptics. In a series of four experiments, this study identified that the “newer” compact and smooth phones are not ideal for any user, young or old. The ideal type of keypad is comprised of raised-rubber keys that individuals can readily discriminate. If manufacturers, however, insist on developing these smooth phones, the addition of tactile cues should benefit users. This study illustrates the impact these tactile cues can make on dialing performance. Applications of the research by designers may potentially improve device usability and promote safety for users of all age groups.

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Appendix A

Cell Phone Usage Questionnaire Results Experiment 1

Cell Phone Usage Questionnaire – Experiment 1

Question	Younger Adults		Older Adults	
	Frequency	Percent	Frequency	Percent
1. Have you ever used a cell phone?				
Yes	16	100%	16	100%
No	0		0	0%
2. Do you currently own a cell phone?				
Yes	16	100%	10	62.5%
No	0	0%	6	37.5%
3. How often do you use a cell phone?				
Never	0	0%	1	6.3%
Rarely (1-2 times a month)	0	0%	9	56.3%
Once a week	0	0%	1	6.3%
1-2 times a week	0	0%	2	12.5%
3-5 times a week	1	6.3%	2	12.5%
Once a day	1	6.3%	1	6.3%
More than once a day	14	87.5%	0	0%
4. Are there any reasons you may lack any sensitivity in your fingers?				
Yes	0	0%	2	12.5%
No	16	100%	14	87.5%
5. On a scale from 1-5, how well do you think you'll perform this task?				
1 (Not confident at all)	0	0%	0	0%
2 (Not very confident)	0	0%	2	12.5%
3 (Somewhat confident)	5	31.3%	9	56.3%
4 (Confident)	10	62.5%	3	18.8%
5 (Very Confident)	1	6.3%	2	12.5%

Appendix B
Demographics Questionnaire

Demographic Questionnaire

Directions: Please place check next to the appropriate responses or fill in a response where necessary.

Age: _____

Gender: Male _____ Female _____

Ethnicity: African _____

African-American (not Latino) _____

Asian _____

Caucasian _____

East Indian _____

Latino _____

Native American _____

Middle Eastern _____

Mixed Race _____

Pacific Islander _____

Other _____

Are you a full-time student? ___NO ___YES

If No, what is your current occupation/profession? _____

Last or Highest year of school completed (please circle a number):

1 2 3 4 5 6 7 8 | 9 10 11 12 | 1 2 3 4 5 6 7 8 or more

---Grade School-----High School-- ---College/University/Technical School---

Was English the first language you learned? ___NO ___YES

If No, please give your first language: _____

Cellular Phones Questions

1. Have you used a cellular phone before?

Yes	No

2. Do you currently own a cellular phone?

Yes	No

3. How frequently, on the average, do you use a cellular phone? (Place a check beside the appropriate response)

Never	
Rarely (1-2 times a month)	
Once a week	
1-2 times a week	
3-5 times a week	
Once a day	
More than once a day	

4. Is there any reason you may lack sensitivity in any of your fingers (due to injury, cuts, calluses, etc.)? If yes, explain.

Yes	No

Explain:

5. In this experiment, you will be dialing telephone numbers on a cellular phone solely by touch. You will not be able to see the telephone. On a scale from 1- 5 with 5 being the most confident and 1 being the least confident, how confident do you feel you will perform this task well?

1	2	3	4	5
Not confident at all	Not very confident	Somewhat Confident	Confident	Very confident

Appendix C
Cellular Phone Specifications

Kyocera Model 5135



Cellular Phone Specifications:

- Smooth-Flat Keypad Surface
- 10 mm key length X 5 mm key width
- 12 mm lateral key pitch
- Phone weight
 - 3.30 ounces
- Phone size
 - 3.4 in x 1.7 in x 1.0 in

Kyocera Model



Cellular Phone Specifications:

- Raised-Rubber Keypad Surface
- 9 mm key length X 4 mm key width
- 14 mm lateral key pitch
- Phone weight
 - 4.55 ounces
- Phone size
 - 5.07 in x 1.89 in x 1.02in

Appendix D

Random Numbers for Experiment 1

Trial #	Phone A	Phone B
1.	260-317-5498	625-918-3074
2.	796-024-8351	524-861-7930
3.	941-357-2680	208-153-7046
4.	146-328-5702	169-247-0358
5.	642-058-3187	509-463-8162
6.	472-653-8901	821-640-7539
7.	796-425-0813	142-068-3975
8.	613-027-9584	963-528-4017
9.	864-210-9573	470-592-2831
10.	407-159-3682	514-207-3968
11.	968-314-7205	962-857-0413
12.	047-295-8136	509-482-1637
13.	426-193-8570	615-073-9284
14.	940-253-7168	748-605-3192
15.	753-162-8409	839-524-1706
16.	870-419-5637	281-390-5746
17.	253-186-9704	314-856-9720
18.	362-584-0791	927-406-5138
19.	425-817-3095	487-502-1396
20.	156-028-4973	180-396-5742

Appendix E

Informed Consent Forms Experiments 1 & 3

North Carolina State University

INFORMED CONSENT FORM for RESEARCH (Experiments 1 & 3)

Title of Study: Measuring Age Differences in the Effectiveness of Tactile Cues in Cellular Phones

Principal Investigator Christina C. Mendat

We are asking you to participate in a research study. The purpose of this study is to examine how well individuals can dial cellular phones solely by touch. In this study, you will be dialing 10-digit telephone numbers on a cellular phone without the aid of vision

INFORMATION

If you agree to participate in this study, you will be asked to fill out a demographics questionnaire and an opinion survey. You will then take a vocabulary assessment as well as a digit-substitution task. You will then participate in the experimental session where you will dial several 10-digit telephone numbers on different cellular phones without the help of vision. This experiment will last about 45 minutes to an hour.

RISKS

We don't foresee any risks or discomfort during this experiment. A comfortable cushion will be used to place your arm during the dialing tasks. However, if you feel any discomfort at all, the experimental session will be terminated and your compensation will be granted.

BENEFITS

An increasing number of individuals are using and owning cellular phones. We hope you will become more familiar with different characteristics that may help you in using and/or buying your own cellular phone.

CONFIDENTIALITY

The information in the study records will be kept strictly confidential. Data will be stored securely and measures will be taken to protect the security of data. No reference will be made in oral or written reports, which could link you to the study.

COMPENSATION (for younger adults)

For participating in this study you will receive 2 research credits, which will count towards your research requirements for Psychology 200. If you withdraw from the study prior to its completion, you will receive one credit for each 30 minutes or part thereof that you have participated in the experiment.

COMPENSATION (for older adults)

For participating in this study you will receive \$10. If you withdraw from the study prior to its completion, you will receive compensation in the amount commensurate with the time you have participated.

CONTACT

If you have questions at any time about the study or the procedures, you may contact the researcher, principal investigator name here, at address, or [phone number]. If you feel you have not been treated according to the descriptions in this form or your rights as a participant in research have been violated during the course of this project, you may contact Dr. Matthew Zingraff, Chair of the NCSU IRB for the Use of Human Subjects in Research Committee, Box 7514, NCSU Campus (919/513-1834) or Mr. Matthew Ronning, Assistant Vice Chancellor, Research Administration, Box 7514, NCSU Campus (919/513-2148)

PARTICIPATION

Your participation in this study is voluntary; you may decline to participate without penalty. If you decide to participate, you may withdraw from the study at any time without penalty and without loss of benefits to which you are otherwise entitled. If you withdraw from the study before data collection is completed, your data will be returned to you or destroyed at your request.

CONSENT

“I have read and understand the above information. I have received a copy of this form. I agree to participate in this study with the understanding that I may withdraw at any time.”

Subject's signature _____ Date _____

Investigator's signature _____ Date _____

Appendix F

Instructions Experiment 1

Instructions – Experiment 1

Introduction

Hello! My name is XXXX (enter experimenter name) and I am a student in Psychology here at NC State. I am going to read these instructions to you to make sure that I say everything I need to say.

The experiment in which you are participating is designed to study the discrimination of cellular phone key surfaces. In accordance with the ethical principles of the American Psychological Association, I am informing you that you are free to leave this experiment at any time without penalty.

Informed Consent Form

Please read this informed Consent Form. It will tell you about this experiment and your rights and responsibilities as a participant. If you decide to participate in this study, please sign at the bottom of the form.

Information

Before we begin, I need to get some information from you. Please take a few moments now to complete these two questionnaires (hand out the opinion survey and the demographic survey).

Assessments

Before we begin the actual experiment, I need you to participate in two small tasks. This first task is a vocabulary inventory (pass out task and read respective instructions). In this next activity you will be matching digits to symbols (pass out task and read respective instructions). Now we can review how the main experiment will be conducted.

Overview

In this experiment, you will be presented with two different cellular phones. Your job will be to dial each of the 10-digit telephone numbers presented on the computer screen.

Before I tell you how we are going to proceed, I would like to tell you briefly about the materials we will be using today. Behind this device I have two cellular phones (raise a phone for the participant to see briefly). Each phone has all the keys that are normally on a cellular phone. I will place a cellular phone in your hand (point to the area) for you to dial. This device will also prevent you from seeing the cellular phone during the experiment, so that you can only dial by touch using your thumb as you might do with your own phone. This computer monitor (point to monitor) will display the 10-digit telephone numbers you will be dialing.

Procedure

Now here is how we are going to proceed. In this experiment, you will dial telephone numbers with first one phone and then the other. You will be dialing a total of 20 telephone numbers with cellular phone A and 20 telephone numbers with cellular phone B. You will only be able to feel the surfaces.

When the experiment begins, I will say "Begin." At that time cellular phone A will be placed in your hand and a 10-digit telephone number will be displayed on this monitor (point to the monitor). As soon as the number is displayed you should start dialing the telephone. You will not need to dial a 1 before the numbers as you might do on your own phone. Only dial the numbers presented on the screen. You will not be able to look at the phone and will not be able to make corrections. When you have finished dialing, say out loud "Done." At that time, I will record the number you dialed and a new number will be displayed on the screen. You will then dial the number and say out loud when you are done. We will proceed in this way until you finish the first 20 numbers and you will have a rest period for about 3 minutes. After the rest period, we will proceed in the same way until we have finished up the last 20 numbers with cellular phone B.

Remember, your task is to dial these numbers as quickly and as accurately as possible.
Do you have any questions so far?

Do you have any questions before we start the actual experiment? If you do please ask them now because I am not able to answer any questions once the experiment has started. Please make sure you are comfortable in your chair and place your hand through this opening. OK. Do you have any questions at all?

Before we begin the experiment, I need you to clean your dialing hand with rubbing alcohol. This is to keep the equipment clean and sanitary. Is that OK with you? If you would please wipe your hands with rubbing alcohol at this time, we will then begin.

OK. Let's Begin....."Begin".....

Wrap-up:

Thank you very much for your time. Now, before you leave there are a few questions I would like to ask you.

- 1) Did you notice any differences in the keypad surfaces?
- 2) Do you know of any reasons that you may have had difficulty in dialing the telephone numbers?
- 3) On a scale from 1-5, with 1 being the least confident and 5 being the most confident, how well do you feel you performed the dialing tasks on the telephones?
- 4) Do you typically dial a cellular phone with your thumb? Do you use your forefinger instead?

Before you leave, I'd like to tell you some more about the experiment. The purpose was to examine dialing performance with different cellular phone keypad surfaces.

In this experiment, one keypad surface had soft-rubber keys and the other had smooth-plastic keys. The goal was to see if you could dial more effectively with one key type than the other.

(For undergraduates) Also, I would like to ask you to not mention this experiment to anyone else once you leave here today. The reason is that someone you know may participate in this experiment. As you might guess, if anyone knows about the experiment before they come, it may bias the results. We would appreciate it if you said nothing about this experiment to anyone else, OK?

Thank you again for your time! Do you have any other questions or comments before you leave?

Appendix G

Experiment 1 Error Analysis Tables

Table 1.**Table of Means for Omission Errors**

<u>Keypad Type</u>	<u>Age Group</u>	
	<u>Younger</u>	<u>Older</u>
Raised Rubber	.03 (.08)	.10 (.19)
Smooth Flat	.13 (.13)	.94 (1.14)

Note. Values in parentheses are standard deviations.

Table 2.**Analysis of Variance for Omission Errors**

Source	Df	F	Pr>F
Cell Phone	1	11.85	.002*
Age Group	1	8.08	.008*
Cell Phone X Age	1	7.22	.012*
Error (cell)	30		
Error	30		

Note. Values with asterisks are significant at the .05 level.

Table 3.**Table of Means for Wrong Action Errors**

<u>Keypad Type</u>	<u>Age Group</u>	
	<u>Younger</u>	<u>Older</u>
Raised Rubber	1.14 (1.36)	2.47 (1.62)
Smooth Flat	3.99 (2.03)	4.30 (1.48)

Note. Values in parentheses are standard deviations.

Table 4.**Analysis of Variance for Wrong Action Errors**

Source	DF	F	Pr>F
Cell Phone	1	29.80	.000*
Age Group	1	4.35	.046*
Cell Phone X Age	1	1.248	.273
Error (cell)	30		
Error	30		

Note. Values with asterisks are significant at the .05 level.

Table 5.**Table of Means for Navigation Errors**

<u>Keypad Type</u>	<u>Age Group</u>	
	<u>Younger</u>	<u>Older</u>
Raised Rubber	.23 (.50)	.74 (.84)
Smooth Flat	.34 (.50)	2.83 (1.79)

Note. Values in parentheses are standard deviations.

Table 6.**Analysis of Variance for Navigation Errors**

Source	Df	F	Pr>F
Cell Phone	1	22.92	.000*
Age Group	1	26.61	.000*
Cell Phone X Age	1	18.63	.000*
Error (cell)	30		
Error	30		

Note. Values with asterisks are significant at the .05 level.

Appendix H

Stimulus Development Process for Experiment 2

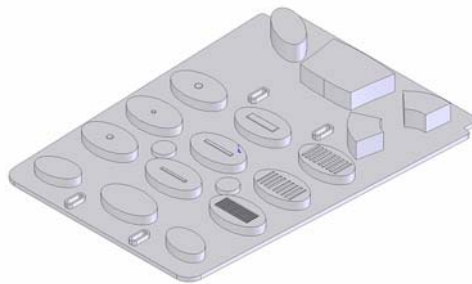
Stereolithography Process

Stereolithography

Stereolithography is also known as 3D layering or 3D printing. This process allows us to create various three-dimensional objects from computer drawings (most often done in CAD modeling programs). For this study, we are able to model existing cellular phone keypads with a software program and add our own tactile cues to specified dimensions. A great benefit from this procedure is that we are able to ensure the keypad stimuli are of consistent proportions and that the tactile cues are also of the same dimensions regardless of which type of keypad surface (soft-rubber or smooth-plastic) to which they are added.

Development Process

- A solid model of a part is created in the SolidWorks® 3D CAD software system.
 - ⇒ For this experiment, the keypad surface was modeled with the software producing an exact replica of the keypad while adding various tactile cues to specified components (see below).



- The solid model is exported to an STL file (stereolithography format).
- The STL file transforms the solid virtual surface of the keypad into a series of interlocking triangles.
- The STL file is “sliced” to form 2D contours
- The Rapid Prototyping process deposits one cross sectional slice of material on top of the next until the part is complete
- Postprocessing -
 - A table is raised to just below the surface of a vat of liquid ultraviolet-curable (thermosetting) resin.
 - A high-power laser selectively scans the contour of the slice and then hollows in the interior portion.
 - The process repeats until the part is complete.
 - Supports are removed, and the uncured liquid resin on the part is carefully cleaned.
 - The part is placed in an ultraviolet oven to fully cure the part. The part is then sanded, repaired and cured.

Appendix I

Informed Consent Form Experiment 2

North Carolina State University**INFORMED CONSENT FORM for RESEARCH (Experiment 2)**

Title of Study: Measuring Age Differences in the Effectiveness of Tactile Cues in Cellular Phones

Principal Investigator: Christina C. Mendat

We are asking you to participate in a research study. The purpose of this study is to examine how individuals are able to discriminate between different cellular phone key surface types. In this study, you will touch two keys on several phones and then you will be asked whether the two keys are the same or different.

INFORMATION

If you agree to participate in this study, you will be asked to fill out a demographics questionnaire first. You will then participate in the experimental session where you feel the keys of different phones without the aid of vision and asked whether the two keys are the same or different. This experiment should not exceed 30 minutes.

RISKS

We don't foresee any risks or discomfort during this experiment. A comfortable cushion will be used to place your arm during the dialing tasks. However, if you feel any discomfort at all, the experimental session will be terminated and your compensation will be granted.

BENEFITS

An increasing number of individuals are using and owning cellular phones. We hope you will become more familiar with different characteristics that may help you in using and/or buying your own cellular phone.

CONFIDENTIALITY

The information in the study records will be kept strictly confidential. Data will be stored securely and measures will be taken to protect the security of data. No reference will be made in oral or written reports, which could link you to the study.

COMPENSATION (for younger adults)

For participating in this study you will receive 1 research credit, which will count towards your research requirements for Psychology 200. If you withdraw from the study prior to its completion, you will receive one credit or each 30 minutes or part thereof you have participated in the experiment.

COMPENSATION (for older adults)

For participating in this study you will receive \$10. If you withdraw from the study prior to its completion, you will receive compensation in the amount commensurate with the time you have participated.

CONTACT

If you have questions at any time about the study or the procedures, you may contact the researcher, principal investigator name here, at address, or [phone number]. If you feel you have not been treated according to the descriptions in this form or your rights as a participant in research have been violated during the course of this project, you may contact Dr. Matthew Zingraff, Chair of the NCSU IRB for the Use of Human Subjects in Research Committee, Box 7514, NCSU Campus (919/513-1834) or Mr. Matthew Ronning, Assistant Vice Chancellor, Research Administration, Box 7514, NCSU Campus (919/513-2148)

PARTICIPATION

Your participation in this study is voluntary; you may decline to participate without penalty. If you decide to participate, you may withdraw from the study at any time without penalty and without loss of benefits to which you are otherwise entitled. If you withdraw from the study before data collection is completed, your data will be returned to you or destroyed at your request.

CONSENT

“I have read and understand the above information. I have received a copy of this form. I agree to participate in this study with the understanding that I may withdraw at any time.”

Subject's signature _____ Date _____

Investigator's signature _____ Date _____

Appendix J

Cell Phone Usage Questionnaire Results Experiment 2

Cell Phone Usage Questionnaire – Experiment 2

Question	Younger Adults		Older Adults	
	<u>Frequency</u>	<u>Percent</u>	<u>Frequency</u>	<u>Percent</u>
1. Have you ever used a cell phone?				
Yes	16	100%	16	100%
No	0	0%	0	0%
2. Do you currently own a cell phone?				
Yes	16	100%	12	75%
No	0	0%	4	25%
3. How often do you use a cell phone?				
Never	0	0%	2	12.5%
Rarely (1-2 times a month)	0	0%	2	12.5%
Once a week	0	0%	1	6.3%
1-2 times a week	1	6.3%	1	6.3%
3-5 times a week	2	12.5%	5	31.3%
Once a day	1	6.3%	1	6.3%
More than once a day	12	75%	4	25%
4. Are there any reasons you may lack any sensitivity in your fingers?				
Yes	1	6.3%	0	0%
No	15	93.8%	16	100%
5. On a scale from 1-5, how well do you think you'll perform this task?				
1 (Not confident at all)	0	0%	0	0%
2 (Not very confident)	0	0%	2	12.5%
3 (Somewhat confident)	4	25%	6	37.5%
4 (Confident)	7	43.8%	5	31.3%
5 (Very Confident)	5	31.3%	3	18.8%

Appendix K
Instructions Experiment 2

Instructions – Experiment 2

Introduction

Hello! My name is XXXX (enter experimenter name) and I am a student in Psychology here at NC State. I am going to read these instructions to you to make sure that I say everything I need to say.

The experiment you are going to serve today is aimed to study the discrimination of cellular phone key surfaces. In accordance with the ethical principles of the American Psychological Association, I am informing you that you are free to leave this experiment at any time without penalty.

Informed Consent Form

Please read this informed Consent Form. It will tell you about this experiment and your rights and responsibilities as a participant. If you decide to participate in this study, please sign at the bottom of the form.

Information

Before we begin I need to get some information from you. Please take a few moments now to complete these two questionnaires (hand out the opinion survey and the demographic survey).

Overview

In this experiment, you will be presented with pairs of cellular phone keys. Your job will be to tell me if the two keys feel the “same” or “different.” The computer monitor will indicate when you should feel the blocks and when you should wait for the next block to be presented.

Before I tell you how we are going to proceed, I would like to tell you briefly about the materials we will be using today. Behind this device I have some blocks with two keys affixed onto them (raise a block for the participant to see briefly. Each phone has only two keys for you to examine – in the center of the block. Each block will be placed in your hand for you to examine with your thumb the two key surfaces. This device will prevent you from seeing the stimuli during the experiment.

Procedure

Now here is how we are going to proceed. You will be examining a total of 20 pairs of surfaces. The blocks will be placed in your hand and the surfaces will be presented side-by-side in center of the block. You will only be able to feel the surfaces. Each block will be presented to you in this same area.

When the experiment begins, I will say "Begin." At that time a block will be placed in your hand and you should feel the two keys located in the center/middle of the block. You can feel both of the surfaces as long as you wish until you are able to make an informed decision. When you think you know whether the two keys are the same or different, you will say “Same” or “Different.” Make sure you speak clearly when you have made your decision. I will say, “OK,” and you can rest your hand in the same position until I say “Begin,” and you will feel the next set of keys to determine whether they are the same or different. We will proceed in this way until we finish the first 10 pairs of surfaces and we will have a rest period for about 2 minutes. After the rest period, we will proceed in the same way until we have finished up the last 10 pairs of surfaces. I want to let you know that when you are deciding whether the two keys are the same or not, there is no penalty for guessing. So, even if you can't tell whether they are the same or different, please just make an educated guess. Do you have any questions so far?

Do you have any questions before we start the actual experiment? If you do please ask them now because I am not able to answer any questions once the experiment has started. Please make sure you are comfortable in your chair and place your hand through this opening. OK. Do you have any questions at all?

Before we begin the experiment, I need you to clean your hands with a sanitary wipe. This is to keep the equipment clean and sanitary. Is that OK with you? If you would please wipe your hands with rubbing alcohol at this time, we will then start with the experiment. At this time, I would like to take two measurements of your thumb. Is that OK with you? (take thumb circumference and pad measurements)

OK. Let's Begin....."Phone 1".....

Wrap-up:

Thank you very much for your time. Now, before you leave there are a few questions I would like to ask you.

- 1) Did you notice any differences in the keypad surfaces?
- 2) Do you know of any reasons that you may have had difficulty in examining the surfaces?
- 3) On a scale from 1-5, with 1 being the least confident and 5 being the most confident, how well do you feel you performed the discrimination tasks?
- 4) Do you typically dial a cellular phone with your thumb? Do you use your forefinger instead?

Before you leave, I'd like to tell you some more about the experiment. The purpose of this experiment is to examine the texture discrimination performance with different cellular phone keypad surfaces

In this experiment, you were able to feel four different types of keypad surfaces including a raised dot key, a raised line key, a more texture key and one flat key surface. The goal was to see if you could feel the difference between, for instance, a raised dot key and a flat key.

(For undergraduates) Also, I would like to ask you to not mention this experiment to anyone else once you leave here today. The reason is that someone you know may participate in this experiment. As you might guess, if anyone knows about the experiment before they come, it may bias the results. We would appreciate it if you said nothing about this experiment to anyone else, OK?

Thank you again for your time! Do you have any other questions or comments before you leave?

Appendix L

Cell Phone Specifications Experiment 3

Nokia Model 5190**Cellular Phone Specifications:**

- Soft-Rubber Keypad Surface
- 10 mm key length X 5 mm key width
- 13 mm lateral key pitch
- Phone size
 - 5 ¼ in X 1 ¾ in

Appendix M

Random Numbers for Experiments 3 & 4

Trial #	Order 1	Order 2	Order 3	Order 4	Order 5
1.	853-271-4960	290-871-4635	109-835-6274	407-968-1352	579-386-0241
2.	281-390-5746	395-072-8164	485-972-0316	197-048-5263	710-482-5369
3.	314-856-9720	573-846-0912	375-901-2468	590-371-8524	138-629-5047
4.	927-406-5138	406-517-3928	286-395-1704	379-482-0615	869-370-2415
5.	487-502-1396	694-750-2831	502-741-3869	470-381-9526	314-075-8269
6.	180-396-5742	894-571-3026	631-859-2740	039-716-8425	069-417-2358
7.	795-860-2314	153-824-0697	705-839-1624	649-735-1802	647-509-3128
8.	948-735-2610	086-275-3149	861-735-2940	853-074-2961	027-965-8413
9.	586-490-3172	207-582-3641	904-826-1357	261-836-4905	831-560-4729
10.	738-496-2510	791-385-0246	376-591-4078	935-704-6182	693-120-5784

Note. Only orders 1-3 were used for Experiment 4.

Appendix N

Cell Phone Usage Questionnaire Results Experiment 3

Cell Phone Usage Questionnaire – Experiment 3

Question	Younger Adults		Older Adults	
	<u>Frequency</u>	<u>Percent</u>	<u>Frequency</u>	<u>Percent</u>
1. Have you ever used a cell phone?				
Yes	14	100%	14	100%
No	0	0%	0	0%
2. Do you currently own a cell phone?				
Yes	13	92.9%	12	85.7%
No	1	7.1%	2	14.3%
3. How often do you use a cell phone?				
Never	0	0%	2	14.3%
Rarely (1-2 times a month)	0	0%	5	35.7%
Once a week	0	0%	1	7.1%
1-2 times a week	0	0%	4	28.6%
3-5 times a week	1	7.1%	0	0%
Once a day	0	0%	1	7.1%
More than once a day	13	92.9%	1	7.1%
4. Are there any reasons you may lack any sensitivity in your fingers?				
Yes	1	7.1%	2	14.3%
No	13	92.9%	12	85.7%
5. On a scale from 1-5, how well do you think you'll perform this task?				
1 (Not confident at all)	0	0%	2	14.3%
2 (Not very confident)	1	7.1%	4	28.6%
3 (Somewhat confident)	10	71.4%	7	50.0%
4 (Confident)	2	14.3%	0	0%
5 (Very Confident)	1	7.1%	1	7.1%

Appendix O

Experiment 3 Error Analysis Tables

Table 1.**Table of Means for Omissions Errors**

<u>Key Type</u>	<u>Age Group</u>	
	<u>Younger</u>	<u>Older</u>
Cell Phone A	.05 (.09)	.31 (.59)
Cell Phone B	.01 (.03)	.31 (.57)
Cell Phone C	.03 (.11)	.49 (1.08)
Cell Phone D	.01 (.03)	.41 (.91)
Cell Phone E	.01 (.03)	.36 (.76)

Note. Values in parentheses are standard deviations.

Table 2.**Analysis of Variance for Omission Errors**

Source	DF	F	Pr>F
Cell Phone	4	1.15	.34
Age Group	1	2.99	.10
Cell Phone X Age	4	1.22	.31
Error	26		

Note. Values with asterisks are significant at the .05 level.

Table 3.**Table of Means for Wrong Action Errors**

<u>Key Type</u>	<u>Age Group</u>	
	<u>Younger</u>	<u>Older</u>
Cell Phone A	1.79 (2.19)	3.74 (2.63)
Cell Phone B	.64 (.60)	3.07 (2.21)
Cell Phone C	.61 (.53)	3.65 (1.07)
Cell Phone D	.89 (.96)	3.54 (2.26)
Cell Phone E	.31 (.25)	2.56 (1.72)

Note. Values in parentheses are standard deviations.

Table 4.**Analysis of Variance for Wrong Action Errors**

Source	DF	F	Pr>F
Cell Phone	4	3.99	.005*
Age Group	1	30.23	.000*
Cell Phone X Age	4	.70	.60
Error	26		

Note. Values with asterisks are significant at the .05 level.

Table 5.**Table of Means for Navigation Errors**

<u>Key Type</u>	<u>Age Group</u>	
	<u>Younger</u>	<u>Older</u>
Cell Phone A	.02 (.08)	.75 (1.06)
Cell Phone B	.00 (.00)	.54 (.73)
Cell Phone C	.01 (.03)	.72 (.71)
Cell Phone D	.04 (.11)	.51 (.75)
Cell Phone E	.00 (.00)	.29 (.45)

Note. Values in parentheses are standard deviations.

Table 6 .**Analysis of Variance for Navigation Errors**

Source	DF	F	Pr>F
Cell Phone	4	2.20	.07
Age Group	1	10.44	.003*
Cell Phone X Age	4	2.03	.10
Error	26		

Note. Values with asterisks are significant at the .05 level.

Appendix P

Cell Phone Usage Questionnaire Results Experiment 4

Cell Phone Usage Questionnaire – Experiment 4

Question	Younger Adults		Older Adults	
	<u>Frequency</u>	<u>Percent</u>	<u>Frequency</u>	<u>Percent</u>
1. Have you ever used a cell phone?				
Yes	10	100%	10	100%
No	0	0%	0	0%
2. Do you currently own a cell phone?				
Yes	10	100%	8	80%
No	0	0%	2	20%
3. How often do you use a cell phone?				
Never	0	0%	0	0%
Rarely (1-2 times a month)	0	0%	3	30%
Once a week	0	0%	3	30%
1-2 times a week	0	0%	0	0%
3-5 times a week	1	10%	0	0%
Once a day	2	20%	0	0%
More than once a day	7	70%	4	40%
4. Are there any reasons you may lack any sensitivity in your fingers?				
Yes	0	0%	0	0%
No	10	100%	10	100%
5. On a scale from 1-5, how well do you think you'll perform this task?				
1 (Not confident at all)	1	10%	0	0%
2 (Not very confident)	0	0%	6	60%
3 (Somewhat confident)	6	60%	2	20%
4 (Confident)	1	10%	2	20%
5 (Very Confident)	2	20%	0	0%