Rethinking Display Requirements for Esports and High Interactivity Applications

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Abstract

Media technology is continuing its transition from passive streaming to participatory interactive experiences, including well-known applications such as web browsing, video conferencing and gaming, as well as emerging and more demanding uses like AR/MR/VR and esports. How should display traits such as latency, refresh rate and size change to meet this trend? We review recent studies from NVIDIA Research and others on requirements for esports as the cutting edge of this trend toward interactivity, and discuss the studies' implications for other interactive applications.

Author Keywords

Displays; esports; perception; performance; latency; refresh rate; display size.

1. Introduction

Modern displays are becoming ever smarter, with more on-device computational features such as refresh rate conversion or image enhancements. However, gamers often purposefully ignore them by turning them off [1]. To understand this behavior, consider that players must perform interactive tasks to advance in games or competitions. Displays play a critical role in these tasks by delivering visual information about the game state, including visual feedback to user actions. Any delay in the display harms player performance, slowing down user reaction to game events. This performance penalty can be even more severe in tasks requiring precision, which require multiple corrective actions, each needing visual feedback from the display. Consequently, serious players of esports (competitive video games) try to minimize the latency between their input device and display by turning off many features in the rendering and display pipeline, such as edge enhancement, motion smoothing, frame/refresh[1] rate up-conversion and even vertical synchronization (which introduces frame tearing).

The influence of display parameters on player experience and task performance depends on the visual information presented and the interactive task to be performed. Therefore, no single display setting is optimal for all video games. For example, story-based, narrative games with visually compelling scenery will likely benefit most from image enhancements. On the other hand, competitive games demanding quick reactions will probably reward play with lower latency more than play with higher visual fidelity.

While we focus on the demands of esports players, many other display viewers are becoming interactive users, working with technologies and in applications including AR/MR/VR, digital design, drone control, telesurgery, and perhaps even remote conferencing with larger groups. Esports players arguably place the most emphasis on player performance. For them, winning and losing is the central experience in esports, with players striving to win even at the cost of degrading visual experience. While other interactive application users may not be so demanding, we argue that their future display needs will be similar to esports players demands. Just like today's esports players, tomorrow's users will process and act on visual information, with their productivity heavily dependent on task performance. In this manuscript, we survey the effects of display parameters on esports player performance, and their implications for other high interactivity applications.

2. Display Parameters and Player Performance

We overview display parameters such as latency, refresh rate, size, resolution, brightness, and contrast in terms of their effects on player performance. We provide quantitative data of the measured effects on esports player performance if available, or instead infer guidelines for players based on behavioral studies on related tasks. These data and guidelines are generally well aligned with what today's esports consumers look for in esports products.

Latency and Refresh Rate: As mentioned earlier, the speed of completing interactive tasks depends on how quickly visual feedback to one's actions become available. Esports players try to minimize the latency between user input (typically made using mice and keyboards) and the system output generated (e.g., the light distribution on the display surface).

There are three primary sources of latency in displays. The first is the time for processing and converting the input video signal to the electronics driving display scanout. These processes can involve copying to dedicated image buffers in the display, creating latency. A second source of latency is the scanning update of the electric signal driving the pixel values on the panel. The update of a display image typically starts at the top of the panel and takes about one refresh period until finishing the update at the bottom of the panel. The third source of latency is pixel response time, given the driving signal for a new color value. This differs among panel technologies and driving electronics. OLED and inorganic LED (ILED) pixels update almost instantaneously, while IPS-type LC pixels with(out) overdrive technologies can take 5-10(s) of milliseconds to update.

Many displays in today's market add significant latency during processing time, so that despite refreshing at 60 or 120 Hz, they present images with 30-60 ms of display latency. On the other hand, esports displays avoid any processing of in-display buffers, refresh at rates up to 500 Hz (at the time of writing), and employ additional acceleration technologies such as LCD overdrive. With these combined measures, esports displays can reduce display latency to 3-5 ms.

Higher refresh rate generally means lower latency, but there are cases where refresh rate is increased at the cost of increasing latency. For example, any refresh rate up-conversion involving interpolation requires two base frames to generate intermediate

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[1] Conventionally, the term *refresh* refers to the update of the information presented on displays, while the term *frame* refers to the update in the frame buffer in GPUs.

frames between, meaning that any displayed image must be at least one frame time older.

Which benefits player performance more, higher frame rate or lower latency? Spjut and colleagues investigated this question for first-person targeting tasks [2], which is arguably the fastest-paced esports genre [3]. Participants repeatedly performed a first-person targeting task (Fig. 1) in 12 conditions combining four refresh rates (60, 120, 240, and 360 Hz) and three latencies (25, 55, and 85 ms). Importantly, to avoid confounding the effects of frame rate and latency, mean latency was held constant across the four refresh rates by delaying frame delivery at higher frame rates. Without such manipulations, higher frame rates would have reduced the mean latency. Participants targeted moving targets in two ways: 1HIT, where the target can be eliminated with one successful click as with a sniper rifle, with each click requiring a 0.5s wait before the next; and TRACK, where target elimination required 1s of accumulated time with the mouse down on the target as with a laser gun.

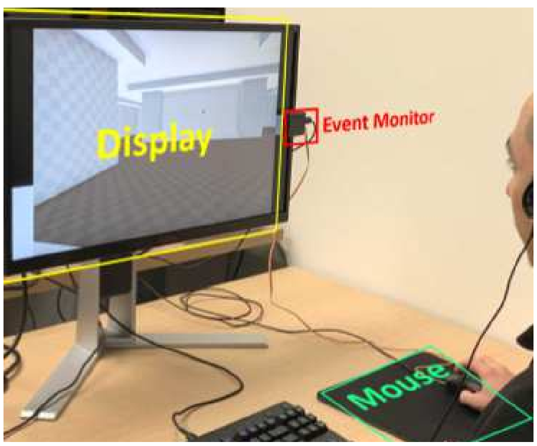

Figure 1. A user sitting at the setup for the latency and refresh rate study. Participants only used the mouse to aim at targets presented on screen. An event monitor recorded the latency affiliated with each click in real time.

Latency was the most influential factor affecting player performance for both types of targeting (Fig. 2). Notably, the increase in task completion time caused by latency was much greater than the increase in latency itself, particularly as target motion complexity increased. More corrective actions are required for more unpredictable target motions, amplifying latency effects. Frame rate's effect on player performance was not significant for 1HIT targeting, but was significant for TRACK targeting, though still far less pronounced than latency's effect.

Interestingly, Spjut and colleagues observed that most participants noticed the change in frame rate more readily than the change in latency, even though latency's effect dominated their performance [2]. This may imply a certain trade-off between perception and performance in players' overall experience: in fast, precision-oriented competitive games rewarding in-game performance, reduce latency at all costs. Alternatively, in games that do not require timely interaction, maximize visual fidelity at the expense of latency, including various visual enhancement features such as frame rate up-conversion like NVIDIA's DLSS3, which enhances motion quality.

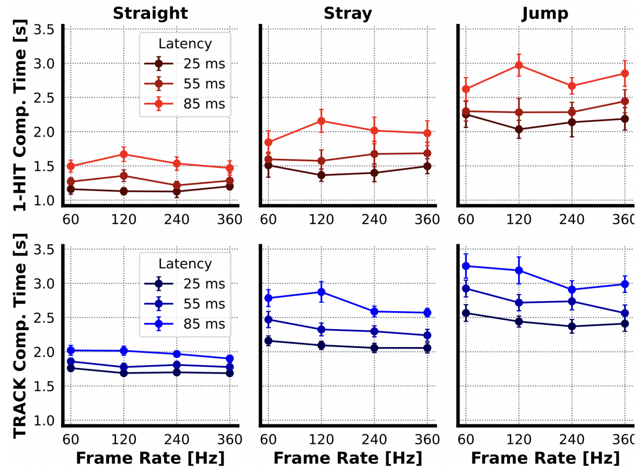

Figure 2. Targeting task completion time as a function of frame rate and latency. Lower means better performance. Latency had a more significant effect than frame rate across the board. Both 1HIT and TRACK task performance benefited primarily from shorter latency, where TRACK task performance benefited slightly from increased frame rate.

Display Size and Field of View: Today's esports players prefer 24-27" displays, a range that includes most esports displays on the market. To explain this size preference, we need to examine the geometrical configuration of information on the display, and of the display itself in its physical environment.

Across the countless game genres and titles, one common trend is that the display center shows how the game events unfold over time, whereas its periphery often shows key status information, such as player health, team communication, or miniaturized game maps. Players use the display's center to monitor how their action is realized in the game, while from time to time glancing at the display periphery to track their status. This creates a tradeoff in field of view (FOV) of the physical display: on one hand, larger FOVs increase detail in the display center, enabling quicker and more precise understanding of game events; while on the other hand, smaller FOVs allow more rapid glancing to the display periphery, reducing the risk of missing important changes in game status. Gamers seem to have settled on a 40-50° physical FOV for first-person shooter games.

The arrangement of the display in its physical environment is also important. Esports players typically use a configuration similar to most office workers: they sit at a desk on which they place their mouse, keyboard[2], and display. Thus display viewing distance is limited by the depth of the desk. Combined with the FOV preference mentioned above, 24-27" displays became the dominant choice of esports players.

Yet if we could freely vary viewing distance and display size, what physical size would maximize esports player performance?

[2]Keyboards and mice are the dominant input interface for competitive esports.

Kim and colleagues measured the effect of display size on first-person targeting tasks. The task was similar to that shown in Fig. 1, and the FOV was maintained at 50° across all conditions by scaling display size and viewing distance together (Fig. 3). The tested diagonal display sizes were 13", 26", 39", 52", and 65", where viewing distance ranged from 31 to 155 cm. To avoid confounding factors, all display size conditions were emulated using one 65" display: visual content was scaled to the desired size while the inactive display area was rendered as black. Content resolution was kept constant at 768 x 432 and up-sampled to the physical resolution of each display size condition using an uninterpolated, nearest-neighbor method.

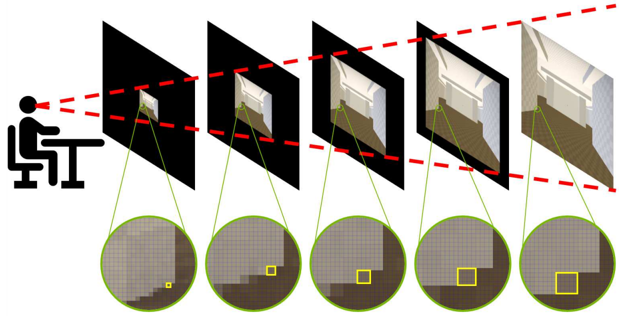

Figure 3. The experimental setup for the display size experiment. All conditions were displayed on a single 65" display at varied viewing distances resulting in equal physical display field of view. Pixels were bound together using nearest neighbor sampling to ensure uniform angular resolution across viewing conditions.

Targeting performance improved as display size grew. As size increased from 13" to 26", performance improved significantly. Performance continued to improve beyond 26", but those improvements were mild and not statistically significant. Participants' mouse movements showed that larger display size helped with various aspects of targeting ranging from faster initial reactions to faster and more accurate pointing motions.

Interestingly, sizes above the commonly preferred display size range (24-27") did not reduce performance. This shows that players need not worry about declining performance when considering display sizes larger than 24-27", as long as one can afford the space to configure the right FOV.

We still do not know what causes the display size effects on targeting performance. Kim and colleagues noted that retinal blur and binocular disparity vary more rapidly across visual eccentricity when display size is small (and displays closer). If poorer peripheral visual input caused the display size effects, they hypothesized, then the effects would be more pronounced as target eccentricity increased. However, their analysis shows that effects were larger at lower target eccentricity, leaving later, higher-level stages of visual perception as possible causes. This observation aligns with other behavioral studies in which participants perceived 3D space more effectively and efficiently when using larger displays [5]. We look forward to future studies to identify the mechanism of this display size effect.

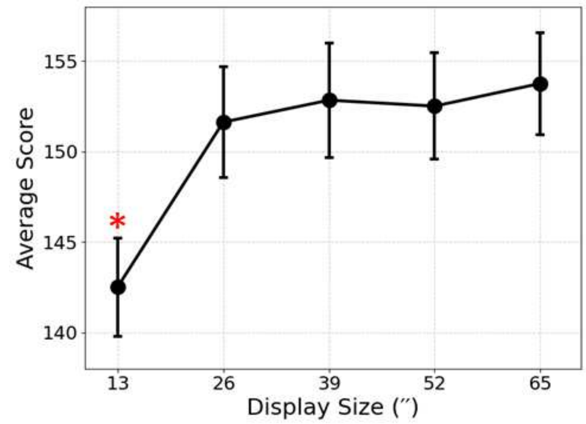

Figure 4. Targeting task score as a function of display size, wherein the physical field of view of the display is held constant by changing viewing distance and size together. Higher means better performance. The average score is computed by summing the remaining time in all trials for a user, where failed trials were counted as 0. A red star marker indicates the point below it is significantly different from all other points presented.

Resolution: Esports players care more about visibility of task targets than fidelity of the surrounding scenery. Once resolution is sufficiently high to make important features visible, they tend to prioritize frame rate or latency over visual detail. This is consistent with player preference in game graphics settings: players turn off most visual fidelity enhancements unless they help player performance by reducing latency or increasing target visibility. Human ability aligns with this preference: we react faster to low- and mid-range frequencies than to higher frequencies [6,7].

Nonetheless, higher resolution can improve performance in esports. In some game situations including precise targeting, the visibility of tiny features can make the difference between success and failure. Even slight improvements of larger detail can increase situational awareness. The challenge is enabling a more effective tradeoff between resolution and latency.

Brightness and Contrast: Humans generally react faster to stimuli that are brighter and in higher contrast [7]. However, one must consider specific characteristics of game content and the display. For example, dimly lit games (with low average luminance) may benefit from OLED displays that produce higher contrast images, thanks to superb representation of true black. On the other hand, brightly lit games (high average luminance) may be better suited to LCDs: LCDs can produce bright imagery with low power consumption, and OLED displays often limit overall brightness to avoid overheating due to power dissipation.

3. Discussion

We argue that esports players are at the vanguard of a broad and growing range of people who use displays actively rather than viewing them passively, and who prioritize task performance over visual experience in highly interactive applications. Below, we offer examples of these applications, including some that clearly demand the same sorts of display traits as esports, and some that may do so. We also briefly survey a few technologies that will help improve these traits, in both the short and long terms.

Applications Needing Esports Display Traits: We have identified low latency, moderate (40-50°) fields of view and high contrast as crucial display traits for esports; with less important traits including high frame rates, task-relevant resolution improvements, and larger display sizes. The most obvious non-esports applications benefiting from the same traits are drone control and other forms of remote operation, which often have display setups and competitive demands very much like esports. In fact, to avoid costly accidents, operators often spend less time flying physical drones than virtual facsimiles in games. AR/MR/VR also clearly benefits from esports display traits, with low display latencies important for reducing simulator sickness, foveated resolution a key enabler for low latencies, and high contrast necessary for seamless merging of the virtual with the physical in AR/MR.

Other applications may benefit from interactive esports display traits, but this benefit must still be confirmed. Video conferencing has become much more common thanks to the pandemic, and has proven to be surprisingly fatiguing, particularly with large interactive groups. Research shows that low latencies improve video conferencing communication, but has not yet examined sub-100 ms latencies. High contrast should be particularly important in conveying non-verbal communication such as gaze and facial expression. Digital design and other more traditional applications rewarding expertise will likely also benefit from esports display traits such as reduced latency and high contrast, with basic research showing that fine mouse motion is particularly sensitive to target contrast and feedback latency. Lastly, interactive, embedded displays have become increasingly common in settings like cars, exercise equipment, airports, malls and museums. Research shows that the touch interfaces used in these settings benefit from very low latencies [8], and their often outdoor environments should reward high contrast display.

At the extreme end of large displays are display walls, often applied to interactions with “big data.” In these applications the data, viewer position, and view distance all vary with time. Latency in display wall systems can modulate the manner of interaction: users of a low latency system will engage more tightly and make physical movements toward the location of activity, while users of a high latency system will retreat to distant viewing for context. While maximum resolution is needed for regions directly in front of a near-distance viewer, it is a waste of bandwidth for someone looking at the entire display from a distance. Moreover, multiple viewers may be utilizing the display simultaneously. While the scenario may not correspond with esports, there are common display needs.

Improving Esports Display Traits: In the short to medium term, ILED displays promise reduced latency and improved contrast by avoiding LCD pixel twist times and reducing black levels, without the lifetime-brightness tradeoffs of current OLED technology. Across a range of display technologies, color reproduction is becoming more vibrant. Although luminance has a stronger influence on reaction time than chroma [9], chromatic contrast can improve reaction times when there is little luminance contrast. Vibrant color reproduction is also crucial in AR/MR applications, which must match the colors of virtual objects to physical environments.

In the long term, with in-display delays already approaching 1ms, most latency reduction must happen elsewhere, and displays must change to accommodate it. Frames themselves create delay, with every pixel as old as the time to create the entire image. Instead, frameless rendering displays each pixel as soon as it is made, and potentially, important pixels before less important ones. Display processing and indeed video standards do not currently accommodate this. With their foveation, tightly coupled AR/MR/VR rendering and display systems offer a partial solution. Yet a full answer will include frameless and other latency-reduction methods; and will support esports and other high interactivity applications.

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