Display Size and Targeting Performance: Small Hurts, Large May Help

Joohwan Kim
imjoohwankim@gmail.com
NVIDIA
USA

Arjun Madhusudan
amadhusudan@ncsu.edu
NCSU
NVIDIA
USA

Benjamin Watson
bwatson@ncsu.edu
NCSU
USA

Ben Boudaoud
bboudaoud@nvidia.com
NVIDIA
USA

Roland Tarrazo
rtarrazo@nvidia.com
NVIDIA
USA

Josef Spjut
jspjut@nvidia.com
NVIDIA
USA

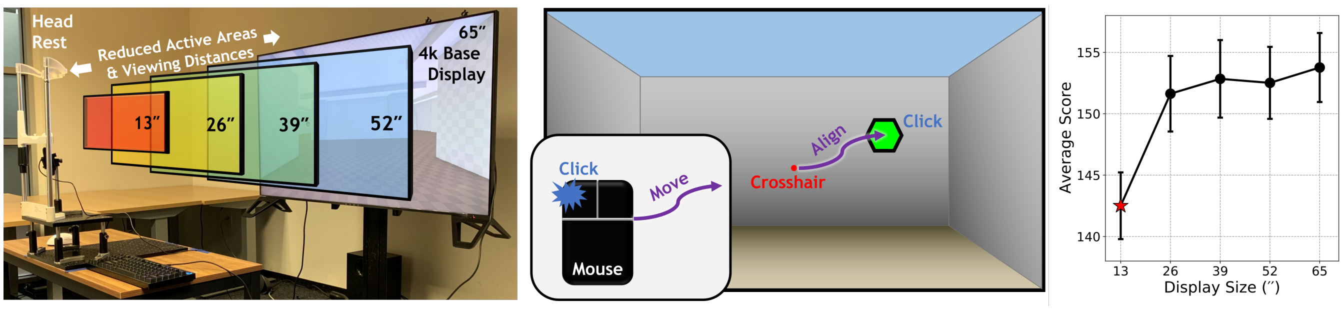

Figure 1: (Left) Experiment setup including scaling of display size and distance across all 5 conditions, maintaining field of view. (Center) Targeting task demonstrating use of the mouse to align a crosshair with the target then click. (Right) Score calculated out of completion time and accuracy (see 4.4) show significant differences between the 13" and all other conditions (denoted by a red star) as well as a rising trend as screen size increases from 13″ to 65″.

ABSTRACT

Which display size helps gamers win? Recommendations from the research and PC gaming communities are contradictory. We find that as display size grows, targeting performance improves. When size increases from 13″ to 26″, targeting time drops by over 3%. Further size increases from 26″ through 39″, 52″ and 65″, bring more modest improvements, with targeting time dropping a further 1%. While such improvements may not be meaningful for novice gamers, they are extremely important to skilled and competitive players. To produce these results, 30 gamers participated in a targeting task as we varied display size by placing a display at varying distances. We held field of view constant by varying viewport size, and resolution constant by rendering to a fixed-size off-screen buffer. This paper offers further experimental detail, and examines likely explanations for the effects of display size.

SA '22 Conference Papers, December 6–9, 2022, Daegu, Republic of Korea

CCS CONCEPTS

• **Human-centered computing** → **Pointing devices**; **User studies**; • **Hardware** → **Displays and imagers**; • **Applied computing** → **Computer games**.

KEYWORDS

display size, first person targeting, first person games

ACM Reference Format:
Joohwan Kim, Arjun Madhusudan, Benjamin Watson, Ben Boudaoud, Roland Tarrazo, and Josef Spjut. 2022. Display Size and Targeting Performance: Small Hurts, Large May Help. In *SIGGRAPH Asia 2022 Conference Papers (SA '22 Conference Papers), December 6–9, 2022, Daegu, Republic of Korea.* ACM, New York, NY, USA, 8 pages. https://doi.org/10.1145/3550469.3555396

1 INTRODUCTION

Does monitor size help esports players win? If so, what size is best? Recommendations from the PC gaming and research communities are contradictory. While PC gamers advocate 24-27″ screens [prosettings.net 2021b,c,d,e], research shows that large screens (> 40″) benefit some spatial tasks [Hancock et al. 2015; Tan et al. 2006].

Reconciling these recommendations is difficult, as both have weaknesses. The PC gaming community relies heavily on anecdotal evidence and recommendations of display professionals, which are dominated by other screen characteristics (latency, brightness, color gamut, etc.) and environmental factors (desktop size, placement of other input devices, etc). Yet research has not focused on the most meaningful tasks in competitive video gaming. Esports players must often make critical judgements and perform precise tasks with extremely tight constraints, and train for years on carefully configured machines [Kari et al. 2019].

We resolve this conflict by measuring performance in a first-person targeting task across display sizes ranging from 13″ to 65″, while carefully controlling confounding factors such as field of view (FoV), latency, resolution, brightness and viewer posture. First-person targeting is among the most basic, yet critical, skills in first-person shooters (FPS), one of the most popular esports genres. We extend research findings by demonstrating that larger display sizes support modest improvements in targeting — to our knowledge, providing the first study systematically measuring targeting task performance as a function of display size. Analysis of mouse movements offers potential explanations for these improvements.

2 RELATED WORK

In this study, we focus on performance impacts of display size. We begin this review of prior work by briefly discussing other system, environmental, and perceptual factors known to affect gaming performance — we must control these to isolate display size effects. We then discuss display size, including practice from the PC gaming community, and studies from the research community.

2.1 Factors Influencing Gaming Performance

Many system characteristics other than display size affect gaming performance. *End-to-end latency*, the time from user input to presentation of an associated change on the output device, has a strong effect [Spjut et al. 2019a]. Large latency significantly increases basic task times [Claypool 2005; Claypool and Claypool 2010; Liu et al. 2021; Spjut et al. 2019a], and hinders higher-level game tasks such as winning competitions or achieving goals. Lower *update rate*, the frequency of presenting rendered frames, also harms targeting, especially when targets move [Janzen and Teather 2014; Spjut et al. 2019a]. Other system traits affecting performance include screen brightness, contrast and color gamut; as well as mouse polling rate and DPI. These are typically controlled with careful calibration.

Additional factors affecting gaming performance include environmental effects, such as viewer distance, posture, and ambient brightness; and perceptual effects such as visual acuity and color deficiency. Experimenters control environmental effects by setting constraints, and perceptual effects with measurement.

2.2 Display Size Effects on Performance

Professional esports athletes choose 24-27″ screens across different game titles and genres [prosettings.net 2021b,c,d,e]. Leading display websites suggest 24-34″ for esports [Giovanni 2021; prosettings.net 2021a], though they recommend larger screens for more immersion [Giovanni 2021; Wazir 2021]. Lastly, gamers opine that sub-27″ is best [Notty_PT 2021; u/Awesome45630 2021; u/marc_4x4 2021], suggesting that small display sizes improve situational awareness without harming performance [Notty_PT 2021].

Yet such gamer consensus is limited by experience, and can ignore potential confounding factors. For example, esports display recommendations are made for heuristically selected viewing distances [Giovanni 2021; prosettings.net 2021a; Wazir 2021], confounding display size with FoV. A second confounding factor is latency [Claypool 2005; Claypool and Claypool 2010; Liu et al. 2021; Spjut et al. 2019a], with many TVs applying image processing that increases it [Cumming and Giovanni 2021] (though this processing can be disabled) [Morrison 2021]. Gamers rarely discuss the other confounding factors reviewed in Sec. 2.1.

While we are not aware of any research examining the effects of display size in a PC gaming context, a few studies address display size effects on related tasks. Some show that large screens can reduce task time. Hancock et al. found that display sizes 40″ and larger reduced cognitive load and reaction time [2015], though larger screens also had higher resolution. Two other studies found that larger screens improved spatial task performance by facilitating egocentric spatial perception [Ni et al. 2006; Tan et al. 2006], which may be related to increased sense of immersion when using larger displays [Hou et al. 2012]. Browning and Teather measured 2D targeting performance on four display sizes ranging from 3.9 to 15.6″ and observed performance reduction in the smallest display size [Browning and Teather 2014], where resolution and FoV changed with display sizes. In contrast, other studies show that display size has no or even opposite effects. Display size did not affect egocentric distance estimation [Riecke et al. 2009] or perceptual decision-making times in traditional sports [Spittle et al. 2010]. Wang et al. measured 2D targeting performance on four display sizes ranging from 10.6 to 55″ with resolution and FoV kept constant, where performance degraded at larger display sizes[Wang et al. 2013]. Overall, prior work suggests that larger display size can improve performance for some tasks, but leaves us uncertain that display size has similar effects in PC gaming. Our research specifically addresses the gaming context, with its demanding tasks which players train for for years.

2.3 Display Size Effects on Visual Perception

Display size can impact visual perception, even when FoV is unchanged. To maintain FoV, screens of larger size must be placed at correspondingly longer distance. This affects both optical blur (defocus of a retinal image) and binocular disparity (slight differences between the retinal images of the two eyes). Blur and disparity are best described using diopters (D), the inverse of distance to an object measured in meters (m): $D = 1/m$. Blur is proportional to the difference between the eye-to-object and eye-to-point of focus dioptric distances, while disparity is proportional to the difference between the eye-to-object and eye-to-point of fixation (where the two eyes' sight lines converge) dioptric distances [Held et al. 2012].

Increased blur and disparity can make viewers more uncertain about an object's position. Consider a viewer focusing and fixating at a flat screen's center. As distance to the screen varies from 0.33 to 2 m, the dioptric distance to the screen center varies from 3 to 0.5 D, and the distance to a point at 20° of eccentricity (angular distance from the view center) on the same screen varies from 2.85 to 0.47 D. Thus at shorter distances (e.g. 0.33 m), blur and disparity can be large (proportional to 3-2.85 = 0.15 D); while at longer distances (e.g. 2 m), they will be about five times smaller (0.5-0.47 = 0.03 D). Increased blur at close viewing distance can make object localization imprecise due to loss of high spatial frequencies [Wilcox et al. 2000], and increased binocular disparity at close distance can reduce visual signal strength due to a weaker match between the binocular inputs [Alberti and Bex 2018]. If these perceptual effects of display size adversely affect gaming performance, we will see a greater performance degradation at larger eccentricities. We demonstrate this was not the case in our results in Sec. 6.2.2.

2.4 Display Size Effects on Spatial Cognition

The visual system estimates depth (distance to objects) by combining information from many depth cues [Howard and Rogers 2002]. Using depth, we improve understanding of our 3D spatial environment. Some depth cues are pictorial and can be rendered correctly to a screen, including perspective (closer objects appear larger), texture gradient (closer pattern repetitions appear at lower frequencies), and occlusion (closer objects hide farther objects). Other depth cues are physiological, requiring a specialized device to reproduce, including binocular disparity, vergence[1], blur, and accommodation[2]. When depth cues conflict or have differing reliability, the visual system estimates depth as a weighted sum of cues, where weights depend on cue reliability [Landy et al. 1995; Schrater and Kersten 2000; Vishwanath et al. 2005].

When varying display size and viewing distance, physiological depth cues change, while pictorial cues do not. Such depth cue variation may affect spatial perception and so performance of spatial tasks. For example, our motor system may perform spatial alignment tasks more precisely when the targets are perceived to be physically larger, even if angular sizes are kept constant.

2.5 Summary

To summarize, changes in display size cause variation in visual perception, spatial cognition, and ergonomic choices that can affect player performance. Previous studies on the effects of display size on spatial tasks report mixed results, and did not definitively study these effects on esports player performance while controlling confounding variables. We measure display size effects on targeting, a fundamental task in esports, while holding display FoV and many other confounding factors constant.

3 CONTRIBUTIONS

- We investigate the effect of display size (and distance) on targeting task performance in PC gaming.
- We show that targeting performance improves as display size grows, with the most prominent effect between 13″ to 26″.
- Our analyses of player motor responses suggest that spatial processing is less efficient at smaller display sizes.

4 EXPERIMENTAL METHODS

To assess the effect of display size on targeting tasks in FPS games, we performed an experiment measuring task completion time and accuracy while varying display size. We held FoV constant by scaling viewing distance in proportion to display size.

[1]the muscular orienting of the eyes to converge on a target object
[2]the muscular focusing of the eye lens

4.1 Design

Our experiment uses a fully crossed, mixed design, with three independent variables: *display size* (Sec. 4.3, within-subject, 5 levels), *target size* (Sec. 4.3, within-subject, 3 levels), and *skill level* (Sec. 4.2, between-subject, 3 levels). Dependent variables were time, accuracy and score (Sec. 4.4).

4.2 Participants

32 volunteers, aged 22 to 39 (31 male and 1 female), gave informed consent to participate in the experiment. One participant halted due to visual fatigue, and another could not concentrate due to frequent distractions. We excluded these two participants. We classified the remaining 30 participants into three groups based on their skill ratings in the games they play. The highly *skilled* group included 10 participants (aged 22 to 37) who play competitive shooters (e.g., Counter-Strike: Global Offensive (CS:GO), Overwatch, or Valorant) and have reached skill rankings in the top 40% of all players. The moderately skilled *competitive* group were 10 participants (aged 23 to 35) who also play competitive shooters, but have not reached a top 40% skill ranking. The lowest skilled *casual* group had 10 participants (aged 23 to 39) who did not play competitive shooters. All participants used a mouse as their habitual gaming input device.

4.3 Apparatus and Conditions

We conducted our experiments using a 65″ HP Omen X 3840x2160 display with 144 Hz update rate. Participants sat at a desk with a chin rest to maintain viewing position. We moved the display to controlled positions between each condition to maintain FoV as display size changed. The PC rendering our experiment environment used an Intel Core i7-9700k CPU, NVIDIA RTX 2080Ti GPU and 32 GB of RAM; and was equipped with a Logitech G Pro Wireless mouse operating at 3200 DPI. The virtual environment was implemented using the open-source FirstPersonScience (FPSci)[3] [Boudaoud et al. 2022; Spjut et al. 2019b] software framework, which interactively renders first-person views of a 3D environment while recording target positions and player aiming direction in every frame. The test target was a static green icosahedron, with a size and eccentricity randomly selected from a designated range (Table 1) within the 103° virtual FoV.

Table 1: Target names, size and eccentricity in degrees of visual angle (measured in in-game FoV, not real-world FoV).

Target	Width (°)	Width (px)	Eccentricity (H x V)
Small	0.6°	3 px	1-7° × 0-1.7°
Medium	1.2°	6 px	2-14° × 0-3.4°
Large	2.4°	13 px	4-28° × 0-6.8°

We tested five display size conditions (13, 26, 39, 52, and 65″). We emulated these sizes by rendering to a central subset of the display, varying in size according to the current condition. The display outside of this central subset was black. Rendered resolution was always 768x432, one-fifth of the HP Omen X display resolution in each dimension. The 13″ condition used this image directly. For all larger display size conditions, we upscaled the rendered content

[3]https://github.com/NVlabs/FPSci

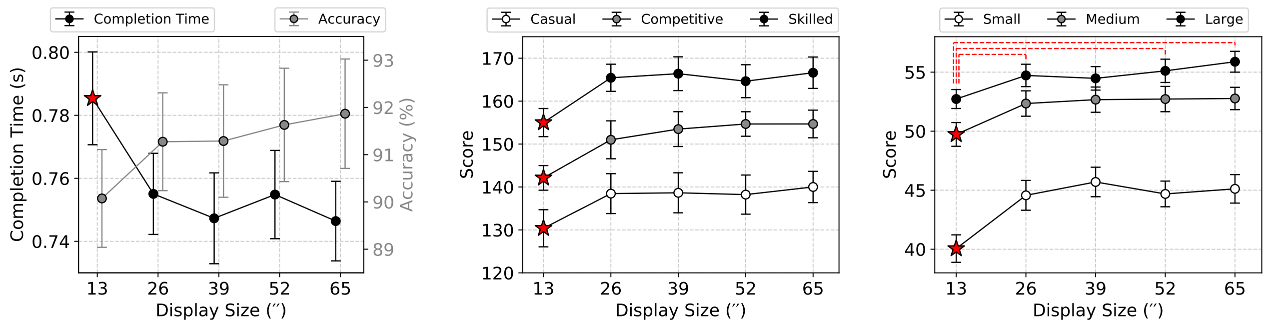

Figure 2: Performance measures as a function of display size where the plotted values are (Left) completion time and accuracy, (Center) mean of individual scores for each skill level, and (Right) mean of individual scores on the given target size. Red stars show significant differences between the marked size and all other sizes. Bars show standard errors of the group means. Dashed lines show significant pairwise differences. Performance measures were significantly worse at 13″ in most cases.

using nearest neighbor sampling. This formed an emulated pixel on each NxN physical pixel block, where N varied with display size condition: 1 for 13″, 2 for 26″, 3 for 39″, 4 for 52″and 5 for 65″. All other display characteristics — e.g. color, brightness, contrast, and latency — did not vary, as we used only one physical display.

The horizontal FoV of the emulated screens was kept at 50° across all display size conditions, selected based on a 26″ monitor viewed from a 62 cm distance. To achieve constant FoV, we varied viewing distance in proportion to display size, meaning an emulated pixel always subtended 4.2 arcmin (′). While this resolution is coarser than the ITU's recommended 1′/pixel [BT.2020-1 2015; BT.709-5 2002], it is preferred by esports players, who value competitive advantage over image quality. In pursuit of this advantage, many esports players sit closer to their displays to see finer detail [urnotjustin 2021]. Because human reaction time is primarily determined by information in low spatial frequencies [Felipe et al. 1993], this resolution should not limit our findings' generality.

4.4 Task

Participants performed a targeting task from a first-person view of a 3D virtual environment (see Fig. 1, center), similar to previous studies of esports player performance [Ivkovic et al. 2015; Kim et al. 2020; Spjut et al. 2019a]. To control the direction of the rendered view, participants moved the mouse, with vertical motion controlling view pitch and horizontal motion controlling view yaw. To perform the task, participants had to align the target with a red dot at the center of the view — the *crosshair* — then click the left mouse button. The target was hit if the crosshair overlapped any part of the target at click time; otherwise it was a miss.

Each trial started with a small, red reference target spawned in an unchanging reference direction. When ready to begin, participants aligned the crosshair with the reference target and pressed the left mouse button. If aligned correctly, the red reference target disappeared, and a test target appeared after a random delay. The delay's duration was randomly drawn from a truncated exponential distribution whose minimum, mean, and maximum values were 0, 0.5, and 5 s respectively. This random delay allowed accurate measurement of reaction time by preventing participants from predicting the moment the test target would appear [Nickerson and Burnham 1969; Oswal et al. 2007]. We instructed participants not to move the mouse during this delay, and if participants did move, we displayed a warning message and restarted the trial.

We applied a heavy target miss penalty, encouraging participants to optimize for accuracy. Trials began when the test target appeared, and ended when the participant clicked, or reached the maximum trial time of 1.5 s — about twice the average trial time. For one successful trial with time T, participants received score of $S = 1.5 - T$. For example, a trial time of 0.73 s received a score of 0.77 (= 1.5 - 0.73). The score for a miss (clicked, but not on target) was 0. We report the sum of all scores in the stated condition or session.

4.5 Procedure

Finishing the experiment required one visit of roughly two hours. The procedure was divided into visual acuity assessment, mouse sensitivity adjustment, training, data collection, and survey phases.

We began by measuring visual acuity of each participant at distances of 31 cm and 155 cm, the shortest and longest viewing distances used in the experiment. The font and size of letter stimuli used in the acuity test was selected according to the standard method used in eye clinics [Bailey and Lovie 1976]. This measurement took about 10 minutes in total. Acceptable visual acuity at both distances ensured that participant acuity was not confounded with display size and distance. The average visual acuity of our participants was slightly higher than normal 20/20 vision (a minimum angular resolution (MAR) of 1′). At both 31 cm (μ = 0.99′, σ = 0.19′) and 155 cm (μ = 0.90′, σ = 0.18′) our participants outperformed 20/20 vision. No participants showed MAR worse than 1.5′ (equivalent to 20/30 vision). This means that the minimum angle that could be resolved by the participants was considerably finer than the angular size of our emulated pixels (4.2′).

Participants used their first display size condition to adjust mouse sensitivity[4] and train. The first size was determined by experimental display size ordering (see next paragraph), which was counterbalanced across participants, meaning that the display size for mouse sensitivity adjustment was also balanced. Mouse acceleration was disabled. We oriented participants with the task and

[4]the ratio of the angular displacement of in-game view rotation to the physical travel distance of the mouse

scoring system, and they sought a mouse sensitivity they liked. To do so, participants performed a session of 90 mouse calibration trials (like experimental trials, with participants attending to mouse sensitivity), which they could repeat as often as they desired. Once participants chose mouse sensitivity, it could not be changed. Next participants performed a training session with 225 trials, each providing feedback (hit or miss, task time) helping participants optimize their movements. Participants could repeat this session as often as they liked. These two phases required 20-30 minutes.

Next participants performed five data collection sessions, each with a different display size. The ordering of display sizes varied between participants, based on a Latin square for the 10 participants in each skill group. Each data collection session had 225 trials and took about 10 minutes to complete, where 3 sets of 75 trials for each target size were distributed randomly within a session. When participants finished a trial, onscreen text told them if they hit or missed the target. When they finished a session, participants saw their total score, the sum of scores from all trials in that session. The participant was required to read this score aloud to the experimenter. After all sessions were over, the experimenter gave the average of all session total scores to the participant.

We used a prize to motivate participants. The highest-scoring participant was awarded a Logitech G Pro Wireless mouse. During the experiment, we maintained a leaderboard displaying the top three scores. These scores were per-participant averages across all sessions, motivating them to excel in all display size conditions.

After data collection, participants filled out a survey (see Supplemental Material) that asked for the size of their home display, their preferences for and confidence with the experimental display sizes.

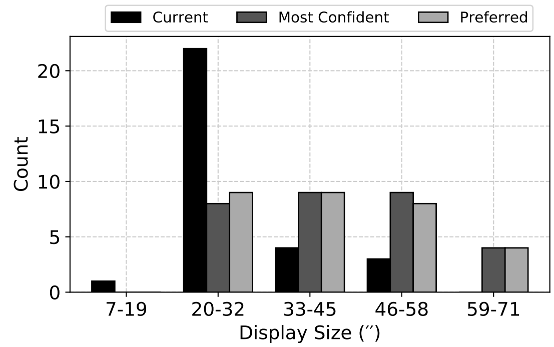

Figure 3: Size survey results demonstrating that while most participants currently use a 20-32″ monitor, overall they felt most confident with and preferred display sizes from 20-59″.

5 EXPERIMENTAL RESULTS

We tested the statistical significance of our results using analyses of variance (ANOVA), and followed up significant effects with post-hoc paired T-tests with Holm-Bonferroni correction [Holm 1979] for multiple comparisons. We compared the group means of individual values. See Supplemental Material for detailed statistics.

Mean score improved with display size, particularly from 13″ to 26″, while differences among larger display sizes (39″ , 52″ , and 65″) were not significant (Fig. 1). ANOVA showed a significant main effect of display size on score ($F_{4,116}$=35.12, P<.001). In post-hoc tests, scores earned while using the 13″ display were significantly lower than all other sizes (P<.001).

Larger display size affected completion time and improved accuracy (Fig. 2 left). ANOVA showed significant main effects of display size on both mean task completion time ($F_{4,116}$=19.79, P<.001) and accuracy ($F_{4,116}$=2.99, P=.022). Post-hoc tests showed that times at 13″ were significantly longer than all other sizes (P<.001).

Although skill level did significantly affect score ($F_{2,27}$=13.12, P<.001, μ = *skilled*: 163.6, *competitive*: 151.2 and *casual*: 137.1), it did not interact with display or target size: the overall display size trends above existed at all skill levels (Fig. 2 center). In post-hoc tests, scores earned with 13″ displays were significantly lower than scores earned with all other display sizes, at all skill levels.

We also found similar trends at all target sizes (Fig. 2 right). ANOVA showed significant main effects of display size ($F_{4,116}$=35.12, P<.001) and target size ($F_{2,58}$=258.37, P<.001), as well as a significant interaction between target size and display size ($F_{8,232}$=3.73, P<.001). Post-hoc tests showed that when seeking small and medium targets, participants scored significantly less when using the 13″ display than when using all other display sizes (P<.001). When seeking large targets, participants using the 13″ display again scored less than those using any other size (P<.001), except the 39″ display.

Although their performance did not differ significantly when display size was 26″ or greater, participants grew to prefer larger screens by the post-experiment survey (Fig. 3). Most participants reported their current display sizes being 20 to 32″screens with a few exceptions. In contrast, participant-reported confidence and preference were evenly distributed among 20-58″.

In summary, our results showed a significant improvement in targeting performance when comparing the 26″ and 13″ displays.

6 DISCUSSION

Targeting task performance was significantly worse when using the smallest display size. There was also a more modest yet consistent trend of larger display sizes being beneficial, although it did not reach statistical significance: score, completion time, and accuracy tended to improve with growing display size beyond 26″.

6.1 Targeting Movement Mechanics

To reveal how display size affected participant perception and performance, we analyzed the movement mechanics of targeting.

6.1.1 Initialization, Movement, and Verification. We decomposed targeting motion into disjoint initialization, movement, and verification phases; and studied how display size affected phase duration.

The initialization phase begins when a task target appears on screen and ends when a participant initiates mouse movement. During this phase, participants perceive local changes in luminance and color as the target spawns, interpret its position, plan an initial movement, and begin to execute this programmed motor plan using their hand and arm muscles. The movement phase starts when mouse movement begins and ends when mouse movement ceases (before the click). This includes one or more iterations of making a movement, assessing the alignment of the crosshair and target, and making additional corrective movements if necessary. The

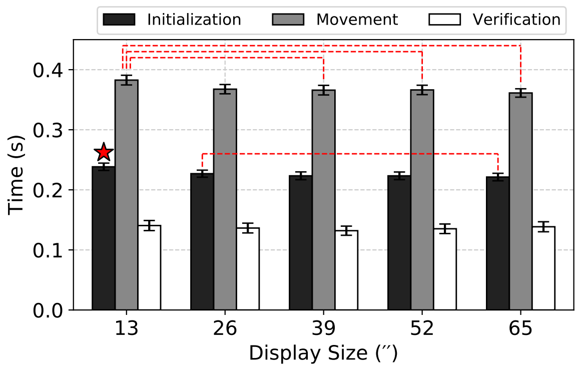

Figure 4: Duration per targeting phase. Both initialization and movement decreased monotonically with display size, but verification did not.

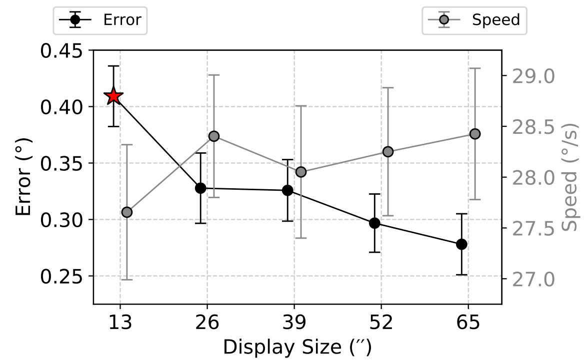

Figure 5: First submovement error and speed vs. size. The submovement was slowest and least accurate on 13″ and fastest and most accurate on 65″.

verification phase begins when mouse movement stops and finishes when the participant clicks the left mouse button. This includes assessing the alignment between the crosshair and target as well as planning and executing a click action using the finger muscles.

To detect these three phases, we applied a speed-based submovement classifier to the view direction time series recorded in FPSci. Submovements are atomic motions initiated by the human motor system, comprising nearly all of human motion [Chen et al. 2015; Chua and Elliott 1993; Hsieh et al. 2017]. Our algorithm uses a dual velocity-threshold approach to detect submovements, detecting a wide range of non-overlapping submovement shapes. This algorithm is inspired by and similar to previously used submovement classifiers for mouse movements [Meyer et al. 1988]. Prior to detection, the view direction time series was smoothed using a 7 Hz, 5th order Butterworth low-pass filter. The start of a submovement was detected when the net view direction speed exceeded 5 °/s. The end of a submovement was detected when this speed dropped below 4 °/s while in a submovement. Two additional duration criteria were imposed based on known characteristics of submovements: a submovement could not start within the first 100 ms of a trial, and two submovements could not be closer than 50 ms apart.

Figure 4 provides times per phase across display size. ANOVA showed a significant main effect of display size on the duration of initialization ($F_{4,116}$=30.13, P<.001) and movement ($F_{4,116}$=9.98, P<.001). In post-hoc tests, initialization with the 13″ size was significantly longer than all other sizes (P<.001). Initialization with the 26″ size was also significantly longer than 65″ size (P=.040). Movement with the 13″ size was significantly longer than the 39″ (P=.021), 52″ (P=.023), and 65″ (P=.015) sizes. Both initialization and movement took longest with 13″, and decreased as display size grew, becoming shortest with 65″. This was not true of verification.

6.1.2 Speed and Accuracy of the First Submovement. Speed and accuracy of human motions are known to be reciprocally related [Plamondon and Alimi 1997; Wobbrock et al. 2008], making motor planning a Pareto optimization problem. We examined speed and accuracy of the first submovement to see how display size affected participants' motor response.

The quality of the first submovement seems to improve with growing display size (Fig. 5). ANOVA shows a significant main effect of display size on first submovement accuracy ($F_{4,116}$=12.37, P<.001). Post-hoc tests show that accuracy with the 13″ size was significantly worse than all other conditions. Larger display sizes enabled better submovements; they were slowest and least accurate with the 13″ size, but fastest and most accurate on 65″.

In conclusion, analysis shows that small display size adversely affects many targeting components: the initialization and movement phases, as well as both speed and accuracy of the first submovement. Notably, the 13″ display lengthens the time needed for initial perception and motor planning, even as it degrades subsequent targeting movements in both speed and accuracy.

6.2 Origin of Effects

What could have caused poor performance at the smallest display size, even when FoV and resolution are constant? We consider personal and display factors, visual perception, and spatial cognition.

6.2.1 Personal and Display Factors. Despite our best efforts, there were potential confounding personal and display factors we could not exclude from our experiment. The most notable of these were visual acuity, personal familiarity, and apparent pixelation.

The measured visual acuity of our participants was slightly — yet still significantly — higher at the longest viewing distance than the shortest. However, the group mean was close to normal 20/20 acuity at both distances, with every participant's acuity more than high enough to resolve the angular resolution of the content (see Sec. 4.5). Note also that the high spatial frequencies lost due to poor acuity affect reaction time less than low frequencies[Felipe et al. 1993]. Thus, visual acuity is not likely to cause measured effects.

Personal familiarity with certain display sizes was another uncontrolled factor, and was biased towards the esports recommendations of 24-27″ displays (Fig. 3). While this might have improved targeting with displays this size range, performance was at least as good with larger sizes, and participants preferred most larger sizes.

Lastly, apparent pixelation, or so-called screen door effect, was different at each display size. At the smallest size, each content pixel corresponded to one physical pixel, effecting a relatively standard sub-pixel configuration. At the largest size, each content pixel corresponded to 25 (a 5 x 5 block) physical pixels, creating a non-standard

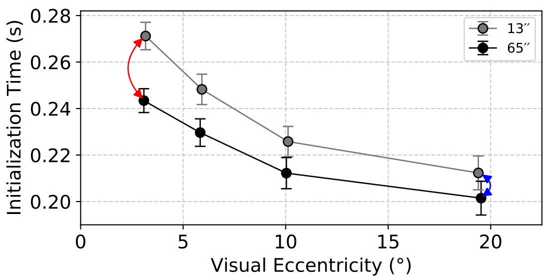

Figure 6: Initialization time is longer at short viewing distance across all visual eccentricities. Visual eccentricities varied continuously, but we present means over four intervals for ease of visualization. Initialization time increases more at lower eccentricities (red arrow) than higher ones (blue arrow), indicating degradation in peripheral vision is not a major cause of increased initialization time (see Sec. 6.2.2). The three other display sizes yielded times similar to 65″.

sub-pixel configuration. While our experiment did not control this factor, we believe it unlikely to have meaningfully influenced our experiment's results. In a pilot study, we used a laptop display at its native resolution, designed for a close viewing distance. The display did not have apparent pixelation, yet we observed a notable degradation in player performance at the smallest display size (see Sec. 2.1. in Supplemental Material).

In summary, these personal and display factors could have affected this experiment results. However, previous studies [Hancock et al. 2015; Tan et al. 2006] and our pilot studies without many or most of these potentially confounding causes have reported similar results, suggesting that display size effects had other causes.

6.2.2 Visual Perception. Players of competitive shooter games tend to gaze at the center of the screen [Khromov et al. 2019]. Since quick and precise targeting is a predictor of success, players fixate on the central crosshair, keeping their fovea (the central retinal area with high spatial acuity) ready for fine-scale alignment anytime. Simultaneously, they use their visual periphery (the retina outside the fovea with high motion sensitivity) to detect and localize the target. It is likely our participants would have also used this strategy.

Closer viewing distances can degrade peripheral vision by increasing binocular disparity and retinal defocus blur of the peripheral visual targets (Sec. 2.3). If this reduced targeting performance with the smallest display, the differences between initialization times with the 13″ and 65″ displays should grow with eccentricity. In contrast, those differences shrank with eccentricity (Fig. 6), rejecting this factor as the root cause.

6.2.3 Spatial Cognition. The final explanation we consider is a change in spatial cognition. Even when pictorial cues (e.g. display content and FoV) are held constant, changes in physiological cues (e.g. vergence and accommodation) can change perception of size (Sec. 2.4). Such later-stage perception may in turn activate various visual pathways — such as the quickly responding magnocellular pathway [Felipe et al. 1993] — via known feedback paths from later to earlier cognitive stages [Cudeiro and Sillito 2006]. Although investigating such mechanisms is beyond the scope of this study, we hope that future studies do so.

6.3 Limitations and Future Work

We held FoV and resolution constant, while viewing distance varied with display size. Some factors are intrinsically tied to viewing distance and cannot be controlled. These factors include visual fatigue at near viewing [Sheedy et al. 2003], individual preferences in viewing distances [Sakamoto et al. 2012], and individual comfort factor due to the level of tonic accommodation (the resting level of the eyes' focusing distance) [Rosenfield et al. 1993]. In addition, our participants were heavily biased toward certain age groups (22-39) and gender (all males except for one participant). Last but not least, many of these factors can interact. For example, resolution often increases with display size, clarifying fine detail. We leave study of these factors and their relationships to future work.

6.4 Implications for Gamers

FPS gamers are among the most selective when specifying their gaming setups, with displays as a core component. Gamers deciding on a display may consider size's effect on gaming performance. Our results show that small displays can harm performance, and that larger displays at least do not harm performance. A larger display may be a sensible decision for an FPS gamer of any skill level.

Using a larger display has some implications for the rest of a gaming setup. Larger displays can be placed farther away from the gamer, providing more room for the mouse and keyboard. Additionally, by manipulating distance, larger displays provide a wider range of usable FoVs while avoiding the screen-door effect.However, placing very large display sizes properly may require more planning, especially on a desk. The necessary viewing distance may exceed the depth of the desk, and the extra height of the display may affect viewing angle.

For FPS gamers deciding on which display to use, larger displays should be considered without fear of a performance disadvantage.

7 CONCLUSIONS

We measured effects of display size on first-person targeting performance while keeping the field of view and resolution constant. Targeting performance improved significantly going from 13″ to 26″. It continued to improve modestly beyond 26″, although the improvement did not reach statistical significance. Our experimental control and analyses rule out individual differences in visual acuity and distance-dependent change in peripheral visual quality as possible explanations. This leaves change in size and space perception as a possible cause. For gamers, a simple recommendation is to play first-person games on screens ≈25″ (diagonal) or larger in size as long as a reasonable FoV can be maintained.

ACKNOWLEDGMENTS

We acknowledge anonymous reviewers for their valuable comments, Rachel Brown for discussions on statistical methods, Seth Schneider for initially raising the problem statement on display size, and Anjul Patney for thoroughly reviewing an early draft.

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