Visual Search on a Mobile Device while Walking

Ji Jung Lim
San José State University
San José, CA, USA
innoixdesign@gmail.com

Cary Feria
San José State University
San José, CA, USA
cary.feria@sjsu.edu

ABSTRACT

As smartphone usage increases, safety concerns have arisen. Previous research suggested cognitive impairments while using mobile devices in walking conditions. Mobile user interfaces that are designed in ways not to require users' full attention may mitigate the safety concerns. Primary focus of this research was on the perception process during visual search rather than the physical target selection by finger tapping, which most previous research focused on. The effects of object size, contrast, and target location on mobile devices while walking and standing were examined. A serial visual search using "T" and "L" shapes on a mobile device was conducted, which controlled for the physical target selection involvement. The results showed that walking, bigger object size, and the target position in the outer area of the mobile device display slowed the visual search reaction time. This suggests mobile interface improvement possibilities by proper object sizing and placement.

Author Keywords

Human Factors; mobile interaction; mobile user interface; visual search; walking; target acquisition

ACM Classification Keywords

H.5.2 [Information Interfaces and Presentation]: User Interfaces - Interaction styles

General Terms

Design; Experimentation; Human Factors; Performance; Verification

INTRODUCTION

Smartphones that support multi-touch screens have become ubiquitous as hand-held computing devices as well as mobile phones since the iPhone was released to the market in 2007 [10]. The smartphone market has been the fastest growing segment in the mobile phone market for the last 3 to 4 years. According to a mobile market research report by ComScore, in 2010, there were 45.5 million smartphone subscribers out of a total of 234 million cell phone subscribers in the United States [4]. Moreover, a digital media research firm, Berg Insight, reported in 2011 that global shipments of smartphones had increased 74% from 2009 to 2010 [3]. Berg Insight also predicted that there would be 2.8 billion smartphone users globally by 2015.

Smartphones and 3G / 4G (fast) mobile wireless networks have increased the usage of advanced functions (i.e., web surfing, emailing, text messaging, taking picture and videos, etc.) on smartphones that used to be major functions on PCs, and these mobile wireless networks have enabled even faster communication among smartphone users. Because of the new, fast communication trends, immediate responses using a smartphone are generally expected nowadays. Thus, advanced function usages (i.e., web surfing, emailing, text messaging, taking picture and videos, etc.) on the smartphone while walking are easily witnessed on the street and have become common practice. This trend has raised a safety concern. Running into objects or people, or falling into manholes or puddles has caused injuries and the numbers of instances often are reported in the media [21]. According to Richtel, the amount of injuries associated with pedestrian cell phone usage has increased over recent years. More than 1000 pedestrians visited the emergency room in 2008 because of cell phone usage related injuries. In 2007, the number of pedestrian emergency room visits for the same reason doubled compared to the previous year, and that happened again in 2008. Hatfield & Murphy [9] reported that pedestrians who crossed the street talking on the phone walked much slower and were much less attentive to the road situation or traffic, compared to pedestrians who crossed without using a mobile phone. Hatfield & Murphy's research suggested that using a mobile phone whilst crossing roads creates unsafe pedestrian behaviors.

Numerous studies after Hatfield and Murphy's study have confirmed that there is significant cognitive distraction of mobile phone users who cross oncoming traffic. This cognitive distraction of mobile phone users on roads increases situation unawareness, unsafe behaviors, and more risk for accidents or injuries regardless of pedestrian gender or age [11, 19, 25].

In spite of this astonishing growth of smartphone usage and safety issues, not much has been studied in the way of mobile user interface design solutions to reduce cognitive workload and enable successful multi-tasking on a mobile device while walking. Presumably in a walking condition, information-processing abilities would be decreased, and cognitive workload would be increased because of dual tasking (i.e. reading while walking or searching while

MobileHCI'12, September 21–24, 2012, San Francisco, CA, USA.

walking) or multitasking (i.e. reading, searching, selecting a target while walking) [20].

Well-designed mobile interfaces using effective visual search attributes, such as color, brightness, size, etc. may improve the visual search performance on mobile devices as well as abilities to walk. In the present study, the performance of visual searches (i.e. searching for targets among distracters) is examined. Visual search, which consists of perceiving and searching information on the display, would be the very first task among any other major tasks, such as menu navigation, text input, etc. A more efficient visual search process may reduce user's cognitive workload for the tasks on a mobile device and mitigate the safety concerns. To measure mobile users' information processing abilities while walking, a conventional serial visual search paradigm [29] was used; participants were instructed to search for a target ("T" shape) among distracters ("L" shapes) in different rotated orientations. This visual search paradigm was used to reduce effects of other variables that are not relevant to this study such as reading abilities, color preference, etc. The differences in cognitive workload between mobile device users in a walking condition versus a standing condition were measured using the workload self-assessment based on the NASA Task Load Index (TLX) [18].

Visual search accuracy per target location on a mobile device was also evaluated to understand the effects of the target location on visual search performance. Mobile user interface designs with the optimal target location should reduce visual search time and increase accuracy. Understanding the effects of object size, object contrast, and location on a mobile device is expected to lead to mobile user interface design solutions that reduce cognitive workloads, allow for efficient task completion on mobile devices, and alleviate safety issues while using mobile devices in walking conditions.

RELATED WORK

Smartphone use while walking

Many studies have evidenced a negative performance effect on target selection and reading on a mobile device while walking. Schildbach & Rukzio [24] found negative performance effects of walking on reading and selecting targets on a mobile phone. The negative performance effect of walking can be caused by many different environmental factors, such as vibration, light, glare, noise, weather, temperature, uneven terrain, etc. To compensate for the negative performance effects of mobile phone usage while walking, mobile user interface design solutions (i.e. adding bigger buttons, providing a walking mode of user interface, etc.) have been suggested in previous studies [12, 24].

Reading while walking

Vadas et al. [27] investigated reading performance on a mobile device while walking. The results indicated that walking led to decreases in reading accuracy, increases in mental workload, and increases in stress levels compared to stationary usage. Studies by Schildbach & Rukzio [24] found that increasing target size could not compensate for the negative performance effect of walking on a reading task. This was because larger text requires more scrolling on a mobile phone.

Visual search on mobile device

Nowadays, there are many features to interact with on mobile devices, and there is so much information to read on mobile phones. Activities of visually searching, reading, and selecting the target on a mobile screen while walking have increased accordingly. Previous studies [12, 24, 27] have examined reading and comprehension performance using text and paragraphs on the screen. However, on mobile devices, people perform not only reading, but also visually searching objects, such as icons, photos, and videos, in a grid view or list view. In the current study, a conventional visual search paradigm (i.e., searching for the target ("T" shape) among distracters ("L" shapes) was used. The conventional visual search paradigm is a suitable fit for the current study in order to examine the effects of visual search attributes during mobile device usage and to reduce irrelevant factor effects, such as reading and comprehension abilities.

Target size on mobile device while walking

Hasegawa et al. [8] examined the effect of text font size on the legibility on a mobile display and reported that legibility was higher with larger characters (2.5 mm height) than medium (2.0 mm height) and small (1mm height) characters. Decreasing the character sizes resulted in an increase of subject evaluation of legibility and error rate, and a decrease of viewing distance.

Lin et al. [14] examined the effects of target size, walking speed, and walking difficulties on stylus-based tapping performance and validated the effectiveness of Fitts' Law [7] on a mobile phone usage while walking. Fitts' Law is a classic human computer interaction principle, which defines the correlation between selection time, target size, and distance between the starting point to the center of the target. That is, the reaction time increases when the target size decreases and when the distance to the target increases. Lin et al. [14] also reported that walking increased the task completion time, error rates and cognitive workloads of target selection tasks on mobile phones. They also examined the effect of target sizes 1.9mm to 6.4 mm in diameter, and found that a larger target size decreased the error rate and the selection time in all the following conditions: seated, slow walking, fast walking, and obstacle course.

In Lin et al.'s study, a single target was displayed at a time and participants needed to select the actual target by tapping on it in the display. This task involved not only visual perception but also physical targeting activities. In the current study, the primary focus of the study is the visual perception and cognitive activities of users on a mobile device display. To avoid the physical targeting process, which is unrelated to the focus of the study, the selection buttons were separated from the actual visual search display (target and distracters) and remained at the same location.

Lin et al. [14] used a wide range of target sizes (1.9mm to 6.4 mm). In the current study, two different target sizes were used, 6.74mm and 9.5 mm, which are larger than the target sizes Lin et al. used in their study and are now commonly used in mobile phone user interfaces. The object sizes used in the current study are the actual size of application icons and menu icons on the Android phones and iPhones [1, 2]. Lin et al. [14] found that the target size 6.4mm condition maintained an error rate of less than 10% for the obstacle course condition, and Park et al. [21] reported that 7mm and 10mm target size performed better than 4mm in their target selection study. The two object sizes used in the current study are thus good object sizes to examine the interaction between object size, object contrast, target location, and the walking condition on a mobile user interface.

Target contrast during visual search on mobile device

Schaik and Ling [23] studied the effect of contrast during a visual search on a computer display. Black (#000, hexadecimal color code in HTML and CSS) on grey (#BBB) with a contrast ratio of 10.94:1 and white (#FFF) on grey (#BBB) with a contrast ratio of 1.92:1 were compared, but were not found to differ. Hasegawa et al. [8] examined the effect of display contrast on legibility on mobile phone screens, however, there was no effect found. In Hasegawa et al.'s [8] study, meaningless text was used to measure legibility, and the task was performed only in a sitting condition. Although the previous studies did not find an effect of contrast either on a computer display nor a mobile device while sitting, it is unknown whether contrast has an effect on a mobile device display while walking. In the current study, the effect of contrast on a mobile display while walking is investigated with a conventional visual search paradigm, which controls for irrelevant factors such as reading ability and character familiarity.

Visual attention during visual search on mobile device

Many studies regarding eye tracking on desktop computers have been done to understand users' visual attention movement and gazing dwell time while interacting with the computer user interface and to apply the findings to user interface design strategies. However, eye tracking on mobile phones has not often been done. One of the reasons for this is that the history of smartphone usage is relatively much shorter than the history of desktop computer usage. Another reason is that it is very difficult to measure users' fixation points and eye movements accurately on mobile phones because of the small sized display, the frequent head movement, and the jitter of the eye fixation while holding the mobile phone [5, 17]. In the current study, a visual search paradigm was used to measure users' visual attention on a mobile device display, which avoids the issues with eye tracking measurement. The cell location of the target on a 4 by 6 grid display was manipulated to examine which area of the display got more attention and accuracy on target detection. To avoid the physical targeting aspect of visual search activities and measure the perception process only on a mobile device display, selection buttons are located in a constant location rather than physically pressing on the target location.

Target location during visual search on mobile device

Lin et al. [14] found that, consistent with Fitt's Law [7], target size and distance to the target affect target selection, as measured by tapping on a mobile display, while walking in the obstacle course condition. Park et al. [21] recommended using the center area of a mobile display for the general input elements because the results of their target selection performance study suggested that the center area of the mobile display provides higher pressing convenience, higher success rate, and fewer errors than the outer areas of the display.

According to Fitts' Law, the farther the distance to the target, the greater the reaction time. Since attention begins at the previous target location, the distance from the previous target to the subsequent target may affect the reaction time. The center (inner) area of display is more likely closer to the previous target location than the outer area of the display. Thus, better performance (shorter reaction time and lower error rate) in the center (inner) area of the mobile display was expected in the current study, consistent with the findings of the study by Park et al. [21].

Discussion of related work

Previous studies have found visual information processing impairments while walking; however, comprehensive user interface design solutions for mobile devices have not yet been proposed much. In the present study, mobile device usage performance while walking was compared with stationary usage. Effects of the visual search attributes of object contrast and size were examined on a mobile user interface while walking to assess whether and which attributes can compensate for the negative performance effect of the mobile device usage performance in a realistic walking simulation. In addition the target location on the user interface was investigated to understand the mobile user's visual focus of attention on a mobile device display.

HYPOTHESES

H1. Smaller object size will result in lower visual search performance on a mobile device.

H2. Walking will result in lower visual search performance on a mobile device.

H3. Targets in locations near the center (inner area) of the display will result in better search performance than targets in outer locations.

METHOD

The current study aimed to understand the effects of object size and object contrast during visual search performance while using a mobile phone in walking and standing conditions. In addition, the study aimed to examine the effects of the target location. The experiment was conducted on an indoor test track.

Participants

29 participants (females and males) participated in the study for university class credit. Participants were at least 18 years old. Participants who owned a mobile phone (either feature phone or smartphone) and do not have a visual impairment were recruited. During recruitment, there were no restrictions on right handed or left handed participants.

Experimental design

A within-subjects design was used. The experiment was divided into two blocks.

Visual search task

A visual search performance task using the shapes "T" and "L" was conducted (See Figure 1).

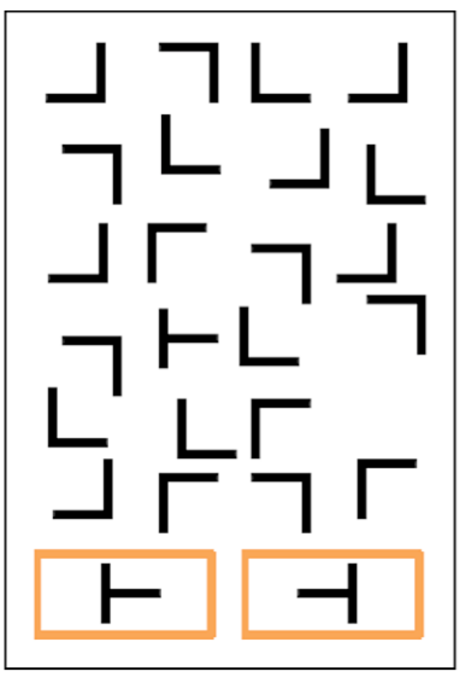
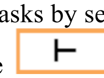
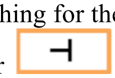


Figure 1. Example of the target and distracters shown on the mobile phone screen for the visual search performance task.

The mobile phone screen displayed the target "T" shape in two different orientations: the top of the "T" shape faced either right or left. There were multiple "L" shapes as distracters in four different orientations: the top of the "L" shapes faced top, right, bottom, and left. Combinations of one target and between 20 and 23 distracters were displayed in a 4 by 6 grid. The number of "L" shapes and their orientation were randomly chosen on each trial. Participants performed the visual search tasks by searching for the target "T" and selecting either the  or  button based on the orientation of the target on the screen.

Independent variables

The first independent variable, ***object*** (target and distracters) ***size***, had two levels, small and large. The small target font size was 6.74 x 6.74 mm. The large object size was 40% larger in height and width, 9.50 x 9.50 mm, than the small object size. (See Figure 2.) The cell size of the 4 by 6 grid remained the same.

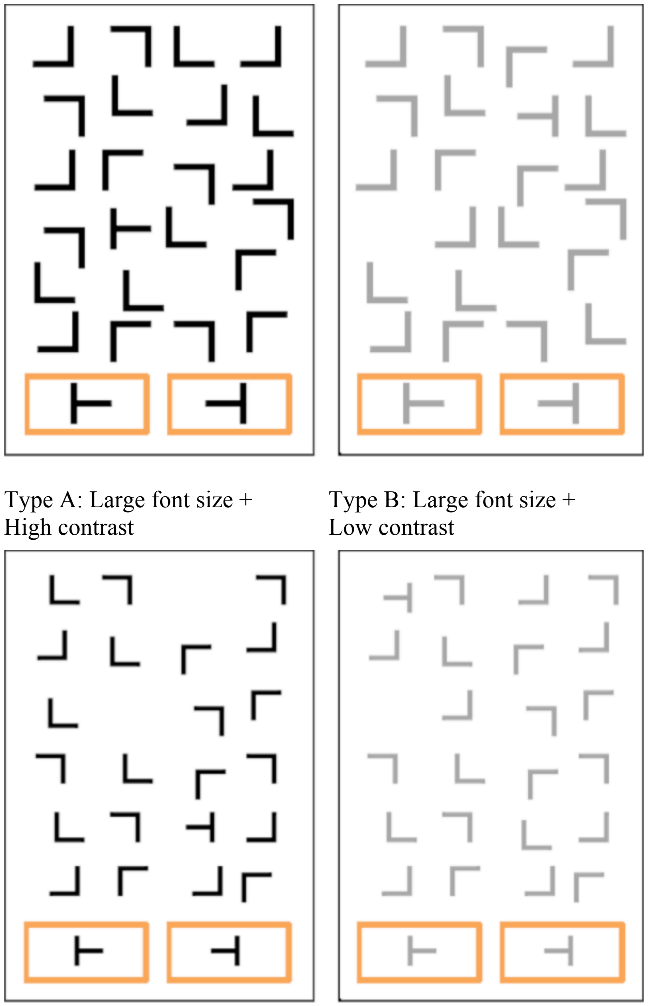
Figure 2. Two different object font sizes.

The second independent variable, ***object contrast,*** had two levels "high" and "low." High contrast (contrast ratio: 21.00:1) showed a black (Web color: #000) object on a white (Web color: #FFF) background and low contrast (contrast ratio: 2.85:1) showed a light gray (Web color: #999) object on a white (Web color: #FFF) background. (See Figure 3.)

Figure 3. Two different object contrasts.

In each trial, the mobile screen displayed one of the four different array types in a random order. Four different array types were Type A: Large font size and High contrast, Type B: Large font size and Low contrast, Type C: Small font size and High contrast, and Type D: Small font size and Low contrast. (See Figure 4 for screen samples.) On any given trial, the target and all the distracters had the same size and contrast.

A single object (either a target or a distracter) was presented in each cell of the 4 by 6 grid. A jitter, between 0 to 3 pixels in 4 different directions (top, down, left, and right), was randomly applied for each object.



Type A: Large font size + High contrast

Type B: Large font size + Low contrast

Type C: Small font size + High contrast

Type D: Small font size + Low contrast

Figure 4. The four different array types.

The third independent variable was *walking* condition. Half of the participants were walking while performing the visual search performance test on a mobile phone in the first block, and standing while performing the trials in the second block. The other half of the participants were standing while performing the trials in the first block and then walking in the second block to counterbalance the order of walking and standing conditions. To measure the walking speed difference, participants were asked to walk at their comfortable (normal) walking speed for 1 lap before the beginning of the block of the walking condition. The walking speed while performing the trials for 1 lap were compared with the comfortable (normal) walking speed.

The fourth independent variable was *target location*. A single target was randomly presented in one of the 24 grid cells on each trial. Each cell was assigned a unique id (see Figure 5). The center (inner) area of the display was defined as ID 6, 7, 10, 11, 14, 15, 18, and 19, which were the 2nd and 3rd columns in the 2nd through 5th row in the 4 by 6 grid.

1	2	3	4
5	6	7	8
9	10	11	12
13	14	15	16
17	18	19	20
21	22	23	24

Figure 5. 4x6 grid locations on the mobile display, with the inner area colored gray and the outer area colored white.

Materials

A Motorola Droid 2 phone with a resistive touch-screen and Android operation system was used during the study. The visual search prototype application was implemented using Flex and Adobe Air.

Test track

To simulate the real life visual searching situation while walking, a non-linear, circular shaped track around obstacles was designed in a 7.93m x 16.98m indoor lab. (See Figure 6.)

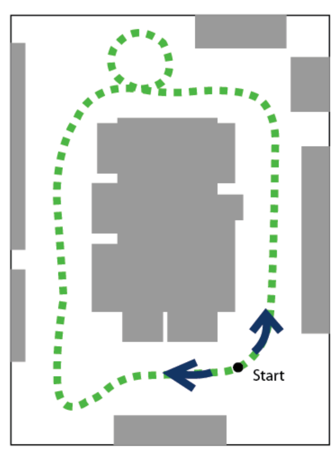


Figure 6. The test track layout in the indoor lab with obstacles marked with solid sections and the test track marked with a dotted line.

To reduce learning of the environment, participants were asked to walk on the track in two different directions, clockwise and then counter-clockwise around obstacles (i.e., machines, chairs, etc.) until the block was completed. The 46.08m-length track was drawn on the lab floor around the obstacles. (See Figure 6.)

To avoid possible injuries during the experiment, all obstacles' corners were padded, and participants were allowed to walk around the track before the experiment to get acquainted with the environment.

Dependent measures

To measure the visual search performance, reaction time (RT) and error rate (ER) were measured. The data of the target selection (correct and wrong), and reaction time (ms) were recorded automatically. There were 300 trials, including 1 practice trial in each block.

To assess participants' workload, participants were asked to fill out a questionnaire after each block. The questionnaire included a workload self-assessment based on the NASA Task Load Index (TLX) [18] (See Figure 7) and self-assessment questions regarding visual search performance and emotional response while walking and while standing. In the workload self-assessment questionnaire, mental demand, physical demand, temporal demand, performance, effort, and frustration were measured on 5-point scales.

Mental Demand	Very low 5–4–3–2–1 Very high
Physical Demand	Very low 5–4–3–2–1 Very high
Temporal Demand	Very low 5–4–3–2–1 Very high
Performance	Perfect 5–4–3–2–1 Failure
Effort	Very low 5–4–3–2–1 Very high
Frustration	Very low 5–4–3–2–1 Very high

Figure 7. Workload self-assessment based on NASA TLX 5-point scale.

The experimenter also recorded participants' walking errors, such as bumping into the obstacles or having to readjust direction, in order to observe any walking performance changes.

Procedure

Prior to the experiment, participants confirmed their normal vision and mobile phone ownership. Participants listened to the visual search task instructions and the track layout details. The instructions included walking directions details (alternating direction: clockwise and then counter-clockwise) and walking speed (walking at a normal walking speed) for the walking block. Participants were also instructed to use two hands: one hand for holding the phone and the other hand for selecting one of the buttons. The auto-rotation feature on the mobile phone was turned off during the study to ensure that the screen displayed in a vertical orientation only. Before the walking block, participants were asked to walk around the track once in their normal walking speed, to compare their normal walking speed with their walking speed during the visual search trials for one randomly chosen lap in the walking block.

In the first block, participants performed the visual search trials either while walking or standing. In the second block, participants performed the visual search trials in the opposite condition.

After each block, participants filled out a post-block questionnaire, including the workload self-assessment questionnaire based on the NASA Task Load Index (TLX). Participants also filled out a post-experiment questionnaire regarding daily personal phone usage at the end of the experiment.

RESULTS

Reaction time

The mean reaction time was calculated for each participant in each of the sixteen conditions and was submitted to a 2 (walking condition) x 2 (object size) x 2 (contrast ratio) x 2 (location) repeated measure analysis of variance (ANOVA). Trials with incorrect responses were excluded from the data.

There was a significant main effect of the walking condition on the reaction time, $F(1, 28) = 20.02$, $p < .001$. The mean reaction time of the walking condition (M = 1957.29 ms, SD = 398.44 ms) increased by 19.29% over the standing condition (M = 1640.78 ms, SD = 334.22 ms).

There was a significant main effect of the object size on the reaction time, $F(1, 28) = 14.02$, $p < .01$ (see Figure 8). On average, the reaction time of the bigger object size (M = 1827.70 ms, SD = 333.22 ms) increased by 3.24% over the reaction time of the smaller object size (M = 1770.37 ms, SD = 304.65 ms). The results showed the opposite effect of the hypothesis (that the reaction time would decrease when object size increases). The spacing between objects might have affected the results. Bigger objects (target and distractors) in the given 4x6 grid space decreased the size of the spacing between objects, thereby creating a higher density in the display.

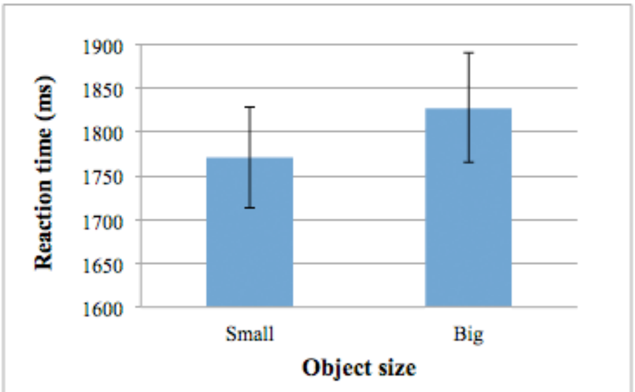


Figure 8. Object size main effect on reaction time. Error bars represent standard errors.

The effect of density on visual search tasks has been reported in many previous studies [6, 26, 28], and the effect of density might interfere with the object-size effect in the current study.

There was no significant main effect of the contrast ratio on the reaction time, $F(1, 28) = 0.20$, $p > .05$.

As hypothesized, a significant main effect of the target location on the reaction time was found, $F(1, 28) = 47.82$, $p < .001$. On average, the reaction time when a target was presented in the inner area (*M* = 1727.77 ms, *SD* = 300.21 ms) decreased by 7.62% over the reaction time when a target was presented in the outer area (*M* = 1870.30 ms, *SD* = 340.94 ms) of the mobile device screen.

There was a significant interaction between the target location and the walking condition, $F(1, 28) = 6.77$, $p < .05$ (see Figure 9). The difference in reaction time between the inner area and the outer area was smaller in the walking condition than in the standing condition.

No other 2-way, 3-way, and 4-way interactions were significant.

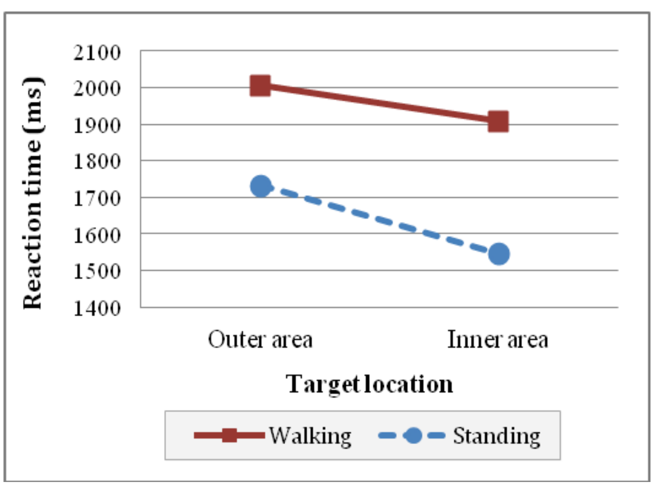


Figure 9. Interaction between walking condition and target location on reaction time

Error rate

The mean error rate was calculated for each participant in each of the sixteen conditions and was submitted to a 2 (walking condition) x 2 (object size) x 2 (contrast ratio) x 2 (location) repeated measures ANOVA. The error rate was calculated by dividing the number of trials with incorrect responses by the total number of trials in each condition.

There was a significant main effect of contrast ratio on the error rate, $F(1, 28) = 4.82$, $p < .05$. The error rate of the high contrast ratio condition (*M* = 0.008, *SD* = 0.011) was significantly higher than the error rate of the low contrast ratio condition (*M* = 0.005, *SD* = 0.005). However, both error rates were less than 1%, and the effect could be trivial. The error rate data did not produce any other significant main effects or interactions.

Walking speed

To measure the walking speed changes between the normal walking speed and the walking speed while using a mobile device, participants were asked to walk around the track for one lap in their normal walking speed and the time for one lap was logged prior to the trials. In addition, participants were instructed to keep their normal walking speed during the trials and the walking time during the trials for one randomly chosen lap was logged. A dependent samples t-test was conducted to test for a difference between the participants' normal walking time and their walking time while performing the visual search trials on the mobile device. Results showed that walking time during the visual search trials on the mobile device (*M* = 5400.35 ms, *SD* = 665.39 ms) was significantly longer than the normal walking time (*M* = 4419.04 ms, *SD* = 394.73 ms), $t(28) = -10.405$, $p<.001$. On average, the walking speed during the visual search trials took 22.21% longer than the normal walking speed.

Workload self-assessment based on NASA TLX

Participants assessed their mental demand, physical demand, temporal demand, performance, effort, and frustration for the trials based on their subjective judgment after each block: one block for the walking condition and the other block for the standing condition. In the workload self-assessment based on the NASA TLX, 5-point scales (Very low 5–4–3–2–1 Very high) were used. To compare workload self-assessment ratings between the walking condition and the standing condition, dependent samples t-tests were used.

The mental demand of the standing condition (*M* = 3.62, *SD* = 1.115) was significantly less than the walking condition (*M* = 2.90, *SD* = 1.081), $t(28) = 4.638$, $p < .001$. The physical demand of the standing condition (*M* = 4.17, *SD* = 0.966) was significantly less than the walking condition (*M* = 3.38, *SD* = 1.015), $t(28) = 4.075$, $p < .001$. The effort of the standing condition (*M* = 3.48, *SD* = 1.184) was significantly less than the walking condition (*M* = 2.83, *SD* = 1.002), $t(28) = 3.494$, $p < .01$. There was no significant difference between the temporal demand of the standing condition (*M* = 3.24, *SD* = 0.951) and the walking condition (*M* = 3.17, *SD* = 1.002), $t(28) = 0.338$, $p > .05$. Prior to the trials, participants were instructed to focus on the visual search task primarily and that might have led the participants to not rush on the trials regardless of being in the walking or standing conditions. There was no significant difference between the participants' perception of their visual search task performance between the standing condition (*M* = 4.21, *SD* = 0.774) and the walking condition (*M* = 4.07, *SD* = 0.704), $t(28) = 0.891$, $p > .05$. There was no significant difference between the frustration during the visual search tasks while standing (*M* = 4.17, *SD* = 1.037) and while walking (*M* = 3.86, *SD* = 1.156), $t(28) = 1.470$, $p > .05$. These results suggest that participants perceived that the trials in the walking condition required more mental demand, physical demand, and effort than the trials in the standing condition.

The overall workload self-assessment score based on NASA TLX was calculated by summing all 6 ratings of each participant for the walking condition and for the standing condition. The overall workload self-assessment scores of the walking and standing conditions were compared using a dependent samples t-test. Overall workload self-assessment ratings in the standing condition (*M* = 22.90, *SD* = 4.186) were significantly less than in the walking condition (*M* = 20.21, *SD* = 3.913), $t(28) = 3.941$, $p < .001$.

DISCUSSION

Although several previous studies have examined the effects of mobile user interface attributes on target search performance while walking, the focus of the previous studies was physical target selection performance [14, 21, 24]. Few studies have investigated the effects of mobile user interface attributes in the perception process during mobile interface use. The current study aimed to examine the perceptual processes that facilitate visual search tasks during mobile use while excluding physical target selection aspects. The visual search process is required in many activities on the mobile user interface. The current study revealed that walking, object size, and target location had significant effects on the visual search reaction time.

As hypothesized, walking slowed visual search, and this is consistent with the results of previous studies using related tasks. Mizobuchi, Chignell, and Newton [16] reported that text input while walking was slower than while standing during their mobile text entry performance research. Schildbach and Rukzio [24] examined the effect of walking on target acquisition and text reading task performance and confirmed the negative effect of walking for both tasks. Lin et al. [14] examined the task of tapping on predefined targets on a PDA and found that the obstacle course condition had a slower task completion time than the seated condition. In these previous studies, physical target selection with finger tapping on a target displayed on a mobile device was examined. The current study revealed that negative performance effects happened not only in physical tasks but also in the visual perception process during visual search on a mobile device.

The workload self-assessment rating of the current study showed that mental demand, physical demand, and effort in the walking condition were greater than in the standing condition. This is consistent with Lin et al.'s [14] target acquisition study, which showed that the obstacle course condition had a higher perceived workload rating than the seated condition. The finding that workload is increased for a visual search while walking suggests a need for future work to design user interfaces for mobile devices that can reduce the user's mental and physical workload while walking.

In the current study, large object size was expected to lead to better visual search performance, but interestingly the large object size slowed the visual search completion. There was no significant effect of object size on the error rate. These results contrasted with previous findings [8, 14, 24]. The difference in results between the current study and previous studies might be due to the inter-object spacing difference between the larger object display and the smaller object display. In the current study, unlike the previous studies, larger object size reduced the spacing between objects in the display, and the reduced spacing between objects may have made the visual search more difficult. Hasegawa et al. [8] increased spacing between letters as the letter size increased in the display. In the study of Lin et al. [14], the spacing effect between objects was not applicable because they displayed one target at a time.

The current result that visual search is slowed with the smaller spacing between objects along with larger object size is consistent with some previous studies on the effect of inter-object spacing. Ling and Schaik [15] and Lee, Chao, Ko, and Shen [13] used letters to find the effect of inter-object spacing and found that high density increased the visual search time, in agreement with the current study's results. However, Everett and Byrne [6] and Tseng and Howes [26] used icons and image thumbnails to find the effect of inter-object spacing and found that a higher density decreased the visual search time. The range of inter-object spacing also might cause the inconsistent results. Vlaskamp et al. [28] found that the inter-object spacing effect varied over different inter-object spacing ranges. Decreasing inter-object spacing decreased the search time in the inter-object spacing range from 7.1° to 3.4°. There was no inter-object spacing effect in the inter-object spacing range from 3.2° to 1.5°. Decreasing inter-object spacing increased the search time for inter-object spacing smaller than 1.5°. In the current study as well as the studies of Ling and Schaik [15] and Lee et al. [13], a smaller inter-object spacing range might have been used unlike the studies of Everett and Byrne [6] and Tseng and Howes [26]. This supports the idea of inter-object spacing involvement in the unexpected results of the object size effect investigation in the current study. This also suggests a need for further investigation on the effect of inter-object spacing in a mobile display.

In the current study, there was no difference in reaction times between the low contrast ratio (2.85:1) and the high contrast ratio (21.00:1), similar to the results of the previous studies. Schaik and Ling [23] studied the effects of background contrast on visual search performance in web pages, and they did not find an effect of contrast on either accuracy or speed. Similarly, Hasegawa et al. [8] evaluated the legibility of characters on a mobile phone display and did not find effects of contrast ratio on letter search time. Zuffi, Brambilla, Beretta, and Scala [31] studied the effects of contrast on readability, and they recommended at least 3:1 as a minimum contrast ratio for good visual performance. The World Wide Web Consortium (W3C) also recommended 3:1 contrast ratio as a minimum contrast ratio in large-scale texts (at least 18 point [6.77 mm] regular or 14 point [5.26mm] bold) [30]. In the current study, the low contrast ratio (2.85:1) used was very close to the industry minimum contrast ratio recommendation (3:1 for large scale texts) and the object sizes used were close to the size of large-scale texts. That might have led to the lack of a significant effect of the contrast ratio on the visual search performance. The current results suggest that the contrast ratio has little effect on a visual search on a mobile device at least for contrasts that are near or above the W3C suggested ratios.

The results showed that visual search was completed more quickly when the target was in the inner area of the mobile device screen than when it was in the outer area. This was expected because the distance between the target location on the previous trial and on the current trial is likely to be less for a target in the inner area than for a target in the outer area. Park et al. [21] examined the effect of location on physical target selection task performance on a mobile device and found improved performance near the center of the display. Unlike Park et al.'s study, the current study isolated the effects of target location on the perceptual processes in visual search. To control for the physical aspect of target selection, selection buttons were separated from the target display area. The current study showed that the target location affects not only physical target selection but also visual perception processes during mobile use. This result has important implications for mobile device user interface design. It suggests that placing targets such as contents to read, or call-to-action buttons, in the inner area of the display is likely to facilitate perceptual task performance on a mobile device.

SUMMARY AND FUTURE DIRECTIONS

Along with the exponential increase of smartphone and tablet use, mobile device usage while walking has increased followed by the increase of safety concerns. Many previous studies have reported a negative performance effect of walking during physical target selection tasks on a mobile device. Unlike the previous studies, the current study aimed to examine the visual perception and attention processes during visual search tasks on a mobile device by controlling for physical target selection aspects.

In the current study, the results confirmed the negative performance effect of walking and found effects of the object size and the target location during visual search tasks. Small (6.74mm) object size resulted in faster reaction time than larger (9.5mm) object size. When the target appeared in the inner area of the mobile device, the visual search was faster than when it appeared in the outer area of the mobile device screen. This suggests that placing major content and call-to-action items in the inner area of the display would likely facilitate task performance on a mobile device. The effect of target location found in the current study merits further investigation. In future studies, the optimal location and the treatment of specific mobile user interface elements, like alerts and call-to-action buttons, should be examined in an ecological approach.

REFERENCES

1. Android user interface guidelines. Retrieved from http://developer.android.com/guide/practices/ui_guidelines/icon_design.html
2. Apple iPhone human Interface guidelines. Retrieved from http://developer.apple.com/library/ios/documentation/userexperience/conceptual/mobilehig/MobileHIG.pdf
3. BergInsight: Smartphone markets and technologies (2nd ed.). (2011). Retrieved from http://berginsight.com
4. ComScore Report: Smartphone market share. (2010). Retrieved from http://www.comscore.com/Press_Events/Press_Releases
5. Drewes, H., Luca, A. D., & Schmidt, A. (2007). Eye-gaze interaction for mobile phones. *Mobility: Proc. of 4th International Conference on Mobile Technology, Applications and Systems* (pp. 364-371). New York: ACM Press.
6. Everett, S. P., & Byrne, M. D. (2004). Unintended effects: Varying icon spacing changes users' visual search strategy. *Human Factors in Computing Systems: Proc. of CHI 2004* (pp. 695-702). New York: ACM Press.
7. Fitts, P. M. (1954). The information capacity of the human motor system in controlling the amplitude of movement. *Journal of Experimental Psychology, 47*(6), 381-391.
8. Hasegawa, S., Miyao, M., Matsunuma, S., Fujikake, K., & Omori, M. (2008). Effects of aging and display contrast on the legibility of characters on mobile phone screens. *21st Symposium on Human Factors in Telecommunication*, *2*(4), 7-12.
9. Hatfield, J., & Murphy, S. (2007). The effects of mobile phone use on pedestrian crossing behavior at

signalised and unsignalised intersections. *Accident Analysis and Prevention*, *39*, 197–205.
10. Honan, M. (2007). Apple unveils iPhone. Macworld. Retrieved from http://www.macworld.com/article/54769/2007/01/iphone.html
11. Hyman, I. E., Boss S. M., Wise, B. M., McKenzie, K. E., & Caggiano, J. M. (2010). Did you see the unicycling clown? Inattentional blindness while walking and talking on a cell phone. *Applied Cognitive Psychology*, *24*, 597-607.
12. Kane, S. K., Wobbrock, J. O., and Smith, I. E. (2008). Getting off the treadmill: Evaluating walking user interfaces for mobile devices in public spaces. *Proc. of MobileHCI 2008 (pp.* 109-188). New York: ACM Press.
13. Lee, D., Chao, C., Ko, Y., & Shen, I. (2011). Effect of light source, ambient illumination, character size and interline spacing on visual performance and visual fatigue with electronic paper displays. *Displays*, *32*(1), 1-7.
14. Lin, M., Goldman, R., Price, K. J., Sears, A., & Jacko, J. (2007). How do people tap when walking? An empirical investigation of nomadic data entry. *International Journal of Human-Computer Studies*, *65*(9), 759-769.
15. Ling, J., & Schaik, P. (2006). The influence of line spacing and text alignment on visual search of web pages. *Displays*, *8*(2), 60-67.
16. Mizobuchi, S., Chignell, M., and Newton, D. (2005). Mobile text entry: relationship between walking speed and text input task difficulty. *Proc. of MobileHCI 2005 (pp.* 122-128). New York: ACM Press.
17. Nagamatsu, T., Yamamoto, M., & Sato, H. (2010). MobiGaze: Development of a gaze interface for handheld mobile devices. *Human Factors in Computing Systems: Proc. of the 28th of the International conference extended abstracts* (pp. 3349-3354). New York: ACM Press.
18. NASA Ames Research Center: Manual of NASA Task Load Index (TLX), v 1.0. (1987). Retrieved from http://human-factors.arc.nasa.gov/groups/TLX/index.html
19. Nasar, J., Hecht, P., & Wener, R. (2008). Mobile telephones, distracted attention, and pedestrian safety. *Accident Analysis and Prevention*, *40*, 69-75.
20. Ophir, E., Nass, C., & Wagner, A. D. (2009). Cognitive control in media multitaskers. *Proc. of the National Academy of Sciences*, *USA*, *106*, 15583-15587. doi: 10.1073/pnas0903620106
21. Park, Y. S., Han, S. H., Park, J., & Cho, Y. (2008). Touch key design for target selection on a mobile phone. *Proc. of MobileHCI 2008 (pp.* 423-426). New York: ACM Press.
22. Richtel, M. (2010). Forget gum. Walking and using phone is risky. *New York Times.* Retrieved from http://www.nytimes.com/2010/01/17/technology/17distracted.html
23. Schaik, P. V., & Ling, J. (2001). The effects of frame layout and differential background contrast on visual search performance in web pages. *Interacting with Computers*, *13*, 513-525.
24. Schildbach, B., & Rukzio, E. (2010). Investigating selection and reading performance on a mobile phone while walking. *Proc. of MobileHCI 2010 (pp.* 93-102). New York: ACM Press.
25. Stavrinos, D., Byington, K. W., & Schwebel, D. C. (2009). Effect of cell phone distraction on pediatric pedestrian injury risk. *Pediatrics*, *123*, 179-185.
26. Tseng,Y., & Howes, A. (2008). The adaptation of visual search strategy to expected information gain. *Proc. of CHI* 2008 *(pp.* 1075-1084). New York: ACM Press.
27. Vadas, K., Patel, N., Lyons, K., Starner, T., & Jacko, J. (2006). Reading on-the-go: a comparison of audio and hand-held displays. *Proc. of MobileHCI 2006 (pp.* 221-226). New York: ACM Press.
28. Vlaskamp, B. N. S., Over, E. A. B., & Hooge, I. T. (2005). Saccadic search performance: the effect of element spacing. *Experimental Brain Research*, *167*(2), 246-259.
29. Wolfe, J. M., & Horowitz, T. S. (2004). What attributes guide the deployment of visual attention and how do they do it? *Nature Review Neuroscience*, *5*, 1-7.
30. World Wide Web Consortium (W3C), Web content accessibility guidelines (WCAG) 2.0 Retrieved from http://www.w3.org/TR/WCAG/
31. Zuffi, S., Brambilla, C., Beretta, G., & Scala, P. (2007). Human computer interaction: legibility and contrast. In R. Cucchiara (Ed.), *Proc. of International Conference on Image Analysis and Processing 2007 (pp.* 241-246). New York: IEEE.