Latency of 30 ms Benefits First Person Targeting Tasks More Than Refresh Rate Above 60 Hz

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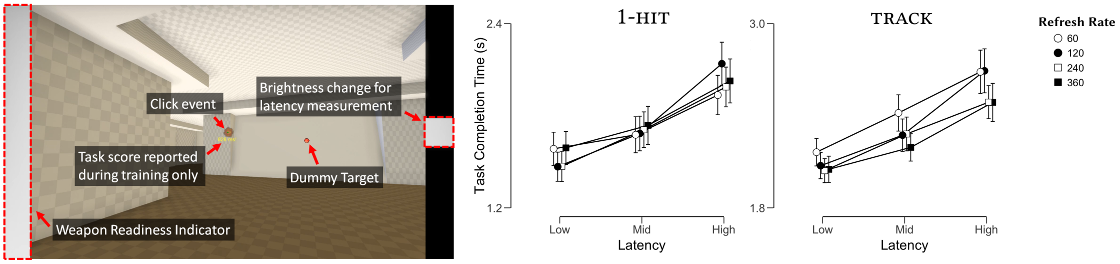

Figure 1: Left: Highly skilled players use a controlled hardware setup to perform first person targeting tasks common in video games. 1-HIT tasks require a single click on target to eliminate it, and TRACK tasks require the aim be maintained on the target for one second. For both types of tasks, a variety of target motions were provided of varying difficulties. Center: For the 1-HIT tasks, latency has a significant effect on task completion times while the effect of refresh rate is not statistically significant. Right: For TRACK tasks, latency still has a significant effect and the effect of refresh rate is minor and marginally significant.

ABSTRACT

In competitive sports, human performance makes the difference between who wins and loses. In some competitive video games (esports), response time is an essential factor of human performance. When the athlete's equipment (computer, input and output device) responds with lower latency, it provides a measurable advantage. In this study, we isolate latency and refresh rate by artificially increasing latency when operating at high refresh rates. Eight skilled esports athletes then perform gaming-inspired first person targeting tasks under varying conditions of refresh rate and latency, completing the tasks as quickly as possible. We show that reduced latency has a clear benefit in task completion time while increased refresh rate has relatively minor effects on performance when the inherent latency reduction present at high refresh rates is removed. Additionally, for certain tracking tasks, there is a small, but marginally significant effect from high refresh rates alone.

CCS CONCEPTS

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

KEYWORDS

esports, visual perception, competitive gaming

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1 INTRODUCTION

When two competitors of similar skill face off in a challenge that includes reaction time, most often the winner will be the one who responds first. When that action must be taken by means of a computer interface, it is essential to minimize the latency in that link between computer and human. *Latency* is a core metric of the computer system and when combined with the human response time, represents the effective input latency of the esports environment.

This work studies latency and refresh rate effects on First Person Shooter (FPS) task performance. We isolate the effects of latency and refresh rate by artificially adding latency to higher refresh rate settings. We minimize adaptation effect by recruiting skilled esports

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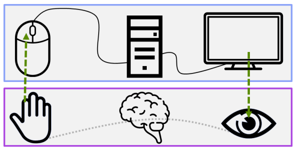

Figure 2: The time from mouse input to display output is the computer latency (top) while the time from the display output to the user input is the reaction time (bottom). Icons designed by Freepik from Flaticon.

athletes and providing a sufficiently long adaptation session per each latency and refresh rate condition.

We find that 30 ms of latency has a significant effect on FPS-task performance. Refresh rate's effect was present when continuous visual feedback is required, yet the effect is relatively weak and marginally significant in comparison. In practice, higher refresh rates remain critically important as they also reduce latency.

2 BACKGROUND

The human-computer interaction (input/output) loop is at the center of understanding player performance for esports tasks (Fig. 2). People interact with computers using a variety of input devices. Many gamers use gamepads, but competitive gamers in FPS games almost exclusively use the mouse and keyboard for input, placing the mouse input latency on the critical path for shooting tasks. Therefore, we have chosen to focus on mouse-related tasks for this study. Display output is a multi-step process with beginning and end points that may change depending on perspective. Generally speaking we will define the display output process as follows:

(1) The GPU delivers the current frame over a display interface
(2) The display writes the frame data to the pixels, row by row
(3) Some time later the pixels arrive at their final values
(4) Light arrives at our eye from the newly set pixel values[1]

Motion perception, reaction time, and performance. To be able to hit a target, a player needs to perceive its location and velocity, plan the appropriate mouse movement and execute this movement while observing the action as it unfolds. This process is known as visually-guided control of action where the visual system constantly monitors the target motion for planning the next motor response. However, this process has an inherent delay. Fitts' Law [Fitts 1954] states that the time it takes a human to select a target is related to the ratio of target size and distance. Looser showed that first-person targeting, like the tasks analyzed in this work, fairly closely follow Fitts' Law [Looser et al. 2005]. Our hand movements (reaching, grasping and intercepting) often accompany 150-200 ms sensorimotor delay [Bradshaw and Watt 2002; Saunders and Knill 2004; Wolpert and Ghahramani 2000], which may be broken down to 40 ms for our visual system to perceive the motion [Tadin et al. 2012] and 100 ms to apply the appropriate motor command.

Broadly speaking, two aiming strategies are known in the FPS gaming community. *Tracking* is a closed loop control process where the visual system monitors changes caused by motor responses, then plans the next motor response. In contrast, *flicking* is a predictive, open-loop strategy that executes planned movement and clicking actions as fast as possible. A traditional view of pointing tasks is that they starts with an open-loop phase and transition to a closed-loop phase for fine adjustment[Watson et al. 2003].

Refresh rates as low as 10-30 Hz (and the accompanied latency) are known to significantly harm performance in pointing and tracking tasks [Chen and Thropp 2007]. Among different game genres, FPS is considered the most sensitive to refresh rate and latency [Claypool and Claypool 2010]. Up to 60 Hz, increase in refresh rate has been shown to monotonically improve performance in FPS tasks [Claypool and Claypool 2007; Janzen and Teather 2014]. However, the range of refresh rates covered in these studies are rather outdated compared to today's esports norms (144 and 240 Hz). In these lower refresh rate studies, the effect of refresh rate could be easily confounded with that of latency. This study seeks to better understand latency and refresh rate as independent variables through studying impacts at higher refresh rates.

Shorter latency has also been shown to benefit FPS task performance [Ivkovic et al. 2015; Janzen and Teather 2014]. Janzen and Teather [Janzen and Teather 2014] speculated refresh rate has a greater effect than latency below 60 Hz, but they did not isolate the two factors as we do in our experimental design (Section 4). Ivkovich et al. [Ivkovic et al. 2015] report that latency as low as 41 ms can adversely affect FPS tasks, but the subjects were given no time to adapt to new latency levels and the presented target motion was rather simplistic compared to today's competitive games.

3 FPS SOFTWARE

We developed an application called `FirstPersonScience` that we use to conduct our user studies. Our application is similar to many FPS training applications available today [Games 2019; Statespace 2019]. This application supports first person camera and movement controls, though we disable player movement for all experiments in this study. The user is able to specify their mouse sensitivity setting as they would in most FPS games so that our aiming tasks behave similarly to what they are used to. During each trial, a target is provided based on motion parameters which are described in more detail in Section 4. As the user performs the intended task, `FirstPersonScience` tracks and records their behavior, and generates a score which is reported at the end of the session.

Since our experimental design required uniform average latency across all delivered refresh rates, we artificially injected latency for the high refresh rate settings by buffering computed frames. More detail about how we controlled latency and the desktop PC hardware used can be found in the supplement.

4 METHODS

We designed two experiments that measure the effects of refresh rate and latency on aiming accuracy and speed for two different types of weapons. The first experiment, called 1-HIT, examines a finite-interval weapon which is able to eliminate a target in a single hit. If the user misses the shot, then another attempt is allowed after half a second. We anticipate that many users will choose a flicking strategy when using this weapon, though we did not instruct them

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[1] Note that some displays provide a short pulse of illumination after the pixels are written, by flashing a backlight (for LCD panels) or pulsing the OLED pixel devices. For this study we focus on displays with continuous illumination.

Table 1: Average measured click to photon latency across refresh rates including added delay. Includes measurements for all clicks in 1-HIT trials on one of two test machines. Similar latencies were found for TRACK and more generally for the systems used. (Standard deviation in parenthesis)

Refresh Rate (Hz)	Low Latency (ms)	Mid Latency (ms)	High Latency (ms)
60	22 (6.0)	55 (5.9)	88 (5.8)
120	24 (2.6)	58 (3.4)	91 (4.0)
240	25 (1.5)	54 (2.4)	87 (2.8)
360	22 (1.4)	52 (1.4)	82 (1.5)

on strategy. The second experiment, called TRACK, uses a weapon that only delivers a small amount of damage while held over the target, requiring one second of total damage in order to complete the task. We expect users will have to use a tracking strategy when using this weapon type. We describe both experiments together because they share most of their design in common. We explicitly point out any differences in the following sections.

Subjects. Eight subjects (aged 27-36) voluntarily participated in the 1-HIT experiment. The subjects are all male, with self-identified ethnicities of Caucasian, Hispanic, Asian, and African-American. These subjects were all globally ranked. 4 are top 1% in fighting games (a different genre), 2 are in the top 20% in CS:GO and Overwatch, 1 in the top 7% of Overwatch and the final subject is a top 1% player in CS:GO, though all play at least one FPS-style game regularly with games of choice including CS:GO, Overwatch, Fortnite, and Apex Legends. All subjects habitually play video games for between 5-60 hours per week. Six of these eight original subjects participated in the TRACK experiment, three of them being semi-professional players. Users were placed at an experimental test setup as shown in the supplement.

Conditions. We tested aiming performance over 4 refresh rates and 3 latency ranges, which comprise 12 conditions. The selected refresh rates were: 60 Hz (today's baseline), 120 Hz (today's gamer), 240 Hz (gaming enthusiast) and 360 Hz (experimental). All click-to-photon latencies were recorded during the trials (mean/standard deviation values are reported in Table 1). Latency was artificially added to approximately equalize mean latency among different refresh rates.

Procedure. Subjects first completed the 1-HIT experiment for all twelve (latency/refresh rate) conditions and then executed the TRACK experiment for these same conditions. The order of conditions within an experiment was counter-balanced among subjects to minimize the ordering effect. Each experiment took 2-3 hours to complete, spread across 3-5 days.

Every condition consisted of one adaptation and one data collection session. Each session consisted of 220 trials containing five target motion types for the 1-HIT experiment, and 120 trials containing three target motion types for the TRACK experiment (Section 4). The target motion type ordering was randomly selected during sessions by our application. The only instruction given to subjects was to complete all the tasks as quickly as possible, and subjects were encouraged to adjust their aiming strategy for this goal. One session took 6-15 minutes to complete, resulting in 12-30 minutes spent per condition (combining adaptation and data collection sessions). According to our subjects, this time was sufficiently long for adapting to and forming an aiming strategy for the new condition, but not so exhausting as to cause strain in the wrist and hand muscles. Subjects were encouraged to take a break between sessions to avoid adverse effects of fatigue or muscle strain. We instructed our subjects to consciously make their best effort in all conditions. We also openly displayed top 5 scores (with the name of the player) on a leaderboard to encourage competition. The leaderboard was especially effective due to the subjects' competitive spirits.

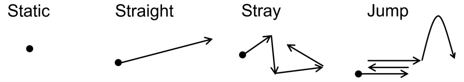

Figure 3: Motion types used for targets

Tasks. At the start of each trial a dummy target appears in a reference direction and the user presses the space bar to initiate the trial. The target appears after 0.25 s at a random location with eccentricity of 5∼15° horizontal and 0∼1° vertical relative to the reference direction. The task is to move the mouse in order to change the view perspective, aligning the central aiming crosshair with the target, then click to damage the target. To mimic the behavior of sniping weapons in 1-HIT, the minimum interval between consecutive shots is 0.5 s. The target is destroyed with a single successful shot. A total of 5 s is provided per each trial, where a maximum of 10 shots could be made. For TRACK we mimic the behavior of laser-style weapons where the mouse button must be depressed while the crosshair overlaps the target for a combined duration of one second, resetting target health when a new trial begins. We increased the time limit to 6 s in the TRACK experiment because the task took longer when the perceived aiming difficulty was similar to 1-HIT. The target's distance was fixed to keep it 1.50° and 2.55° in perspective angle from the virtual camera, for 1-HIT and TRACK experiments respectively. All target motion was restricted to a spherical surface, centered on the user, with a fixed radius. The five types of motion are summarized in Figure 3 and Table 2.

Hypotheses. We hypothesize that:

- Task completion time decreases with lower latency
- Task completion time decreases with higher refresh rate
- TRACK benefits more from higher refresh rate than 1-HIT
- Task completion time varies with target motion types
- Latency and refresh rate effects are more pronounced when target motion is more unpredictable.

5 RESULTS

Figures 4 and 5 show the task completion time as a function of refresh rate and latency. The results revealed a significant effect of latency on subject's mean completion time for both experiments ($F(2.00, 14.00) = 49.67$, $p<0.001$, $\eta_p^2=0.88$ for 1-HIT and $F(2.00, 14.00) = 59.28$, $p<0.001$, $\eta_p^2=0.92$ for TRACK). Thus we accept the latency effect hypothesis. The main effect of refresh rate was found slightly above significance for TRACK ($F(3.00, 15.00) = 4.59$, $p=0.018$, $\eta_p^2=0.479$) and it did not reach significance for 1-HIT

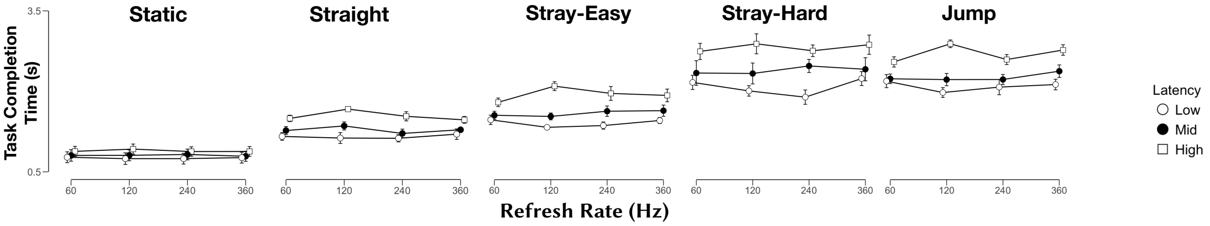

Figure 4: Task completion times for 1-HIT.

Table 2: Task parameters. All targets spawn from 5-15° latitude and 0-1° longitude. Jump targets only move horizontally except when jumping.

	Task	Speed (°/s)	Size (°)	Motion Period (s)	Jump	Count
1-HIT	Static	0	1.50	∞	no	30
	Straight	8-15	1.50	∞	no	30
	Stray Easy	8-15	1.50	1-1.2	no	40
	Stray Hard	8-15	1.50	0.5-0.6	no	40
	Jump	8-15	1.50	0.2-0.8	yes	80
TRACK	Straight	10-20	2.55	∞	no	20
	Stray	10-20	2.55	1-1.2	no	50
	Jump	10-20	2.55	1-1.2	yes	50

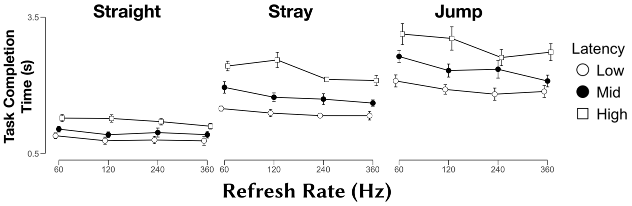

Figure 5: Task completion times for TRACK.

($F(3.00, 21.00) = 0.93$, p=0.44, η_p^2=0.12). Thus we accept the refresh rate effect hypothesis only for the TRACK experiment. Our results also show that tracking benefits more from refresh rate, suggesting that smooth and accurate motion representation mattered more for TRACK than 1-HIT. Thus we accept our hypothesis that tracking performance is more sensitive to refresh rate.

We also examined the effect of motion type on subjects task completion time and those results along with detailed ANOVA for both experiments are presented in the supplement.

6 DISCUSSION

We found a significant effect of latency and motion type on gamers' performance in terms of task completion time, confirming that latency remains important [Claypool and Claypool 2010; Ivkovic et al. 2015; Janzen and Teather 2014] for today's competitive gaming settings. We also observed that refresh rate can play an important role for TRACK tasks (less significant than the other two factors) but not for 1-HIT tasks. This may suggest that competitive players rely on flicking, the open-loop strategy, for in-game pointing tasks.

Although we sought to best represent the performance impact of latency, refresh rate, and target motion in a controlled environment, there are limitations in our study. Subjects could aim only by changing the perspective view and were restricted to stay in one position, while most competitive players move while aiming.

The importance of high refresh rate visualization cannot be understated. In essence, what our study shows is not that high refresh rate is unimportant, but that high refresh rate is important largely because of the latency reduction it provides.

We present the first study to carefully examines these variables independently at higher modern refresh rates (>60 Hz). We show that a lower latency system can provide a higher level of player performance in FPS targeting tasks. We also show small but statistically significant improvement in performance of some tasks at higher refresh rates. We believe our study is a good step towards replacing conventional wisdom in esports with objective knowledge.

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