178
34

EMPIRICALLY DERIVED GUIDELINES FOR TOUCH SCREEN TARGETS

by

Michael Randolph Leahy

Thesis submitted to the Faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

in

Computer Sciences and Applications

APPROVED:

D. S. Hix, Chair

J. D. Arthur

J. F. Moore

B. A. Williges

April, 1990

Blacksburg, Virginia

EMPIRICALLY DERIVED GUIDELINES FOR TOUCH SCREEN TARGETS

by

Michael Randolph Leahy

Deborah S. Hix, Chair

Computer Sciences and Applications

(ABSTRACT)

Users are often frustrated when a touch screen monitor inaccurately records their touches. Enlarging touch sensitive regions improves touch accuracy, but few specific guidelines are available in the literature. A controlled field experiment determined the effect of target location and visual target size on user accuracy and empirically derived quantitative guidelines for determining touch target size based on target location. The experiment was conducted in a grocery store using a piezo-electric monitor in a public access kiosk. Participants pressed the screen as target squares appeared one at a time. Visual target size, horizontal viewing location, and screen sector of target were varied. X and Y offset between the target center and the touch location were recorded. Results showed significant differences caused by target sector in X offsets among columns and in Y offsets among rows, but no differences caused by target size. Results showed that persons tended to touch below the target, with touch distance increasing as the location of the target moved down the screen. To a lesser extent, persons tended to touch toward the sides of the screen. Using collected data for each of nine screen sectors, graphs were prepared showing the relationship between touch target size and expected accuracy under harsh conditions. These empirically derived, quantitative guidelines will help designers plan for the worst case and create screens that decrease user errors and frustration.

Acknowledgements

I wish to thank my major professor, Dr. Deborah Hix, for her guidance, collaboration, and encouragement of my interest in human factors; Drs. Beverly Williges and James Arthur, for assisting me when I asked; and Bill Reinhart, for patiently explaining statistics to me.

I would like to thank Dr. John Moore for serving on my committee and, along with Dr. Dick Winett, for providing employment and a goal-oriented research project to grow with and learn from; Lee Hite, for being a wonderful resource person, coworker, and friend; Lisa McCarthy Indelicato, for helping with graphic designs; and the rest of the staff of Learning Resources Center (Dolly Randolph, Alice Walker, Ed Schwartz, David Taylor, Don Inman, Margaret Kates-Cechini, Lynn Miller, Cynthia Wimberly) for making a family-style office that recognizes individual talents.

My thanks to Dr. Anthony Hall of the IBM Corporation, for giving me a detailed explanation of his research into the performance of the InfoWindow Monitor; Mr. Barry Dyvers, Manager of the Krogers Co., Inc. store at Tanglewood Mall, for allowing me to conduct a three day study; and the National Cancer Institute, for funding the grant which provided the equipment used in this study.

Thanks to all my friends from Alpha Phi Omega, Newman Community, and Encounter-With-Christ retreats, for challenging me to reach beyond myself and the present; and Anne Marie Tisler, for walking with me and nourishing me, editing my papers and pushing me, being my friend and loving me.

I especially would like to thank my parents for supporting me all these years, encouraging me to enjoy my stay in Blacksburg while urging me to graduate; and Mary, my sister, for sharing love and fun with me.

Table of Contents

List of Figures

List of Tables

EMPIRICALLY DERIVED GUIDELINES
FOR TOUCH SCREEN TARGETS

Chapter 1. Introduction

Touch screens were first developed for use by airline flight controllers (Johnson 1967). In recent years the range of applications has grown to include vehicle control panels, employee and literacy training, information systems, patient monitoring from nurses' stations, and power plant monitoring (Olson, 1987; Usher and Illet, 1986; Weisner, 1988). Each application has unique user characteristics and design constraints. However, all touch screen designs must display touch targets on the screen in a manner that accurately records user choices without obstructing other information on the screen.

The Nutrition for a Lifetime System (NLS) is a nutritional information system developed for use in grocery stores (Winett, Moore, Wagner, *et al.*, 1990), which encourages grocery shoppers to follow the National Cancer Institute's (NCI) nutritional guidelines for increasing fiber and decreasing fat in the diet (Greenwald, Sondik, and Lynch, 1986). System components used by the shoppers include a laser disc player, which shows video segments explaining NCI's fat and fiber guidelines and ways to achieve those guidelines, and a touch screen monitor, which allows users to select and view program segments, respond to questions posed by the segments, and record grocery lists. Shoppers using the original version of NLS recorded their grocery lists with an optical mark reader; the second version of NLS, however, uses the more reliable touch screen entry system (Bowers, Leahy, and Reinhart, 1989). Touch screen entry of grocery lists has resulted in fewer mechanical problems and greater user satisfaction (L.A. Hite, personal communication, 1989).

Despite improvements to the NLS, however, system developers remained concerned about touch screen accuracy. Research participants associated with the NLS research project were paid for their participation and taught to use the touch screen by project staff members. Other NLS users were grocery shoppers not associated with the research project. These casual users received no instructions on touch screen use and were motivated by curiosity to use the system. Experience showed these casual users became frustrated and walked away after using screens they thought recorded their touches inaccurately. Few users availed themselves of the on-screen training, possibly because they did not want to take the time to learn to use a system they might never use again. To improve user satisfaction, the NLS project took steps to increase the accuracy of the touch screen entry system. Improvements were targeted toward inexperienced touch screen users and constrained by existing hardware. The author hypothesized that *visual target size* and *target location* might have significant effects on user accuracy. The research reported here was based on an IBM study which examined the effects of height and horizontal viewing location on user accuracy (Hall, Cunningham, Roache, and Cox, 1988). The experiment reported here was expanded to examine target size and location. Reasonable facsimiles of the protocol and questionnaires had to be followed because IBM had not released the actual materials to the public domain. The program using the touch screen monitor was written by Lee Ann Hite, programmer for the NLS project. The author conducted the experiment, compiled the statistics, and analyzed the results. Results will be reported to the NLS project and recommendations will be incorporated into future versions of the NLS.

Overview of Design Considerations

Developers must consider numerous factors when designing screens for use on touch screen monitors. Touch screen monitors present unusual problems because they have input and output functions that share the same display space and operate simultaneously. Thus, input constrains output and vice versa. Touch screen monitors are also susceptible to errors caused by mechanical failures and user behaviors. Several methods have been suggested to lessen the effect of these error sources.

Factors Affecting Screen Design

Monitor technology. Five touch screen technologies have been developed: infrared beam, surface acoustic wave, capacitance, cross-point matrix, and piezo-electric (Carroll, 1986; Pickering, 1986). One piezo-electric monitor, used by this research study and the NLS, which has gained popularity recently, is the IBM InfoWindow Touch Monitor (model 5144) ("IBM InfoWindows", 1989; Winett *et al.*, 1990). Piezo-electric monitors have a glass overlay fitted over the video tube, held in place by a piezo-electric transducer in each corner (Pickering, 1986). Touches to the overlay transfer force to the transducers, which generate voltages proportional to the force. Coordinates of a touch are calculated from the transducer voltages. Piezo-electric monitors are not sensitive to temperature, humidity, or incidental contact (insects, light debris, etc.), although some cannot handle a wide range of forces.

Targets. Programs with touch screen monitors display several items on the screen and ask users to press one. The program behaves differently depending on the item chosen. The items, or *targets*, are composed of two parts, the visual target and the touch sensitive region. Some visual targets are graphical images (artwork or still-frame video) that closely resemble the corresponding physical object. For instance, a stop sign or a police officer with outstretched arm might symbolize the command "stop". Other visual targets have words describing the choice. A literacy program might show a picture of a book and ask the user to choose the correct spelling for "book". When users try to press visual targets, they actually touch the touch screen overlay. The touch sensitive region defines the portion of the touch screen overlay assigned to that target. Thus, touches within a touch sensitive region select the corresponding visual target and trigger the corresponding action.

The visual target and touch sensitive regions need not be identical sizes. Visual targets are often smaller and centered within touch sensitive regions. Boundaries of touch sensitive regions are usually invisible since the region and visual target frequently have different sizes and shapes. A few researchers, however, have suggested highlighting the boundaries to clarify that touches within the bounded region will be associated with the visual target (Valk, 1985; Pickering, 1986). The number of targets on screen varies inversely with size of touch sensitive regions. If only a few targets are on screen, each target can be large, easy to see and (at least intuitively) easy to press. Placing more targets on the screen forces each target to be smaller and possibly more difficult to touch.

Error Sources in Touch Screen Monitors

Pickering (1986) identified two categories of errors in touch screen monitors: mechanical errors and user performance errors. Mechanical errors are systematic deviations attributed to the touch screen device: optical parallax, finite resolution of transducer, transducer drift or failure, and misregistration of overlay. User performance errors are deviations caused by behaviors of users: eye dominance and handedness, hit accuracy, and desire to avoid obscuring target with finger. Before a touch screen system can be effective, each of these factors must be compensated.

Optical parallax. Optical parallax refers to the apparent displacement of objects when viewed from different angles (Webster, 1985; Baggen, 1987). This displacement occurs because the screen of most monitors (except flat screen monitors) is a concave meniscus shape (Giancoli, 1984). The concave meniscus is a diverging lens that bends light coming from the monitor outward, away from the center of the screen and causes images to shift toward the outside of the screen. Touch screen monitors with glass overlays accentuate parallax because light bends once as it passes through the face of the video tube and bends a second time as it passes through the overlay. Parallax causes the perceived image to appear farther from the intended location, which causes errors because the image moves but the touch sensitive region remains at the original, non-parallax shifted location.

Finite resolution of transducer. The InfoWindow monitor measures touch locations by piezo-electric transducers at each corner of the overlay and coordinates are calculated from force measurements made by transducers. The transducers resolve multiple screen touches to a single coordinate. Thus, the derived coordinate may be far from locations the user touched. Resolution to a single touch also means that the monitor cannot distinguish between a hand and a finger touching the screen. Nor can a piezo-electric monitor follow a moving finger. Another problem is that users who touch the screen at a sharp angle instead of a right angle may transfer an unusual amount of force to a single transducer and cause errors in touch location calculations. When transducers try to record the maximum amount of force (for touches in the extreme corners), they may not fully measure the force before the monitor logic records the voltages for use in calculations. Finally, transducers have difficulty consistently distinguishing between small differences in forces (i.e., two adjacent touches), and difficulty consistently resolving identical touches to identical locations.

Transducer drift or failure. A drifted transducer has gradually changed the range of forces it can read or voltages it can generate. A failed transducer generates, for some range of forces, voltages that are unacceptably far from expected voltages. In each case, the transducer must be replaced before the touch screen will work properly.

Misregistration of overlay. A misregistered overlay destroys the alignment between visual pixels on the screen and corresponding touch points on the touch screen, causing systematic errors in the calculated coordinates of touches. Recalibrating the touch resolution algorithm to recognize the existing location of the overlay or physically adjusting the overlay to bring it into proper alignment may correct this problem.

Hand and eye dominance. Beringer and Peterson (1985) found that right-handed, right-eyed users touched slightly to the right of the target, while left-handed, left-eyed users touched slightly to the left.

Hit accuracy. Hit accuracy refers to the overall ability of a user to press a target. Accuracy may be affected by state of the user (i.e., fatigue), shakiness or an absence of coordination, impairment of arm or hand movement, and so on. This error will vary randomly between users.

Desire to not obscure target with finger. Users often try to avoid obscuring the target with their hand or fingers. Occasionally, a user must stand at an unusual location or hold their hand in an awkward position to maintain a clear view of the target, while at the same time trying to press it. Unusual positions often decrease the accuracy of the touch. A large target can minimize touch error and allow the user to view the target as it is pressed. Messages which appear on the screen should also be placed where they are not easily obscured by hands and fingers. For example, if a message appears at random times in the lower right corner of the screen, right-handed users touching a target in the center might make compensations so that the lower right remains in constant view.

Methods to Overcome Errors

To reduce the errors associated with touch screen devices, researchers have proposed a number of techniques including modified touch strategies, user training, user models, and error tolerant targets. Some compensate for both mechanical and user performance errors, while others anticipate user errors, but do not compensate for general mechanical errors.

Modified touch strategies. One method suggested to compensate for systematic errors in accuracy involves modifying touch strategies. Standard touch strategy, *land-on*, records the location of first contact with the touch sensitive surface (Potter, Weldon, and Shneiderman, 1988). The simplest modified strategy that enhances accuracy requires the user to touch the target twice (*double-touch*), first touch to select the target and second touch to confirm or activate it (Valk, 1985). More complex schemes require touch screen devices (capacitance, infrared, surface acoustic wave) to follow finger movement (Pickering, 1986; Potter *et al.*, 1988). *First-contact* tracks finger location with a cursor until a valid touch sensitive region is encountered, at which time that region is selected. *Take-off* uses a cursor to track a finger touching the screen and records the last location touched as the desired location. Researchers continue to debate which scheme users prefer, as well as whether the improved accuracy of complex schemes justifies the increased mental processing (Pickering, 1986; Potter *et al.*, 1988; Weisner, 1988).

User training. Training users to press the screen more accurately is another way to improve the performance of touch screens (Beringer and Peterson, 1985; Potter *et al.*, 1988). This training can take two forms: instructions on pressing the targets and feedback on presses. Instructions tell users how to touch the screen, such as pressing the center of the target and standing centered in front of the screen. Visual feedback shows the user where the touch location is being recorded. Two common methods of feedback use a cursor to show the current finger location and objects that highlight themselves when pressed.

User models. A third technique to improve touch screen performance is the use of user models (Beringer and Peterson, 1985). These models determine expected touch biases and make automatic compensations. Individualized user models require that each user touch predetermined locations on the screen enough times to establish consistency. Individualized models also require that the identity of the user be known to the computer. A generalized user model would use touch data from a large number of users to form a model. Individualized models have difficulties in public systems because of the large number of users and the difficulty of collecting enough data on each user in the rigorous manner required. Beringer and Peterson (1985) admit that reliable user models probably require over 100 touches and that costs incurred in collecting the data may not offset improved accuracy. The generalized model fails because of excessive variability in the general public of height, eye sight, accuracy, and so on. In addition, touch biases due to right-handedness tend to cancel out those due to left-handedness (Pickering, 1986).

Another form of user modeling is adaptive user modeling (Weisner, 1988). In this scheme, adjustments are made based on performance over the last *m* touches or *n* minutes. This form of compensation works well with stationary users who use the touch screen for a long period of time, but does not handle users who move around freely or situations with multiple users over a short period of time.

Error tolerant targets. When users miss targets, they either press regions that do not accept touches or they press adjacent targets. *Error tolerant targets* are surrounded by *buffers* or *guard zones* and have enlarged touch sensitive regions. Buffers and guard zones are regions that either ignore touches or generate an error message, such as a beep, for an invalid touch (Pickering, 1986; Hall *et al.* 1988). Buffers give immediate feedback to the user that the target was missed. In addition, buffers help prevent valid yet incorrect touches whose associated actions may be frustrating or costly, if not impossible, to correct.

Large touch sensitive regions increase the chance of hitting the correct target. A wide range of touch sensitive regions has been suggested. Based on empirical testing, Baggen (1987) suggests a 7.5 mm^2 target accurately records touches 85% of the time. Beringer and Peterson (1985) worked with 3.15 mm^2 touch units and found that most misses were within one unit of the target, so a 9.5 mm^2 target (one extra unit in each direction) "might eliminate most errors" (Beringer and Peterson, 1985, p. 457). Hall *et al.* (1988) developed a table giving the expected accuracy of targets ranging from 20 mm^2 to 40 mm^2. For example, their table gives the expected accuracy of a 24 mm^2 target as slightly less than 95%. Pickering (1986) offered the only advice found concerning target location, noting that most people err by pressing "low" and that targets in the corners tend to be the least precise due to parallax. Therefore, touch sensitive regions should be adjusted to accept "low" touches and should be enlarged for corner targets.

Chapter 2. Materials and Methods

A controlled experiment provided data for testing the experimental hypotheses of this research: both size and location of a visual target affect the accuracy of a user trying to touch that target on a touch screen.

Equipment

This study used an IBM InfoWindow Touch Monitor (model 5144) and an IBM PS/2 model 50Z, housed inside an information kiosk, located at the front of the Kroger, Co. Inc. grocery store at Tanglewood shopping mall in Roanoke, Virginia. The InfoWindow monitor had a piezo-electric touch screen with a resolution of 640 x 350 touch points (pixels). Density was 2.53 points per millimeter in the horizontal direction and 1.83 points per millimeter in the vertical direction. The center of the monitor was 130.8 cm from the floor and inclined 15° away from the participants (Figures 1 and 2) (Hall *et al.*, 1988). A tape measure fastened to the side of the kiosk facilitated rapid measurement of participants' heights. Markers were placed on the floor showing lines perpendicular to the monitor, 20° to the left of perpendicular, and 20° to the right of perpendicular.

An IBM InfoWindow PILOT program displayed targets randomly on the screen and recorded participants' touches. The entire touch screen accepted touches. The monitor measured X and Y offsets from target center to touch location in touch units (pixels), and elapsed time from target presentation to touch in seconds. Horizontal viewing location, target number, X and Y offsets, and elapsed time were recorded for each target pressed.

Participants

Forty-five participants from the Kroger grocery store were recruited as they walked by the NCI information kiosk. Interested persons received an information sheet to read

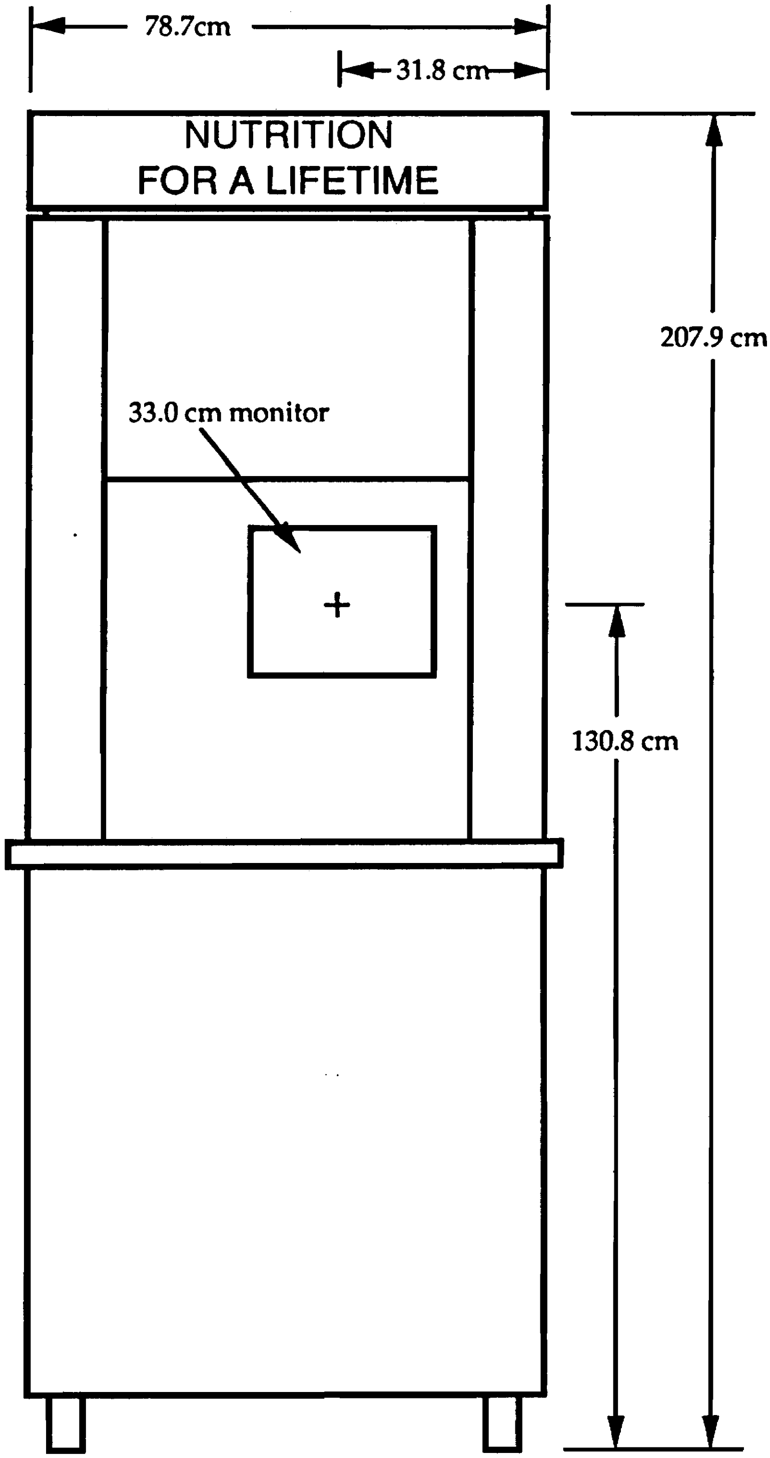


Figure 1. Front view of the Nutrition for a Lifetime kiosk.

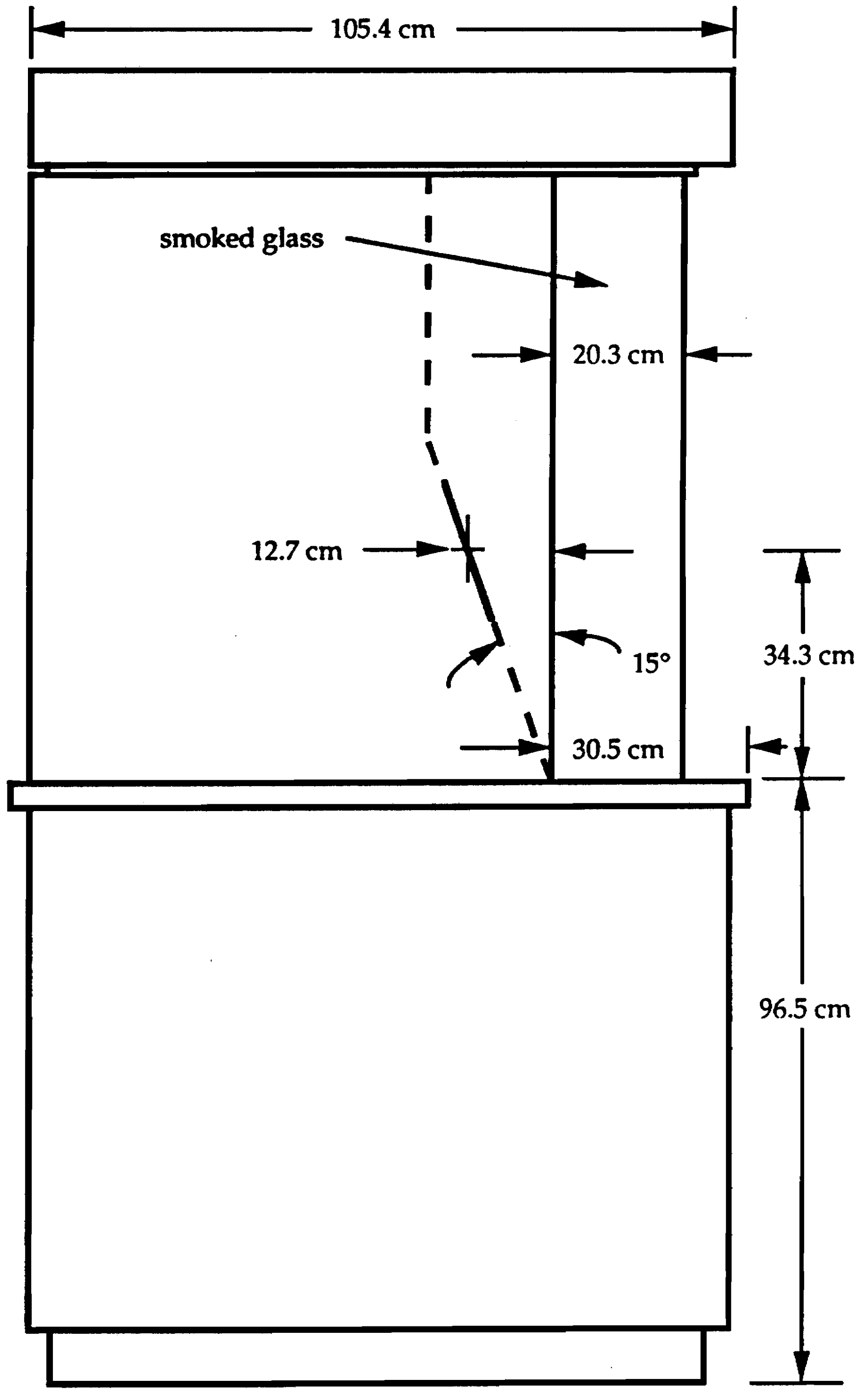


Figure 2. Side view of the Nutrition for a Lifetime kiosk.

(Appendix A) and completed an eligibility questionnaire (Appendix B) based on the questionnaire used by Hall (personal communication, 1989). The most important requirements were corrected vision (wearing glasses if necessary,) no bifocals, self-reported normal color vision, and unimpeded movement in the preferred arm. Those meeting the eligibility requirements signed an informed consent form (Appendix C) before the experiment began. All participants who completed the experiment received $5.

Experimental Design

User performance was assessed by a 3 x 3 x 9 (target size x horizontal viewing location x screen sector) factorial analysis (Figure 3). The target size was a between-subjects variable, while horizontal viewing location and screen sector were within-subjects variables. Each sector had 4 targets; scores for the 4 targets were averaged to give a score for the sector.

Three target sizes, 7.5 mm^2, 12.2 mm x 12.6 mm, and 20 mm^2, were used (Figure 4). The small target, 7.5 mm^2, was chosen because it was the smallest target Baggen (1987) found with an 80% touch accuracy rate. The medium target size, 12.20 mm x 12.60 mm, was used by Hall *et al.* (1988) to develop a single accuracy guideline for the screen. The large target size, 20 mm^2, was substantially larger than the other two sizes, but not so large that when the target was pressed the act was trivial. The ratio between the area of the large target and the medium target (2.6) was chosen to be close to the ratio between the areas of the medium and small targets (2.7). Each participant saw only one target size to avoid asymmetric transfer of skill (B. Williges, personal communication, 1989). Participants were assigned to a target size group in a cyclic fashion to assure equal numbers of participants in each group (i.e., 15 participants saw each target size). Red targets against a black background were chosen to accentuate potential parallax problems (Hall *et al.*, 1988; A.D. Hall, personal communication, 1989).

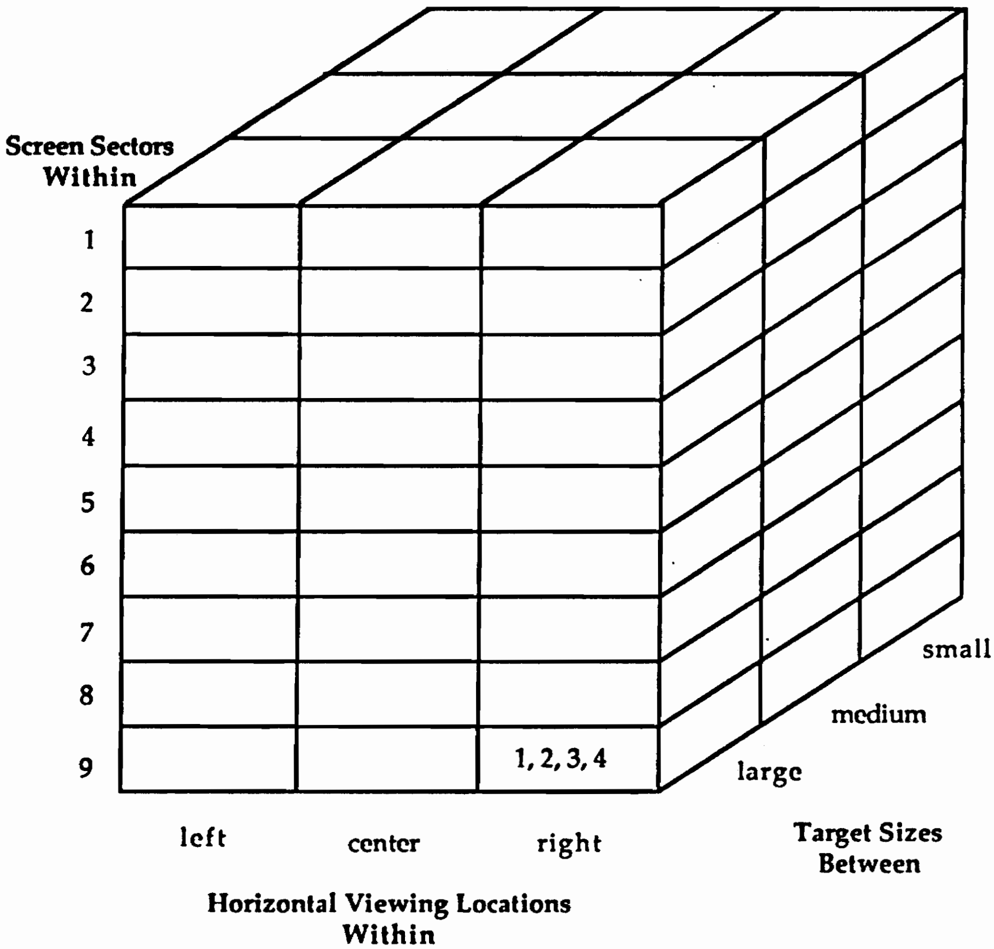


Figure 3. Three-dimensional representation of the independent variables.

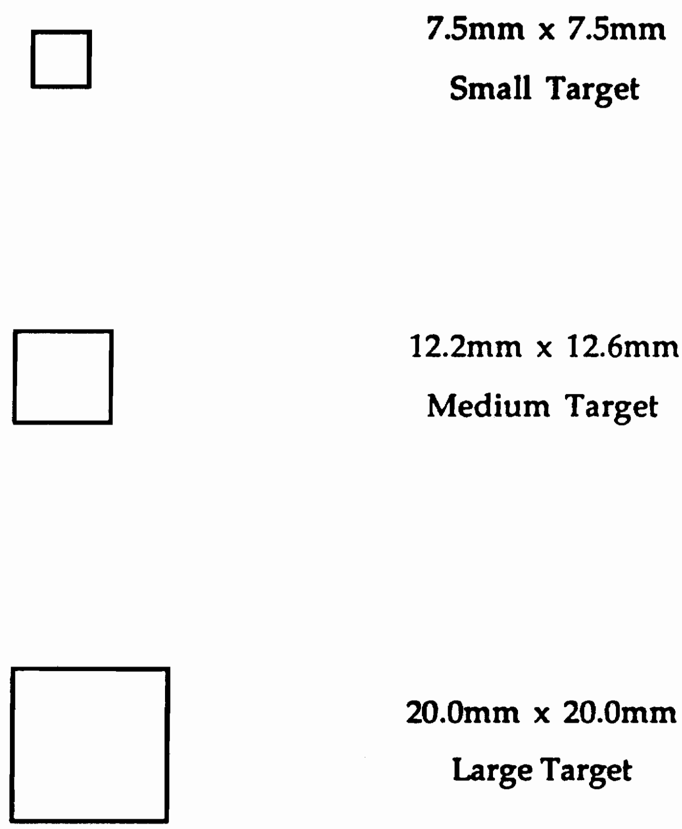


Figure 4. Size comparison of visual targets.

Three horizontal viewing locations were tested for each subject: perpendicular to the screen, 20° to the left of perpendicular, and 20° to the right of perpendicular. Side viewing locations represented the locations from that two 50 percentile US adults standing side by side would view the screen (Hall *et al.*, 1988). Locations were randomly ordered for each participant.

The screen was divided into 3 rows and 3 columns to form 9 logical sectors of equal size. Each sector was further divided into 4 logical quadrants, with a red square target centered in each quadrant. Figures 5, 6, and 7 show the placement of square targets for each of the three target sizes. Sectors and targets were separately numbered in row-wise order; neither sector nor target numbers were displayed on the screen. Targets were presented in random order to each participant.

Procedure

Participant height and eye height were measured, a brief verbal description of the experiment was given (Appendix D), and participants were assigned a target size condition (small, medium, large). A pretest, designed to familiarize participants with the targets and the force required to activate the touch screen, was administered before the experiment began. Each participant stood in front of the monitor and practiced pressing five targets. These targets were identical to those used for the experiment and appeared on the screen one at a time.

Participants were tested at each of three horizontal locations (left of center, center, right of center), with order determined randomly. Before each test began, a sign was displayed on the screen that directed the participant to stand at one of three locations in front of the monitor and to press the screen to begin. Each of 36 targets was presented to the participant one at a time in random order. After the participant viewed the target and pressed the screen, the monitor beeped, the target vanished and another target appeared. No feedback on touch accuracy was given to the participant. After all 36 targets were touched, the participant moved to the location

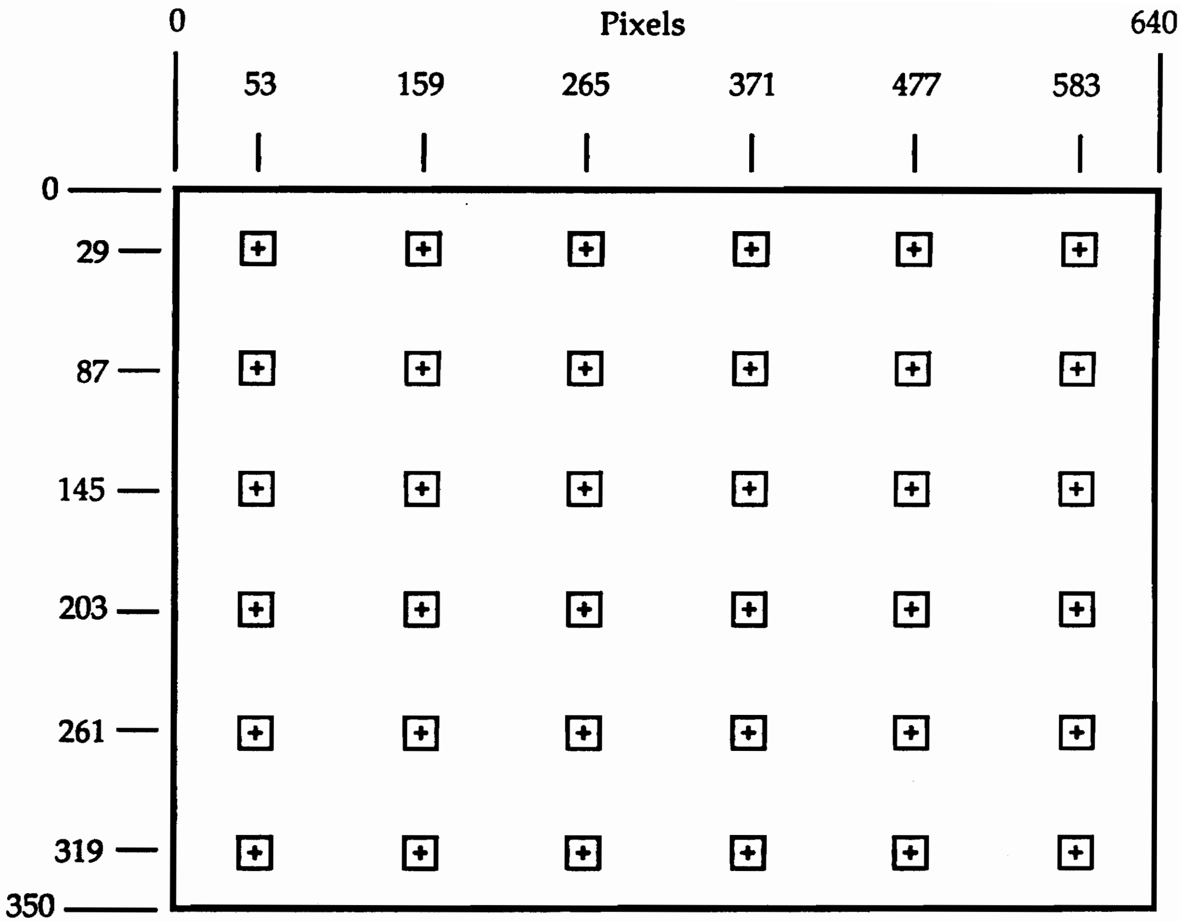


Figure 5. Screen layout with small targets.

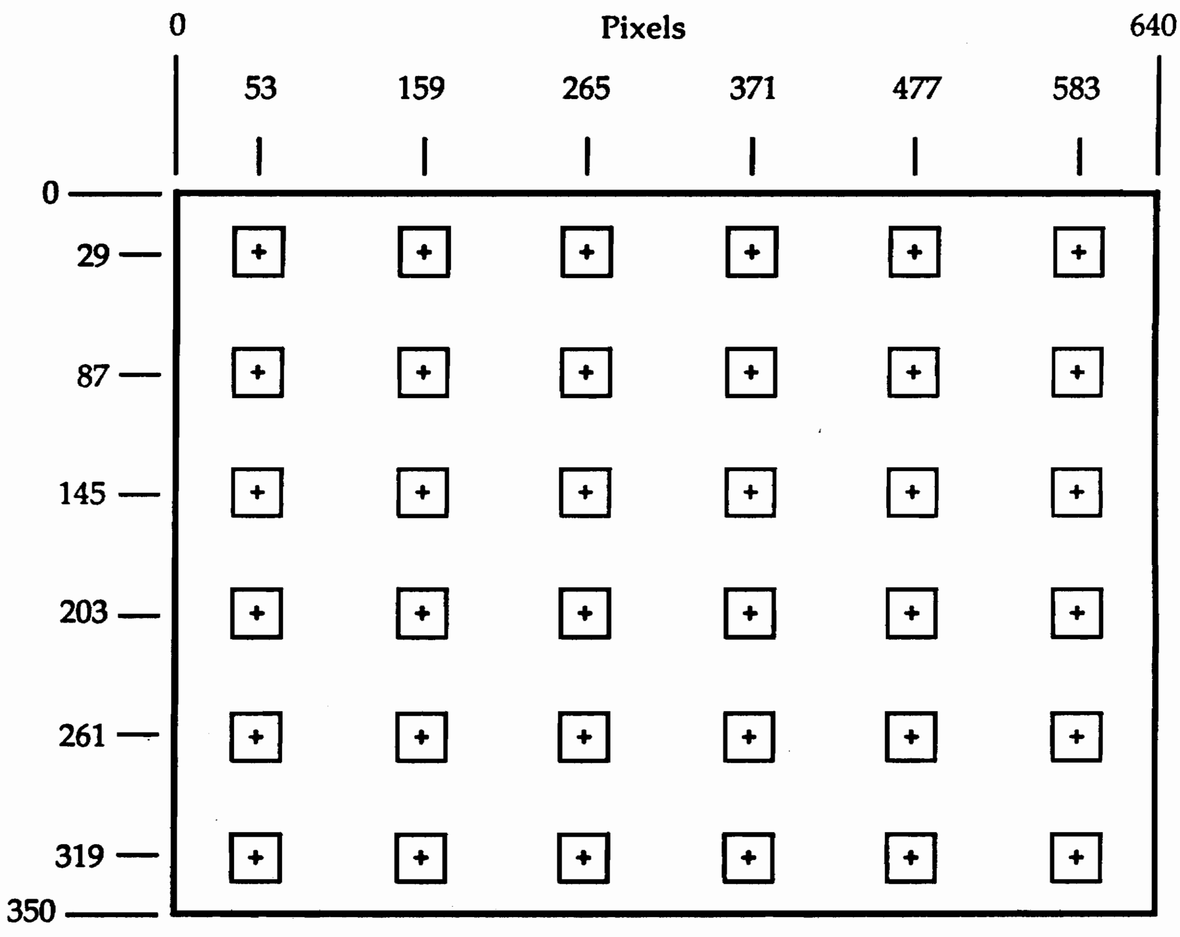


Figure 6. Screen layout with medium targets.

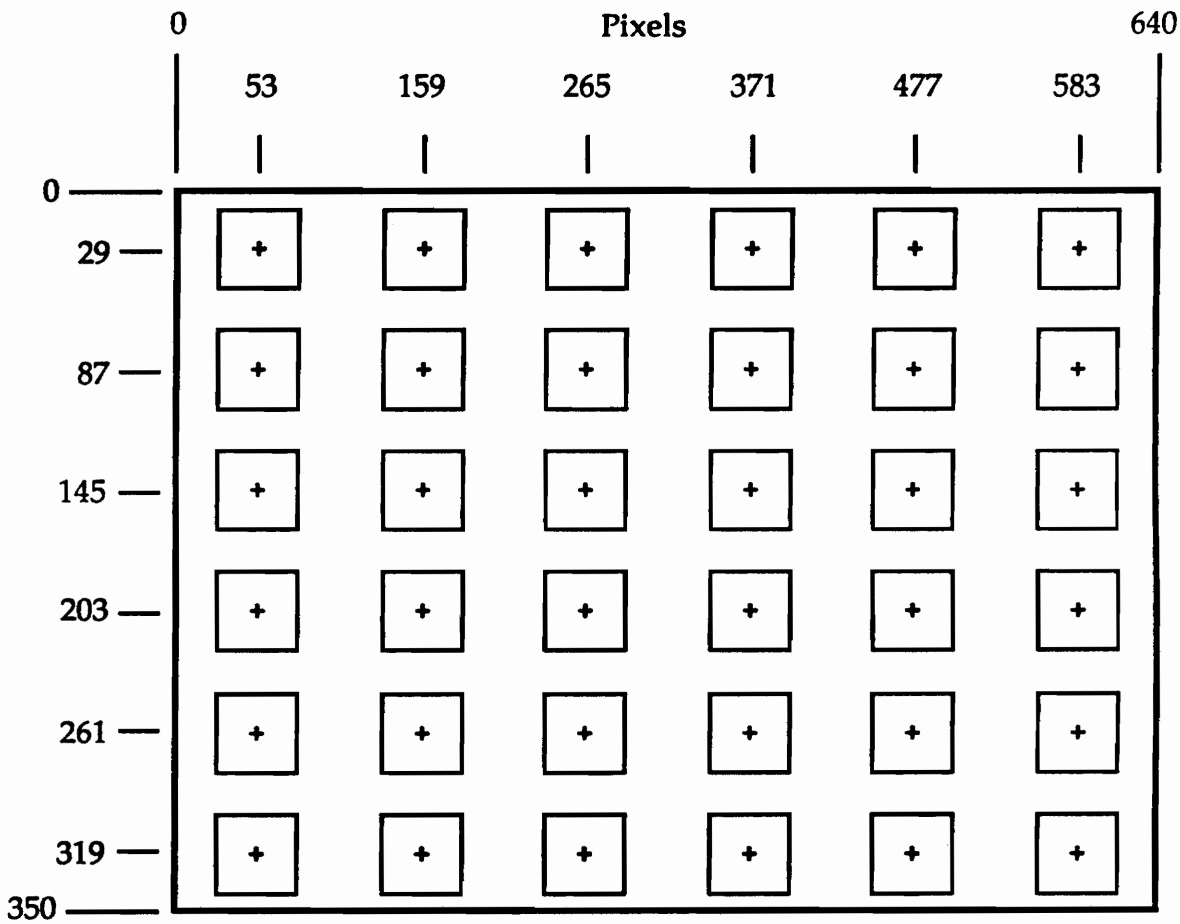


Figure 7. Screen layout with large targets.

indicated by a sign displayed on the monitor, where the procedure was repeated with 36 more targets of the same size. Upon completion of the third test, the participant answered a subjective questionnaire designed to evaluate user satisfaction with the touch screen system (Appendix E). The questionnaire was based on one used by Hall (personal communication, 1989). The participant was thanked for helping with the study and received $5.

Analyses

Data were analyzed using the Statistical Analysis System to perform analyses of variance and the multiple range test developed by Ryan, Einot, Gabriel, and Welsch (REGW) (SAS Institute, 1985). The REGW multiple range test is recommended for ANOVAs which control the maximum experimentwise error rate and have equal block sizes and no need of confidence intervals. Data were analyzed to determine expected accuracy for targets within each sector. A program written in Pascal analyzed all regions with integer borders sized between 0 mm and 40 mm and counted the number of touches that would have been accepted had the touch region been centered around the center of the visual target. Results for each sized region and the percentage of total touches that would have been recorded by that touch sensitive region were recorded in a SAS dataset and plotted using PROC GCONTOUR.

Chapter 3. Results and Discussion

Performance Measures

X Offset Results. X offsets measured directed distance from target centers to touch locations along the X axis (Figure 8). Positive X offsets indicated touches to the right of target center. Values from the analysis of variance (ANOVA) test for X offset are shown in Table 1 (tables are given in Appendix G). Differences based on sector, viewing location, and a two-way interaction of sector and viewing location were significant at $\alpha = .01$. Differences based on size, however, were not significant.

The multiple-range test developed by Ryan, Einot, Gabriel, and Welsch (REGW) (SAS Institute, 1985) indicated the sectors that had significantly different mean X offsets (Table 2). X offsets ranged from -6.07 mm to 4.90 mm, with sectors in each column significantly different from those in the other two columns (Table 3). Figure 9 shows that participants erred to the left of the target when they touched sectors on the left of the screen and erred to the right of the target when they touched sectors on the right of the screen. Comparisons of mean X offsets indicated significant differences between each horizontal viewing location. Participants erred to the left when standing to the right and erred to the right when standing to the left.

X Offset Discussion. Differences among X offsets may be due to parallax from the touch screen monitor. As described earlier, the monitor screen and the touch screen overlay bend light outward, toward the screen edges. Therefore, target centers of the right-hand sectors appeared further to the right than they actually were, while target centers of left-hand sectors appeared to the left of their actual location. Variations among horizontal viewing location can be explained by noting that a participant who stood centered in front of the screen had no net X offset, since the left bias of touches to the left-hand targets canceled the right bias of touches to the right-hand targets. A participant to the right of the screen saw light from the right column with little

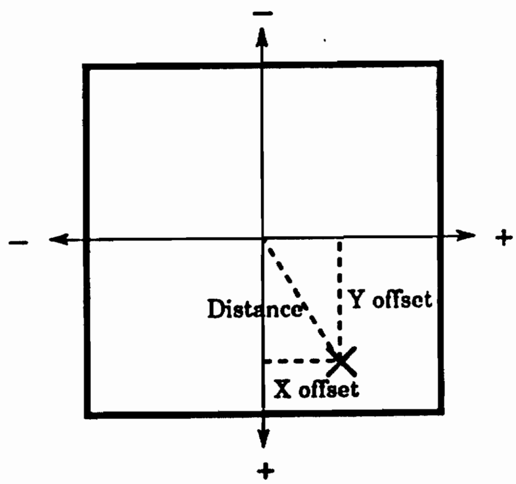


Figure 8. Relationships between target center and touch location.

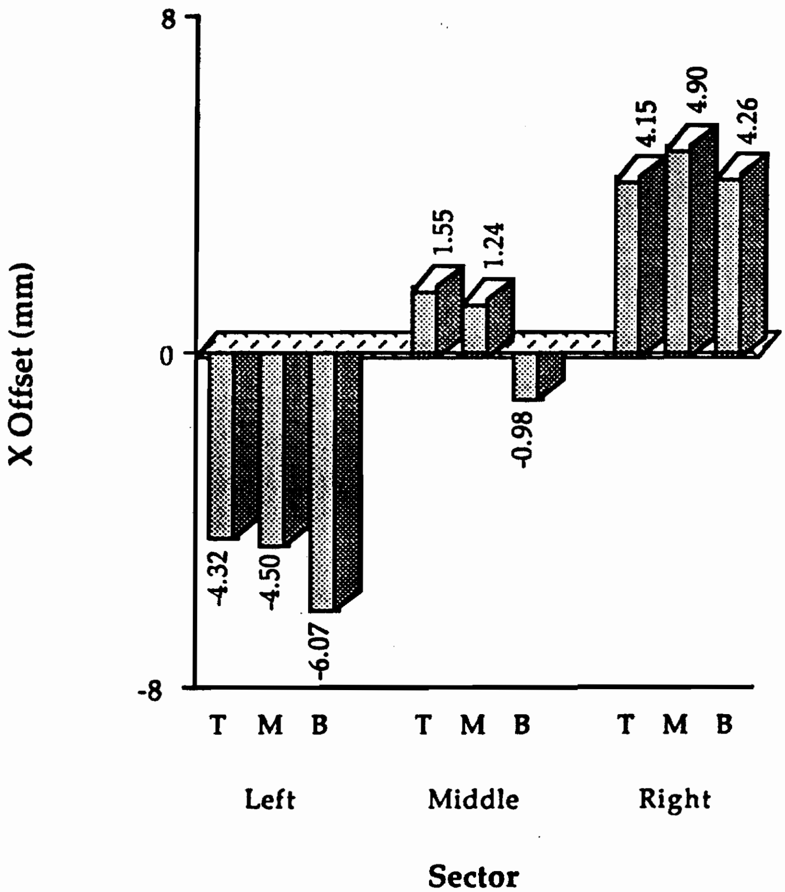


Figure 9. Effect of sectors on X offset.

bending, but saw light from the center column bending to the left and light from the left column bending even more to the left. This additive effect causes a net X offset to the left. The effect is similar for someone standing to the left.

A second factor that may have contributed to significant differences between X offsets was glare on the screen. Glare came from two primary sources at the Kroger store, overhead lights and windows facing the parking lot. Overhead lights were present in all directions and would have contributed equally to X offsets of the top row sectors. Windows facing the parking lot were located behind and to the right of the participant, and may have affected only the sectors on the right side of the screen. Several participants had difficulty finding the lower right targets.

The location of the screen in the kiosk may have been responsible for differences in the X offsets. As noted in Figure 1, the screen was located in the right half of the kiosk. Privacy panels made of smoked glass protruded (20.32 mm) from the top half of the kiosk (Figure 2). These panels impeded free access to the screen from the sides, especially the right side. At least one participant mentioned that it was difficult to touch the right columns when standing on the right (Appendix F, question 10). Another participant suggested that the screen be raised.

X Magnitude Results. Mean X magnitude averaged magnitudes of the X offsets (X offset distances without regard for direction). Results of ANOVA tests on X magnitudes are shown in Table 4. Sector, horizontal viewing location, and a two-way interaction between sector and viewing location caused significant differences among X magnitudes at $\alpha = .01$. Target size did not cause significant differences among mean X magnitudes. REGW's multiple-range tests showed that sectors in the center column were not significantly different from each other, but they had X magnitudes significantly smaller than outside sectors (Table 5). X magnitude of the lower left sector was significantly different from X magnitudes of other sectors in the right and left columns. Participants had significantly smaller X magnitudes when they stood to the left of the screen than when they stood in front of the screen (Table 6).

The interaction between sector and horizontal viewing location is shown in Figure 10. Post hoc Simple-Effect F-Tests (Table 7) revealed significant differences among sectors at all viewing locations. Results of REGW's multiple-range tests for each location showed significant differences spread among the sectors (Tables 8, 9, and 10). X magnitudes of left-hand sectors were significantly larger when viewed from the right, while X magnitudes of right-hand sectors were significantly larger when viewed from the left. The magnitudes of center sectors were significantly smaller when viewed from the center location.

X Magnitude Discussion. X offsets showed significant differences among all columns while X magnitudes did not. This is reasonable since the magnitudes of mean X offsets of outside columns were approximately the same, differing only in direction. X magnitudes showed no significant differences between outside columns. X magnitudes were affected by the same sources of error as X offsets.

Y Offset Results. Y offsets measured directed distance from target centers to touch locations along the Y axis (Figure 8). Positive Y offsets indicated touches below the target center. Values from the ANOVA test for Y offset are given in Table 11. Differences based on sector, viewing location, and a two-way interaction of sector and viewing location were significant at $\alpha = .01$. Differences based on size, however, were not significant. REGW's multiple-range test indicated the sectors that had significantly different Y offsets (Table 12). Y offsets ranged from -3.14 mm to 11.93 mm, with sectors in each row significantly different from those in other rows. Participants pressed above the target when touching sectors on the top row and touched below the target for the lower two rows (Figure 11). When participants stood to the left of the screen,

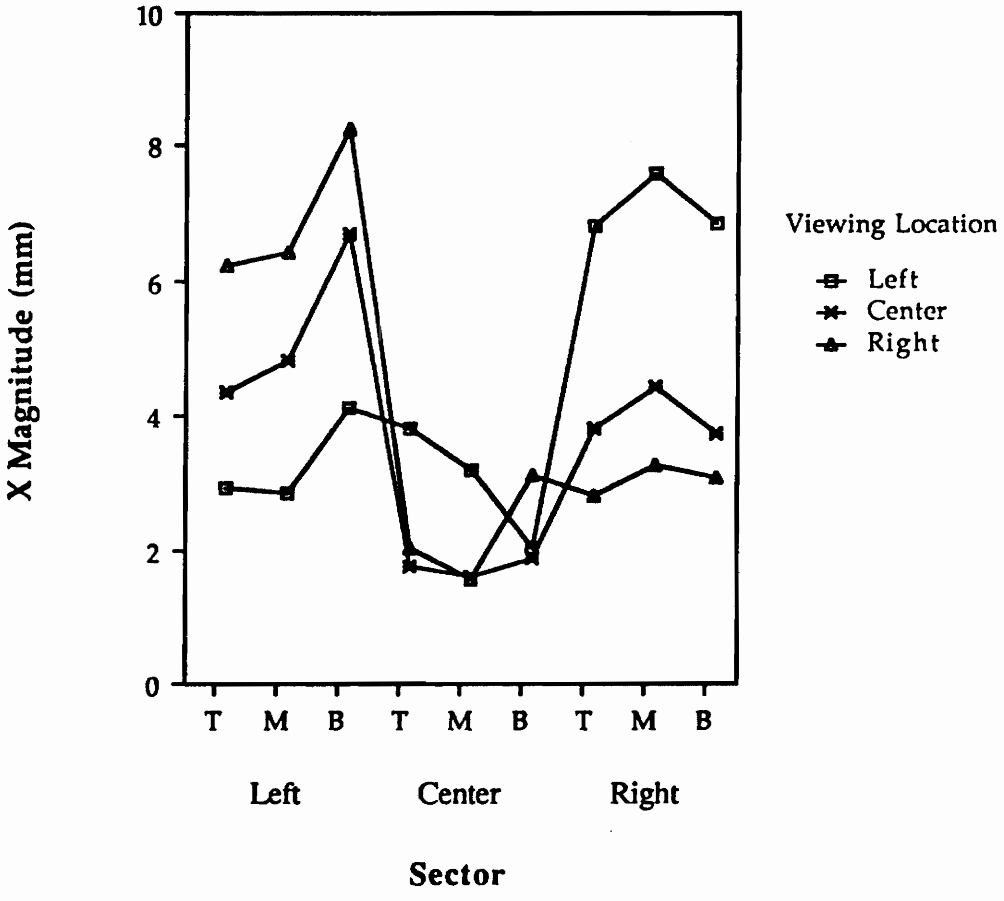


Figure 10. Effect of interaction between sector and horizontal viewing location on X magnitude.

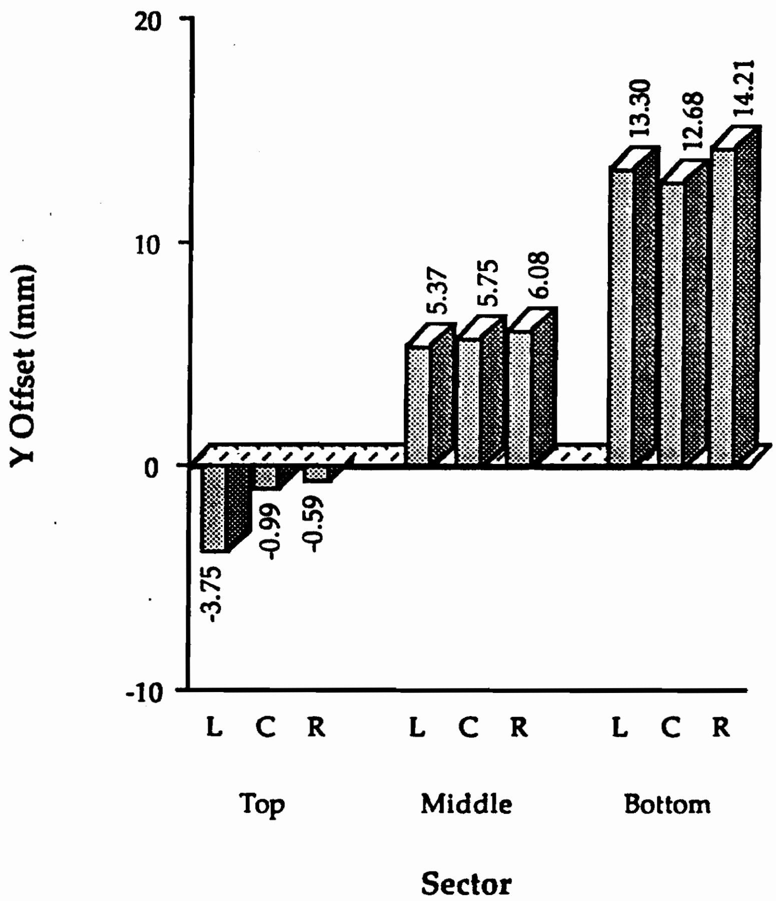


Figure 11. Effect of sectors on Y offset.

touches were significantly lower than when participants stood to the right or in front of the screen (Table 13).

The interaction between horizontal viewing location and screen sector is shown in Figure 12. Post hoc Simple-Effect F-Tests (Table 14) revealed significant differences among the mean Y offset of screen sectors at all three horizontal viewing locations. A series of REGW's multiple-range tests was conducted at each horizontal viewing location on mean Y offsets. At each viewing location (Tables 15, 16, and 17), mean Y offset for each row was significantly different from the means of other rows. Differences in subject height also affected mean Y offset. Mean height of the participants was 171.5 cm and mean eye height was 161.0 cm. Accuracy was correlated with height ($r(45) = .48$, $p < .01$) and eye height ($r(45) = 0.47$, $p < .01$).

Y Offset Discussion. Differences among Y offsets were due to parallax of the touch screen monitor. Light that exited the monitor above the perpendicular line of sight bent upward while light that exited below bent downward. Targets at the top of the screen appeared higher than they were, while targets at the bottom of the screen appeared lower. Glare from overhead lights, as discussed for X offsets, may have affected Y offsets.

Y Magnitude Results. Mean Y magnitude averaged magnitudes of the Y offsets (Y offset distances without regard for direction). Results of ANOVA tests on Y magnitudes are shown in Table 18. Sector, horizontal viewing location, a two-way interaction between sector and horizontal viewing location, and a two-way interaction between sector and target size caused significant differences among Y magnitudes at $\alpha = .01$. Target size did not have a significant effect on Y magnitude. REGW's multiple-range test showed that there were significant differences in Y magnitudes among rows (Table 19). Participants were least accurate when standing to the left of the monitor (Table 20).

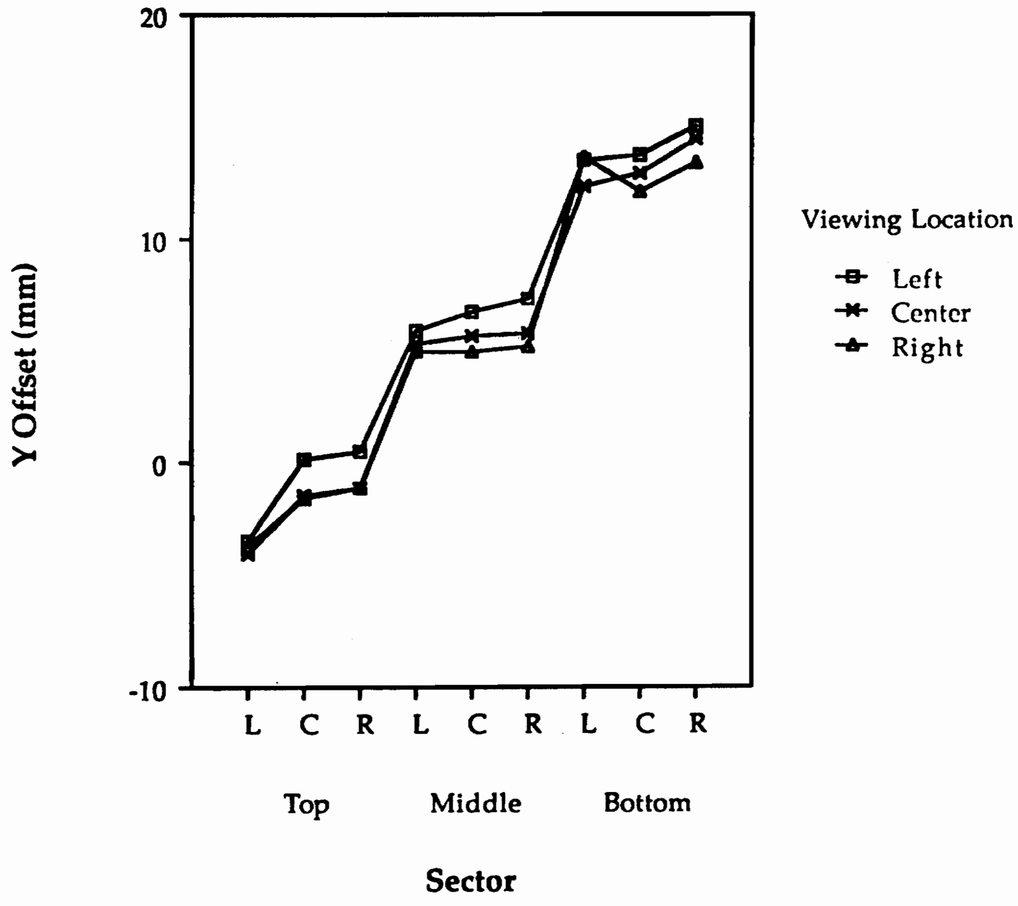


Figure 12. Effect of interaction between sector and horizontal viewing location on Y offset.

The interaction between sector and horizontal viewing location is shown in Figure 13. Post hoc Simple-Effect F-Tests (Table 21) revealed significant differences among sectors at all horizontal viewing locations. Results of REGW's multiple-range tests for each location showed significant differences spread among the sectors (Tables 22, 23, and 24). When users stood at the center and right locations, accuracy in the top left sector was not significantly different from the middle row; at each viewing location, remaining sectors were significantly different from sectors in other rows. Figure 14 shows the interaction between sectors and visual target size. Significant differences were present for all target sizes (Table 25). With one exception, for all target sizes, the bottom row had significantly larger Y magnitudes and the top row had significantly smaller Y magnitudes than the other two rows (Tables 26, 27, and 28). The one exception was the Y magnitude of the top right sector with small targets, which was not significantly different from the Y magnitude of sectors in the middle row.

Y Magnitude Discussion. Y magnitudes, like Y offsets, had significant differences between rows. Optical parallax caused differences among rows. Figures 12 and 13 are remarkably similar, suggesting that sector is the primary cause of variation among targets.

Distance from Target Center to Touch. Distance from center of target to actual touch location was derived from the X offset and the Y offset of each touch (Figure 8). Results from ANOVA tests on distance are given in Table 29. Sectors, horizontal viewing location, and a two-way interaction between sectors and viewing location affected the mean distance significantly at $\alpha = .01$. Distances on the bottom row were 2.3 times distances on the top row and 1.3 times distances on the middle row (Table 30). Within each row, the center sector produced significantly smaller distances than the outside sectors. Users were consistently less accurate when targets were viewed from the left than when viewed from the center or right (Table 31). Figure 15 graphically represents touch variation among sectors. The first symbol plotted, average touch

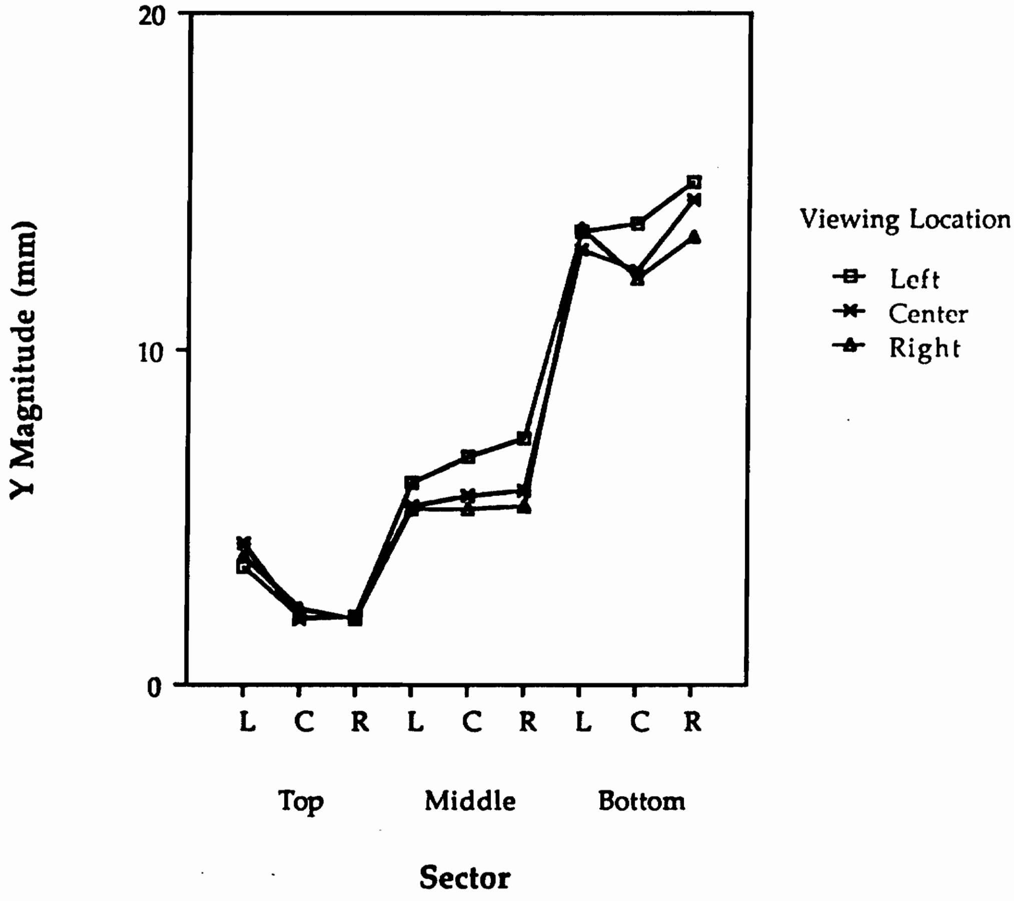


Figure 13. Effect of interaction between sector and horizontal viewing location on Y magnitude.

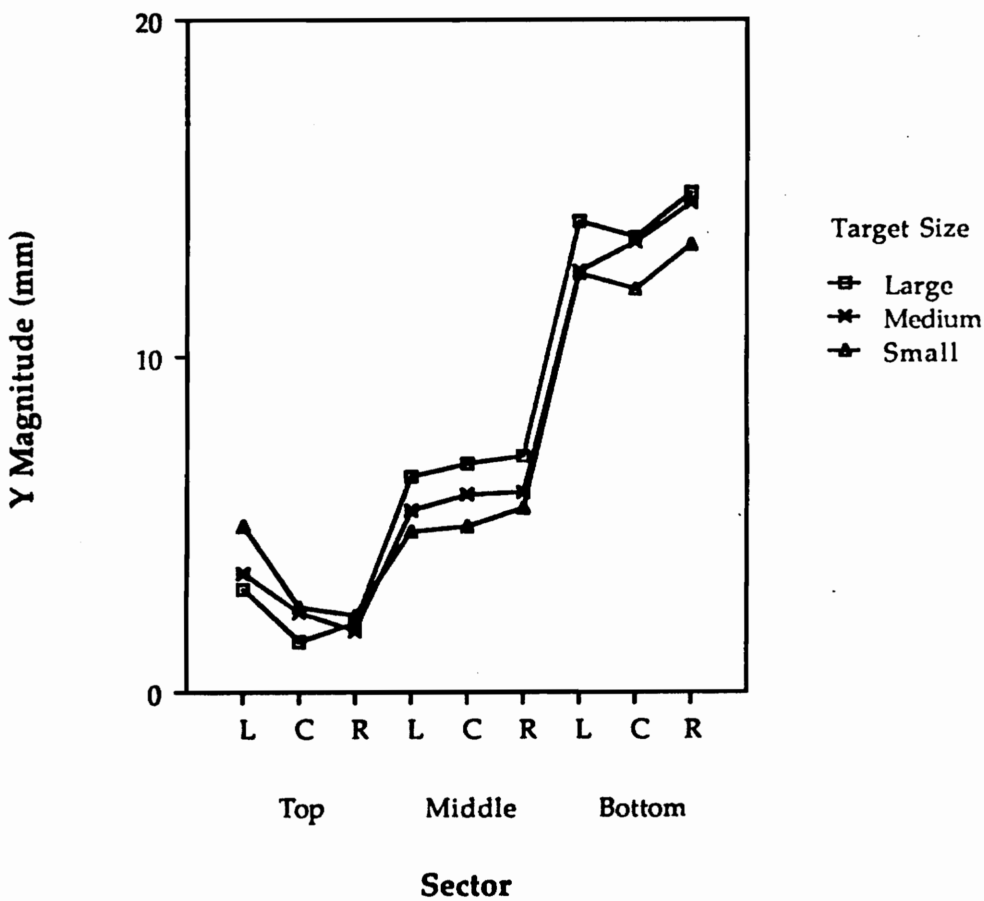


Figure 14. Effect of interaction between sector and target size on Y magnitude.

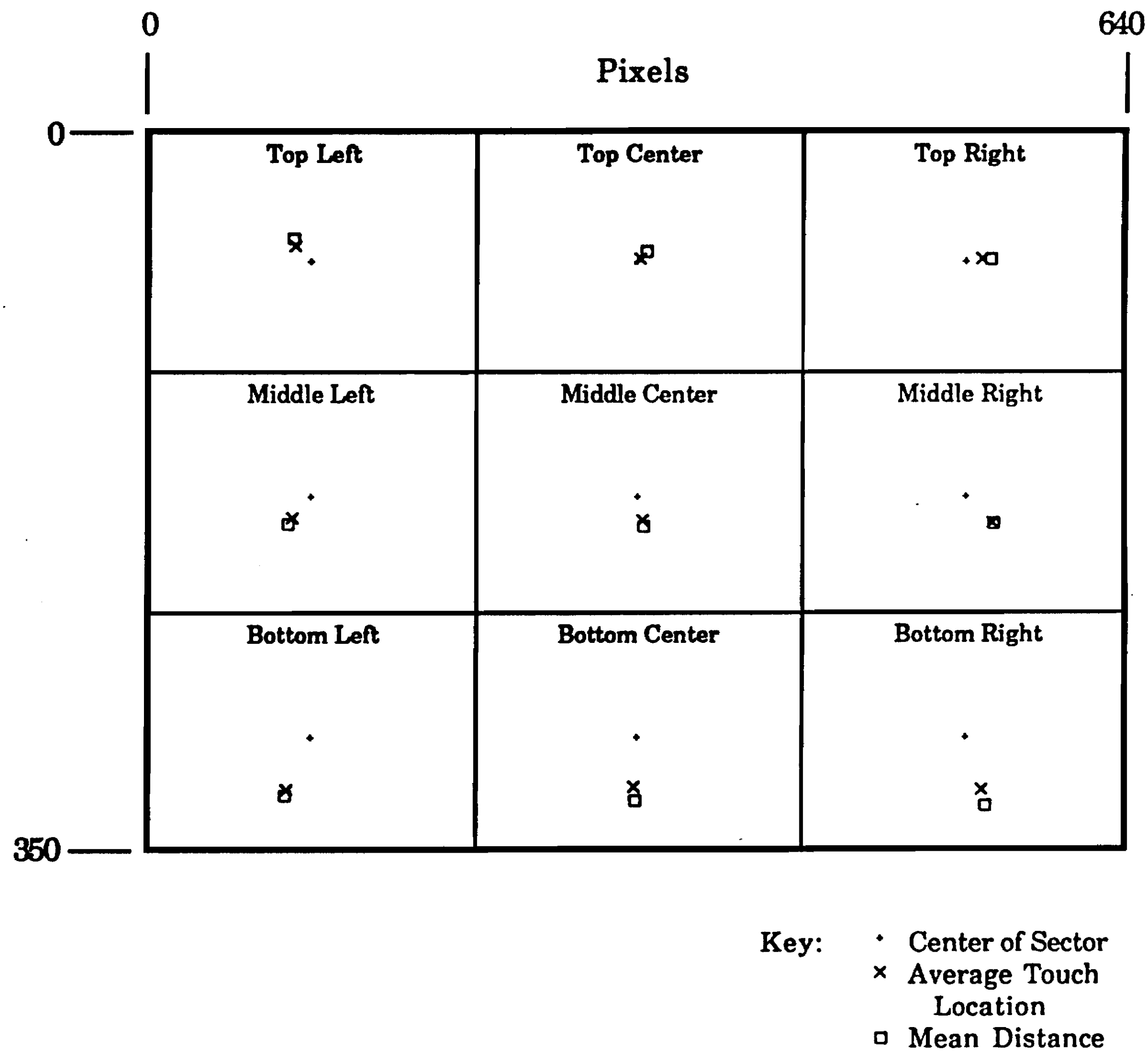


Figure 15. Screen layout showing average touch location and mean distance from center for each sector.

location, uses mean X and Y offsets as coordinates. The second symbol, mean distance, shows the mean distance along the line extending from the actual target center through the average touch location.

Figure 16 shows the horizontal viewing location by screen sector interaction. Post hoc Simple-Effects F-Tests revealed that screen sector means for distance were significantly different at all viewing locations (Table 32). A series of REGW's multiple-range tests was conducted on mean distances at each horizontal viewing location (Tables 33, 34, and 35). There were significant differences spread among the sectors at each location, with the mean distance in sectors along the bottom row significantly different from the upper two rows at each horizontal viewing location.

Distance Discussion. Participants generally touched below the target, with touches to the top row of sectors closest to the target center and touches to the bottom row farthest from the target center. Within each row, participants touched toward the outside of the screen. These results could be anticipated from the X and Y components of distance. Because the magnitude of Y offsets was larger than the magnitude of X offsets, distances tended to differ significantly by rows, as did Y offsets. To a lesser extent, the outside sectors of each row had larger distances than the center row, a trait shared with the X offsets. Mean distance was further from the center than the mean touch (except in the middle right sector), which prevented the use of mean X and Y offsets as absolute predictors of touch locations.

Elapsed Time Results. Elapsed time measured the time between presentation of target and screen press. Results of ANOVA tests are given in Table 36. Differences based on sector were significant at $\alpha = .01$. REGW's multiple-range test indicated that sectors in the upper corners caused delays significantly longer than in the lower center (Table 37). Mean times ranged from 0.85 sec to 0.96 sec.

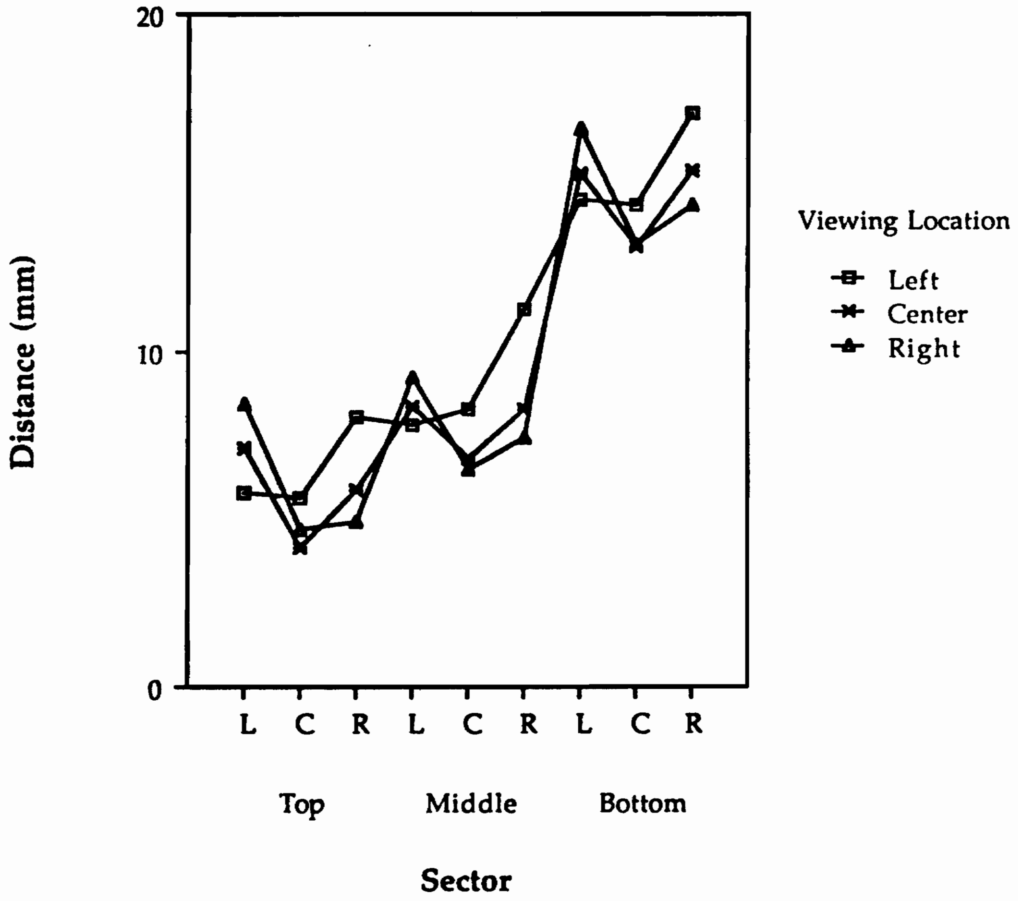


Figure 16. Effect of interaction between sector and horizontal viewing location on distance.

Elapsed Time Discussion. Mean elapsed times had a range of only 0.11 sec. Participants held their hand at the center of the screen, ready to press the next button. The short distance to reach all parts of the screen would explain the small time range. Sectors on the top row had longer delays than sectors on the bottom rows, which may have been caused by gravity and fatigue since more exertion was required to reach the top of the screen than the bottom.

Subjective Measures

Results from the post-test questionnaire completed by participants (Appendix F) showed that only a small amount of force was required to press the screen (mean=2, range=1-5) and that participants found it easy to touch the red squares on the screen (mean=1.5, range=1-7). They were satisfied with their view of the squares on the screen (mean=1.5, range=1-6) and found it easy to view the squares (mean=1.4, range=1-5). Thirty-two of the forty-five participants reported arm fatigue, although most were not very tired (mean=5.2, range=1-7). Of these, 16 said that their arm was tired at the end of the second set of targets (mean=2.4, range=1-3). Most agreed that images on the screen were sharp (mean=1.6, range=1-6). Although two participants reported tired eyes during the study, overall there was very little eye fatigue reported (mean=6.3, range=2-7).

Nine participants did not identify the button that had been used in their experiment. Instead, they tended to choose the next smaller size. When shown the three different squares on a sheet of paper and asked to choose the one they would rather use, 24 participants preferred the medium sized button and 17 preferred the largest button. Those who preferred the medium button commented that it was about the size of a finger and it would not overwhelm nearby text. Those who preferred the largest button felt that it would be easier to touch because accuracy was not as critical. They also felt it was easier to see, especially with the curved screen.

Written comments suggested subjects liked using the system. Common complaints mentioned fingerprints, glare on the screen, and the awkwardness of touching areas of the screen when standing away from the center. Two persons suggested raising the screen.

General Discussion

Target sector. The screen sector of a target clearly has an affect on the accuracy of a user's touches. Distance between target center and touch location increased significantly as the target moved down the screen. Within each row, targets in the center column had shorter distances to mean touch location than targets on the outside. These results compare favorably with the recommendations of Pickering (1986) and Hall *et al.* (1988).

Horizontal viewing location. When participants moved among horizontal viewing locations, they had significant changes in touch accuracy. Results showed, however, that target sector had more influence on touch accuracy than viewing location did. In addition, most systems are not designed to be used by persons standing exclusively to one side, but are designed to be used from a wide range of viewing locations. For these reasons, suggestions took all three locations into account and did not try to make separate suggestions for each viewing location.

Target size. This experiment showed that, for targets smaller than 20 mm^2, visual target size did not significantly influence touch accuracy. Strictly speaking, the results are only valid for target sizes between 7.5 mm^2 and 20 mm^2, but they should generalize to visual target sizes smaller than 7.5 mm^2 for three reasons. First, users could not be expected press a target smaller than 7.5 mm^2 more accurately than they did the 7.5 mm^2 target. Second, few applications could adequately label each target in a space of less than 7.5 mm^2. And third, users might have difficulty finding very small targets on the screen, losing them amidst the other objects or the glare on the screen. One explanation for the lack of difference due to target size was the verbal instruction given by the experimenter that emphasized accuracy over speed (Appendix D).

Additional studies are required before either the conjectures concerning very small targets can be accepted or the explanation of the lack of differences can be accepted or discounted.

Guidelines

Most work in touch screen design has produced only vague, non-numeric heuristics for determining target size or location. Hall *et al.* (1988) developed a graph to show expected accuracy as contour lines with touch sensitive region dimensions as axes. The model used to derive that graph, however, did not consider target location as an important factor. Results of the study reported here expand the work of Hall *et al.* (1988) by developing empirically derived quantitative guidelines which consider target sector for designing touch screen interfaces.

Figure 17 relates sector location with the size of touch sensitive regions and gives expected touch accuracy for the target. For example, a target in the top left sector which was 38 mm^2 would be expected to accurately record touches over 99% of the time, while a similarly sized target in the bottom left sector would be expected to accurately record between 50% and 90% of the touches.

Figure 17 was developed by a post-hoc analysis of subject touches. All touches were considered in the analysis, with no regard to target size or horizontal viewing location. First, all touches were put into the same quadrant by taking the absolute value of the X and Y offset. Next, a grid of 36 x 36 points was set up, at one mm intervals. Touch sensitive regions extending from the origin to each of the grid points were simulated. The number of touches falling within each touch sensitive region was counted and expressed as a percentage of the total number of touches. Contour lines of the percentages were plotted using the SAS procedure GCONTOUR. The scale of the contour graph was changed from 0-36 mm to 0-72 mm to show the size of the desired target, not the distance from the center of the target to the side.

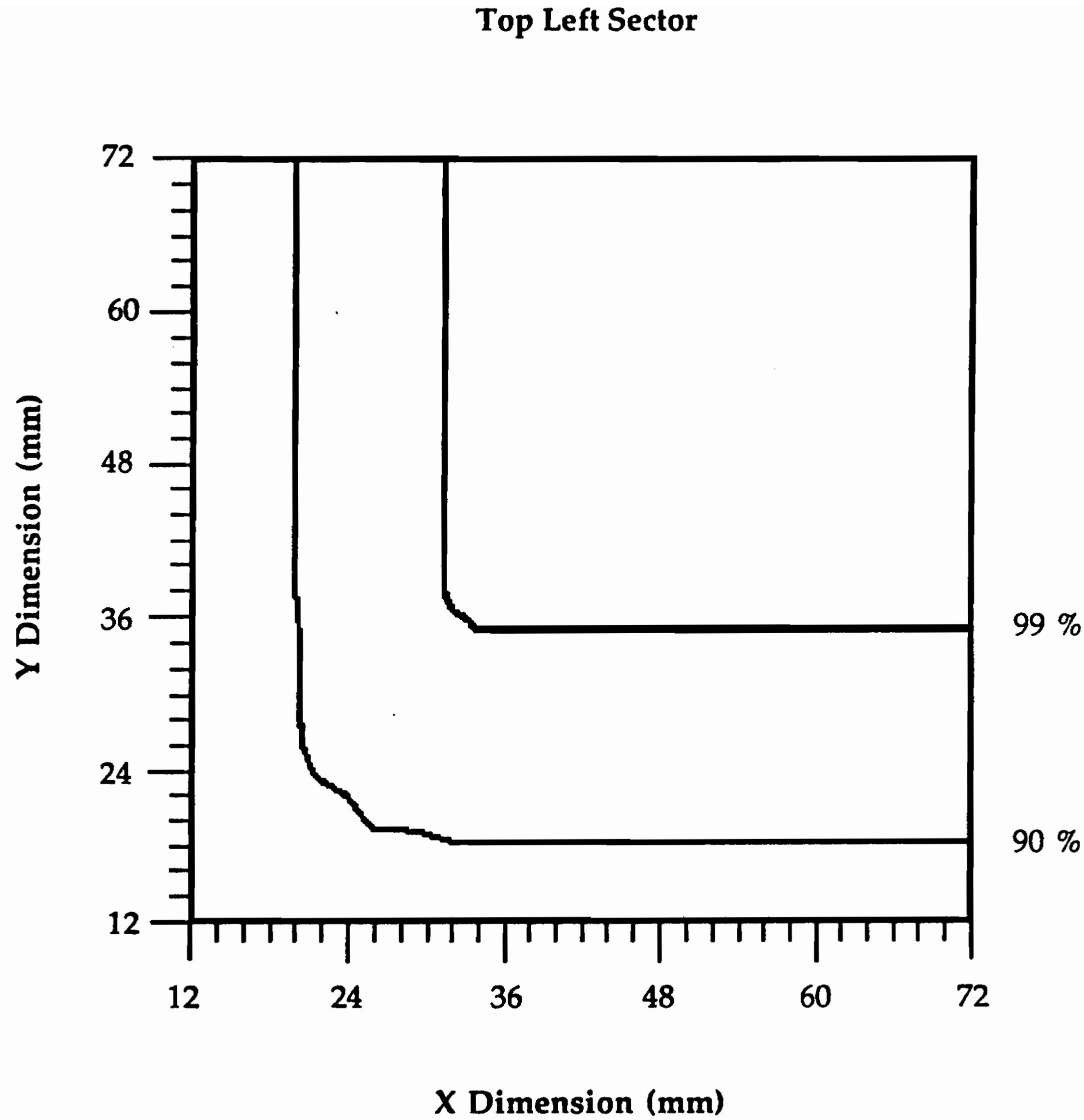


Figure 17. Expected accuracy of touch sensitive regions.

Top Center Sector

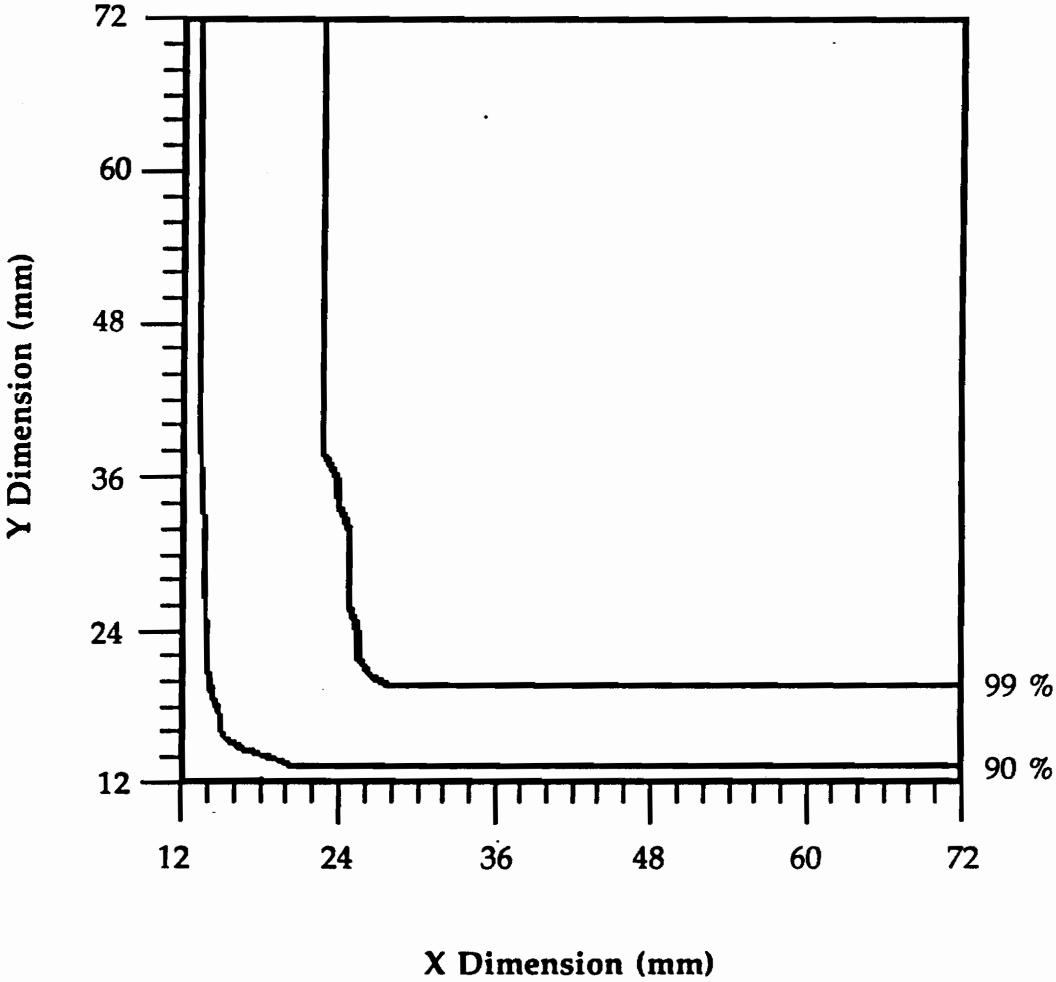


Figure 17. Expected accuracy of touch sensitive regions (continued).

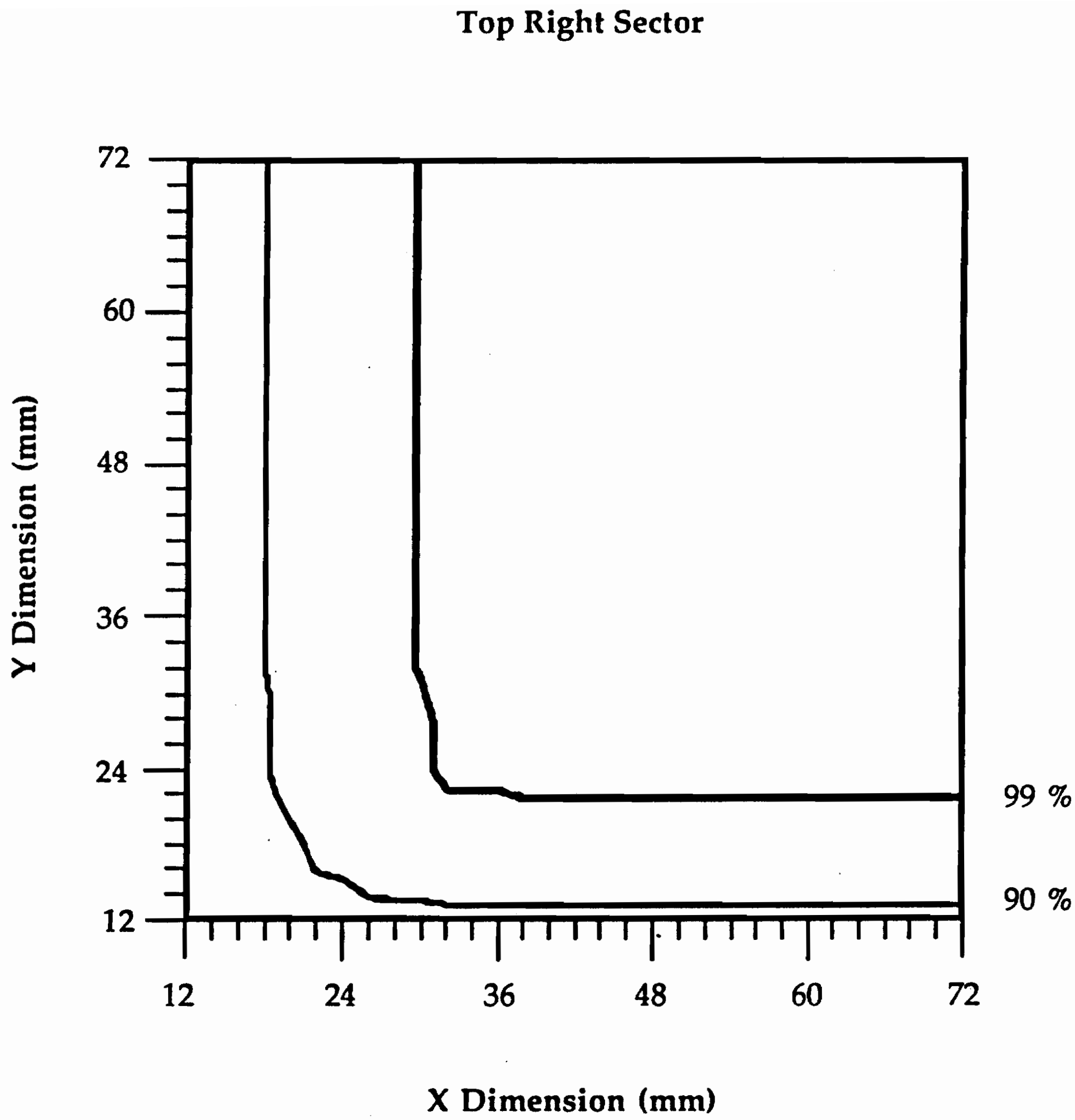


Figure 17. Expected accuracy of touch sensitive regions (continued).

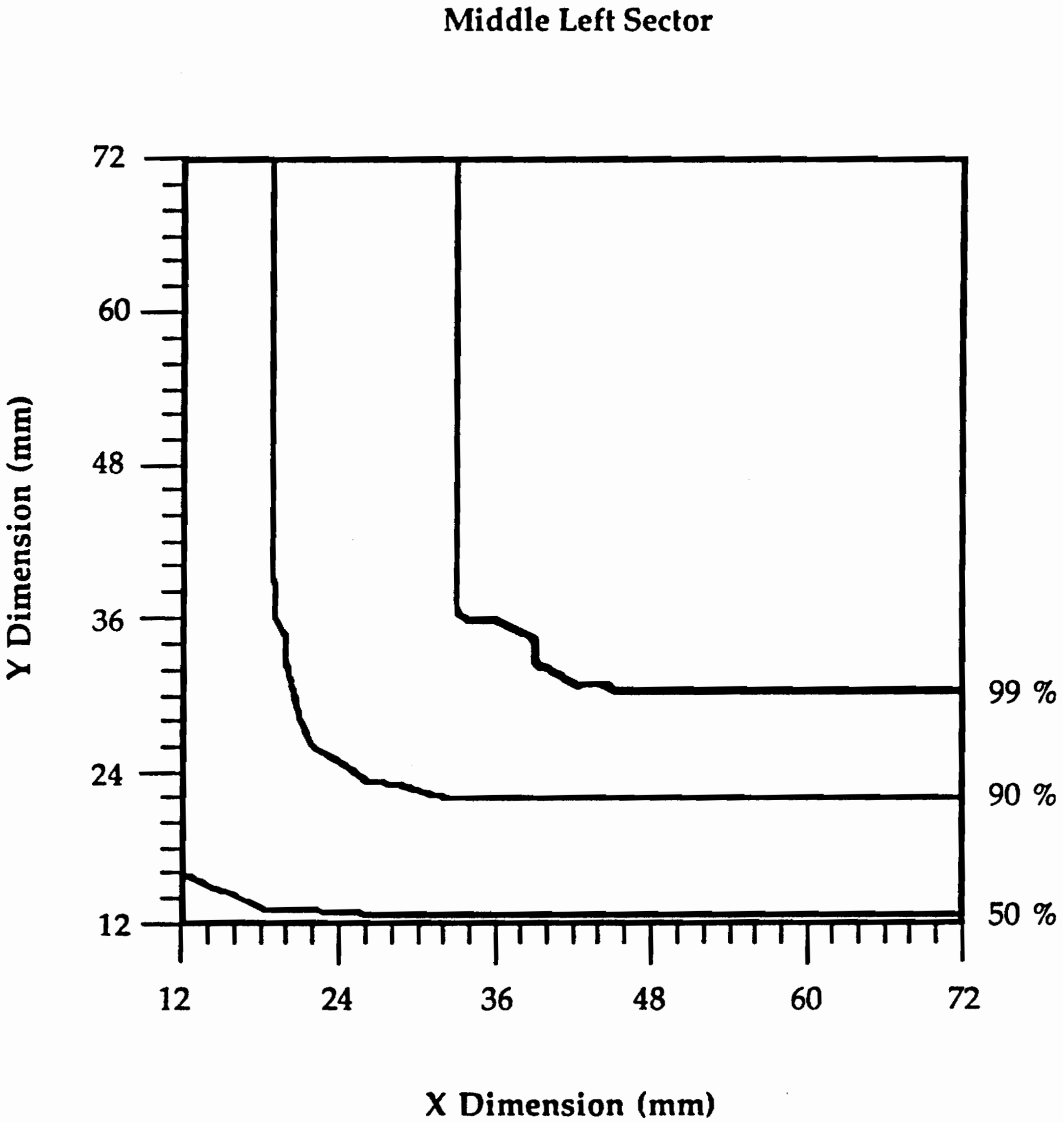


Figure 17. Expected accuracy of touch sensitive regions (continued).

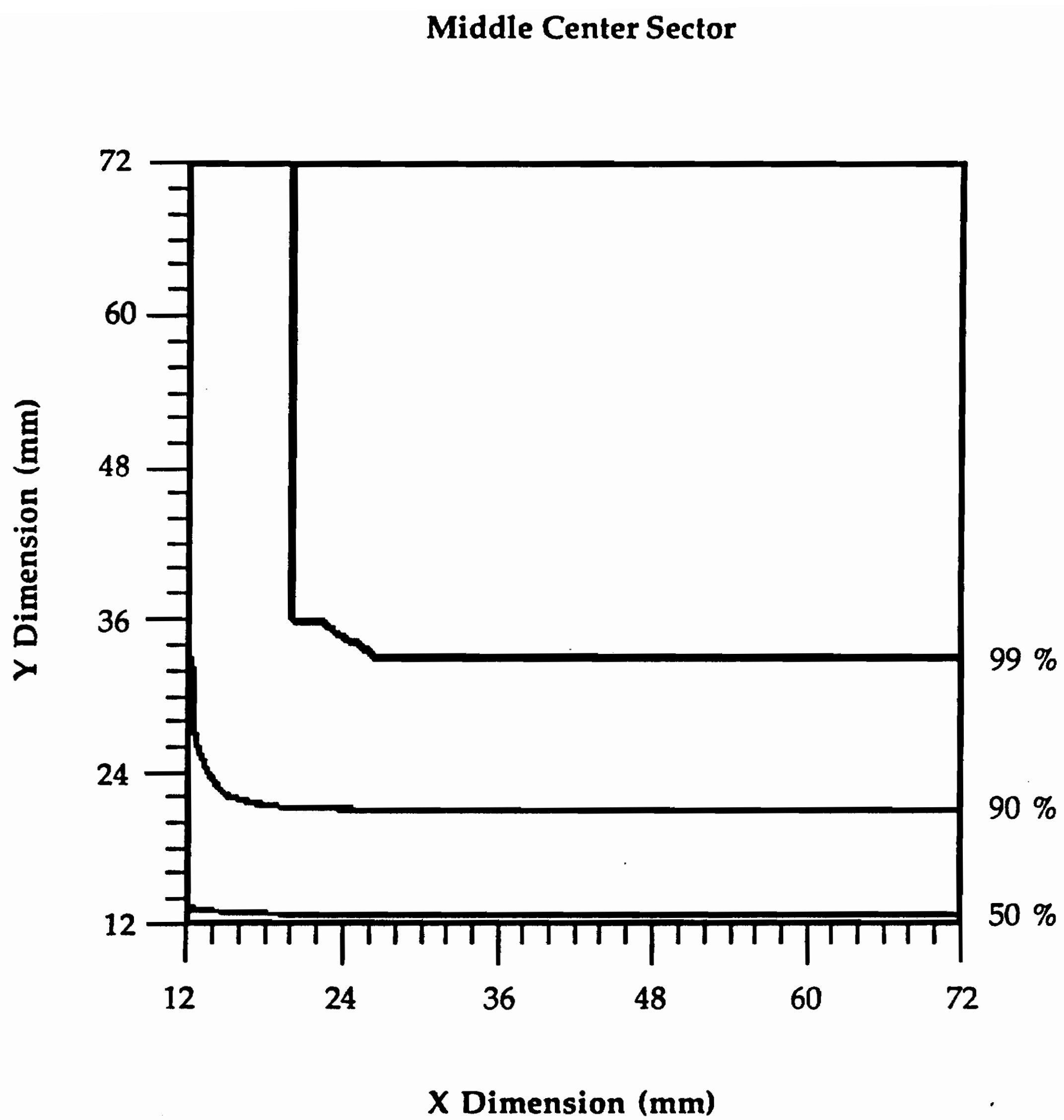


Figure 17. Expected accuracy of touch sensitive regions (continued).

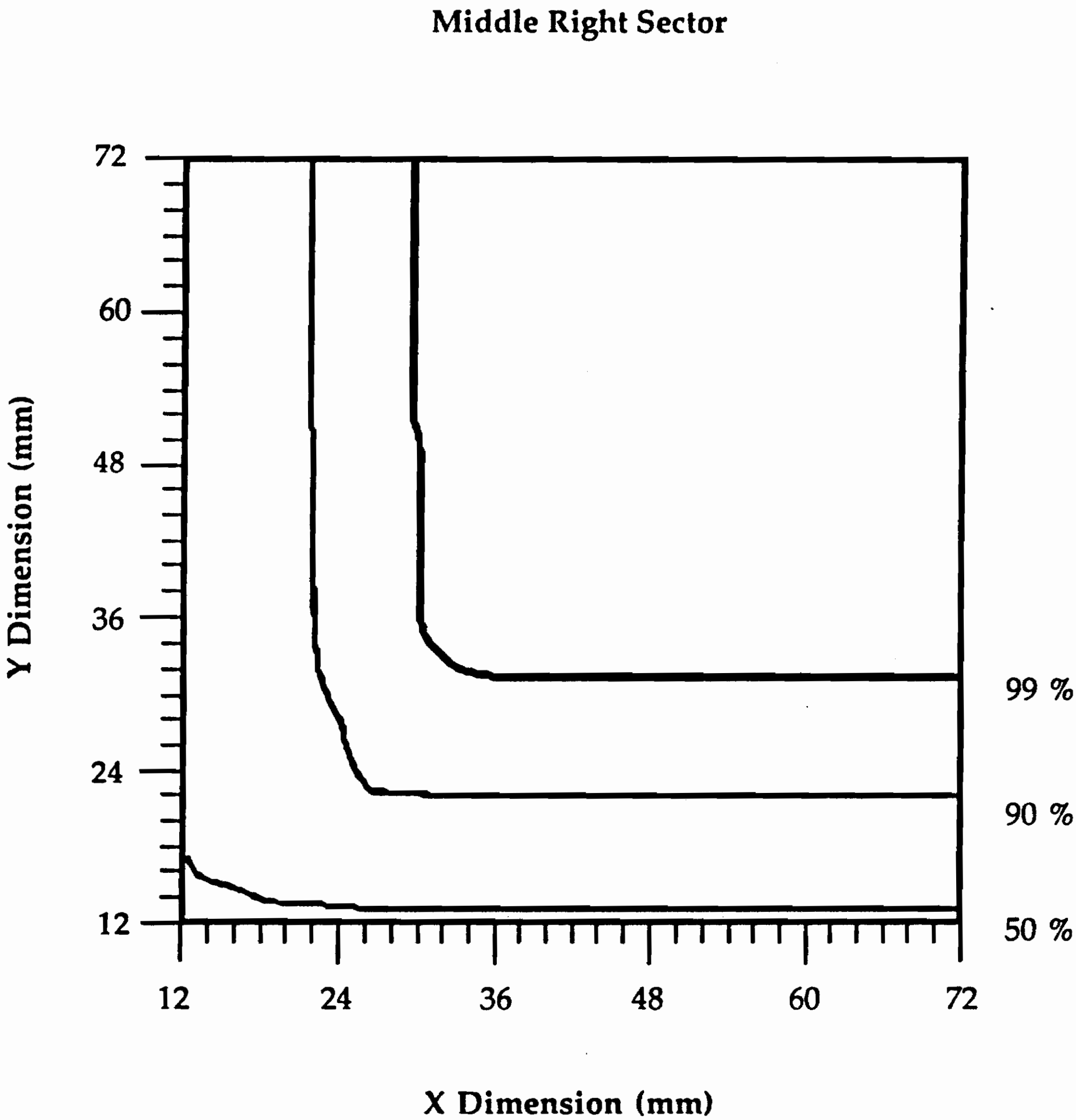


Figure 17. Expected accuracy of touch sensitive regions (continued).

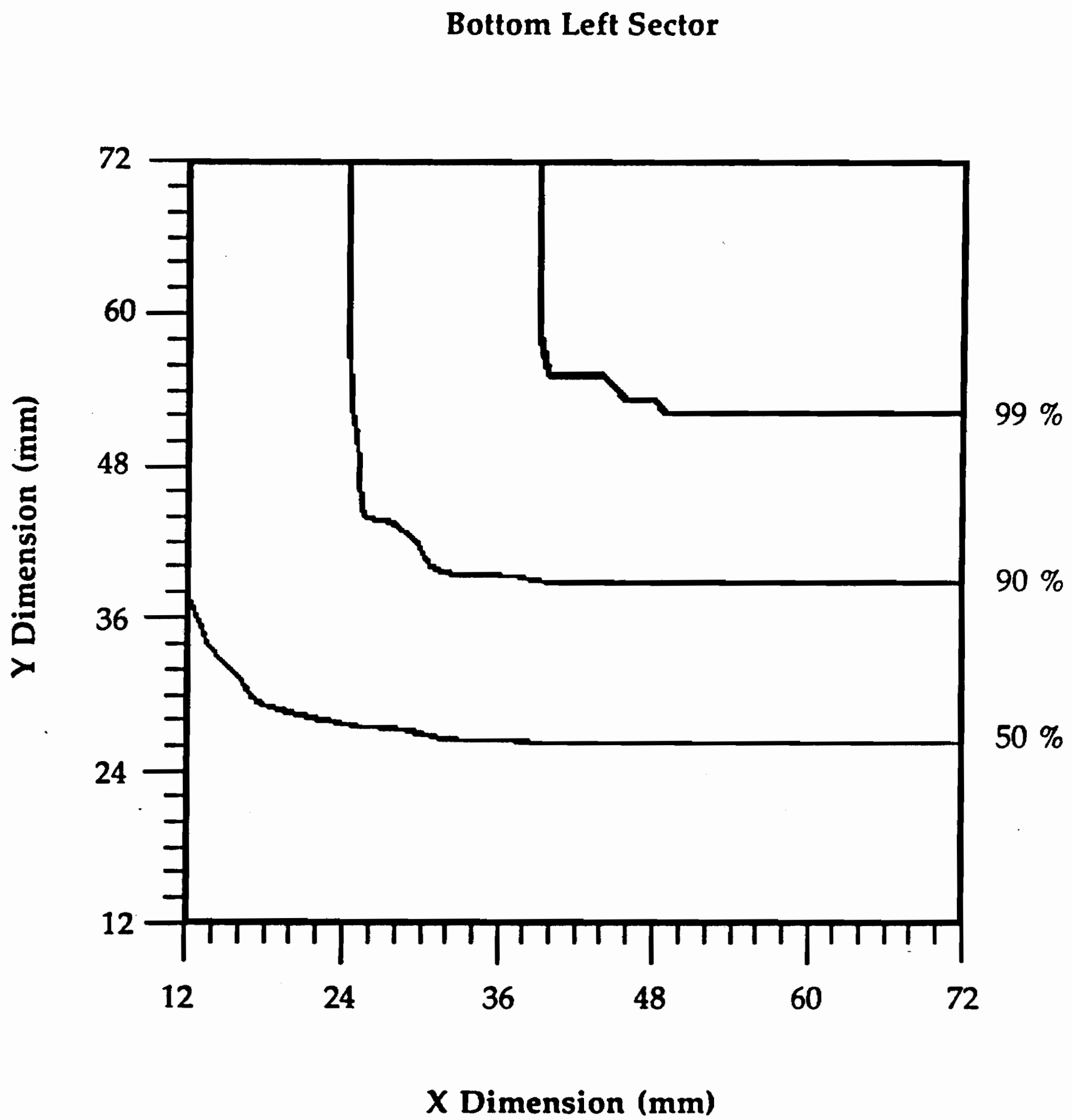


Figure 17. Expected accuracy of touch sensitive regions (continued).

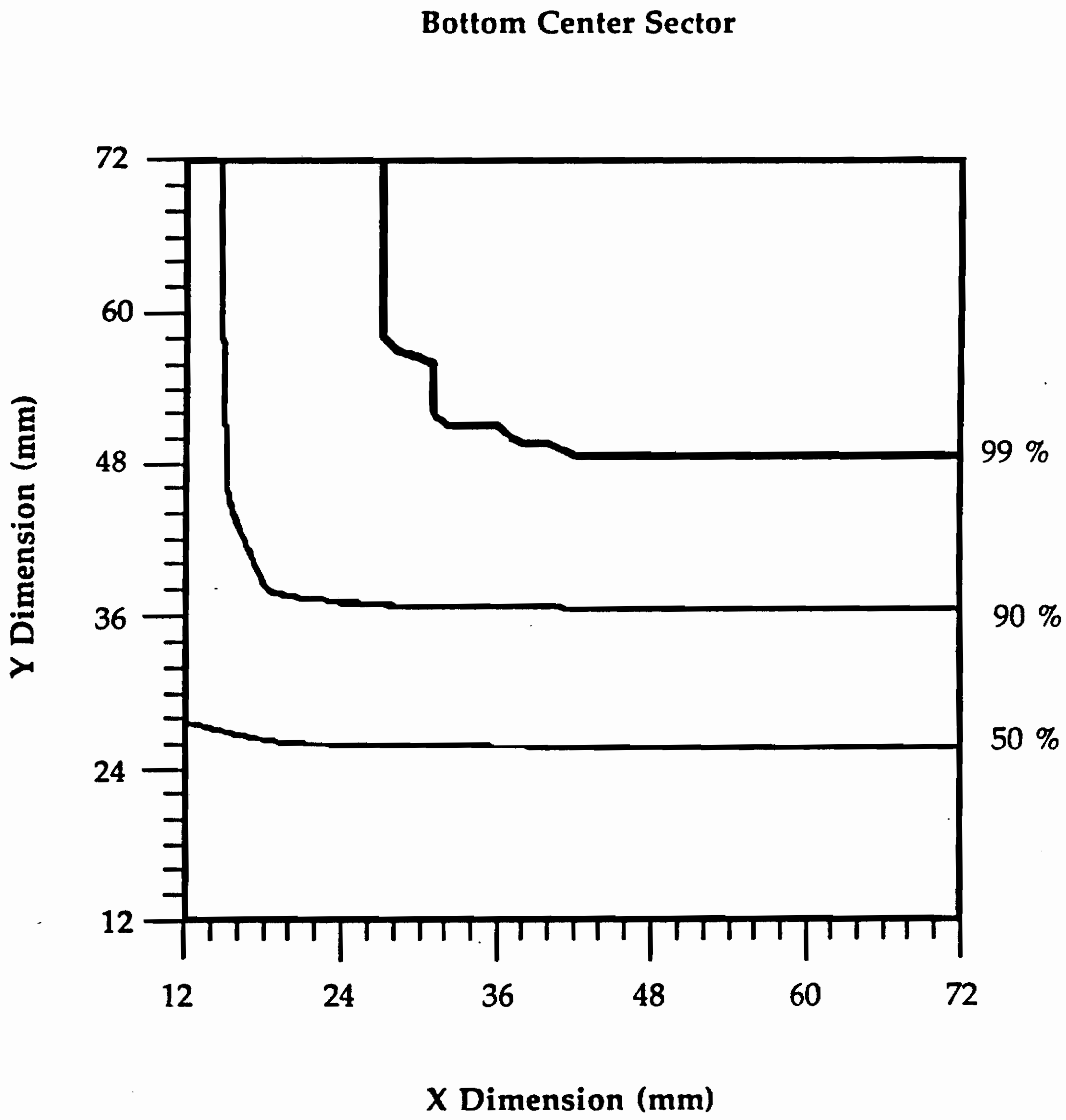


Figure 17. Expected accuracy of touch sensitive regions (continued).

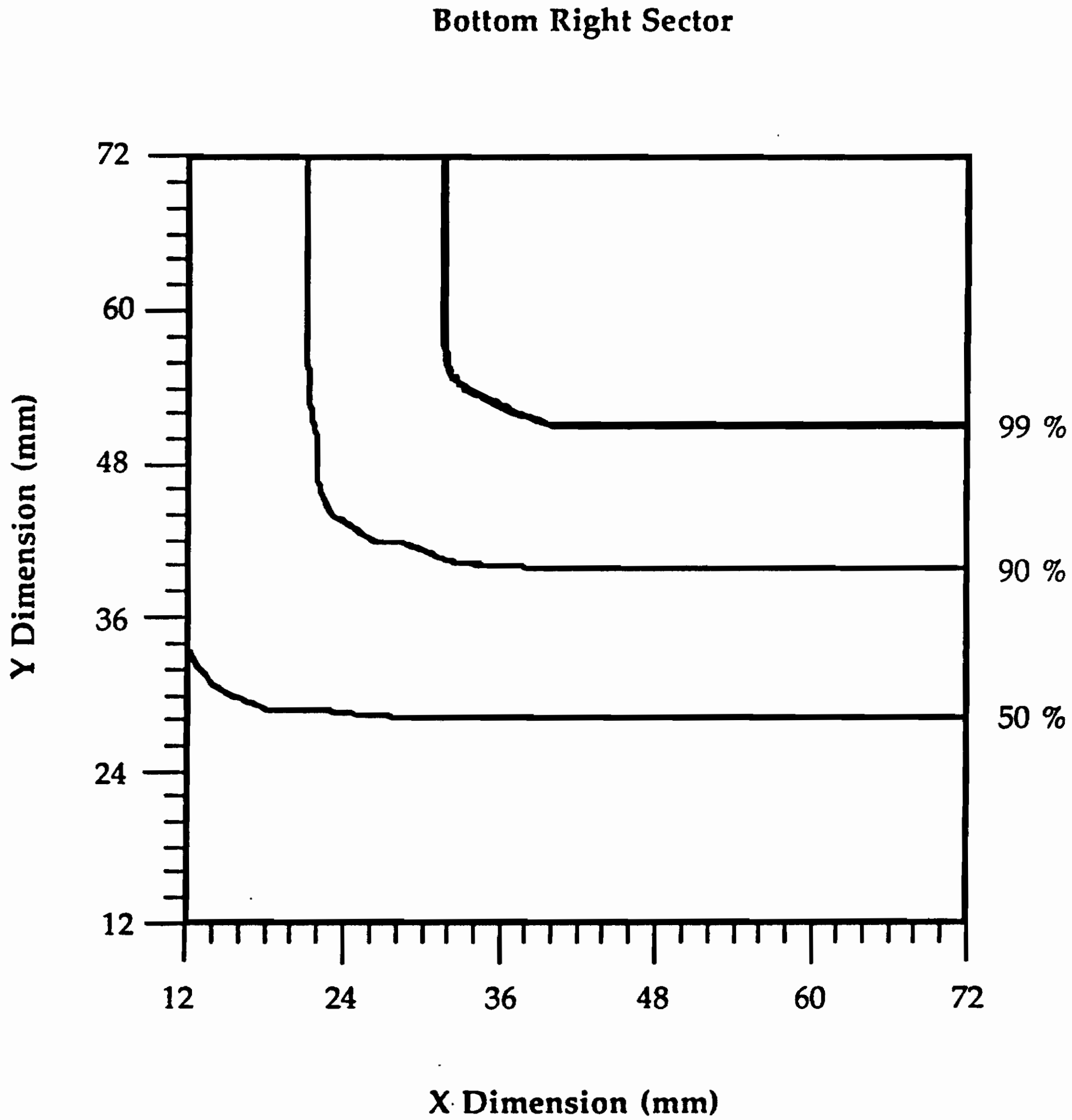


Figure 17. Expected accuracy of touch sensitive regions (continued).

These expected accuracy charts are designed for the worst case. Testing was conducted under adverse conditions (glare, noise, no compensation for height differences, and so forth,) and should be robust to changing conditions. The charts should work with monitors placed at a slightly different height or angle from the one used in this study. In addition, placing all touches in the same quadrant before deriving the accuracy charts caused the charts to be conservative. For example, the true accuracy regions are probably not symmetric about the horizontal axis--the region above the target center is probably more accurate than the region below. Because the charts are symmetric, they base their predictions on the less accurate side. Finally, these charts are robust because the touches used as data were collected on screens with only one target. Users would probably be more accurate pressing a target if another target were nearby.

- Give targets at the bottom of the screen a taller touch sensitive region than targets at the top of the screen.

- Give targets on the outside of the screen a wider touch sensitive region than targets in the center of the screen.

- Put a buffer area around each target. This region, which does not accept touches, compensates for missed targets by preventing the user from making an incorrect choice.

- Center the monitor in the kiosk. If that is not possible, do not obstruct the side approaches to the monitor.

Limitations of the Study

The study had several limitations that constrained the use of its results.

- This study used a piezo-electric monitor and did not test any other monitor technologies. Results may not apply to other varieties of monitors.

- The experimental protocol stressed that it was more important to be accurate than fast when pressing targets. Results may have been different if accuracy was not stressed or if participants had been given no hints on how to press the targets.

- Only square targets were tested. Touch behavior may differ with different shapes.

- Only three target sizes were tested, in the range of 7.5 mm^2 to 20 mm^2. Assertions that visual target size has no significant affect on accuracy can only be made about targets within this range.

- Question 12 of the Posttest did not use the best stimulus possible. Although the question presented three targets which were the same size as the targets shown on the screen, it did not present them in the same manner (i.e., targets should have been red against a black background instead of line drawings on a white page.) Had a better stimulus been used, each participant might have chosen a different sized target as the one preferred or the one used during the experiment.

Future Research

The work in this study can be expanded in several directions.

- Experiment with larger visual target sizes to see if size continues to cause no significant differences.
- Try different types of monitors to see what effect technology has on location dependencies.
- Conduct study with different prompting levels (accuracy stressed to some participants, not mentioned to others).
- Generate expected accuracy tables that allow for targets not centered within the touch sensitive region. These tables would recommend smaller touch sensitive regions which would use less screen space.

Literature Cited

Baggen, E.A. (1987). *A human factors evaluation of current touch entry technologies.* Doctoral dissertation, Virginia Polytechnic Institute and State University, Blacksburg, Va.

Beringer, D.B., and Peterson, J.G. (1985). Underlying behavioral parameters of the operation of touch-input devices: Biases, models, and feedback. *Human Factors, 27*(4), 445-458.

Bowers, V., Leahy, M., and Reinhart, W. (1989). *Shopping List Entry System.* Unpublished manuscript.

Carroll, A.B. (1986). Touch technology: Variety of systems spur maturity. *Information Display,* 2(11), 15-20.

Giancoli, D.C. (1984). *General Physics.* Englewood Cliffs, N.J.: Prentice-Hall, Inc.

Greenwald, P., Sondik, E., and Lynch, B.S. (1986). Diet and chemoprevention in NCI's research strategy to achieve national cancer control objectives. In Breslow, L., Fielding, J.E., and Lave, L.B. (Eds.), *Annual Review of Public Health* (Vol. 7, pp. 267-91). Palo Alto, Calif.: Annual Reviews Inc.

Hall, A.D., Cunningham, J.B., Roache, R.P., and Cox, J.W. (1988). *Factors affecting performance using touch-entry systems: Tactual recognition fields and resolution characteristics* (Technical Report Number TR 29.0787). Research Triangle Park, N.C.: IBM Corporation.

IBM InfoWindows: A Scarce Commodity. (1989). *The Videodisc Monitor, 5*(12), 5.

Johnson, E.A. (1967). Touch displays, a programmed man-machine interface. *Ergonomics, 10*(2), 271-277.

Olson, J.B. (1987). Case study: The first automotive-display touch panel. *Information Display, 3*(1), 12-16.

Pickering, J.A. (1986). Touch-sensitive screens: the technologies and their application. *International Journal of Man-Machine Studies, 25*(2), 249-269.

Potter, R.L., Weldon, L.J., and Shneiderman, B. (1988). Improving the accuracy of touch screens: An experimental evaluation of three strategies. *CHI '88 Proceedings,* 27-32.

SAS Institute. (1985). *SAS User's Guide: Statistics.* SAS Institute, Cary, N.C.

Usher, D.M., and Ilett, C. (1986). Touch-screen techniques: Performance and application in power station control displays. *Displays,* 7(2), 59-66.

Valk, M.A. (1985). An experiment to study touchscreen "button" design. *Proceedings of the Human Factors Society, 29th Annual Meeting,* 127-131.

Webster's new ninth collegiate dictionary. (1985). Springfield, Mass.: Merriam-Webster, Inc.

Weisner, S.J. (1988). A touch-only user interface for a medical monitor. *Proceedings of the Human Factors Society, 32nd Annual Meeting*, 435-439.

Winett, R.A., Wagner, J.L., Moore, J.F., Walker, W.B., Hite, L.A., Leahy, M., Neubauer, T., Arbour, D., Walberg, J., Geller, E.S., Mundy, L.L., and Lombard, D. (1990). *An experimental evaluation of a prototype public access nutrition information system for supermarkets.*

Appendix A
Description of the Experiment

Computers are becoming common in libraries, shopping malls and stores and provide many types of information. Frequently, people communicate with these computers by a touch screen monitor. This type of monitor can sense when and where someone touches its screen. Typically, the computer will put pictures of several topics on the screen, asking persons to press a topic of interest. The computer will then present information about the selected topic.

This experiment will find out if some areas of the screen are easier to touch than other areas. This information will be used to improve the **Nutrition for a Lifetime System*** and other interactive touch screen systems.

Your participation is voluntary. Before beginning, you will be asked to fill out a questionnaire to determine if you meet the experiment's requirements. If you meet these requirements and agree to participate, your height will be measured and you will be asked to complete three tasks. In each task, you will be asked to stand at a different location in front of the screen and press 36 red squares on the screen. The squares will appear one at a time and will be scattered across the screen. Once you've completed the experiment, you will be asked a few questions to help us improve the touch screen system.

---

*The **Nutrition for a Lifetime System©** is a research project sponsored by the National Cancer Institute, Kroger, Co. Inc., and the Virginia Tech Center for Research in Health Behavior. © Virginia Polytechnic Institute and State University 1988.

The experiment should take about 15 minutes and you will receive $5 for your help. You may ask questions at any time, and you may leave at any time if you decide not to complete the experiment.

When you press a square, try to touch the red square and not the black background. If you miss and touch the black, don't worry--most people miss the square occasionally. We are testing the touch screen system, not you! You will not be graded on how well you do, and your results will not be associated with your name. Your assistance will help improve the **Nutrition for a Lifetime System** and other interactive touch screen systems.

Appendix B
Eligibility Questionnaire

Number _____

1) Do you wear glasses or contact lenses at work or while reading?

Yes No

2) If so, are you wearing them now?

Yes No

3) Do you wear bifocals?

Yes No

4) Do you have any difficulty distinguishing between colors?

Yes No

5) Are you right-handed?

Yes No

6) Do you have any difficulty moving the fingers, wrist, elbow or shoulder of the arm you will use?

Yes No

7) Have you ever participated in an experiment which used touch panel devices, or have you used a touch screen for more than thirty (30) minutes in the previous two months?

Yes No

8) Are you at least eighteen years old?

Yes No

Appendix C

Informed Consent

I agree to participate in a brief experiment involving a touch screen computer, for the purposes of improving the screens of the Virginia Tech Center for Research in Health Behavior's **Nutrition for a Lifetime System** and other interactive information systems. I understand that I may withdraw at any time, and that my name will not be associated with the information that I give.

Date: ____

Signed: ____

Name: ____

Cash Receipt

I ____________________________________ have received $5.00 for participating in the touch screen experiment sponsored by the Virginia Tech Center for Research in Health Behavior.

Signed: ____

Address: ____

SSN: ____

Date: ____

Appendix D
Pretest Protocol

During the pretest, the following verbal description was given to participants.

You are about to see five red squares appear on the screen, one at a time and in random locations. Press each square as it appears. When pressing the squares, it is more important to be accurate than fast.

After you have pressed the five squares, the screen will ask you to stand on one of the three blue lines on the floor. When you stand on a line, line your body up with the line so that you sight down the line, like this. (*Demonstrate by standing on one of the two outside lines.*) From each of the three blue lines, you will press 36 squares. As you press each one, it will disappear and be replaced by another one.

You can start the experiment by pressing the screen. Feel free to ask questions during the experiment. Do you have any questions now?

Appendix E
Posttest Questionnaire

Number _____

1) Pressing my finger against the screen only required a small amount of force.

tend to agree						tend to disagree
*	*	*	*	*	*	*

2) I found it easy to touch the red squares on the screen.

tend to agree						tend to disagree
*	*	*	*	*	*	*

3) I was satisfied with my view of the squares on the screen.

tend to agree						tend to disagree
*	*	*	*	*	*	*

4) I found it easy to view the red squares on the screen.

tend to agree						tend to disagree
*	*	*	*	*	*	*

5) If you experienced any difficulties seeing the squares on the screen,

a) what contributed to that difficulty?

b) what areas of the screen were difficult to see?

6) Was your arm tired during any part of the study?

Yes No

7) If your arm grew tired during the study,

a) you saw three sets of boxes and you stood at three different positions. Indicate when you got tired during the experiment.

b) how tired was your arm?

tired not tired

* * * * * * *

8) I felt that the images on the screen were sharp.

tend to agree tend to disagree

* * * * * * *

9) Were your eyes tired during any part of the study?

Yes No

10) How tired were your eyes at the end of the third set of buttons?

tired not tired

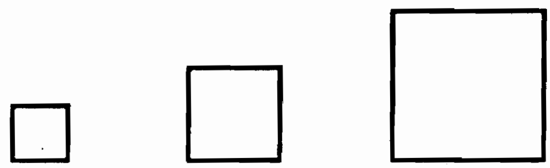
* * * * * * *

11) Touch screen systems, when fully developed, will be frequently used in education and marketing. Based on your experiences, what comments or suggestions do you have that will make touch screen systems easier to use or understand?

12) This experiment is also looking at different button sizes. Below are the three buttons used in this experiment.

a) Which one did you use?

b) Which one would you prefer using? Why?



1 2 3

Appendix F

Results of the Posttest Questionnaire

1. **Pressing my finger against the screen only required a small amount of force. (tend to agree=1, tend to disagree=7)**

   45 responded
   mean = 1.96
   range = 1 - 5

2. **I found it easy to touch the red squares on the screen. (tend to agree=1, tend to disagree=7)**

   45 responded
   mean = 1.51
   range = 1 - 7

3. **I was satisfied with my view of the squares on the screen. (tend to agree=1, tend to disagree=7)**

   45 responded
   mean = 1.53
   range = 1 - 6

4. **I found it easy to view the red squares on the screen. (tend to agree=1, tend to disagree=7)**

   45 responded
   mean = 1.40
   range = 1 - 5

5. **If you experienced any difficulties seeing the squares on the screen,**

A. **What contributed to that difficulty?**

Comments	Question 4
light glare	4
curvature of the screen	5
move it more to the left	1
things facing the screen and lighting	2

B. What areas of the screen were difficult to see?

Comments	Question 4
extreme edges top & bottom & sides	
from the right side	
bottom, if any	1
light on right side of line	2
corners and edges	1
It was difficult to see on the right or left side when standing on that side but it was only slightly difficult	2
edges	

6. Was your arm tired during any part of the study?
Yes / No

38 responded
16 yes
22 no

7. If your arm grew tired during the study,

A. where were you standing and when during that set of squares?
B. how tired was your arm?
(tired=1, not tired=7) [ie, not energetic=1, energetic=7]

All subjects	Yes	No
32 responded	16 responded	16 responded
mean = 5.16	mean = 4.06	mean = 6.25
range = 1 - 7	range = 1 - 6	range = 1 - 7

Comment	During Which Third Did Arm Tire?	Arm Energy
to the right toward the end	3	5
to the right, beginning of set	3	3

right	2	4
left	3	4
on the right side	3	5
the second set	2	3
right side	3	3
right side	3	4
yes, latter third of test	3	4
right side	2	1
left	3	3
center	3	6
left and right sides	2,1	4
on right	2	5
center	1	5

8. **I felt that the images on the screen were sharp.**
   (tend to agree=1, tend to disagree=7)

   43 responded
   mean = 1.60
   range = 1 - 6

9. **Were your eyes tired during any part of the study?**
   Yes / No

   43 responded
   2 yes
   41 no

10. **How tired were your eyes at the end of the third set of buttons?**
    (tired=1, not tired=7)

<u>All subjects</u>	<u>Yes</u>	<u>No</u>
40 responded	2 responded	38 responded
mean = 6.27	mean = 2.50	mean = 6.57
range = 2 - 7	range = 2 - 3	range = 2 - 7

11. **Touch screen systems, when fully developed, will be frequently used in education and marketing. Based on your experiences, what comments or suggestions do you have that will make touch screen systems easier to use or understand?**

Comment

Everything was easy

It was fun!

I like the red better than the normal green or burnt orange

Great system

Screens that do not show fingerprints!

Possibly a slower pace

Place a screen cover over the monitor to eliminate the curve illusion and make the screen flat in appearance

It helps to remove smudges from screen

I think that this system will work well for what its purpose is

I thought it was easy and very understandable

It seems more difficult for me, as a right handed person, to use the screen when standing to the right of it

Keep the button mostly in the middle of the screen

This touch screen system was very up to date!

Easily understood

Seems fine to me

Raise screen

Making use of them more often [would make things easier to learn]
Thought it was easy with child on arm
- didn't require devoted attention
- didn't require precise coordination

Place the squares in the middle portion of screen

Make square bigger & in one spot to touch if possible

Paralax condition exists between the safety glass and screen. Distance between each should be reduced.

Just make people aware of how hard they need to press

It was a bit uncomfortable at bottom side of the screen when worked from front side.
- Suggestions: the level of the screen need be raised a bit.
- Moment of arm was not good suddenly pressure might be from bottom coming up, or the finger might not be aligned with the hand/arm.

I think it was easy and interesting

Don't use green screens

Make the picture a little sharper around the edges

From right viewing side, arm seemed to weaken very fast

I think it would be great!

The lights in the background;
the objects facing the computers

12. This experiment is also looking at different button sizes. You saw one of the three buttons used in the experiment.

A. Which one did you use?
B. Which one would you prefer using? Why?

17 participants preferred the largest size button.

Comment	Button Reported Used	Button Actually Used
nervous & shaky	2	3
accuracy not as critical	3	
bigger	1	2
size comparison to end of finger; also 1 and 2 would be difficult to see with the curved screen	3	
because it is larger	2	
because its larger, easier to see and easier to touch	3	
it is larger and I wouldn't miss it	3	
easier	2	
easier access; less chance of missing square and repunching screen	3	
the bigger the easier to touch!	1	2
prefer just because it's bigger	2	
bigger is better!	2	
less tiring on eyes	2	3
because you can see it better	1	

24 participants preferred the medium size button.

Comments	Button Reported Used	Button Actually Used
a medium size is better than too small or too large	2	
better fits tip of finger	2	
appears on this sheet to stand out more clearly	1	
easy to see, not too big or small	2	
size of finger tip	1	
because #1 is too small and #3 is too large	2	3
because of better sighting	1	
easy to see	2	
can see them better	2	
little bit bigger	1	
enough to put your finger on without distracting you from the info on the screen	?	1
#1: too small #2: easy to view #3: too large; not necessary	3	
the screen view becomes more clear	1	
2 was fine and 3 would be fine but 1 was too small	2	
it is the medium	1	
easy to view; seems less stressful over longer periods	2	3
good size	2	

3 participants preferred the smallest button.

Comments	Button Reported Used	Button Actually Used
won't get in the way of words	1	

1 participant indicated no preference.

Comments	Button Reported Used	Button Actually Used
does not matter	1	3

Appendix G

Statistical Results

Table 1: ANOVA Summary Table For X Offset (mm)

SOURCE	df	SS	MS	*F*	*p*	
SIZE	2	22.40	11.20	0.54	.5848	
SUBJ(SIZE)	42	865.46	20.61			
SECTOR	8	18903.44	2362.93	428.14	<.0001	*
SECTOR*SIZE	16	63.99	4.00	0.72	.7688	
SECTOR*SUBJ(SIZE)	336	1854.40	5.52			
VIEW	2	3131.89	1565.95	136.67	.0001	*
VIEW*SIZE	4	4.68	1.17	0.10	.9815	
VIEW*SUBJ(SIZE)	84	962.48	11.46			
SECTOR*VIEW	16	89.66	5.60	1.79	.0285	
SECTOR*VIEW*SIZE	32	76.51	2.39	0.76	.8231	
SECTOR*VIEW*SUBJ(SIZE)	672	2101.16	3.13			

* $p < .01$

Table 2: REGW's Multiple Range Test Comparing X Offsets of Target Sectors*

Target Sector:	7	4	1	8	5	2	3	9	6
Mean Value (mm):	-6.07	-4.50	-4.32	-0.98	1.24	1.55	4.15	4.26	4.90

*means with a common line do not differ significantly at $\alpha = .01$.

Table 3: REGW's Multiple Range Test Comparing X Offsets of Horizontal Viewing Locations*

Viewing Location:	Right	Center	Left
Mean Value (mm):	-1.77	-0.29	2.13

*means with a common line do not differ significantly at $\alpha = .01$.

Table 4: ANOVA Summary Table For Magnitude Along the X-Axis (mm)

SOURCE	df	SS	MS	*F*	*p*	
SIZE	2	11.58	5.79	0.40	.6753	
SUBJ(SIZE)	42	613.74	14.61			
SECTOR	8	2247.38	280.92	57.95	.0001	*
SECTOR*SIZE	16	53.84	3.37	0.69	.7999	
SECTOR*SUBJ(SIZE)	336	1628.74	4.85			
VIEW	2	115.37	57.69	12.93	.0001	*
VIEW*SIZE	4	7.94	1.98	0.44	.7760	
VIEW*SUBJ(SIZE)	84	374.73	4.46			
SECTOR*VIEW	16	2230.27	139.39	44.37	<.0001	*
SECTOR*VIEW*SIZE	32	61.61	1.93	0.61	.9553	
SECTOR*VIEW*SUBJ(SIZE)	672	2111.34				

* $p < .01$

Table 5: REGW's Multiple Range Test Comparing X Magnitudes of Target Sectors*

Target Sector:	5	8	2	3	1	9	4	6	7
Mean Value (mm):	1.96	2.18	2.33	4.31	4.35	4.40	4.53	4.98	6.20

*means with a common line do not differ significantly at $\alpha = .01$.

Table 6: REGW's Multiple Range Test Comparing X Magnitudes of Horizontal Viewing Locations*

Viewing Location:	Center	Right	Left
Mean Value (mm):	3.53	3.92	4.29

*means with a common line do not differ significantly at $\alpha = .01$.

Table 7: Simple-Effects F-Test on X Magnitude for Each Horizontal Viewing Location

Viewing Location	df	$MS_{X\ Magnitude}$	*F*	*p*
Left	8	192.80	58.09	<.0001 *
Center	8	129.09	38.90	<.0001 *
Right	8	237.82	71.66	<.0001 *

* $p < .01$

Table 8: REGW's Multiple Range Test Comparing X Magnitudes of Target Sectors at the Left Viewing Location*

Target Sector:	8	4	1	5	2	7	3	9	6
Mean Value (mm):	1.87	2.68	2.75	3.02	3.64	3.96	6.64	6.70	7.43
	———	———	———	———			———	———	———
		———	———	———	———	———			

*means with a common line do not differ significantly at $\alpha = .01$.

Table 9: REGW's Multiple Range Test Comparing X Magnitudes of Target Sectors at the Center Viewing Location*

Target Sector:	5	2	8	9	3	1	6	4	7
Mean Value (mm):	1.45	1.60	1.72	3.57	3.64	4.22	4.29	4.66	6.55

*means with a common line do not differ significantly at $\alpha = .01$.

Table 10: REGW's Multiple Range Test Comparing X Magnitudes of Target Sectors at the Right Viewing Location*

Target Sector:	5	2	3	9	8	6	1	4	7
Mean Value (mm):	1.40	1.85	2.64	2.92	2.96	3.13	6.07	6.26	8.09

*means with a common line do not differ significantly at $\alpha = .01$.

Table 11: ANOVA Summary Table For Y-Offset (mm)

SOURCE	df	SS	MS	*F*	*p*	
SIZE	2	591.88	295.94	3.58	.0367	
SUBJ(SIZE)	42	3473.84	82.71			
SECTOR	8	47634.80	5954.35	943.35	<.0001	*
SECTOR*SIZE	16	35.29	2.21	0.35	.9914	
SECTOR*SUBJ(SIZE)	336	2120.81	6.31			
VIEW	2	386.98	193.49	32.97	.0001	*
VIEW*SIZE	4	46.67	11.67	1.99	.1037	
VIEW*SUBJ(SIZE)	84	492.92	5.87			
SECTOR*VIEW	16	131.55	8.22	3.51	.0001	*
SECTOR*VIEW*SIZE	32	82.47	2.58	1.10	.3244	
SECTOR*VIEW*SUBJ(SIZE)	672	1574.15	2.34			

* $p < .01$

Table 12: REGW's Multiple Range Test Comparing Y Offsets of Target Sectors*

Target Sector:	1	2	3	4	5	6	8	7	9
Mean Value (mm):	-3.75	-0.99	-0.59	5.37	5.75	6.08	12.68	13.30	14.21
	———	———	———	———	———	———	———	———	
								———	———

*means with a common line do not differ significantly at $\alpha = .01$.

Table 13: REGW's Multiple Range Test Comparing Y Offsets of Horizontal Viewing Locations*

Viewing Location:	Right	Center	Left
Mean Value (mm):	5.28	5.51	6.58

*means with a common line do not differ significantly at $\alpha = .01$.

Table 14: Simple-Effects F-Test of Y-Offset for Each Horizontal Viewing Location

Viewing Location	df	$MS_{Y\text{-Offset}}$	*F*	*p*
Left	8	1952.24	833.40	<.0001 *
Center	8	2048.97	874.70	<.0001 *
Right	8	1969.58	840.81	<.0001 *

* $p < .01$

Table 15: REGW's Multiple Range Test Comparing Y Offsets of Target Sectors at the Left Viewing Location*

Target Sector:	1	2	3	4	5	6	7	8	9
Mean Value (mm):	-3.44	0.15	0.50	5.90	6.67	7.33	13.42	13.66	14.96

*means with a common line do not differ significantly at $\alpha = .01$.

Table 16: REGW's Multiple Range Test Comparing Y Offsets of Target Sectors at the Center Viewing Location*

Target Sector:	1	2	3	4	5	6	8	7	9
Mean Value (mm):	-4.07	-1.49	-1.10	5.28	5.60	5.74	12.30	12.91	14.39

*means with a common line do not differ significantly at $\alpha = .01$.

Table 17: REGW's Multiple Range Test Comparing Y Offsets of Target Sectors at the Right Viewing Location*

Target Sector:	1	2	3	4	5	6	8	9	7
Mean Value (mm):	-3.73	-1.64	-1.17	4.95	4.99	5.17	12.07	13.30	13.57
	———	———	———	———	———	———	———	———	
								———	———

*means with a common line do not differ significantly at $\alpha = .01$.

Table 18: ANOVA Summary Table For Magnitude Along the Y-Axis (mm)

SOURCE	df	SS	MS	F	p	
SIZE	2	113.08	56.54	2.07	.1385	
SUBJ(SIZE)	42	1145.81	27.28			
SECTOR	8	25189.22	3141.03	308.66	<.0001	*
SECTOR*SIZE	16	382.53	23.91	2.34	.0026	*
SECTOR*SUBJ(SIZE)	336	3427.57	10.20			
VIEW	2	136.62	68.31	15.49	.0001	*
VIEW*SIZE	4	5.71	1.43	0.32	.8613	
VIEW*SUBJ(SIZE)	84	370.45	4.41			
SECTOR*VIEW	16	192.93	12.06	5.05	.0001	*
SECTOR*VIEW*SIZE	32	100.52	3.14	1.31	.1169	
SECTOR*VIEW*SUBJ(SIZE)	672	1605.56	2.39			

* $p < .01$

Table 19: REGW's Multiple Range Test Comparing Y Magnitudes of Target Sectors*

Target Sector:	3	2	1	4	5	6	8	7	9
Mean Value (mm):	2.02	2.09	3.83	5.49	5.86	6.12	12.68	13.30	14.21

*means with a common line do not differ significantly at $\alpha = .01$.

Table 20: REGW's Multiple Range Test Comparing Y Magnitudes of Horizontal Viewing Locations*

Viewing Location:	Right	Center	Left
Mean Value (mm):	6.96	7.16	7.75

*means with a common line do not differ significantly at $\alpha = .01$.

Table 21: Simple-Effects F-Test of Y Magnitude for Each Horizontal Viewing Location

Viewing Location	df	$MS_{Y\ Magnitude}$	*F*	*p*
Left	8	1160.01	485.52	<.0001 *
Center	8	1020.62	427.18	<.0001 *
Right	8	992.14	415.26	<.0001 *

* $p < .01$

Table 22: REGW's Multiple Range Test Comparing Y Magnitudes of Target Sectors at the Left Viewing Location*

Target Sector:	3	2	1	4	5	6	7	8	9
Mean Value (mm):	2.03	2.06	3.53	5.99	6.75	7.34	13.43	13.66	14.96
	———	———	———	———	———	———	———	———	
								———	———

*means with a common line do not differ significantly at $\alpha = .01$.

Table 23: REGW's Multiple Range Test Comparing Y Magnitudes of Target Sectors at the Center Viewing Location*

Target Sector:	2	3	1	4	5	6	8	7	9
Mean Value (mm):	1.98	2.06	4.18	5.29	5.62	5.74	12.30	12.91	14.39

*means with a common line do not differ significantly at $\alpha = .01$.

Table 24: REGW's Multiple Range Test Comparing Y Magnitudes of Target Sectors at the Right Viewing Location*

Target Sector:	3	2	1	4	5	6	8	9	7
Mean Value (mm):	1.96	2.22	3.79	5.20	5.22	5.28	12.07	13.30	13.57

*means with a common line do not differ significantly at $\alpha = .01$.

Table 25: Simple-Effects F-Test of Y Magnitude for Each Target Size

Target Size	df	$MS_{Y\ Magnitude}$	*F*	*p*
Large	8	1241.51	121.70	<.0001 *
Medium	8	1093.73	107.22	<.0001 *
Small	8	861.23	84.43	<.0001 *

* $p < .01$

Table 26: REGW's Multiple Range Test Comparing Y Magnitudes of Target Sectors at the Large Target Sizes*

Target Size:	2	3	1	4	5	6	8	7	9
Mean Value (mm):	1.51	2.00	3.04	6.40	6.79	7.03	13.52	14.04	14.84

*means with a common line do not differ significantly at $\alpha = .01$.

Table 27: REGW's Multiple Range Test Comparing Y Magnitudes of Target Sectors at the Medium Target Sizes*

Target Sector:	3	2	1	4	6	5	8	7	9
Mean Value (mm):	1.76	2.30	3.53	5.38	5.87	5.89	12.53	13.39	14.54

*means with a common line do not differ significantly at $\alpha = .01$.

Table 28: REGW's Multiple Range Test Comparing Y Magnitudes of Target Sectors at the Small Target Sizes*

Target Sector:	3	2	4	5	1	6	8	7	9
Mean Value (mm):	2.29	2.46	4.71	4.91	4.94	5.46	11.99	12.47	13.27
	(common line: 3–2)		(common line: 4–6)				(common line: 8–9)		

*means with a common line do not differ significantly at $\alpha = .01$.

Table 29: ANOVA Summary Table For Distance (mm)

SOURCE	df	SS	MS	*F*	*p*	
SIZE	2	107.13	53.57	1.45	.2457	
SUBJ(SIZE)	42	1549.80	36.90			
SECTOR	8	17974.76	2246.85	342.13	<.0001	*
SECTOR*SIZE	16	158.87	9.93	1.51	.0930	
SECTOR*SUBJ(SIZE)	336	2206.59	6.57			
VIEW	2	207.22	103.61	19.09	.0001	*
VIEW*SIZE	4	8.86	2.22	0.41	.8022	
VIEW*SUBJ(SIZE)	84	455.89	5.43			
SECTOR*VIEW	16	1025.72	64.11	23.71	.0001	*
SECTOR*VIEW*SIZE	32	76.67	2.40	0.89	.6500	
SECTOR*VIEW*SUBJ(SIZE)	672	1817.12	2.70			

* $p < .01$

Table 30: REGW's Multiple Range Test Comparing Distances of Target Sectors*

Target Sector:	2	3	1	5	4	6	8	7	9
Mean Value (mm):	4.80	6.26	7.08	7.17	8.43	8.96	13.53	15.45	15.54

*means with a common line do not differ significantly at $\alpha = .01$.

Table 31: REGW's Multiple Range Test Comparing Distances of Horizontal Viewing Locations*

Viewing Location:	Center	Right	Left
Mean Value (mm):	9.35	9.46	10.27

*means with a common line do not differ significantly at $\alpha = .01$.

Table 32: Simple-Effects F-Test of Distance for Each Horizontal Viewing Location

Viewing Location	df	$MS_{Distance}$	*F*	*p*
Left	8	779.29	288.20	<.0001 *
Center	8	775.58	286.82	<.0001 *
Right	8	820.19	303.32	<.0001 *

* $p < .01$

Table 33: REGW's Multiple Range Test Comparing Distances of Target Sectors at the Left Viewing Location*

<table>
<tr><td>Target Sector:</td><td>2</td><td>1</td><td>4</td><td>3</td><td>5</td><td>6</td><td>8</td><td>7</td><td>9</td></tr>
<tr><td>Mean Value (mm):</td><td>5.58</td><td>5.75</td><td>7.80</td><td>7.99</td><td>8.26</td><td>11.22</td><td>14.33</td><td>14.49</td><td>17.03</td></tr>
<tr><td></td><td colspan="2">————</td><td colspan="3">————</td><td>——</td><td colspan="2">————</td><td>——</td></tr>
</table>

*means with a common line do not differ significantly at $\alpha = .01$.

Table 34: REGW's Multiple Range Test Comparing Distances of Target Sectors at the Center Viewing Location*

Target Sector:	2	3	5	1	6	4	8	7	9
Mean Value (mm):	4.16	5.85	6.78	7.09	8.25	8.30	13.11	15.26	15.31
	———	———	———	———			———	———	———
				———	———	———			

*means with a common line do not differ significantly at $\alpha = .01$.

Table 35: REGW's Multiple Range Test Comparing Distances of Target Sectors at the Right Viewing Location*

Target Sector:	2	3	5	6	1	4	8	9	7
Mean Value (mm):	4.66	4.93	6.48	7.41	8.40	9.19	13.16	14.29	16.60

*means with a common line do not differ significantly at $\alpha = .01$.

Table 36: ANOVA Summary Table For Elapsed Time (sec)

SOURCE	df	SS	MS	F	p	
SIZE	2	0.99	0.50	0.20	.8194	
SUBJ(SIZE)	42	104.30	2.48			
SECTOR	8	1.54	0.19	9.04	.0001	*
SECTOR*SIZE	16	0.29	0.02	0.86	.6166	
SECTOR*SUBJ(SIZE)	336	7.16	0.02			
VIEW	2	0.28	0.14	1.14	.3237	
VIEW*SIZE	4	0.03	0.01	0.07	.9913	
VIEW*SUBJ(SIZE)	84	10.14	0.12			
SECTOR*VIEW	16	0.42	0.03	1.34	.1685	
SECTOR*VIEW*SIZE	32	0.73	0.02	1.15	.2656	
SECTOR*VIEW*SUBJ(SIZE)	672	13.34	0.02			

* $p < .01$

Table 37: REGW's Multiple Range Test Comparing Elapsed Times of Target Sectors*

Target Sector:	8	9	6	5	7	2	4	3	1
Mean Value (sec):	0.85	0.87	0.87	0.88	0.89	0.91	0.92	0.95	0.96

*means with a common line do not differ significantly at $\alpha = .01$.

Michael Randolph Leahy

2059 West Lake Drive
Burlington, North Carolina 27215
919-228-1656

Learning Resources Center
Virginia Polytechnic Institute and
State University
Blacksburg, Virginia 24061
703-231-5879

EDUCATION

Master of Science in Computer Sciences and Applications, April 1990.
Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

Thesis Title: Empirically Derived Guidelines for Touch Screen Targets.

Bachelor of Science in Computer Science, December 1986.
Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

PROFESSIONAL EXPERIENCE

Programmer, July 1988 - present.
Learning Resources Center, Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

- Member of interdisciplinary team designing and implementing an interactive nutritional information system using touch screen and videodisc technologies.
    - Developed routines for data capture and analysis.
    - Designed basic layout for data entry touch screens.
    - Responsible for long term software maintenance.
- Consulted with faculty on software supported by the Faculty Self Service Area.

Contract Programmer, summers, 1985 - 1987.
American Telephone and Telegraph Company, Burlington, North Carolina.

- Developed job tracking software for drafting department.
- Developed budget management software.

Undergraduate Consultant, January 1985 - June 1986.
Computer Science Department, Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

- Helped students debug programs.

Programmer / Analyst, summers, 1982 - 1984.
Liberty Finance Company, Gibsonville, North Carolina.

- Developed cash journal, general journal, accounts receivables ledger, and payroll ledger programs.

TEACHING EXPERIENCE

Graduate Teaching Assistant, Spring 1988.
Computer Science Department, Virginia Polytechnic Institute and State University, Blacksburg, Virginia

- Taught Introduction to Software Engineering (CS 2073) laboratory.
- Lectured, assisted with programs, and graded assignments.

PUBLICATIONS

Winett, R.A., Moore, J.F., Wagner, J.L., Hite, L.A., Leahy, M.R., Neubauer, T.E., Walberg, J.L., Walker, W.B., and Lombard, D. (1990). *Altering shoppers' supermarket purchases to fit the National Cancer Institute's guidelines: Results from an interactive information system.*

Winett, R.A., Wagner, J.L., Moore, J.F., Walker, W.B., Hite, L.A., Leahy, M., Neubauer, T.E., Arbour, D., Walberg, J., Geller, E.S., Mundy, L.L., and Lombard, D. (in press). An experimental evaluation of a prototype public access nutrition information system for supermarkets. *Health Psychology.*

PRESENTATIONS

Leahy, M. and Hix, D. (1990). Effect of Touch Screen Target Location on User Accuracy. Paper to be presented at the annual meeting of the Human Factors Society, Orlando, FL, October.

Moore, J.F., Winett, R.A., Wagner, J.L., Walker, W.B., Hite, L.A., Leahy, M.R., Neubauer, T.E., and Arbour, D.F. (1990). Nutrition for a Lifetime: Promoting National Cancer Institute dietary guidelines through interactive systems in supermarkets. Paper presented at the winter meeting of the Society for Applied Learning Technology, Orlando, FL, February.

Winett, R.A., Moore, J.F., Wagner, J.L., Walker, W.B., Hite, L.A., Leahy, M.R., Neubauer, T., Walberg, J., Lombard, D., and Mundy, L.L. (1989). Nutrition for a Lifetime System – Experimental Evaluation. Presentation to the National Cancer Institutes's Principal Investigators Conference on Nutrition Promotion, Rockville, MD, December.

Moore, J.F., Winett, R.A., Wagner, J.L., Walker, W.B., Hite, L.A., Leahy, M.R., and Arbour, D.F. (1989). The use of prescriptive video and feedback strategies in a nutrition promotion project. Paper presented at the annual conference of the Association for the Development of Computer-Based Instruction, Washington, DC, November.

Winett, R.A., Moore, J.F., Wagner, J.L., Walker, W.B., Hite, L.A., Leahy, M.R., Neubauer, T.E., Arbour, D.F., Walberg, J.L., Geller, E.S., and Kramer, K.D. (1989). The Nutrition for a Lifetime System – an interactive public access information system for nutrition promotion in the supermarket: The first experimental test of a prototype. Paper presented at the annual meeting of the Association for the Advancement of Behavior Therapy, Washington, DC, November.

Wagner, J.L., Winett, R.A., Jaquess, D.L., Moore, J.F., Walberg, J.L., Walker, W.B., Hite, L.A., and Leahy, M.R. (1989). The relationship of parent and child food preferences, behavior, and knowledge: Influences of a supermarket intervention. Poster presented at the annual meeting of the Association for the Advancement of Behavior Therapy, Washington, DC, November.

Winett, R.A., Moore, J.F., Wagner, J.L., Walker, W.B., Hite, L.A., Leahy, M.R., Neubauer, T., Walberg, J., and Arbour, D. (1989). Nutrition for a Lifetime -- Interactive, public access information system for nutrition promotion. Paper presented at the annual meeting of the American Public Health Association, Chicago, October.

AWARDS

Outstanding Young Men of America, 1989.

National Merit Scholar, 1982-86.

Marshall Hahn Engineering Scholarship, 1982-83.

Eagle Scout, 1979.

COMMUNITY SERVICE

Associate Advisor, Explorer Post 146, Blue Ridge Mountains Council, Boy Scouts of America, Blacksburg, Virginia.

Member, Alpha Phi Omega National Service Fraternity, Virginia Tech, Blacksburg, Virginia.

Member, Catholic Newman Community at Virginia Tech, Blacksburg, Virginia.

Michael Leahy

Michael Leahy