Everything to Gain: Combining Area Cursors with increased Control-Display Gain for Fast and Accurate Touchless Input

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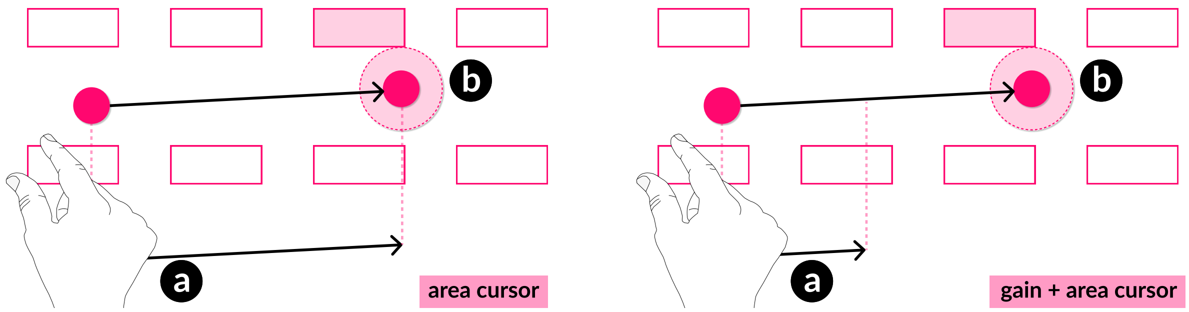

Figure 1: Touchless displays often use pointing interactions where users control an on-screen cursor with mid-air hand movements. Increased levels of control-display gain result in larger cursor displacement due to hand movement (a), allowing more rapid traversal at the cost of precision. Area cursors enable more flexible pointing by implicitly targeting the nearest widget to the cursor (b), reducing the need for precise targeting. We investigate the relationship between area cursors and control-display gain, finding these to be a mutually beneficial combination for touchless cursor control.

Abstract

Touchless displays often use mid-air gestures to control on-screen cursors for pointer interactions. Area cursors can simplify touchless cursor input by implicitly targeting nearby widgets without the cursor entering the target. However, for displays with dense target layouts, the cursor still has to arrive close to the widget, meaning the benefits of area cursors for time-to-target and effort are diminished. Through two experiments, we demonstrate for the first time that fine-tuning the mapping between hand and cursor movements (control-display gain – CDG) can address the deficiencies of area cursors and improve the performance of touchless interaction. Across several display sizes and target densities (representative of myriad public displays used in retail, transport, museums, etc), our findings show that the forgiving nature of an area cursor compensates for the imprecision of a high CDG, helping users interact more effectively with smaller and more controlled hand/arm movements.

CCS Concepts

• **Human-centered computing** → **Gestural input**.

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Keywords

Mid-Air Gestures, Area Cursors, Touchless Interaction, Touchless Widgets, Control Display Gain

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1 Introduction

Touchless interfaces enable users to interact with public displays without direct contact. In addition to offering new input affordances [55], touchless interaction can also enhance the hygiene of using public displays [14, 42, 50] and allow interaction with displays that are out of reach [23, 47, 65] (e.g., behind shop windows or enclosed in museum exhibits). Touchless input spans a growing variety of new public display use cases, including retail [59, 63], restaurants [62], tourism [54, 60, 71], and advertising [40], often differing in display size, control mechanisms, and required levels of precision. This breadth of interaction opportunities has inspired research into novel input techniques, and enhancing the usability of fundamental interactions remains a key challenge to more widespread adoption of the interaction modality.

Touchless displays often use cursor-based pointing interactions, where users manoeuvre an on-screen cursor by moving their hand in mid-air. User interface widgets, such as buttons and sliders, can be targeted by the cursor and activated with a hand gesture or cursor dwell [57, 67]. An important parameter in any pointer-based interaction is the ratio of hand movement to cursor movement, i.e., the control-display gain (CDG) [27]. Higher gain can make it easier to traverse large distances on screen, but at a cost of cursor stability and precision [39, 48, 53]. Lower gain addresses this, though larger and longer cursor motions are necessary, which can decrease responsiveness and increase fatigue. Finding the right balance is key to improving the usability of a touchless cursor interface.

Alternative pointing techniques have been developed to simplify targeting. One such example, which we focus on in this work, is the use of an *area cursor* which reduces the need to move the pointer to precisely overlap the desired target. Area cursors use the region surrounding the pointer for selection instead of just the tip of the pointer, targeting any object that falls within its area [33, 76]. Dynamic area cursors are an enhancement of these, where the targeting range of the cursor expands to enclose the nearest user interface element [18, 28, 37, 46, 56, 66, 69]. These can improve interaction time by implicitly targeting user interface elements from a distance, and enable users to reach targets with less hand/arm movement, improving comfort and helping address concerns around fatigue when using touchless gestures for input [30, 41, 69].

Area cursors are still affected by CDG, even though their implicit and more forgiving targeting might imply the effect of gain is diminished. Users still need to negotiate boundaries between user interface elements and resolve ambiguity between adjacent targets. Users also need to maintain precise control during continuous interactions like drag-and-drop, steering, or slider adjustment [67]. These may be more sensitive to CDG since the cursor needs to move to a position (e.g., on the slider bar) without the same benefits that the area cursor offered for selecting the widget in the first place (e.g., for taking control of the slider handle). Dense target layouts also limit area cursor size and diminish the benefits of selection from a distance [5, 28, 46]. Our work builds on previous studies of CDG and area cursor targeting by exploring the relationship between these aspects of cursor behaviour and input performance. Finding an effective CDG ratio for an area cursor is important for ensuring users can comfortably and effectively reach all targets on screen, whilst remaining in control to avoid unintentional selections.

In this paper, we present two experiments that investigate the complex relationship between the use of an area cursor (specifically the *proxemic cursor* technique [68, 69]) and CDG. We characterised cursor performance at varying CDG levels across various input tasks, layouts and screen configurations, to give novel empirical insights that can help interface designers select an appropriate CDG ratio. Our first experiment (N = 21) investigated input performance and usability across two input tasks (button activation, slider control) with four CDG levels (ranging from 1.0 to 3.5), on four simulated display sizes (ranging from 27" to 55"). Our second experiment (N = 17) investigated input performance and usability in a targeting task with four CDG levels (ranging from 1.0 to 3.5), on two simulated display sizes (27" and 55"), with four levels of target density, since more dense layouts place greater emphasis on cursor precision. Together, these studies give a thorough overview of how gain affects area cursor use under different interface conditions.

Our findings show for the first time that the more forgiving nature of a touchless area cursor can help compensate for the instability of increased control-display gain ratios and that, in conjunction, these enable users to interact effectively with smaller and more controlled hand/arm movements. This beneficial combination improves touchless cursor performance, makes it easier to interact with larger displays, and paves the way towards less fatiguing and lower-effort touchless interactions.

2 Related Work

2.1 Touchless Cursor Interaction

Touchless gesture systems often use cursor-based pointing interactions, where the user controls an on-screen cursor via hand movements in mid-air. There are different ways of mapping hand to cursor movements, but our focus in this research is on interactions where the cursor is controlled by hand translation, i.e., when the user moves their hand to the left, the cursor moves left too. This kind of pointing is used in state-of-the-art sensing platforms like Intel RealSense Touchless [31] and Ultraleap TouchFree [61]. Alternatives like ray-cast pointing can be effective in immersive environments, though are prone to pointing ambiguity [15, 43] and may be less accurate at a distance [13]. For public display scenarios where users are typically standing closer to the screen and interacting as part of a brief encounter, cursor translation is easy for users to understand and is physically comfortable. Designing effective touchless cursor interactions is not straightforward, however, because cursor position may be unintentionally affected by activation gestures [75], ambiguity about activation states can mislead users [21, 22, 67], and users might gesture in unintended ways to improve comfort [25]. Addressing these issues is crucial for touchless input to achieve its potential as an alternative (and hygienic [14, 26, 42, 50]) interaction modality for everyday public displays.

Many works have developed novel cursor adaptations intended to enhance targeting performance across a variety of input modalities. A common approach is expanding the 'width' of the cursor so that it effectively reduces the distance between the cursor position and target. Area cursors [33, 76] use an increased cursor width so that targets (especially small ones) can be more easily selected, though the larger cursor may enclose several nearby targets, especially with dense target layouts. Dynamic area cursors, e.g., *Bubble Cursor* [28] and *Bubble Lens* [46], were motivated by this problem. These expand effective cursor width to enclose the nearest target, such that one is always being implicitly selected, whilst avoiding the issue of multiple targets being within the area cursor.

Dynamic area cursor techniques can improve input performance via reduced movement time and increased accuracy, and when applied to touchless input [18] have the added benefit of reducing cursor instability and noise. There have been many novel adaptations of the dynamic area cursor, e.g., *LazyBubble* [37] changed cursor appearance during the transition between targets, *DynaSpot* [9] and the *Implicit Fan Cursor* [56] varied area cursor size based on movement speed, the *Hand Cursor* [66] used hand distance from the display to alter area cursor size, and *MultiFingerBubble* [16] used adapted cursor behaviour using multiple fingers at once. A simpler variant of the dynamic area cursor is the *Proxemic Cursor* [69], which adopts the targeting behaviour of *Bubble Cursor* [28] without altering cursor appearance: i.e., its effective width expands to the nearest target, but visual width remains the same.

These myriad area cursor enhancements reduce the need for precise pointing by relaxing the constraints for selecting and manipulating user interface controls. However, users must still maintain effective control over the cursor, e.g., for moving across or around user interface elements to reach others, or for continuous operations like slider adjustment or scale gestures that require fine positioning [67]. Whilst users do not need to fully move an area cursor to overlap targets, users still tend to move the cursor towards the desired target to increase confidence in its selection [69]. Therefore, supporting effective cursor control remains important, even though direct targeting is no longer required.

2.2 Control-Display Gain

A key design parameter in a cursor-based user interface is the control-display gain (CDG): the ratio of input movement to corresponding cursor movement on screen [27]. In a touchless system, CDG determines the relationship between mid-air hand movement and on-screen cursor movement, with higher CDG causing larger cursor motions for a given hand motion. Selecting an appropriate gain ratio for a touchless cursor interface is challenging because designers must balance comfort, fatigue, input time and precision, whilst mitigating the instability of touchless cursor control [11, 39, 53, 75] and allowing for individual differences in comfortable range of motion [29].

Increased gain ratios can enhance the ergonomics of interacting with larger displays, by reducing the necessary hand/arm movement to reach distant targets [8]. Minimising the required range of motion to reach distant targets may also reduce fatigue [29, 30], especially for targets located above shoulder height [67]. However, increased gain levels will amplify the instability of a touchless cursor, e.g., due to muscle tremor [72] and sensor inaccuracies. If CDG is too high then there is the risk of reduced pointing accuracy [8] and increased cognitive load, as users must adapt to the amplified cursor movements [12], especially when standing and unable to, e.g., place elbows on surfaces for comfort and stability [25, 29]. Conversely, lower gain may enhance precision [24] at the cost of longer interaction times [1, 36, 53], which can, in turn, increase fatigue because the arm is under tension for longer [30, 34].

Finding an appropriate gain ratio is not straightforward [8, 48] but is fundamental in determining the usability of a touchless cursor. Use of dynamic area cursors further complicate the selection of an appropriate CDG because they allow the cursor to target elements without being directly over them, since users only need to move close enough to make it the nearest target. One assumption is that an area cursor might favour a small CDG because of the reduced necessity to make large cursor movements. However, a higher CDG might be more beneficial for larger displays and could make it easier to move towards targets where an area cursor is less effective, e.g., due to surrounding targets.

2.3 Target Density

An important aspect of evaluating a pointing technique is ensuring it maintains good performance across user interface layouts with varying target density, i.e., working well for both sparse layouts where targets are spaced far apart (e.g., when selecting food items or checking out at a supermarket self-checkout), and more dense layouts with many targets in close proximity (e.g., when browsing a large list of options, filtering transit stations, or keyboard text entry). More dense target layouts affect input performance with regular pointers [5, 32, 64]. They can also reduce the efficacy of dynamic area cursors [5, 28, 46] because the maximum size of the area cursor will be constrained when there are other targets close by, preventing users from activating the desired target from a greater cursor distance. Target 'slips' [6], where the cursor falls off the intended target, are another concern with dense target layouts, especially for touchless cursors that may be unstable or affected by unintentional hand movement during activation gestures [75]. When the effective width of an area cursor is reduced and there is less space surrounding targets, there is increased likelihood of the cursor slipping onto an adjacent target and causing focus-dependent elements (e.g., menus) to disappear [10].

We include target density as a factor in one of our experiments to investigate the relationship between touchless area cursor performance and target density. We do this using a method established by Blanch and Ortega [5], who investigated the impact of 'distractors' (extra targets in addition to the one the user is instructed to select) on pointing performance. We use their distractor target layout algorithm for generating target layouts of varying density.

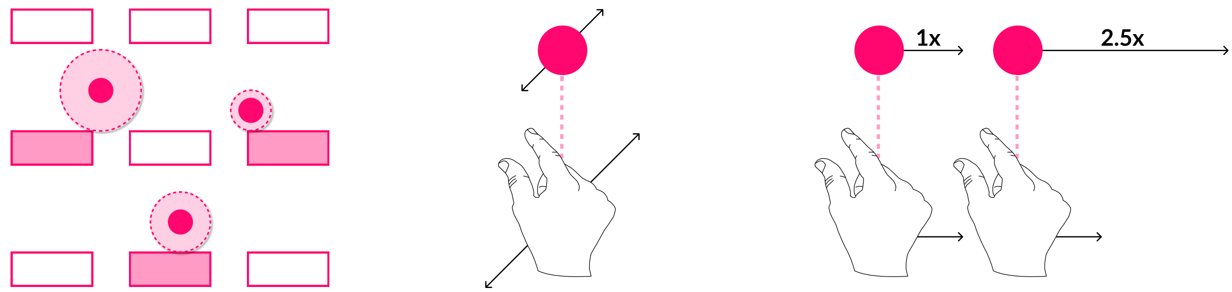
2.4 Summary and Contribution Statement

This paper contributes two experiments investigating the relationship between the use of a touchless dynamic area cursor (specifically the *proxemic cursor* [69] due to its minimalist appearance), control-display gain, and target density, for interacting with public displays. Dynamic area cursors still require movement towards targets and around distractor targets, and previous works have highlighted the challenges in finding balance between low and high gain levels. Our approach differs from prior studies on area cursor targeting through the novel use of CDG for further tuning cursor behaviour. We consider display size as an additional factor in our experiments, because gain might have a more meaningful effect on interactions with larger displays that necessitate larger hand/arm movements (which might impact on comfort and fatigue [30, 69]). This thorough investigation of touchless targeting gives insight into the relationship between area cursors and gain with touchless displays, leading to empirically supported insights that can inform the design of touchless cursor interactions and user interfaces, across a variety of display sizes and target densities, and provokes the need for further research into the impact of gain on area cursors and other enhanced selection techniques.

3 Touchless Cursor Implementation

3.1 Dynamic Area Cursor Mapping

We implemented a proxemic cursor [69] for our experiments. This is a dynamic area cursor whose effective width scales such that it always targets the nearest user interface element (as in Figure 2a). Unlike other area cursors (e.g., *Bubble Cursor* [28]), its visual size does not change, with targeting feedback given through target appearance instead of cursor expansion. This has the effect of encouraging movements towards targets to improve confidence [69].



(a) (b) (c)

Figure 2: Our dynamic area cursor increased its effective width to target the nearest object (a). The cursor moved in accordance with mid-air hand movements in front of the display (b). A constant gain multiplier was applied to cursor movements (c).

We mapped the on-screen cursor position to the centre point of the palm. There was a direct mapping between hand position and cursor position, i.e., we did not use a 'clutch' [8] so that users could move their hand without also moving the cursor. We used an upright display, so users controlled the cursor position using side-to-side and up-and-down hand movements (as in Figure 2b). We did not use hand distance from the display for cursor input (unlike *Hand Cursor* [66]), other than to disengage the cursor if the user's hand was too far from the usable range of the sensor.

3.2 Control-Display Gain

We implemented control-display gain using a constant gain multiplier. Our baseline multiplier of 1.0 gave a direct mapping of hand to cursor movements: i.e., 1 mm of hand movement resulted in 1 mm of cursor movement on screen. We used three increased gain multipliers (1.5, 2.5, 3.5), e.g., a multiplier of 2.5 would cause 2.5 mm of cursor movement for every 1 mm of hand movement (as in Figure 2c). We did not include a lower gain multiplier than 1.0 because this seemed an appropriate minimum. Lower multipliers would require users to make greater arm movements on larger display sizes, requiring a clutch or swapping control between both hands to reach display edges. This necessitates more movement, rather than optimising for less movement and exertion as we aim to do via increased gain. Constant gain multipliers of 2.5 and 3.5 have been used in prior research into pointing ergonomics [53], though we included 1.5 for more granularity at the lower end of the scale.

3.3 User Interface Task Layouts

Our experiments included two types of input task: *slider adjustment* and *button selection*. These are common interactions with different needs for cursor control (e.g., continuous precise adjustment vs discrete coarse selection with an area cursor). Users activated targets using an index finger-to-thumb pinching gesture. Pinching is an effective activation gesture [67] with minimal effect on the midpoint of the palm and does not require movement towards the screen, reducing unintentional target slips during activation [75].

Our slider task used a horizontal slider with a circular handle, used to scale a square (e.g., Figure 3a). Users were shown a target square and needed to adjust the slider so that the two squares matched as closely as possible. Our button selection tasks required activating one of several visible target buttons. In our first experiment, circular buttons were arranged around a circle using the ISO 9241-411 multi-directional selection task layout (e.g., Figure 3b). In our second experiment, circular buttons were arranged in layouts of varying target density, using the layout method described by Blanch and Ortega [5] (e.g., Figure 3c). More details about the experiment tasks and user interface layouts are given later.

3.4 Apparatus

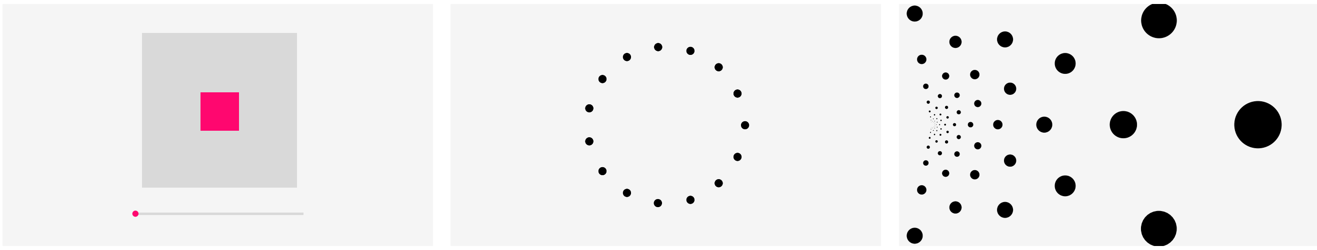
We used the Ultraleap Stereo IR 170 device for hand tracking. We placed the sensor on a 1 m high table, positioned 2.5 m in front of a 55" display with a 16:9 aspect ratio. This sensor placement improved sensing quality for the experiment by keeping hands directly above the sensor at a comfortable height, though in practice such sensors are likely to be integrated as part of the display and facing towards the user. The distance from the display ensured comfortable viewing angles and is a representative interaction distance for this size of display [17, 49]. We simulated various display sizes (27", 32", 43" and 55") by scaling the user interface and presenting it on the same 55" display for consistency.

4 Experiment 1: Display Size × Gain

4.1 Experiment Design

In this experiment, we investigated the relationship between control-display gain (CDG) and display size, when using the proxemic area cursor described previously. We used a within-subjects experiment design with two factors: *CDG* (1.0, 1.5, 2.5, 3.5) × *Display Size* (27", 32", 43", and 55"), giving 16 conditions. We used two experiment tasks: a *slider adjustment task* and a *button selection task*. Both are fundamental operations when interacting with a graphical user interface, and they enabled us to characterise cursor performance during a *continuous* operation that required precise control (slider adjustment) and a *discrete* operation that required fast and accurate targeting (button selection).

4.1.1 Task 1: Slider Adjustment. The user interface based on existing protocol from Waugh et al. [69], displayed a horizontal slider bar beneath a grey 'reference' square, which had a smaller and coloured 'user' square in front (as shown in Figure 3a and Figure 4). The dimensions of the user square were mapped to the slider bar, so that increasing the slider value (by moving the handle towards its



(a) (b) (c)

Figure 3: Users completed slider tasks where they had to match the size of two squares by adjusting a horizontal slider (a). Users also completed button selection tasks using two button layouts: a standard multi-directional selection layout with varying button size and distance (b) and a standard layout with controlled variance in target density (c).

right edge) would increase its size. Users were instructed to adjust the slider so that the user square matched the reference square.

Users had to first acquire control of the slider by targeting the handle then using a pinch gesture; then, whilst holding the pinch gesture, hand movements would reposition the slider handle. The interaction ended when the pinch was released. There were no other targets in this task and so the area cursor would effectively acquire the slider handle from anywhere on screen. This task emphasises the effect of CDG and display size during a continuous and precise input operation, distinct from the benefits of an area cursor.

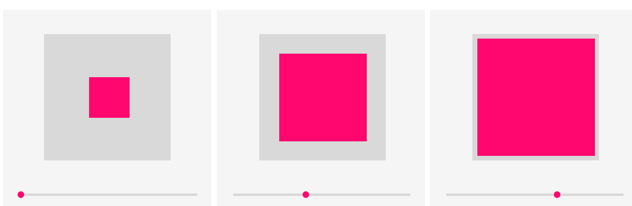


Figure 4: For each slider selection, users had to match the size of the grey reference square using a horizontal slider.

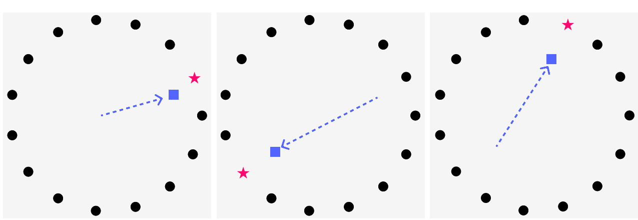


Figure 5: For each selection, users completed a sequence of 15 target (★) selections using the area cursor (■).

4.1.2 Task 2: Button Selection. The user interface displayed 15 circular targets, equally spaced around the circumference of a circle (as shown in Figure 3b and Figure 5). We used four variants of this layout, based on the ISO 9241-411 multi-directional selection task: these varied in terms of target width (24 mm, 32 mm) and amplitude (222 mm, 318 mm). These values were scaled proportionally across the four display sizes to maintain a consistent index of difficulty.

Users completed a sequence of 15 button selections per trial. The next target in sequence was highlighted via colour. Users targeted the intended target using the proxemic cursor, then confirmed selection using the pinch gesture.

4.2 Procedure

At the beginning of the experiment session, participants were shown how to use the touchless cursor system and were instructed to complete practice trials for each task type until they felt they were performant and comfortable, with a minimum practice time of 3 minutes. These practice trials helped to familiarise participants with the interaction tasks and would reduce potential learning effects in task performance data. Participants completed all slider tasks followed by all button tasks, or vice versa. Condition order was balanced within each task group, using a Latin square. Participants completed 12 slider adjustment tasks per condition, totalling 192 trials for Task 1, and completed one sequence of 15 button selections per target width × amplitude combination, per condition, totalling 960 button selections for Task 2. Both sets of tasks were completed within a single 90-minute session, including breaks.

4.3 Measurements

For Task 1, we measured:

- **Task Time:** starting when the hand crossed a threshold above the sensor and continuing until they pressed a physical button on the table with their non-gesturing hand, ensuring consistent timing for the start and end of the task;
- **Time to Target:** the duration between taking control of the slider handle and first reaching the target position (or task end time, if the user stops short of the target without ever fully reaching it);
- **Error Distance:** the pixel difference between final and target slider position;
- **Proximity:** the distance between the slider handle and cursor position when the user performed the pinch gesture.

The *task time* measure includes all phases of a single task, from targeting and taking control of the slider handle, to any final adjustments. We measured *time to target* separately as this may be indicative of initial ballistic movement [45] towards the target, without including time for more subtle adjustment. A potential limitation of *time to target* is that it may not represent the initial movement of slider adjustment if users grossly overshoot the intended target.

For Task 2, we measured:

- **Task Time:** the total duration between the first to the final target selections;
- **Selection Time:** the duration between completing selection N_{-1} and selection N;
- **Error Rate:** the ratio of incorrect selections;
- **Proximity:** the distance between the target and the cursor position when the user performed the pinch gesture.

4.4 Participants

We recruited 21 participants (10 male, 10 female, 1 non-binary; mean age 29 yr, SD 6.4 yr)) via institution email lists and posters. Participants were compensated with a £15 gift voucher. Our institution's ethics committee approved this study. Our experiment data is available via the Zenodo open research data platform [70].

4.5 Results

We used repeated-measures ANOVA for analysis, followed by post-hoc t-test comparisons of estimated marginal means. If data did not have a normal distribution (via the Shapiro-Wilk test) then the Aligned-Rank Transform [74] was applied first, followed by post-hoc comparisons using ART-C [19] where appropriate.

Table 1 and Table 2 show the results and analysis for Task 1 and Task 2, respectively. These tables include summary statistics for each dependent variable, and results from the repeated-measures ANOVA and post-hoc comparisons. Figure 6 and Figure 7 show the mean values for each dependent variable, per condition, for Task 1 and Task 2 respectively.

In summary of Table 1 and Table 2, the key results show that:

- *Display Size* had a significant effect on *task time* in Task 1, with shorter interaction times for 27" and 32" compared to the 43" display only, though had no significant effect on *task time* or *selection time* in Task 2.
- *Display Size* had a significant effect on cursor *proximity* in both tasks. Larger displays encouraged greater use of area cursor targeting. However, no significant differences between the two smallest displays.
- *CDG* had a significant effect on *time* measures in both experiments, though the effect sizes were weak and post-hoc comparisons show a limited number of significant differences, where lower gain was typically better.
- *CDG* had a significant effect on task accuracy, with generally lower *errors* for the smaller gain levels.
- *CDG* had a significant effect on cursor *proximity* in both tasks, with users making greater use of area cursor targeting for lower gain values.

4.6 Discussion

Our findings give insight into the effects of CDG on area cursor performance across different display sizes. Interaction time results show 1.5 CDG was generally faster than higher CDG (Table 1_2, Table 1_5, Table 2_2, Table 2_5)[1] though 1.0 CDG was only significantly faster in Table 1_5, suggesting there may be a 'sweetspot' gain rather than a more general trend of lower being faster. The effect size of these differences is modest, with the higher CDG still yielding usable interaction times. Higher CDG allows users to approach targets with less physical movement, with the area cursor reducing the need to target it as precisely although care may be needed to mitigate the potential for increased error rates (Table 1_8, Table 2_8) which were predominantly caused by slipping onto adjacent targets.

4.6.1 Control-Display Gain for Area Cursors. Whilst area cursors reduce the need to fully reach targets in order to select or activate them, users generally still move towards their intended target to resolve uncertainty [69]. This is reflected through the difference in cursor proximity measures for each task (mean 233 mm vs 86 mm for Task 1 and Task 2, respectively), with users steering the cursor closer to the target in Task 2 to avoid the distractor targets.

We expected lower CDG (1 and 1.5) to reduce cursor speed and promote greater levels of stability [24], although this was not always the case. For the slider control task, the higher gain levels (2.5 and 3.5) meant the slider was more sensitive to subtle movements and so making precise adjustments was more demanding (Table 1_2, Table 1_8). However, the difference in slider error was only 1.1 mm between the two lower gains {1, 1.5} (mean 3.1 mm) and the two higher gains {2.5, 3.5} (mean 4.2 mm). This difference may be negligible for when using a notched slider with discrete steps. For button selection, the error rate was 3.2% higher for gain levels of 2.5 and 3.5 than for 1.0 only (Table 2_5), though this effect was more pronounced on smaller displays (e.g., 3.4% for 27" vs 0.7% for 55" albeit not significantly different (Table 2_9)). Task time results exhibited similar patterns in a subset of gain contrasts, with significant but small differences (Table 2_2, Table 2_5). Higher cursor gains had less detrimental effects on input performance than anticipated, especially on the larger screen sizes, highlighting the potential benefits of applying higher gain to area cursor movement.

4.6.2 Effects of Display Size. Our results show that area cursor targeting was effective across all display sizes and that display size generally had minimal effect on task performance, with only slightly higher error rates for the smallest display size in Task 2 (Table 2_7) and some significant contrasts in Task 1 (Table 1_1, Table 1_4, Table 1_7). This would be expected with direct targeting as it naturally takes longer to reach distant targets, which users offset with faster hand movements. However, with an expanding area cursor, users do not need to move as far towards their intended target.

Users took advantage of the area cursor behaviour to a greater extent with the 43" and 55" displays, as shown by the greater proximity in both tasks compared to the two smallest displays (Table 1_{10}, Table 2_{10}). Proxemic cursors have only previously been evaluated using a 27" display [69], where it was observed that despite the availability of distal targeting, users still gravitated towards the visible region of their intended target. Our results suggest that this behaviour is less prevalent with targets that are farther away and/or being used on a smaller screen size. Area cursors therefore have the potential to be even more effective on larger displays.

5 Experiment 2: Display Size × Gain × Density

5.1 Experiment Design

In this experiment, we investigated the relationship between control-display gain (CDG), display size, and target density, when

[1] Note that Table 1_2 refers to the result labelled '2' in Table 1, Table 2_5 refers to the result labelled '5' in Table 2, etc.

Table 1: Experiment 1 Task 1 summary, ANOVA results, and post-hoc test results. Significant differences are highlighted.

	Task Time	Mean 6390 ms, SD 2799 ms, 95% CI [6081, 6697] ms			
	ANOVA	*Result*	*p*	η_p^2	*Post-Hoc Comparisons*
1	*Display Size*	F(3, 285) = 4.9	.002*	.05	27" < 43"* (p = .01), 32" < 43"* (p = .02), other p ≥ .06
2	*CDG*	F(3, 285) = 3.9	.009*	.04	1.5 < 2.5* (p = .03), 1.5 < 3.5* (p = .01), other p ≥ .14
3	*Display × CDG*	F(9, 285) = .52	.09		
	Time to Target	Mean 1796 ms, SD 1080 ms, 95% CI [1676, 1914] ms			
4	*Display Size*	F(3, 285) = 12.0	< .001*	.11	55" > all* (p ≤ .04), 43" > 27"* (p = .02), other p ≥ .18
5	*CDG*	F(3, 285) = 8.5	< .001*	.08	1 > 2.5 and 3.5* (p ≤ .03), 1.5 > 3.5* (p = .02), other p ≥ .11
6	*Display × CDG*	F(9, 285) = .43	.93		
	Error Distance	Mean 4 mm, SD 3 mm, 95% CI [3.4, 4] ms			
7	*Display Size*	F(3, 285) = 6.6	< .001*	.07	27" < 32" and 43"* (p ≤ .007), 43" < 55"* (p = .03), other p ≥ .64
8	*CDG*	F(3, 285) = 23.4	< .001*	.20	Lower for 1 and 1.5 than all other gain values* (p ≤ .02)
9	*Display × CDG*	F(9, 285) = 1.08	.38		
	Proximity	Mean 233 mm, SD 162 mm, 95% CI [215, 250] mm			
10	*Display Size*	F(3, 285) = 294.2	< .001*	.76	Higher for all larger displays* (all p ≤ .05), except 27" vs 32" (p = .06)
11	*CDG*	F(3, 285) = 7.8	< .001*	.07	3.5 > 1 and 1.5* (both p ≤ .001), other p ≥ .12
12	*Display × CDG*	F(9, 285) = 3.3	< .001*	.09	All contrasts significant* (p ≤ .05), except within 27" vs 55" (p ≥ .05)

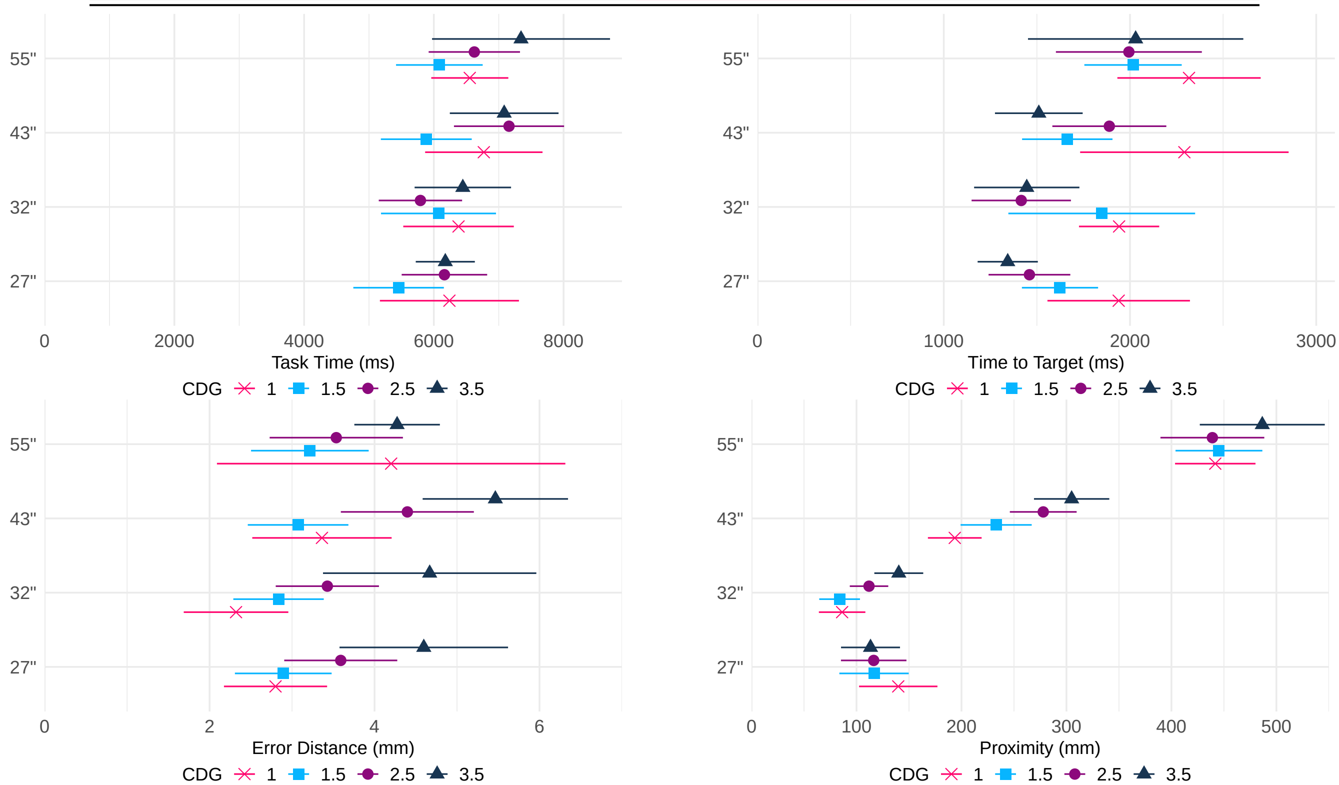


Figure 6: Mean values for Experiment 1 Task 1 results. Error bars show 95% CIs.

Table 2: Experiment 1 Task 2 summary, ANOVA results, and post-hoc test results. Significant differences are highlighted.

	Task Time	Mean 21177 ms, SD 7219 ms, 95% CI [20390, 21963] ms			
	ANOVA	*Result*	*p*	η_p^2	*Post-Hoc Comparisons*
1	*Display Size*	F(3, 290) = .33	.81		
2	*CDG*	F(3, 290) = 3.15	.02*	.03	1.5 < 3.5* (p = .01), other p ≥ .20
3	*Display × CDG*	F(9, 290) = .74	.69		
	Target Time	Mean 1247 ms, SD 424 ms, 95% CI [1200, 1293] ms			
4	*Display Size*	F(3, 290) = .46	.71		
5	*CDG*	F(3, 290) = 2.93	.03*	.03	1.5 < 3.5* (p =.02), other p ≥ .19
6	*Display × CDG*	F(9, 290) = .76	.65		
	Error Rate	Mean 11%, SD 12%, 95% CI [9.7, 12.4]%			
7	*Display Size*	F(3, 290) = 3.81	.01*	.04	27" > 43" and 55"* (p ≤ .04), other p ≥ .08
8	*CDG*	F(3, 290) = 4.39	.004*	.04	1 < 2.5 and 3.5* (p ≤ .007), other p ≥ .21
9	*Display × CDG*	F(9, 290) = .87	.56		
	Proximity	Mean 86 mm, SD 50 mm, 95% CI [80, 91] mm			
10	*Display Size*	F(3, 290) = 55.9	< .001*	.37	Higher for all larger displays* (p ≤ .001), except 27" vs 32" (p = .14)
11	*CDG*	F(3, 290) = 7.0	< .001*	.03	1 > 2.5 and 3.5* (p ≤ .003), other p ≥ .09
12	*Display × CDG*	F(9, 290) = 2.5	.008*	.07	55" > 27"* (p ≤ .009), 55" > 32" when gain ∈ (1, 1.5, 2.5)* (p ≤ .02), 55" > 43" when gain ∈ (1, 1.5)* (p ≤ .03)

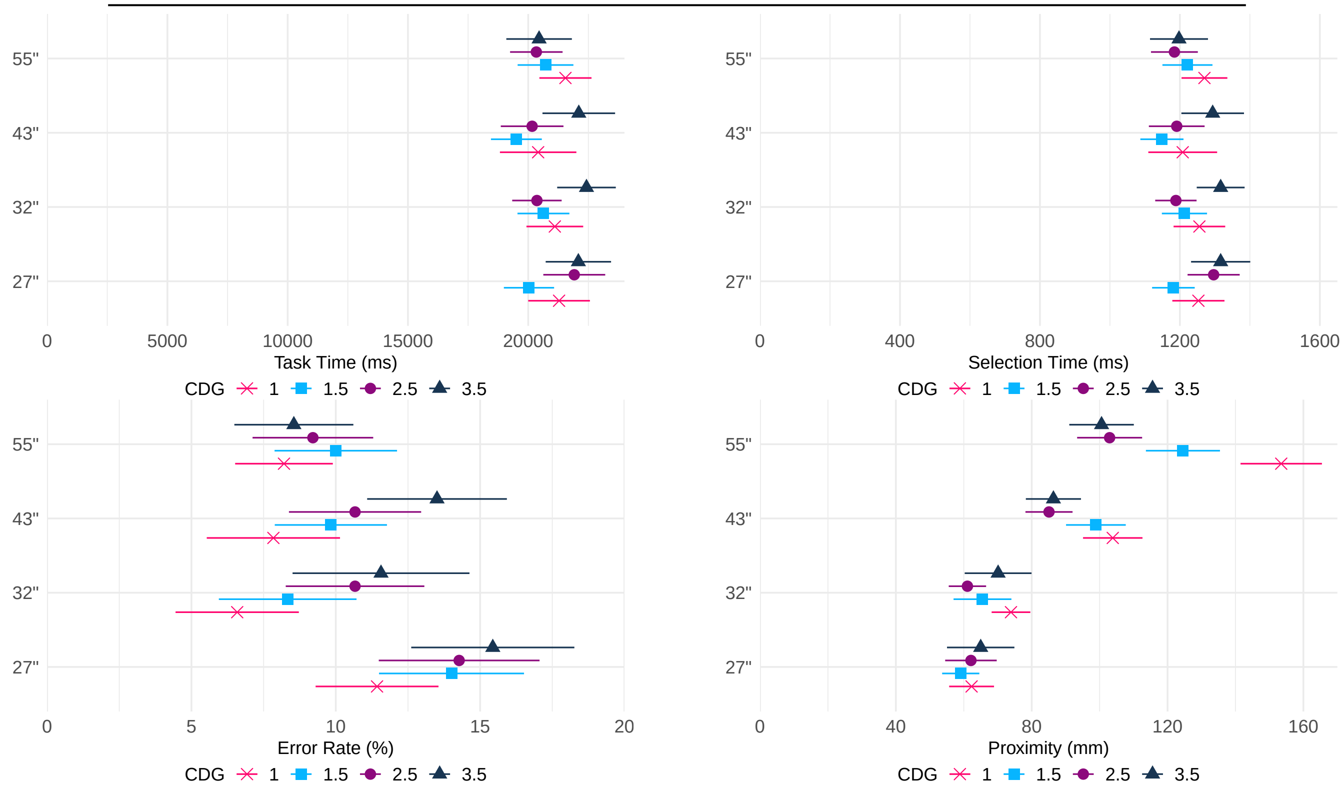


Figure 7: Mean values for Experiment 1 Task 2 results. Error bars show 95% CIs.

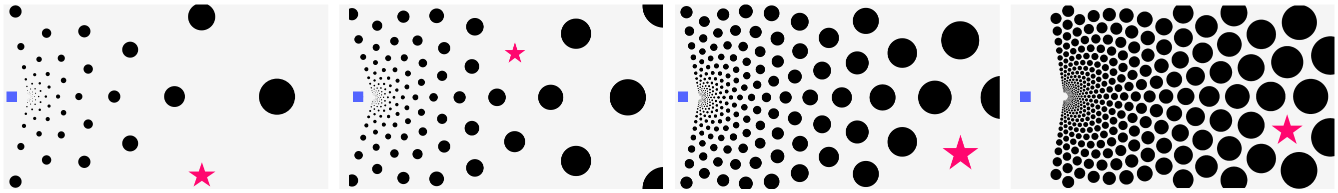


Figure 8: In Experiment 2, users made selections from radial layouts with varying target density: 0.075 (left), 0.15, 0.3, and 0.6 (right). Users alternated selections between randomly chosen targets (★) and the start position (■) on the left edge.

using a proxemic area cursor. We did not vary target density in the previous experiment to avoid having too many conditions that might complicate analysis and cause an excessive amount of interaction time for our participants. However, target density is an important consideration for touchless cursor usage and so the second experiment focuses on this factor. We used a within-subjects experiment design with three factors: *CDG* (1.0, 1.5, 2.5, 3.5) × *Display Size* (27", 55") × *Target Density* (0.6, 0.3, 0.15, 0.075), giving 32 conditions. We used the same CDG ratios as Experiment 1, but only included the smallest and largest display sizes to limit duration and fatigue.

We used a targeting task in this experiment. Users selected circular targets that were systematically arranged on screen using the method established by Blanch and Ortega [5] for evaluating target density in pointing tasks. A target density of 0 represents a single on-screen target and a density of 1 indicates a layout with no space between targets. Targets are positioned radially around a starting position on the left side of the display, becoming larger as the radius from the starting position increases. We used the same density parameters as Blanch and Ortega [5]. Figure 8 shows examples of the target layouts for the lowest and highest density levels used in this experiment. We used an index of difficulty of 3.0 based on pilot tests, as this was appropriately difficult.

Users needed to complete a sequence of target selections. They began each trial by moving to a starting position, indicated by a blue circle, and resting there for 500 ms. Following this, a screen with several distractors and a highlighted target appeared (as in Figure 8). Participants were instructed to select the target as quickly and accurately as possible.

5.2 Procedure

At the beginning of the experiment session, participants were shown how to use the touchless cursor system and were given the chance to complete practice trials, with a minimum of 3 minutes practice time as in the previous study, again until they felt performant and comfortable. Condition order was balanced within each task group, using a Latin square. Each participant performed 13 selections for each of the 32 conditions, resulting in a total of 416 selections per participant. All tasks were completed in a single 60-minute session, including breaks between task blocks.

5.3 Measurements

- **Selection Time:** duration between activating start position and selecting one of the targets;
- **Error Rate:** the ratio of incorrect selections;
- **Proximity:** the distance between target and area cursor position when the user performed the pinch gesture.
- **Sensitivity:** the *index of sensitivity* [5], a measure of the impact that distractor targets had on selection.

Our experiment data is available via the Zenodo open research data platform [70].

5.4 Participants

We recruited 17 participants (10 male, 6 female, 1 not disclosed; mean age 25 yr, SD 8.7 yr) via institutional email lists and posters. Four of these participants also took part in Experiment 1, however, these experiments were conducted nine months apart and so we did not expect this prior experience to affect their results. Participants were compensated with a £10 gift voucher. Our institution's ethics committee approved this study.

5.5 Results

We used repeated-measures ANOVA for analysis, followed by post-hoc t-test comparisons of estimated marginal means. Table 3 shows summary statistics for each dependent variable, and results from the repeated-measures ANOVA and post-hoc comparisons. Figure 9 shows the mean values for each dependent variable, per condition.

In summary of Table 3, the key results show that:

- *Display Size* had a significant effect on *selection time*, though this was mainly attributed to higher times for 55" at the lowest gain level, and for higher densities on the 27" display.
- *Display Size* had a significant effect on *proximity*, with users selecting targets from farther on 55" displays.
- *CDG* had a significant effect on *selection time*. Selection took less time with a gain of 1.0 on smaller screens, and more time with a gain of 1.0 on larger screens. Gain did not affect cursor *proximity*.
- *Density* had a significant effect on *selection time*, with the most dense layout having longer times than the two least dense layouts for the 27" display. There was no significant effect on *selection time* for the 55" display.
- *Density* had a significant effect on *error rate*, with generally increased error for higher densities.
- *Density* had a significant effect on *sensitivity*, with higher density layouts having lower selection performance.
- *Gain* and *Density* had no significant effects on *proximity*.

5.6 Discussion

5.6.1 Effects of Density on Touchless Cursor Use. Target density had an effect on area cursor use (Table 3_3, Table 3_{10}, Table 3_{24}),

Table 3: Experiment 2 summary statistics, ANOVA results, and post-hoc test results. Significant differences are highlighted.

	Selection Time	Mean 1679 ms, SD 392 ms, 95% CI [1646, 1713] ms			
	ANOVA	*Result*	p	η_p^2	*Post-Hoc Comparisons*
1	*Display Size*	F(1, 470) = 9.8	.002*	.02	55" > 27"* (p = .002)
2	*CDG*	F(3, 470) = 4.9	.001*	.03	1 > 1.5* (p = .01), 1 > 2.5* (p < .001), other p ≥ .2
3	*Density*	F(3, 470) = 7.8	< .001*	.05	0.6 > 0.075* (p < 001), 0.6 > 0.15* (p = 0.02), other p ≥ .06
4	*CDG* × *Display*	F(3, 470) = 14.8	< .001*	.09	1 < 3.5 for 27"* (p = .03), other p ≥ .13 for 27", 1 > {1.5, 2.5, 3.5} for 55"* (p < .001), other p ≥ .93 for 55" 55" > 27" for gain 1 only* (p < 0.001), other p ≥ .26,
5	*CDG* × *Density*	F(9, 470) = .42	.93		
6	*Display* × *Density*	F(3, 470) = 2.1	.09		
7	*CDG* × *Display* × *Density*	F(9, 470) = 1.7	.08		
	Error Rate	Mean 13%, SD 13%, 95% CI [12, 14]%			
8	*Display Size*	F(1, 470) = 3.1	.08		
9	*CDG*	F(3, 470) = 4.0	.008*	.02	1.5 < 3.5* (p = .005), other p ≥ .06
10	*Density*	F(3, 470) = 43.4	< .001*	.22	Higher > lower* (p < .05), except 0.15 vs 0.075 (p = .88)
11	*CDG* × *Display*	F(3, 470) = 11.5	< .001*	.07	3.5 > 1 and 1.5 for 27"* (p < .001), other p ≥ .11 55" > 27" for 1* (p = .02), 27" > 55" for 3.5* (p < .001)
12	*CDG* × *Density*	F(9, 470) = 1.3	.22		
13	*Display* × *Density*	F(3, 470) = 2.9	.04*	.02	Corroborates *Density* main effect
14	*CDG* × *Display* × *Density*	F(9, 470) = .35	.96		
	Proximity	Mean 29.6 mm, SD 19.9 mm, 95% CI [27.8, 31.3] mm			
15	*Display Size*	F(1, 470) = 303.1	< .001*	.39	55" > 27"* (p < .001)
16	*CDG*	F(3, 470) = 2.0	.11		
17	*Density*	F(3, 470) = 1.67	.17		
18	*CDG* × *Display*	F(3, 470) = 4.4	.005*	.03	Corroborates *Display Size* main effect 2.5 < 1 for 55"* (p = .02), other p ≥ .27
19	*CDG* × *Density*	F(9, 470) = .22	.99		
20	*Display* × *Density*	F(3, 470) = .48	.69		
21	*CDG* × *Display* × *Density*	F(9, 470) = .35	.96		
	Sensitivity	Mean .18, SD .15, 95% CI [.17, .20]			
22	*Display Size*	F(1, 470) = 14.4	< .001*	.03	27" > 55"* (p < .001)
23	*CDG*	F(3, 470) = 1.1	.34		
24	*Density*	F(3, 470) = 505.3	< .001*	.76	All higher > lower density* (p ≤ .01)
25	*CDG* × *Display*	F(3, 470) = 8.0	< .001*	.05	27" > 55" for 1* (p < .001), other p ≥ .15
26	*CDG* × *Density*	F(9, 470) = .58	.81		
27	*Display* × *Density*	F(3, 470) = 1.86	.13		
28	*CDG* × *Display* × *Density*	F(9, 470) = 1.4	.17		

which aligns with previous findings showing that distractors located between the cursor and the desired target can impact selection performance [5, 28, 46]. The results improve our understanding of how distractors affect touchless cursors in particular, and how this is further affected by the effects of gain and display size. Our results show that increased target density led to increased sensitivity as should be expected (Table 3_{24}), though we saw a greater magnitude of difference between the highest density of 0.6 (mean .39) and all others (mean .12), as seen in Figure 9. There seems to be a non-linear effect of density on sensitivity, with more pronounced differences as density increases.

Density had no significant effect on cursor proximity (Table 3_{17}), so users were consistent in how closely they were approaching targets (mean 18 mm across all densities for 27", mean 41 mm across all densities for 55"). This was partly by necessity due to intermediate distractors, which required users to make a meaningful cursor movement from the starting position towards the target. However, the increased space between targets in lower-density layouts gave

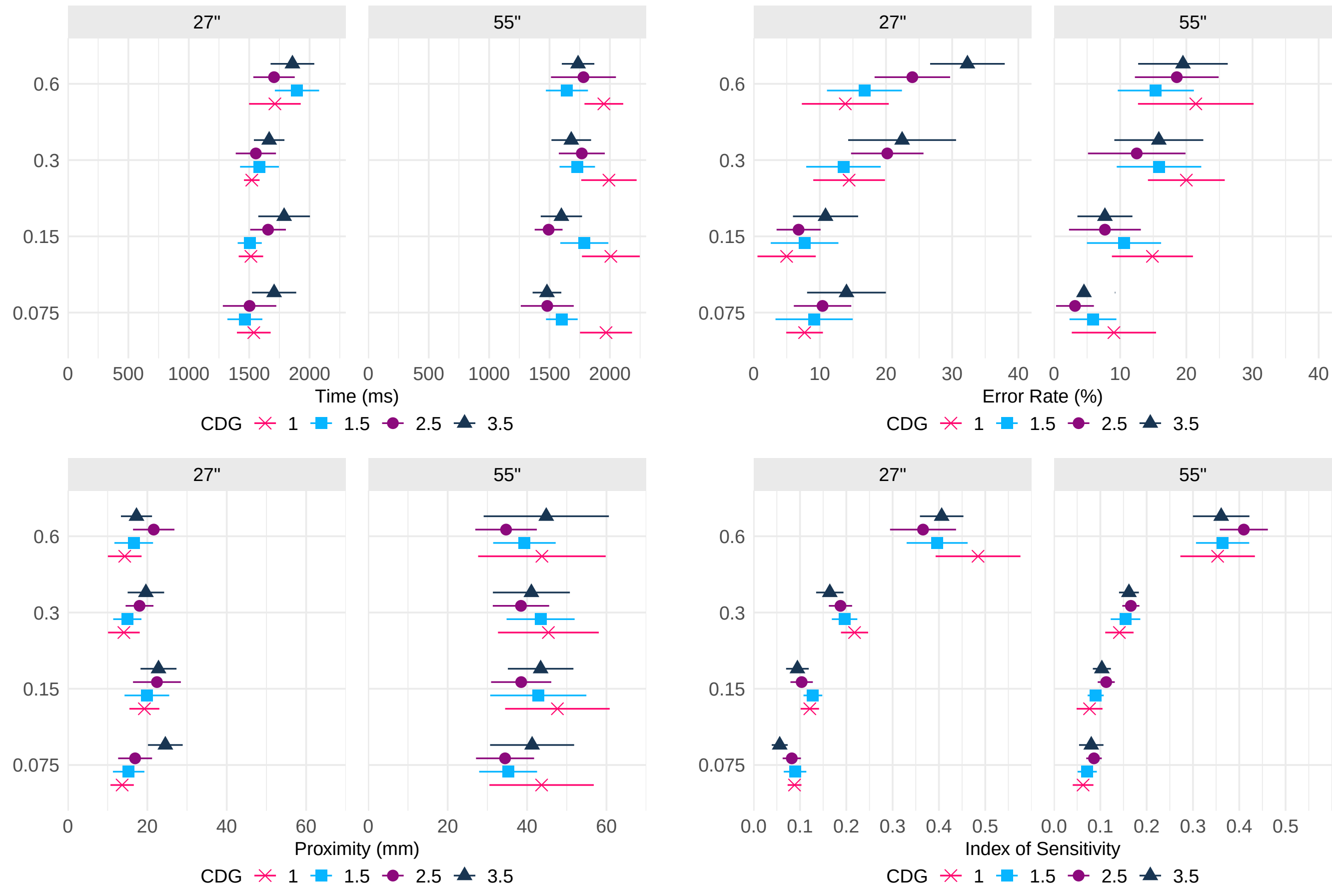


Figure 9: Mean values for Experiment 2 results. Error bars show 95% CIs.

more scope for the area cursor to compensate for instability and undershooting/overshooting errors (Table 3_{3}, Table 3_{10}).

We suggest that a sensible upper bound for target density in a touchless cursor interface should be 0.3, as this seemed to be the point (from our chosen density levels) where input performance was beginning to diminish, most notably for error rate. In more practical terms, target density tells us about the amount of white-space between user interface elements. User interface elements do not typically follow a structured radial layout like those generated by the method [5] used in this experiment. However, ensuring sufficient space between widgets will help with touchless area cursor targeting by, e.g., allowing the area cursor to adapt to the available space and compensate for under/overshoots.

5.6.2 Ideal Gain Depends on Display Size. Our findings show an interesting relationship between control-display gain and display size. The interaction effect for *CDG* × *Display* suggests lower gain often outperformed higher gain levels on the 27" display size: e.g., shorter selection times for 1 vs 3.5 (191 ms faster, Table 3_{4}) and lower error rates for 1 vs 3.5 (-9.2%, Table 3_{11}). For the larger 55" display size, however, the lowest gain level had longer selection times than all others (333 ms slower, Table 3_{4}) and a higher though non-significant difference in error rate (4.7%). This is likely due to the difference in physical dimensions of the user interface elements when scaled to different display sizes. On the smaller display, targets are physically closer together and so a lower gain level maintains the physical correspondence between physical and virtual movements. On the larger display, lower gain is detrimental because it increases the necessary hand/arm movement, which affects performance (Table 3_{4}, Table 3_{11}, Table 3_{25}).

We saw increased use of area cursor targeting on the larger display (proximity 18 mm vs 41 mm for 27" and 55", respectively, Table 3_{15}), again, due to increased physical distance between targets. This was not detrimental to input performance in the presence of distractor targets, however, with sensitivity measures showing robustness against the effect of gain (Table 3_{23}). These findings point to the importance of using gain to find a suitable mapping between hand and cursor movements. Larger displays will naturally require larger cursor displacement and increased gain supports this (Table 3_{4}, Table 3_{11}) because of the flexibility afforded by the dynamic area cursor (Table 3_{15}).

6 Limitations

Both experiments used abstract tasks based on existing protocols (slider task from Waugh et al. [69], and button selection tasks from Blanch and Ortega [5] and ISO 9241-411). These abstractions give generalised insight about how cursor interaction design affects input performance without confounding factors and extraneous user interface elements that may be present in more application-focused designs (e.g., graphics and text). In the next section, we make design recommendations and reflect on examples of existing touchless user interface design, although acknowledge that these are based on generalisations of findings from experimental UI layouts.

We used a range of common display sizes (27–55"), though we did not examine very small (e.g., smartphone [21]) or very large (e.g., wall-sized [59]) displays. Findings should be considered carefully if extrapolating to different sized or vertically-oriented displays. Our largest gain was usable with our largest display, though very large displays may need more extreme gain levels that require additional compensatory adaptions not studied here, e.g., smoothing.

We used hand tracking sensors and focused on interactions that require the precision afforded by these. Alternative sensing approaches (e.g., body-scale depth sensors) were not tested in this work so future work may be necessary to see how our approach works when users interact with more coarse movements. Different sensing approaches may also affect display depth relative to the user and so findings should also be considered carefully, since displays significantly closer or further away would have different viewing angles, and thus viewing size, which may impact usability.

7 Overall Discussion

7.1 Dynamic Area Cursors Support Increased Gain Levels

Our findings show more generally that increased levels of gain are an effective way of minimising hand/arm movements whilst maintaining (or improving) touchless area cursor performance, especially on large displays. Increased gain and area cursor targeting can be mutually beneficial. Increased gain levels can diminish input performance with traditional *point cursors* by increasing instability and making it more difficult for users to acquire targets, especially smaller targets. However, *dynamic area cursors* expand to implicitly target the nearest object and this helps to compensate for cursor movements that might miss the target. Users can also make smaller cursor movements knowing that fully moving to the target may not be necessary, giving a greater level of control over interaction and potentially reducing fatigue [3, 30].

There are situations where increased gain is not ideal. Some of our results suggest that if the gain is increased too much then large gain multipliers (~3.5) become less efficient (Table 1_2, Table 2_5, Table 2_8,Table 3_9). An important consideration is choosing a gain that best suits the size of the display and user interface layout, more specifically in terms of widget locations on screen. If there is too great of a mismatch between hand movement and cursor movement then usability is decreased, reducing the available benefits of area cursor use. *Smaller displays benefit more from more conservative gain multipliers (~1–1.5)* since targets are physically closer together, yielding faster input (Table 1_2, Table 2_2, Table 3_4). *Larger displays will benefit from increased gain (~1.5–3.5)*, however, with the affordances of the area cursor supporting users as they move the cursor across a greater distance on screen. Larger displays are more challenging for users to interact with (Table 3_1), though gain helps close the gap in cursor control performance (Table 3_4, Table 3_{11}). Whilst we used horizontal aspect ratios in our experiments, these recommendations can be generalised to vertical orientation displays since the distribution of targets across the available screen space is likely to be similar.

Our paper focused exclusively on physical displays, however we also anticipate applicability of our findings to other domains where touchless interaction has seen significant adoption, e.g., extended reality (XR) and spatial computing. In XR, it is common to interact with large virtual displays or windows at-a-distance [44], typically through a combination of hand/controller/gaze-directed raycast for targeting, alongside discrete actions or gestures for selection, such as pinch [57]. Indeed, there are many commonalities between touchless computing across physical and virtual displays. Both require mid-air hand/arm movement for interaction, with the potential for inefficient interactions to cause fatigue. Perhaps even more-so for mixed reality where users might be engaging for extended periods of time. This motivates the question of whether a directly mapped area cursor with increased CDG would offer a potentially more performant and/or less fatiguing interaction to the spatial computing status quo of raycasting.

There is also the application of our approach to other forms of XR interaction, particularly immersive interactions with virtual objects or elements, e.g., reaching for a virtual button or grabbing a 3D model. Gain manipulations for hand movements have been successfully used in mixed reality for, e.g., haptic retargeting [2] and translational gain [73], and so we know gain can be manipulated without users necessarily being affected by it, and we believe that there is significant potential in transposing the findings of touchless computing in the physical domain to spatial computing.

7.2 Dynamic Gain Mappings

Cursor gain remained constant during the different input operations, but the slider and button tasks in Experiment 1 each imposed different demands for cursor control and our results suggest that different gain levels may be more beneficial for each task. When users perform a continuous controlled operation like adjusting a slider, the benefits of assisted targeting via area cursor use no longer apply and so gain has a more direct impact on how users move the cursor. Highest gain levels were more detrimental for this continuous operation (Table 1_8), with lower slider errors for the two lowest gains (1 & 1.5: 3.1 mm) versus the highest gains (2.5 & 3.5: 4.2 mm).

Adjusting gain dynamically to suit different input tasks could help to better accommodate different cursor demands. Exploring the use of adaptive gain mappings for proxemic cursors is a compelling topic for future research. Adaptive control-display gain mechanisms have been used for other in-air gesture techniques [24, 48] to allow users to take advantage of high and low gain where appropriate. Such an approach could be used for different input actions with a touchless cursor, by using a higher gain for coarse targeting (e.g., button selection, slider handle selection) and a lower gain for fine-grained adjustment (e.g., slider movement). This seems promising, though research is needed to see if such a difference in cursor movement speed remains usable and easy for users to understand.

We investigated constant gain multipliers in our experiments, though other research has investigated the use of dynamic gain

Table 4: Summary of design recommendations for touchless cursor interfaces.

	Smaller Displays (~27")		**Larger Displays (~55")**	
	Coarse Pointing Tasks	*Fine Pointing Tasks*	*Coarse Pointing Tasks*	*Fine Pointing Tasks*
Gain	~1–2.5	~1–1.5	~2.5–3.5	~1.5–2.5
Adaptation	Lower gain for sliding		Lower gain for sliding	
Density	Low (≤0.15–0.3)	Low (≤0.1)	Moderate (≤0.45)	Moderate (≤0.3)
Layout	Targets towards edges, extra space outside	Targets towards centre	Targets towards edges, extra space outside	Targets towards centre
Benefits	Fast targeting, more space for cursor expansion	Enhanced precision, more controlled hand movement	Improved ergonomics, more space for cursor expansion	Balances precision with ergonomics

ratios that vary according to user behaviour. A common approach is to use *pointer acceleration*, where higher input velocity results in larger on-screen movements and, likewise, slower input velocity results in smaller on-screen movements. Pointer acceleration can sometimes improve input performance [4, 7, 8, 20, 35, 48], albeit with increased risk of overshooting distant targets [8]. Others have adapted gain based on additional inputs, e.g., *Semantic Pointing* [4] considers the 'importance' of a user interface element. Additional alternatives worth further investigation could be to adapt the coordinate space based on what users can comfortably reach rather than assuming the use of a rectangular input plane [29] or to manipulate gain so that the cursor is attracted towards the centre of targets [38]. The use of more complex gain mappings is an interesting topic for future work because it could help to fine-tune touchless cursor performance. However, a non-linear relationship between hand and cursor movements could have detrimental effects on usability since it breaks the spatial mapping between hand position in mid-air and cursor position on screen.

7.3 Designing Touchless Cursor Interactions and User Interfaces

Designers should consider layout density and display size when designing touchless cursor interfaces because these have an impact on usability, and this paper gives suggestions about how to do so. In more practical terms, density will be influenced by target size and the space between targets. Touchless user interfaces for public displays are less likely to feature dense grid or radial layouts that fill the available space, although there are, of course, situations where this may be necessary: e.g., keyboard layouts for touchless text entry (Figure 10), or choosing letters from A–Z for filtering transit destinations. This measure of density can be directly applied to assist with the design of such target layouts [5].

More practically, density should be thought about in terms of localised groupings of user interface controls (e.g., clusters of buttons or menu items) and the presence of 'distractors' in the way of other controls. *Touchless user interface layouts should leave sufficient space around, and between, adjacent controls*, because this creates more space for the area cursor to compensate for targeting inaccuracy. This also permits a more casual [51] approach to interaction by relaxing the demands on precise physical control. *Targets should not be placed too close to the display edges* either because this leaves more visible space beyond targets so that, if users overshoot, they can still see the area cursor when disambiguating between targets. In more locally dense layouts, extra space on the 'outside' edge of the interface might even encourage users to overshoot on purpose, to avoid distractors and give the area cursor more room to expand.

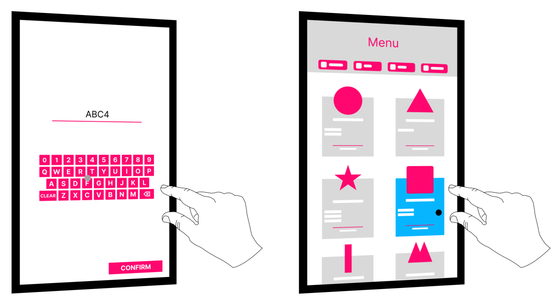


Figure 10: Example touchless user interface layouts inspired by real-world examples [52, 58]: text-entry interface with high-density small targets (left); and menu interface with low density, and both small and large targets (right).

We chose two exemplar user interface layouts (Figure 10) featuring contrasting target size and density to illustrate how our findings can be used in a reflective critique of user interface design. Text entry interfaces like Figure 10–Left present interesting challenges for touchless cursor input because of their high density and small target size. Keyboard layouts are typically not rearranged to make more optimal use of screen space, because users expect familiar layouts to support effective input. Adopting a lower CDG for text entry will improve cursor stability, though has implications for selecting other targets (e.g., buttons at the bottom of the screen in Figure 10–Left). It could be beneficial to adapt CDG based on which region of the screen the cursor is in, e.g., so that low CDG is only enabled when the cursor is close to the dense cluster of small targets. Exploring dynamic CDG use is compelling future research.

In contrast, Figure 10–Right is representative of public display use cases where users are presented with a more limited number of options, in this case for a menu kiosk. The low target density and predominantly large target size mean higher CDG could be adopted for reduced hand movement. The four smaller buttons towards the top of Figure 10–Right would additionally benefit from higher CDG because users do not need to raise their hand as high to target these elements at the top of the screen. Area cursor targeting would be helpful in selecting these smaller targets because the empty space above the buttons creates space for the area cursor to work, although rearranging these into a 2×2 grid would result in more horizontal space to allow more coarse pointing with the area cursor.

We have distilled our recommendations and findings into Table 4, which gives guidance about cursor design and user interface layout design. These recommendations are stratified by display size, broadly small versus large, representing the effect that physical distance between targets has on cursor performance and the relative trade-off of increasing gain level. We have also presented different recommendations for *coarse* and *fine* pointing granularity, recognising that certain applications (or design aesthetics) might necessitate different levels of screen utilisation. For coarse pointing tasks involving reduced number of targets, higher levels of gain can be easily accommodated via area cursor expansion and user interface targets should be positioned accordingly on screen to allow this to happen. Conversely, fine-pointing tasks that involve numerous and/or smaller targets will benefit more from lower gain ratios and targets positioned towards the centre of the screen (or in front of the torso) to reduce necessary physical movement.

8 Conclusion

We investigated the effect of control-display gain on touchless area cursor targeting across a range of screen sizes, target densities, and input tasks for the first time, gaining valuable insight into how to design effective touchless cursor interactions. Choosing an appropriate gain level is not straightforward because of the need to balance the limitations of high and low gain, e.g., precision vs speed vs ergonomics. Our findings show that gain can be increased to improve usability, with the benefits of area cursor targeting help offset weaknesses of increased gain, allowing users to interact effectively without necessarily having to land the cursor directly on targets. Touchless technology is being deployed across myriad public display settings (e.g., digital advertising, retail, tourism), each varying in terms of display size and interaction needs. As touchless technology continues to mature and reach new domains, refining core interaction techniques is important as these will shape everyday interactions with touchless displays. Our work contributes to this need by informing the design of fundamental cursor inputs that will improve everyday interactions.

Acknowledgments

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