How Handheld Mobile Device Size and Hand Location May Affect Divided Attention

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Previous research demonstrates that people increasingly utilize multiple displays along with mobile devices simultaneously, and that this split in attention has detrimental effects on goal-directed behavior. However, few studies have assessed the impact of the physical attributes of mobile devices–including dimensions, weight and screen size–on attention. Understanding how device dimensions and screen size affect attention is an important first step in creating safety guidelines for high risk industries that utilize displays, such as automotive and aeronautics engineering. The aim of this work is to determine to what extent the display dimensions and screen size of mobile devices influence attention. To explore this question, participants interacted with mobile devices of varying sizes while performing a change detection task on a stationary device located behind and above the mobile device. Results of this study suggest that those using a smaller mobile device achieved higher performance on the background change detection task than those using a larger device, while having similar performance in the mobile device task. This work demonstrates that when attention is divided, larger displays may be more attentionally demanding. We recommend that when users or designers are required to consider multitasking between a foreground and background task, in order to optimize background performance they should utilize smaller foreground displays.

INTRODUCTION

According to the Pew Research Center, in 2005 45% of teens had a cell phone, and 33% had used it to send a text message. One in four cell phone-owning teens used their phone to connect to the Internet (Lenhart, Madden, & Hitlin 2005). Now, 92% of teens report going online daily—including 24% who say they go online "almost constantly" (Lenhart, 2015). This growth in mobile device use and Internet availability has increased the opportunity for multitasking and multiple-display scenarios (Smith & Boyles, 2012). Although technology adoption varies by age, teens weren't the only group increasing the use of mobile devices in multi-display activities. A Pew Research Center Survey found that television watchers increasingly use secondary devices to react in real-time to things viewed during television programs. For example, 75% of people polled used their mobile device while watching TV (Ericsson Consumer Insight Summary Report, 2013) and 28% messaged friends who were watching the same program (Smith & Boyles, 2012). This type of situation has been increasing rapidly over the last 15 years and compels researchers to investigate the implications of pervasive multitasking with mobile devices.

Mobile devices' ubiquity and portability also allow for people to take them places screens have never been. Recently, two men playing the mobile game "Pokemon Go" fell off a 90-foot cliff near Encinitas California and survived (Hernandez, 2016) demonstrating a complete lack of awareness brought about by a mobile device. Researchers also argue that people lose awareness of potential dangers when interacting with technology, as evidenced by many dangerous driving behaviors committed while using mobile devices (Sanbonmatsu, Strayer, Medeiros-Ward, & Watson, 2013; Sanbonmatsu, Strayer, Behrends, Ward, & Watson, 2016). For example, Glassbrenner (2005) estimated that at any given daylight hour 10% of U.S. drivers are talking on cell phones. We have also experienced the largest percentage increase in fatalities on U.S. roadways in 50 years for 2015 through 2017, which is likely influenced by driver distraction (National Highway Traffic Safety Administration, 2015, 2017). These studies and surveys demonstrate that people actively engage in multitasking with mobile devices despite dangerous and sometimes life-threatening circumstances.

Given that mobile device use has a significant impact on public safety, it is vital to determine how to make devices safer and less distracting. Researchers have demonstrated that loss of situational awareness occurs along with detriments in performance while using mobile devices (Lim, Change, Lee, & Kim, 2017). Previous research also argues that the wrist and hand are the most salient regions of the body to respond to visual information (Harrison, Lim, Shick, & Hudson, 2009), and others have demonstrated that hands within our visual field increase performance in reaction time tasks when placed near a target (Reed, Grubb, & Steele, 2006).

Yet little work has examined the impact of mobile device dimensions and screen size on multitasking behavior. Many previous researchers have conducted usability studies on smaller screens; some found small decreases in performance in measures like time on task, (Jones, Marsden, Mohd-Nasir, Boone, & Buchanan, 1999) whereas others found performance decreases up to 50% (Han & Kwahk, 1994). Education researchers have demonstrated that learning from videos on mobile devices with smaller screens may negatively impact performance (Maniar, Bennett, Hand, & Allan, 2008). However, none of these studies have explored the effects of mobile device characteristics on performance in the context they increasingly create: multitasking.

The inherent properties of the devices may determine our abilities to attend to information beyond them. In the current study, we performed two experiments to test the effect of device screen size–while controlling for device size and weight–on the performance of a continuous mobile task and a discrete background choice task. Based upon previous findings, in the first experiment we predicted a decrement in performance for the smaller device. In the novel domain of divided attention to the background task, we predicted a tradeoff between more attention allocated to the larger device causing a greater dual task cost in the background task. In the second experiment, we controlled for the device size and weight, predicting that the aforementioned predicted effects would be produced by the screen-size difference.

METHOD

Two experiments were conducted, with the first comparing performance on a mobile device (foreground) and stationary device (background) with users holding one of two mobile device sizes (phone or tablet). To assess the impact of the screen size alone, a second study was conducted with the same design as Experiment 1 but included an additional apparatus, which had the size and weight of the tablet but the screen size of the phone.

Participants

Experiment 1. 46 undergraduates at the University of California, Santa Cruz (13 Males, 33 Females) enrolled in a psychology course and received course credit in exchange for their participation.

Experiment 2. 123 undergraduates at the University of California, Santa Cruz (36 Males, 87 Females) participated. Three participants were removed from the analysis due to technical malfunctions and resulting loss of data.

Apparatus

For the background change detection task, a 48 cm Dell computer monitor (1280 x 1024 pixels) was positioned at approximately 91 cm from the participant. Participants indicated changes with vocal responses. These responses were recorded using a Psychology Software Tools Serial Response Box™ Voice Key with an Audio Technica® ATR20 microphone. Background task stimuli were presented electronically using the E-Prime 2.0 software (Psychology Software Tools, Pittsburgh, PA), which also recorded reaction time and accuracy for each response. In the foreground task, participants used either a 13.7 x 7.1 cm (720 x 1280 pixels) Samsung Galaxy SIII smartphone or a 24.4 x 17.5 cm (1280 x 800 pixels) Samsung Galaxy Tab 3 tablet that was held approximately 76 cm from the participant. The center point on both devices was held constant approximately 12.7 cm below the bottom-center of the Dell computer monitor. Foreground task stimuli were presented by a custom Android application. In **Experiment 2**, we constructed a third device with the screen size of the phone but the weight and dimensions of the tablet (known as the phony tablet). Pressboard was shaped and cut out to accommodate the phone in its center (Figure 1).

Figure 1. Mobile devices for the foreground task with the phone, phony tablet, and tablet conditions from left to right.

Tasks

In the Background task, after a randomized interval between 3 and 10 seconds, participants were tasked with vocally reporting which of 4 arrows changed direction on a computer monitor (see Figure 2B) and reaction time (RT) and accuracy were measured. We characterize this change as discrete and the order of arrow changes were counterbalanced. Additionally, the computer would present one row at four possible heights to the participants, which were randomized. The different heights were utilized to ensure that change detection was tested for all possible locations on the monitor. In the Foreground task, participants controlled the movements of a blue ball by physically tilting the mobile device (see Figure 2A). Participants were asked to keep the ball within the center of a target circle. A weighted jitter, approximately the distance of the radius of the target circle, was applied to the ball. If the blue ball was allowed to slide outside of the circle, a beep would sound at 1-second intervals until the ball was back in the target circle. A numerical error score accumulated in the top left corner of the device, which was utilized as the error score for each block. The center of the target was held at a constant location by participants aligning the target center with a piece of tape behind the device. The background screen was never occluded.

Procedure

Experiment 1. Participants were randomly assigned to either use the phone or the tablet for the duration of the experiment. The experiment was conducted across 5 blocks, beginning with baseline measures of single-task performance for both the mobile device (foreground) and change detection task (background) for 5 minutes each. Afterwards, participants completed 3 dual task blocks, where they performed both tasks simultaneously, each lasting 5 minutes. No ranking of importance was specified for each task in the dual-task blocks. Participants attempted to keep the blue ball within the circle while responding as quickly and accurately as possible to the position of the background stimulus change.

Experiment 2. To assess the impact of the screen size alone, an additional device with the weight and dimensions of the tablet, but the screen size of the phone (phony tablet) was tested. The design and procedure remained the same as Experiment 1 but participants were randomly assigned to one of three groups (phone, tablet, or phony tablet)

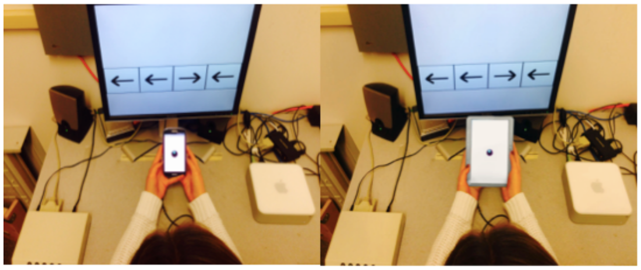

Figure 2. Mobile device foreground and computer choice task display in background.

RESULTS

The results of this study were analyzed for the influence of device on single task trials compared to dual task trials. We assessed the influence of device on Dual Task Cost (DTC) for Experiment 1 and 2 by subtracting performance in the single task conditions from performance in dual task conditions within each participant. Reaction time was used to measure change detection performance to one of four locations in the background task. Prior work supports this analysis as a valid measure for DTC (Castro, Cooper, & Strayer, 2016).

Experiment 1

Dual Task Cost. Dual Task Cost was calculated by subtracting the average single task trial scores from the average dual task trial scores for each participant. There was a not a significant difference in the mobile device error scores for phone (M = -.23, SD = 25.06) and tablet (M = -1.83, SD = 32.92) conditions; $t(42) = .18$, $p = .8$. However, there was a significant difference in the dual task cost of the background reaction times (milliseconds), such that the phone had less dual task cost (M = 111.09, SD = 266.54) than the tablet (M = 283, SD = 310.09) conditions; $t(42)$ = 2.00, p = .026; 95% CI[27.31, 345.71] (See Figure 3). This finding suggests that when multi tasking a larger display may produce slower reaction times than a smaller display in a background task.

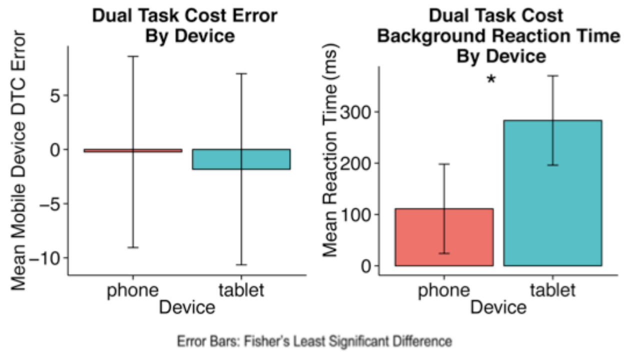

Figure 3. The left graph depicts DTC *Error score* by *mobile device* and the right graph depicts DTC background *reaction time* by *mobile device* calculated by subtracting the single task from the dual task for each condition. Significant differences at the $p < .05$ level are denoted by the *.

Experiment 2.

Dual Task Cost. Dual Task Cost was calculated with the same procedure as Experiment 1. A one-way between subjects ANOVA was conducted to compare the effect of device type on mobile error and background reaction time in the phone, tablet, and phony tablet conditions (Figure 4). There was not a significant difference in the mobile device error scores for phone, tablet, or phony tablet, conditions, $F(2, 120) = 1.17$, $p = .31$, $\eta_p^2 = .02$. There was a significant effect of device type on background reaction time (milliseconds) for the three conditions, $F(2, 120) = 5.71$, $p < .01$, $\eta_p^2 = .09$. Post Hoc pairwise comparisons using the Tukey Honest Significant Differences test indicated that the mean reaction time (milliseconds) for the phone condition (M = 124.49, SD = 212.03) and the phony tablet condition (M = 125.51, SD = 192.18) both showed significantly less dual task cost compared to the tablet condition (M = 271.43, SD = 266.55). Consistent with our prior analysis, these results suggest that the larger screen size in the tablet condition elicited a higher DTC in the background task than the smaller displays in the phone and phony tablet conditions.

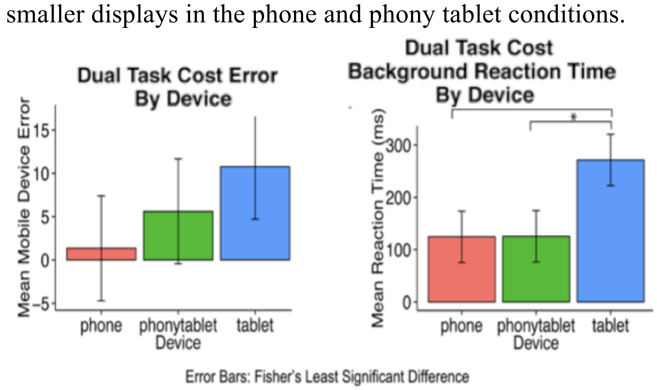

Figure 4.. The left graph depicts DTC *Error score* by *mobile device* and the right graph depicts DTC background *reaction time* by *mobile device* calculated by subtracting

the single task from the dual task for each condition. Significant differences at the $p < .05$ level are denoted by the *.

DISCUSSION

This study explored the effect of differing physical attributes between mobile devices upon participants' abilities to simultaneously perform a foreground and background task. **Experiment 1** determined that participants reacted more quickly to background stimulus changes when using a smaller foreground mobile device, but had similar performance on the mobile device task. **Experiment 2** replicated the effects of the first experiment, and unveiled that the background effect was due specifically to the screen size task—not the weight or dimensions of the device.

We propose that the negative attentional impact of larger screen sizes occurs specifically for information beyond the foreground screen. It seems that larger screens, although possibly priming more attentional focus to that location, do not necessarily enhance performance for that task, and cause detriments to attention allocated to background tasks. This effect may be due to the specific task chosen for the foreground screen, but if the effect holds across different tasks then it could have implications for the growing size of screens in mobile devices and In-Vehicle Infotainment Systems.

Further, in **Experiment 2**, it is clear that the phony tablet acts more like a phone to participants than it does a tablet. It could have to do with the type of attention being deployed. The current study allows us to suggest that hand distance from relevant stimuli, weight, and dimensions of the device may not have as noticeable of an effect on performance as screen size with our task.

Despite the clear finding that screen size influences our ability to attend to information beyond a mobile device, there are several limitations to the ecological validity of this particular task. In everyday use of a mobile device, larger screens will occlude more information beyond the screen. While we controlled for screen occlusion by maintaining the targets of the mobile devices at a fixed point below the background screen, people may not duplicate this behavior in their daily interactions with mobile devices.

Second, the mobile device task we chose encouraged the participants to continuously monitor a difficult visuospatial task. However, the majority of tasks people currently perform with mobile devices include text-based information. Previous research suggests that larger screens improve text-based task performance due to the number of words one can assign to a line (see Brujin, Mul, & Oostendorp, 1992), and that splitting up an overall goal between screens can actually increase performance (Colvin, Tobler, & Anderson, 2004). However, these studies may have limited applicability to mobile devices.

Third, the most dangerous multitasking activities tend to have a continuous, primary background task (e.g. driving) and a discrete foreground task on the mobile device (e.g. texting). Additionally, this scenario presents a larger distance between the two locations, causing them to occupy different fields of view. The applied literature in aviation (e.g. Wickens and Andre, 1990) and driver distraction (e.g. Strayer, Watson, & Drews, 2011) addresses a Near-Field (foreground) and Far-Field (background) presentation of relevant stimuli, which does not have an explicit second screen. The current study may not be applicable to these scenarios and must be tested further.

Future Directions

Future mobile device multi tasking research should further explore hand-distance, or visible hands on the mobile device. Tseng, Bridgeman, and Juan (2012) suggest that hands in the visual field would draw attention to that location, causing a disproportionate amount of processing to that task in a multitasking scenario. This effect could explain why we did not see a difference in the foreground task with mobile devices.

Along these lines, we would like to look at individual differences in strategy as well, such as age and expertise. For example, due to the previously shown effects of training and DTC (see Schumacher Seymour, Glass, Fencsik, Lauber, Kieras, & Meyer, 2001), we may only need time to adjust to larger displays. Research also suggests that there may be an age preference for mobile device screen size. In demographic data, there is an interesting preference for types of mobile devices between age groups. In one study, nearly half of people 18-24 years of age used their phone while watching television daily, while people 55-64 years of age were most likely to use tablets during daily television viewings (Neilson Media Research, 2014). However, our sample only contained the former group, and age did not correlate with performance on phone or tablet. This could potentially lead to a familiarity bias for the phone against the tablet, but post-survey results indicate no correlation in device familiarity with performance.

Conclusions

In these studies we've seen evidence that suggests that when holding a mobile device, larger screens may decrease our ability to attend to information beyond the device. Our work shows that people can attend to background information on a computer with very minimal performance loss to foreground or background tasks if the foreground screen is small. However, once the screen size increases, dual task cost and reaction times for the background task both increase. It is possible that eliminating this configuration of multiple displays from one's routine at work, in the car, or at home could become a proven method for individuals to bolster their efficiency and performance at certain tasks.

We recommend that device designers and users consider how they might implement their displays in conjunction with other devices when making decisions about screen size. For example, the Tesla Model S electric vehicle currently features a 17-inch touch-screen display along its center console. The implications of large screens in dynamic situations should be thoroughly studied because manufacturers of these products are moving rapidly to produce an incredible range of display sizes and types for every scenario imaginable.

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