Size Matters: The Effects of Interactive Display Size on Interaction Zone Expectations

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ABSTRACT

The goal of our research was to understand the effects of display size on interaction zones as it applies to interactive systems. Interaction zone models for interactive displays are often static and do not consider the size of the display in their definition. As the interactive display ecosystem becomes more size diverse, current models for interaction are limited in their applicability. This paper describes the results of an exploratory study in which participants interacted with and discussed expectations with interactive displays ranging from personal to wall-sized. Our approach was open-ended rather than grounded in existing interaction zone models in order to explore potential differences in interaction zones and distances. We found that the existence of different interaction zones and the distance at which these zones are relevant are dependent on display size. In discussion of the results, we explore implications of our findings and offer guidelines for the design of interactive display systems.

CCS CONCEPTS

• **Human-centered computing** → *Interaction design theory, concepts and paradigms*;

KEYWORDS

Embodied interaction, interaction zone, large displays, proxemics.

1 INTRODUCTION

The use of large interactive displays has become more popular as high-resolution displays become cheaper and natural user interfaces become more usable. These displays are used in a wide range of applications that can accommodate co-located collaborative users as well as single-user instances. A common theme across these applications is the notion of different "interaction zones," where different contexts of interaction are enabled at different distances from the display. The same gesture, for example a top-to-bottom hand wave, may elicit different reactions from the system at close and far distances from the display. Despite the growing diversity in display sizes, the heuristics on how to best design interactions for these displays vary greatly, especially for interaction zone distances. Not all display sizes may have the same interaction paradigms and knowing how users expect to interact with a display is valuable when designing for these extra large display environments.

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Proxemics and Interaction Zones. Hall introduced the notion of proxemics to categorize interpersonal distances for interaction [10]: intimate (15-46cm), personal (46-122cm), social (1.2-3.7m), and public (3.7-7.6m). While the theory of proxemics was developed to explain social phenomena, HCI researchers have applied proxemics to interaction design. Ballendat et al. [2] was one of the first to expand upon Hall's original theory. Other researchers have also investigated the use of zones for interaction with displays. Interaction zone distances vary greatly across studies with different levels of granularity. For example, Ju et al. [14] describe four zones: Intimate (0-46cm), Personal (46-61cm), Social (61-100cm), Public (100cm-122cm). Dostal et al. [7] describe three zones: Close (0-125cm), Medium (126-250cm), and Static (>250cm). Later work by Dostal et al. [8] specify expanded distances for interaction (0-2m, 2-3.5m, 3.5-5m, respectively). Dingler et al. [6] describe zones in terms of gesture type: Touch (0m), Fine-grained (0-.5m), General, (.5-2m), and Coarse (2m). For nearly all studies, the farthest zone ends at 3 meters, with Dostal et al's work an exception at 5 meters [8]. Other notable work in this area includes [3, 4, 13, 17, 21, 23].

Display Size Variance. Work in proxemics has focused on medium (e.g., 140cm diagonal) to large (e.g., 390cm diagonal) displays rather than typical monitors (e.g., 68cm diagonal). Inkpen et al. [11] provide an early summary of display factors found in the literature; however, this work does not address the relationship between display size and interaction zone distance. Though Ball et al. [1], Peck et al. [19] and Yost et al. [24] all used the same extra large, high-resolution display, most "large" display research has been limited to what we classify as medium- to large-sized displays. For example, Vogel and Balakrishnan [22] used a 127cm diagonal plasma display, Jakobsen et al. [12] used a 2.8m wide projector display, and Chung et al. [5] created a multi-device environment consisting of two separate 1.2m by 1.8m rear-projected displays. Markussen et al. [18] explored interactions with the virtual space beyond a physical display.

Interaction Considerations. In large display environments, gestures can be used to support and enrich the user's control over the system by providing physical context for interaction. At a close enough distance, the user can directly interact with the display through touch and multi-touch functionality. However, users may not be able to touch all regions of the display, which prompts the need for mid-air interactions [20]. The use of embodied interaction has focused on the use of position for controlling zoom and focus, with users typically viewing this type of interaction as "natural" [15]. This technique has been proven to be useful by many researchers (e.g., [1, 15, 16, 22, 24]). However, it is important to consider how to interpret interactions performed at different distances from the display. The same interaction may have a different response based on the physical location of the user.

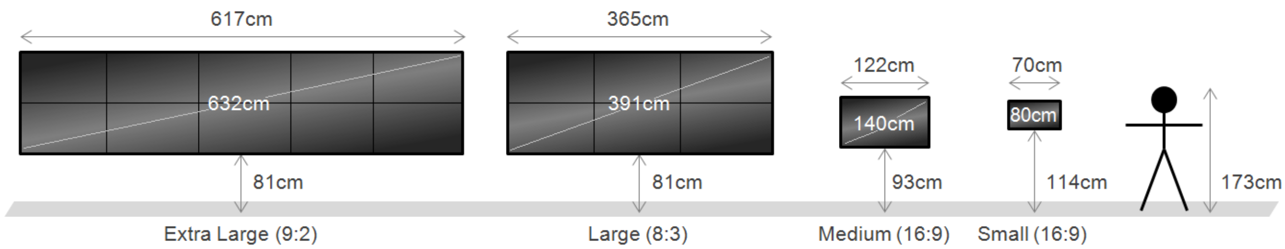

Figure 1: Display width, diagonal, mount position, and aspect ratio relative to average participant height in centimeters.

2 METHODOLOGY

The goal of our work was to investigate user expectations with a range of interactive display sizes, framed by the following research questions:

- What types of interaction zones do users expect?
- Which interaction zones do users find meaningful?
- How does display size affect the expected zone distance?
- Are user expectations affected by the content on the display?

Related work in the areas of proxemics and interactive provide some insights to these questions, but this work is often focused on static interaction zones. Our study was purposefully ungrounded in known interaction zones to discover new zones or distances.

Participants. Twenty-three participants (7 female) were recruited from a large technology organization with a median age range of 25-34 years and average height of 173cm (SD=8cm). All participants had experience with at least one type of visualization (infographics, scientific visualizations, visual analytics) and one type of natural user interface (touch, gesture, voice).

Display Sizes. Four display sizes were used in the study: Extra Large, Large, Medium, and Small. We chose these display sizes because they represented a range of consumer (Small), commercial (Medium, Large), and specialized (Extra Large) display sizes available at the time of the study. Figure 1 is a summary of display sizes, aspect ratios, and mount points of the display conditions used in the study. Displays were positioned on their own walls in a 7x11 meter room and the experiment area was clear of furniture and equipment. The Small display was an ultra-high definition 4K display while the Medium, Large, and Extra Large displays were standard definition 1080p displays. The Large and Extra Large displays were installed as a continuous multi-display unit, therefore the Extra Large and Large displays were assigned as a between subject condition.

Visual Stimuli. One of three types of visualizations was shown on the displays to provide a realistic context of use for participants during their study sessions: Graph, Map, or Text. The visualizations supported actions such as zoom, pan, and details on demand, and were presented in full-screen mode. Multiple types of visualization were chosen as visual stimuli to increase realism of the display interaction while exploring the effects different visual stimuli may have on interaction zone expectations. The visual stimuli were assigned as a within subject condition.

Procedure. For each display, participants were guided from room entry to initial display responsiveness, then on approach to the display until they reached touch distance, then to retreat from the display. They were asked to discuss their interaction expectations using the following guide:

- When do you expect the display to respond to you?
- What happens as you approach the display?
- How close should you be to touch the display?
- As you walk away, when do you expect the display to stop responding to you?

For each question, participants were asked to explain how they expected the display to react and what they expected to see in terms of the visual stimuli. Participants were encouraged to think aloud and were not limited to commenting on only engagement, touch, and exit interactions, nor were they limited in where or when they could move in the room. Unstructured discussion often occurred between questions. If the participant mimed or described gestures and expected reactions from the visualization, the moderator would attempt to simulate these interactions in the visualization tool to confirm expected behavior. Participants were given an opportunity to make additional comments regarding their expectations at the end of the study session. The order of the different display sizes and the assignment of visual stimuli were randomized. All 23 participants experienced the Small and Medium displays, 10 experienced the Large display, and 13 experienced the Extra Large display.

3 RESULTS

Participants expected to be able interact with the displays across five interactions zones. Display size had an effect on certain interaction zones and where these interaction zones were expected. Visualization type was not found to have an effect on interaction zone expectations for any display size.

Interaction Zones. Our first research question asks, *what types of interaction zones users expected when interacting with displays*. We observed five distinct interaction zones. Three zones (Engage, Touch, Exit) were explicitly probed for during the study while two zones (Acknowledge, Intermediate) emerged during analysis of participant behaviors and comments. Table 1 summarizes observed distances of Interaction Zones for each Display Size.

The *Acknowledge* interaction zone was the distance at which participants expected the display to *first recognize* but not necessarily engage with them. The Acknowledge zone was identified through analysis of participant behaviors and comments. A few participants (n=6) expected the display to acknowledge their presence through visual feedback, but not yet accept verbal or gesture input.

The *Engage* interaction zone was the distance at which participants expected to be able to *first interact* with a display. Most participants (n=19) expected only macro gestures (e.g., moving arms and body) to be recognized at this distance. Three participants expected finer micro gestures (e.g., hands and head gestures) to be recognized at this distance.

	Acknowledge			Engage			Intermediate			Touch			Exit		
	M	*SD*	*N*	*M*	*SD*	*N*	*M*	*SD*	*N*	*M*	*SD*	*N*	*M*	*SD*	*N*
Extra Large	4.90	1.7	2	4.34	1.6	13	1.65	0.6	2	0.82	0.4	13	5.39	1.9	13
Large	5.30	1.8	3	3.10	0.7	10	1.56	0.1	5	0.61	0.1	10	4.82	1.2	10
Medium	4.20	1.1	2	2.34	0.9	23	1.49	0.3	8	0.64	0.2	23	3.26	1.1	23
Small	1.20	-	1	1.38	0.6	22	1.18	0.2	5	0.55	0.1	23	1.94	0.9	23

Table 1: Observed distances of interaction zones for each display size in meters (Mean, SD, N participants)

The *Intermediate* interaction zone was a range between the Engage and Touch zones in which participants expected to be able to *interact differently* with a display than in other zones. The Intermediate interaction zone was identified in analysis of participant behaviors and comments. While for most participants (n=17) macro gestures were still recognized, for some participants (n=9), this was also the distance at which micro gestures would now be recognized.

The *Touch* interaction zone was the distance at which participants expected to be able to *touch to interact* with a display. Many participants expected touch to be the primary interaction method with the display and expected the system to stop recognizing macro (n=20) and micro (n=18) gestures at this distance.

The *Exit* interaction zone was the distance at which participants expected to *disengage interaction* with a display. This was the point that the system would no longer recognize any interactions with the display and was usually at a farther distance from the display than the Engage interaction zone. A few participants (n=4) explained that the further preferred distance was out of concern that the display would stop responding to them too soon.

Interaction Zones across Display Sizes. Our second research question asks, *which interaction zones are meaningful for different display sizes.* Non-parametric Kruskal-Wallis tests of display size show significant differences between interaction zones (factors with <5 observations omitted): Extra Large, $\chi^2(2) = 26.46$, $p < .001$; Large, $\chi^2(3) = 31.56$, $p < .001$; Medium, $\chi^2(3) = 59.26$, $p < .001$; and Small, $\chi^2(3) = 46.35$, $p < .001$. Post-hoc Mann-Whitney U pair-wise comparisons show where these zones differed across display sizes (Table 2). All five interaction zones were observed for the Extra Large, Large, and Medium displays. The Small display did not have significant observations of a separate Acknowledge zone.

Display Size Effects on Interaction Zones. Our third research question asks, *how display size affected the distance of an interaction zone.* Non-parametric Kruskal-Wallis tests of interaction zones show significant differences between display sizes (factors with <5 observations omitted): Engage, $\chi^2(3) = 40.11$, $p < .001$; Intermediate, $\chi^2(2) = 6.21$, $p = .045$; Touch, $\chi^2(3) = 10.78$, $p = .013$; and Exit, $\chi^2(3) = 38.90$, $p < .001$. Post-hoc Mann-Whitney U pair-wise comparisons between display sizes show where these sizes differ across interaction zones (Table 3). Small and Medium displays differed in Engage, Touch, and Exit interaction zones. There were some differences between the Medium, Large, and Extra Large displays. The larger the display, the further away the Engage and Exit interaction zones. Note that there was less than 0.5 meter difference between the Intermediate interaction zone distances across all display sizes.

Additionally, we examined the horizontal Field of View (FOV) for the Engage interaction zone distance). A non-parametric Kruskal-Wallis test shows significant differences between display sizes for Engage FOV, $\chi^2(3) = 40.66$, $p < .001$. Post-hoc Mann-Whitney U pair-wise comparisons identify where preferred Engage FOV θ differed across display size (Table 4). There were no significant differences between the Extra Large (M=37°, SD=10°) and Large (M=32°, SD=6°) Engage FOV, and between the Medium (M=15°, SD=5°) and Small (M=16°, SD=7°) Engage FOV. There were differences between the Small/Medium and Large/Extra Large display sizes. Participants preferred Engage distances further away for the Large and Extra Large displays and closer for the Small and Medium displays.

	Small	Medium	Large
Medium	498.0	–	–
Large	265.0***	278.5***	–
Extra Large	264.0***	278.0***	102.0

p < .05*, .01**, .001***

Table 4: Post-hoc Mann-Whitney U pair-wise comparisons between display sizes and Engage field of view.

Visualization Effects on Interaction Zones. Our fourth research question asks, *how content on the display affects interaction zone expectations.* Non-parametric Kruskal-Wallis tests of visualization type (Graph, Map, Text) did not show significant effects by interaction zone (factors with < 5 observations omitted): Engage, $\chi^2(2) = 3.24$, $p = .198$; Intermediate, $\chi^2(2) = 1.93$, $p = .381$; Touch, $\chi^2(2) = 4.46$, $p = .108$; Exit, $\chi^2(2) = 2.22$, $p = .329$. Nor were there effects by display size: Extra Large, $\chi^2(2) = 0.48$, $p = .786$; Large, $\chi^2(2) = 0.29$, $p = .866$; Medium, $\chi^2(2) = 1.01$, $p = .604$; Small, $\chi^2(2) = 2.58$, $p = .276$.

4 DISCUSSION

The goal of our research was to understand 1) what types of interaction zones users expect, 2) which interaction zones are meaningful, 3) how display size affects expected distance, and 4) the effects of content on user expectations. While our study focused on specific interaction zones, participants were asked to identify where these zones existed rather than confirming if these zones existed at a particular distance. The open-ended nature of this study differs from related work that has focused on testing distance hypotheses for various interaction zones.

Zones for Interaction. We observed five distinct interaction zones in our study:

- *Acknowledge*: The distance from a display that a system should first recognize but not yet engage with a user.
- *Engage*: The distance from a display that the user should be able to first interact with a system.
- *Intermediate*: The distance from a display that the user expects to interact differently (e.g. respond to fine-grained gestures) with the system than in further or closer zones.
- *Touch*: The distance from a display that the user can touch the display to interact with the system.
- *Exit*: The distance from a display that the user expects the system to disengage interaction.

	Extra Large				Large				Medium				Small			
	Ack	Engage	Inter	Touch	Ack	Engage	Inter	Touch	Ack	Engage	Inter	Touch	Ack	Engage	Inter	Touch
Engage	19.5	–	–	–	31.0	–	–	–	46.0*	–	–	–	10.5	–	–	–
Inter	7.0	116.5*	–	–	21.0*	105.0**	–	–	19.0*	440.0***	–	–	4.0	318.5	–	–
Touch	29.0*	260.0***	26.0	–	36.0**	155.0***	65.0***	–	49.0**	805.0***	220.0***	–	24.0	730.0***	129.5***	–
Exit	13.5	146.5	3.5*	91.0***	23.0	57.5***	15.0**	55.0***	37.0	420.5**	38.5***	276.0***	4.0	395.0**	32.5*	284.5***

$p < .05^{*}, .01^{**}, .001^{***}$

Table 2: Post-hoc Mann-Whitney U pair-wise comparisons between interaction zones for each display size.

	Engage			Intermediate			Touch			Exit		
	Small	Medium	Large	Small	Medium	Large	Small	Medium	Large	Small	Medium	Large
Medium	315.5***	–	–	23.0	–	–	443.5**	–	–	362.0***	–	–
Large	261.5***	337.0*	–	17.0*	49.5	–	359.5	405.5	–	280.5***	309.0**	–
X Large	260.0***	321.0***	90.0	17.0	43.0	20.0	356.5*	391.5	99.5	289.5***	332.0**	107.0

$p < .05^{*}, .01^{**}, .001^{***}$

Table 3: Post-hoc Mann-Whitney U pair-wise comparisons between display size for each interaction zone.

Hall's Interpersonal		Our study's	Medium	Large
Intimate	15-46cm	Touch	64cm	61cm
Personal	46-122cm	Intermediate	149cm	156cm
Social	1.2-3.7m	Engage	2.3m	3.1m
Public	3.7-7.6m	Ack./Exit	4.2m	5.3m

Table 5: Comparison of Hall's proxemics zones to our study results for Medium and Large display sizes.

Our interaction zones are similar to those proposed in related work (e.g., [6–8, 12]), although with differences in the semantic purpose or expected interaction within those zones. We also note that our results also differ from related work in a variety of ways (e.g., [3, 4, 14]), such as the number and distances of interaction zones, and the ways participants expect to engage. The greatest differences were in the farthest zones proposed by related work (2.7 meters) compared to ours (4 meters) (e.g., [3, 14, 19]).

Display Size Matters. Display size influences where users expected to be able to perform different interactions. As display size increases, so should the interaction zones, with the exception of the Intermediate zone (for fine-grained gestures), which remained constant across display sizes. The results of our study suggest that there are at least three classes of displays:

- *Small*: Personal desktop workstation displays, such as single or multiple-monitor setups.
- *Medium*: Consumer television-sized displays ranging from 100 to 200 centimeters wide.
- *Large*: Wall-scale displays that are measured in meters. This includes our study's Large and Extra Large size displays.

The increasing affordability of displays in the Medium sized display class makes these displays reasonable for home, office, and other types of applications. The Large and Extra Large displays on the other hand are still quite expensive for consumers.

Social and Physical Models for Interaction. Our interaction zones more closely follow the original proxemics zones proposed by Hall [10] than the related work [3, 14], (Table 5). These mappings suggest that users view proximity to a display similarly to how they view proximity in a social setting.

The preferred horizontal Field of View (FOV) at the Engage interaction zone distance is directly related to the optimal angle for human peripheral vision [9] . Preferred FOV θ for the Small and Medium displays was 15 degrees, optimal for reading text. Preferred FOV θ for the Large and Extra large displays was θ of 30 degrees, optimal for viewing color, shapes and symbols (Figure 2). Small displays are appropriate for systems that rely on textual interfaces, Large displays are best for shape and symbol focused interfaces, and Medium displays are fit both text- and symbol-based interfaces.

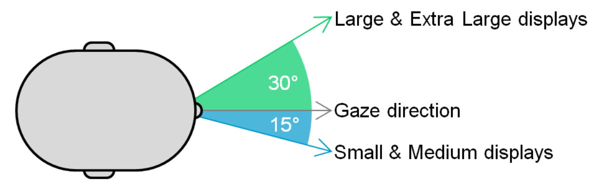

Figure 2: Recommended FOV θ for Small, Medium, Large, and Extra Large display sizes at the Engage interaction zone.

Guidelines for System Design. Our results offer a basic understanding of how display size affects interaction zone distance expectations that can be used to inform the design of an interactive display. They are meant to supplement, rather than to supersede, the contextual design of a system that will make additional considerations for the user, task, and tool (see Table 6).

	Small Desk-size	Medium TV-size	Large Wall-size
Ack./Exit	+0.5m Engage	+1m Engage	+1.5m Engage
Engage	15° FOV	15° (text) 30° (symbols)	30° FOV
Interm.	1.5 meters from display		
Touch	1 meter from display		

Table 6: Recommended distances for interaction zones across multiple display size classes.

5 CONCLUSION

We found that display size matters when designing interactions for small, medium, and large displays. This study describes five distinct interaction zones that vary in distance according to display size and not by visualization type. Our work extends previous work on proxemics-based distance by showing how larger interaction zones are required for larger displays. One size clearly does not fit all. While we found strong evidence of size effects on interaction zones, our work is limited in that we did not explore the effects of orientation (other tenants of Ballendat et al.'s proxemics model [2]), multi-user collaborative environments, or public settings.

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