Touch Zone Sizing for Mobile Devices in Military Applications

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Abstract. Of late, the desire to adopt devices such as Apple iPads for use in military cockpits (for example, as "electronic flight bags" to replace paper-based reference materials) has increased. Two sources for touch screen design guidance for military applications are MIL-STD-1472 and manufacturer (e.g., Apple) interface style guides. However, minimum touch zone size and separation recommendations vary considerably between these sources. This study assessed the impact of manipulating touch zone size and separation in ungloved and gloved conditions. Despite a small sample size (n = 6), significant main effects of gloves and sizing guidelines were found. Unsurprisingly, participants were less accurate hitting targets on the first try when wearing gloves. Participants made no errors (i.e., activating a button other than the target) in the MIL-STD-1472 sizing condition irrespective of gloves. These results indicate that following MIL-STD-1472 guidelines reduces the likelihood of activation errors at the cost of decreased information density.

Keywords: Touch screen · Mobile · UI design · Design guidelines · Aviation · Gloved operation · Electronic flight bags

1 Introduction

1.1 Background

Mobile computing devices have become ubiquitous in everyday life. The average American spends nearly three hours per day on smartphones and tablets for business, entertainment, and other activities [1], interacting with touch screen interfaces while on foot, in cars, on airplanes, and in any other circumstance imaginable. These devices provide access to a wealth of information in a compact, portable format. Unsurprisingly, there is an increasing desire to adopt tablets (such as Apple iPads, Android tablets, or Microsoft Surface tablets) for use in aviation [2]. Tablets are becoming prevalent in military cockpits as "electronic flight bags" that replace paper-based reference materials and support flight management tasks such as fuel calculations.

Designers of mobile apps intended for use in military cockpits must design user interfaces that are compatible with this unique environment. Conditions in the cockpit that can interfere with touch screen operation include motion, vibration, and unexpected acceleration (due to turbulence); flight gloves commonly worn by aviators;

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placement of devices in locations (such as on the aviator's thigh) that are awkward for interaction; and divided attention due to multitasking. However, designers are faced with conflicting guidance regarding such fundamental design features as the size of touch screen active areas.

1.2 Touch Zone Size and Separation Guidelines

For user interfaces designed for military use, MIL-STD-1472 is the prevailing source of human engineering requirements, including detailed guidelines for the size and separation of touch screen active areas [3]. The MIL-STD-1472 touch screen guidelines originally evolved from recommended dimensions for physical buttons and were first published in their current form in 1999, well before the advent of modern touch devices. MIL-STD-1472 specifies a minimum touch zone size of 15 mm (0.6 in) square, with 3 mm (0.12 in) separation between zones for ungloved operation. The minimum touch zone size increases to 20 mm (0.8 in) square for gloved operation (as is common in military cockpits).

Tablet manufacturers also provide guidelines for designing user interfaces for their devices (for example, the iOS Human Interface Guidelines published by Apple). These "style guides" include guidance on touch zone size and separation. The manufacturer recommendations for size and separation tend to be significantly smaller than those in MIL-STD-1472. Apple's iOS guidelines specify a touch zone sizing of 44 × 44 points (a device-independent size measurement to account for varying pixel densities across iOS devices), which translates to a physical size of 8.5 mm (0.3 in) square [4]. The Apple guidelines do not specify a minimum separation between adjacent touch zones.

Increased touch zone size and separation can reduce selection errors, and may be warranted in cockpit environments due to such factors as motion, vibration, and unfavorable viewing and reach angles that can induce errors [5–7]. However, meeting the MIL-STD-1472 guidelines while also achieving desirable information density on a tablet screen can be challenging. Figure 1 shows the difference in vertical sizing between a standard Apple-developed iPad screen and a simple table of contents for an electronic flight bag app developed in accordance with MIL-STD-1472 touch zone sizing guidelines.

The disparity between the manufacturer style guides and the military standard raises several questions. Are the smaller touch zone sizes and separations specified in the manufacturer style guides suitable for applications for use in military cockpit environments (particularly for gloved operation), or are the larger MIL-STD-1472 guidelines still necessary for modern tablets? What effect does touch zone sizing and separation have on touch screen error rates in a moving vehicle? Could smaller touch zone sizing and separation be used to achieve higher information density on modern touch devices without an undesirably large increase in error rate? This technical examination presents the results of a study of human performance under various touch zone sizing and operation (ungloved versus gloved) conditions.

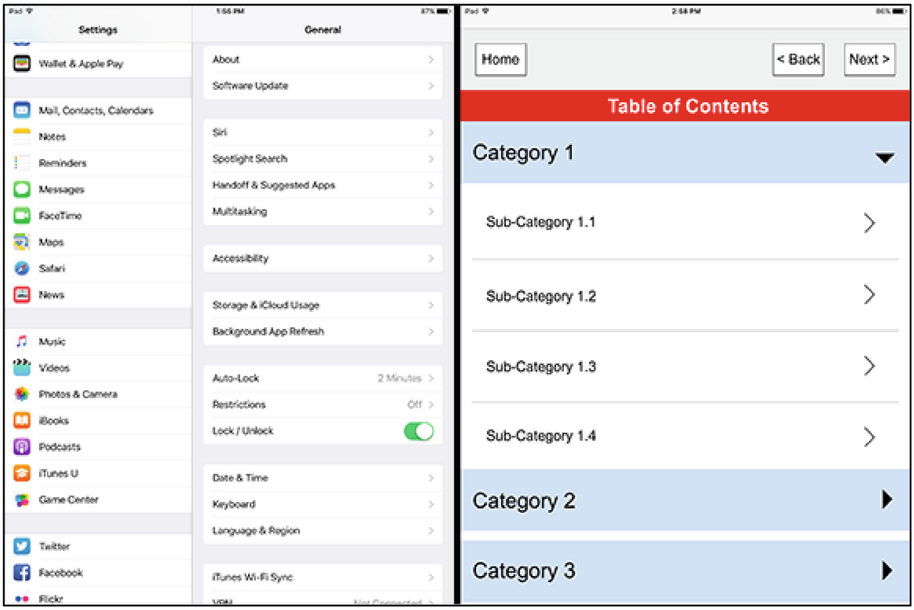

Fig. 1. G. Vertical sizing and separation for iPad screen (left) versus MIL-STD-1472-compliant screen (right).

2 Method

2.1 Design

Touch zone size and separation guidelines (Apple, MIL-STD-1472) and operation condition (ungloved, gloved) were manipulated within participants in a 2 × 2 repeated measures design. Each participant completed four experimental conditions, each consisting of fifty trials in which a specified target button was activated by the participant. To account for practice effects, the order of the conditions was randomized for each participant. The conditions are defined in Table 1.

Table 1. Guideline source and operation condition for each study condition

	Guideline source	Operation condition
Condition 1	Apple	Ungloved
Condition 2	MIL-STD-1472 (Normal sizing)	Ungloved
Condition 3	Apple	Gloved
Condition 4	MIL-STD-1472 (Gloved sizing)	Gloved

2.2 Stimuli

A web app developed for this study presented participants with a grid of numbered buttons on the iPad screen. To facilitate researcher observations, the first button activated in a trial turned green, and subsequent activations turned buttons yellow, orange, red, and purple. A "Clear" button located below the grid of numbered buttons reset the screen for the next trial. Three sets of stimuli with varying button sizing and separation were used for the study; the same stimuli were used for conditions 1 and 3. Apple's iOS guidelines do not specify a minimum separation between touch zones. Inspection of common iOS interface screens revealed a 1 to 2 pixel separation between touch zones, so a 2 pixel (0.4 mm) separation was used in conditions 1 and 3. Table 2 defines the button size and separation used in each condition and Fig. 2 shows resulting button layouts.

Table 2. Button size and separation for each study condition

	Button size	Button separation
Condition 1	8.5 × 8.5 mm	0.4 mm
Condition 2	15 × 15 mm	3 mm
Condition 3	8.5 × 8.5 mm	0.4 mm
Condition 4	20 × 20 mm	3 mm

Each set of fifty trials was structured so that each button in the grid was used as the target at least once. The buttons were subdivided into three categories: corners, with adjacent buttons on two sides; edges, with adjacent buttons on three sides; and middles, with adjacent buttons on four sides. Placement distinction was made in order to assess possible screen position effects on accuracy, as described by Henze et al. [6]. Each set of trials included twelve corner targets, nineteen edge targets, and nineteen middle targets. To achieve these numbers, some edge and middle targets were randomly selected to serve as targets a second time, and all four corner buttons were targeted three times each. The target order was randomized within each condition but was held constant across all participants. Table 3 shows the composition of stimulus items by grid location for each condition.

Table 3. Composition of stimulus items by grid location

	Conditions 1–3			Condition 4		
	Unique	Repeat	Total	Unique	Repeat	Total
Corner	4	8	12	4	8	12
Edge	16	3	19	14	5	19
Middle	15	4	19	12	7	19

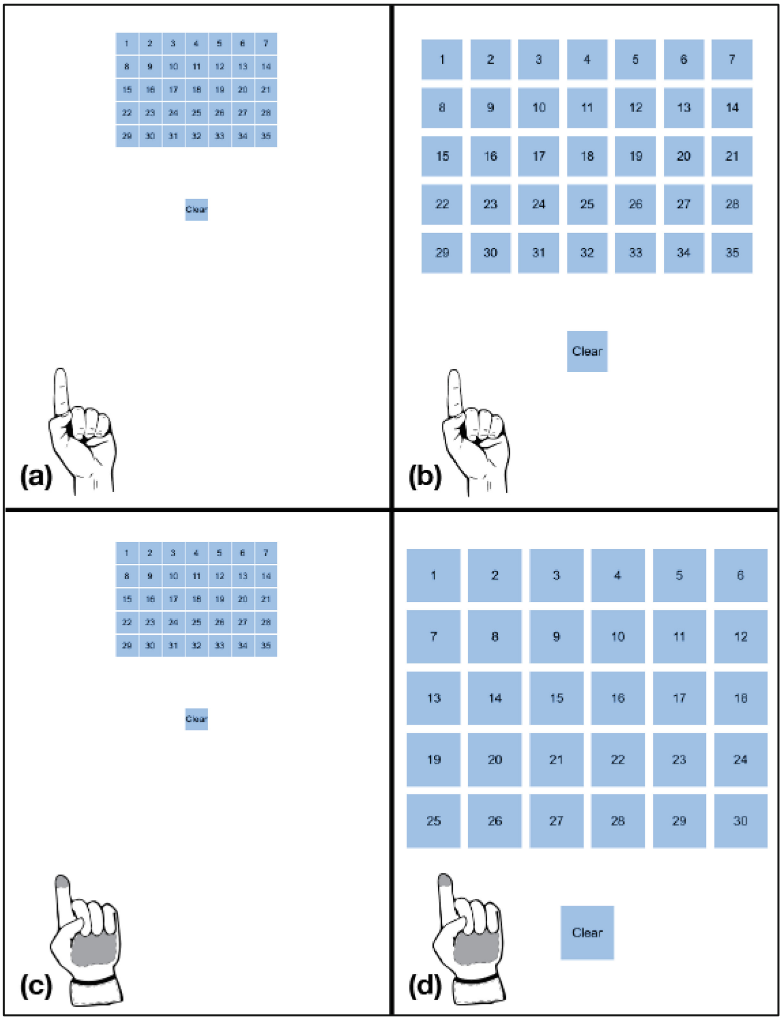

Fig. 2. Illustration of (a) condition 1, (b) condition 2, (c) condition 3, and (d) condition 4. Stimuli are presented to scale

2.3 Materials and Environment

Participants were seated in the back seat of an SUV for the duration of the study. A third-generation Apple iPad was strapped to the participant's thigh using a pilot's kneeboard mount as shown in Fig. 3. If the participant was right-handed, the iPad was mounted on the right leg and the participant was seated in the left seat; if the participant was left-handed, the iPad was mounted on the left leg and the participant was seated in the right seat. The researcher was seated beside the participant, on the same side as the iPad to facilitate observation of the participant's iPad interactions.

Fig. 3. iPad strapped to participant's thigh with pilot's kneeboard mount

To provide a motion and vibration component approximating conditions for in-cockpit tablet use, a second researcher drove the vehicle at low speed (approximately 5 MPH) around a closed road course. The course, located at the Georgia Tech Research Institute's Cobb County Research Facility, was 1.5 miles long and consisted of both paved and gravel roads with hills and curves.

The gloves used for the study were fire-resistant flying gloves of the type commonly worn by military aviators. Conductive fabric was sewn into the tips of the thumb, index, and middle fingers to provide compatibility with the iPad's capacitive touch screen. As shown in Fig. 4, the capacitive material primarily covered the pads of the fingers and did not cover the fingertips. Three sizes of gloves were available, and participants were instructed to select gloves that fit snugly.

Fig. 4. Flying gloves used in the study, with conductive fabric on index and middle fingers

2.4 Task

To begin each trial, the researcher announced the target button number. The participant was instructed to press the target button as soon as he or she located it, without rushing – accuracy was emphasized over speed. Participants were also instructed to use the index finger on the dominant hand to activate buttons, and to avoid steadying the iPad with the non-dominant hand. The researcher observed participant actions and recorded hits, misses, and errors, asking the participant for verbal clarification if necessary. The researcher then said "OK," which signaled the participant to press the Clear button to reset the screen for next trial. The researcher recorded misses for the Clear button in a separate data category.

2.5 Dependent Variables

The dependent variables for the study are defined below:

- *Hit.* The participant accurately selected the target button on the first try.
- *Miss.* The participant touched the screen but did not activate a button (neither the target button nor any other button). Multiple misses could occur within a trial.
- *Error.* The participant activated a button other than the target button. Multiple errors could occur within a trial.
- *"Clear" Miss.* Misses that occurred when the participant attempted to press the "Clear" button at the end of the trial. A "Clear" miss did not count against target accuracy for the trial – the participant could score a hit and "Clear" miss in the same trial.

2.6 Procedure

Upon their arrival to the study site, participants were given an overview of the task and the structure of the study, and written consent was obtained. Participants were then seated in the left or right back seat of the vehicle, based on whether they were right- or left-handed, and fastened their seatbelt. The researcher occupied the opposite back seat in the vehicle. Basic demographic data (gender, age, dominant hand, touch screen experience) were collected, and participants selected the appropriately-sized glove for the dominant hand from the three sizes available. Participants then strapped the iPad to their leg and were given a moment to become familiar with the web app stimuli. After any participant questions were addressed, the driver began driving and the first condition began.

Each condition took approximately six to eight minutes to complete. At the end of each condition, the vehicle was stopped for two to three minutes to allow participants to rest and to reset for the next condition. The total session took approximately 45 min per participant. As the vehicle returned to the parking lot at the conclusion of the session, participants were given an opportunity to make any additional comments on the study and were then dismissed.

3 Results

Six participants took part in the study. Five participants were right-handed (two females, three males) and one male was left-handed. Participant ages ranged from 25 to 42 (M_{age} = 37.2; SD = 6.8). All six participants responded to the question, “How experienced are you with using touch screen devices (like tablets or smartphones)?” with a response of “5 – extremely experienced” on a five-point scale ranging from “1 – not experienced” to “5 – extremely experienced.”

The study used a 2 × 2 within-subjects design with Latin square counterbalancing to control for order effects. The two independent variables were touch zone size and separation (Apple guidelines, MIL-STD-1472 guidelines), and operation condition (ungloved and gloved). The dependent variables were hits, misses, errors, and “Clear” misses, as defined above. Grand means and standard deviations for each experimental condition, reported as number of times in fifty trials that each dependent variable was observed, are shown in Table 4.

Table 4. Grand means and standard deviations for each experimental condition (n = 6)

Condition	Hits (SD)	Misses (SD)	Errors (SD)	“Clear” misses (SD)
1 Apple, no gloves	43.67 (*4.97*)	6.83 (*6.31*)	3.67 (*3.14*)	6.67 (*5.05*)
2 1472, no gloves	46.33 (*2.25*)	5.00 (*3.69*)	0.00 (*0.00*)	3.00 (*3.58*)
3 Apple, with gloves	37.33 (*3.83*)	12.00 (*5.40*)	6.33 (*3.67*)	12.67 (*6.41*)
4 1472, with gloves	42.00 (*4.34*)	13.33 (*8.55*)	0.00 (*0.00*)	11.17 (*5.74*)

A repeated measures analysis of variance was conducted. The results indicate a statistically significant main effect of gloves and sizing guidelines. No significant interaction of sizing guidelines by operation condition was revealed.

A main effect of operation condition on hits was identified, $F(1, 5) = 12.67$, $p = .016$. Participants’ accuracy on touching the target on the first attempt decreased when they had to perform the task with gloves. A main effect of gloves on misses, $F(1, 5) = 9.37$, $p = .028$, and “Clear” misses, $F(1, 5) = 32.93$, $p = .002$, was also revealed. Participants missed the target without selecting anything on the screen and missed the “Clear” target significantly more when wearing gloves. There was no main effect of gloves on errors, $F(1, 5) = 6.40$, $p = .053$. Figure 5 shows the mean performance for each dependent variable in the ungloved and gloved operation conditions.

A main effect of sizing guidelines was revealed for errors, $F(1, 5) = 15.00$, $p = .012$. Participants made no errors in the MIL-STD-1472 conditions, whereas participants did make errors in the Apple conditions. No main effects of sizing guidelines were found for hits, misses, or “Clear” misses. Figure 6 shows the mean performance for each dependent variable in the Apple and MIL-STD-1472 sizing guideline conditions.

To understand the effect of target position on participant accuracy, a 2 (Sizing: Apple, MIL-STD-1472) × 2 (Gloves: no, yes) × 3 (Position: corner, edge, middle) repeated measures analysis of variance was conducted. Percent accuracy was used as the dependent measure because there were an unequal number of trials for each

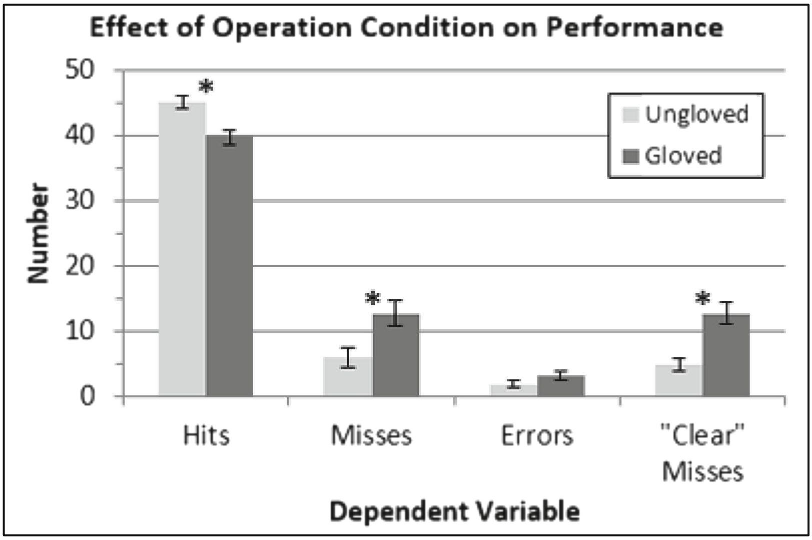

Fig. 5. Mean performance in the ungloved and gloved operation conditions. Bars represent standard error of the mean. * indicates statistically significant difference.

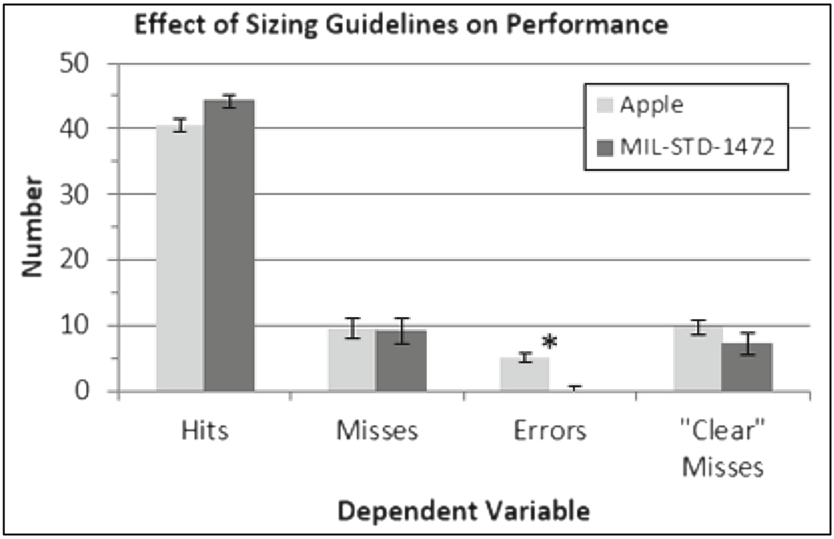

Fig. 6. Mean performance in the Apple and MIL-STD-1472 sizing guideline conditions. Bars represent standard error of the mean. * indicates statistically significant difference.

position: 12 corner, 19 edge, 19 middle. No significant main effects or interactions with target position were identified. Figure 7 shows the mean accuracy for each target position in the Apple and MIL-STD-1472 sizing guideline conditions and for ungloved and gloved operation.

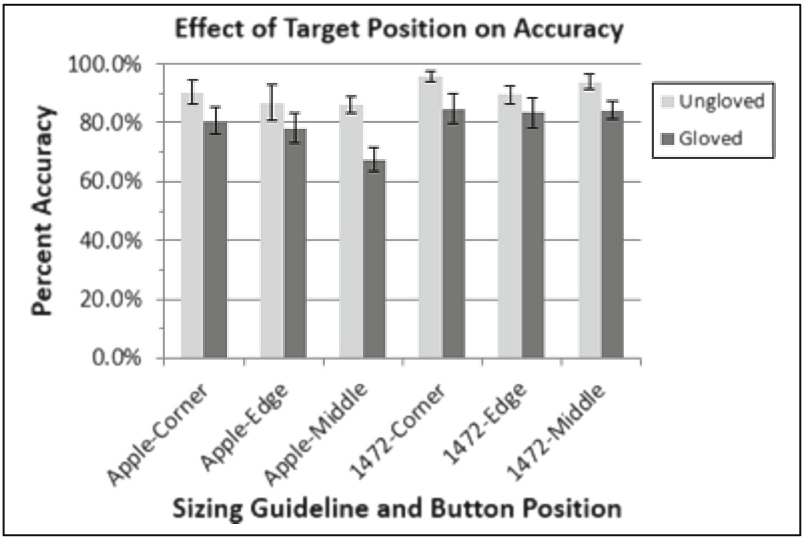

Fig. 7. Mean accuracy for each target position in the Apple and MIL-STD-1472 sizing conditions and for ungloved and gloved operation. Bars represent standard error of the mean.

4 Discussion

Overall accuracy was high during ungloved operation conditions. However, when participants wore gloved, accuracy declined significantly, and misses and "Clear" misses increased significantly. Sizing guidelines had a significant effect on errors such that there were no errors made for the larger buttons in the MIL-STD-1472 condition.

Two sources of misses and "Clear" misses were observed. First, participants touched the screen outside of the active button areas, either in the separation zone between buttons or outside of the button grid for corner and edge buttons and for the "Clear" button. Second, participants initiated scrolling while touching the screen. When a touch event is interpreted as a scroll initiation, button activations are inhibited. Although the data collected did not distinguish between these two types of misses, based on observation it appeared that scrolling was the more common cause. This observation is supported by the fact that miss rates are similar between the Apple and MIL-STD-1472 conditions, despite the fact that the small separation between buttons in the Apple conditions reduces the opportunity for separation zone misses.

The motion of the vehicle as it was driven around the test track was relatively consistent and gentle, but there were a few points in the loop (e.g., transitions between paved and unpaved segments) where the amount of motion made it difficult to accurately operate the touch screen. Vehicle motion contributed to misses and errors in two ways. First, gross movements of the vehicle occasionally disrupted accurate targeting by causing relative motion between the participant's hand and the iPad. Second, even minor vehicle movements at the moment the participant touched the screen caused hand movements that resulted in initiation of scrolling rather than activation of controls.

The effect of gloves on misses and errors can be attributed to two factors. First, the touch screen-compatible area of the gloves was on the pads of the fingers and did not cover the full tip of the finger. This required users to adopt a different method of activating targets when wearing gloves, using the pad of the finger, which had a larger contact area with the screen and also visually obscured more of the target compared with fingertip activation. A glove design that allows use of the fingertip for selection could reduce errors and misses. Second, the smallest gloves that were available were too large for two of the participants, so loose glove fabric sometimes made contact with the screen prematurely, throwing off targeting and occasionally inducing scrolling. The participants for whom the gloves were too large were observed manipulating the gloves frequently to keep the material as tight as possible around the fingertips. In a real-world situation, aviators would likely choose from a wider range of available glove sizes to obtain a better fit, potentially reducing scrolling-induced misses.

5 Conclusion

The results of this study indicate that following the larger MIL-STD-1472 sizing and separation guidelines reduces the likelihood of activation errors; however, this comes at the cost of decreased information density. As decreased information density can result in an increase in the number of control actions (e.g., scrolling to view additional content) and therefore in the number of error opportunities, additional research is needed to investigate the tradeoffs between touch zone sizing and information density.

Future research studies should increase the number of participants and the number of trials for additional statistical power. An effect of target location (corner, edge, middle) is expected such that more errors will occur for middle targets, which provide more opportunity for accidental activation of surrounding buttons. A wider range of glove sizes should be made available to eliminate problems with fit. Data collection should be expanded to distinguish targeting misses and scrolling-induced misses, and also to collect timing data to support consideration of Fitts' Law. Additional sizes of targets and separation distances should also be manipulated to identify optimal user performance with respect to the trade-offs between accuracy, misses, errors, response time, and information density. These data are necessary to understand for critical aviation situations in which time is short and accuracy is required.

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