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The Effects of Network Latency on Competitive First-Person Shooter Game Players

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***Abstract*—Esports gamers, and competitive gamers more broadly, want low network latency to maximize their chances of winning – in general, the lower the network latency, the less time between a player's action and the intended outcome. But how much small reductions in network latency benefit competitive players is not known. This paper presents results from a 25-person user study that evaluates the impact of network latency on experienced *Counter-strike: Global Offensive* players. Analysis of the results shows pronounced benefits to player performance (accuracy and score) for even small reductions in network latency, with subjective opinions on Quality of Experience (QoE) following suit. Latency compensation – a software technique to mitigate the effects of latency – significantly improves player performance and QoE.**

***Index Terms*—Quality of Experience (QoE), esports, FPS**

I. Introduction

Computer games are one of the world's most popular forms of entertainment, with global sales increasing at an annual rate of 10% or more [1]. The largest esport prize pools are about $25 million USD [2], and by 2023, there are expected to be about 300 million frequent viewers of esports worldwide, an increase from 173 million in 2018 [3].

Network latency between a player's computer and the server managing the game state can impact the responsiveness and consistency of an online game, hurting performance and degrading quality of experience. Competitive gamers typically try to reduce network latency or seek out technologies to mitigate its effect. However, despite the conventional wisdom that "faster is better", the degree to which reduced network latency improves player performance and quality of experience for competitive game players is not well-known.

There have been studies on network latency and commercial games [4]–[6], especially latency and first-person shooter (FPS) games [7]–[11] owing to the sensitivity of FPS games to network latency and the prevalence of FPS games in the competitive and esports scenes. However, such studies often evaluate non-expert gamers or high-end latencies (e.g., above 150 ms) that are not typically seen by competitive gamers. Other latency and games research has studied custom games, usually a subset of a full game with the focus on a particular game action [12]–[15]. While valuable for understanding latency and games and even latency and user interaction, it is not clear the extent to which such results pertain to commercial games which have rich interactions and often employ software techniques to mitigate network latency [16]. In general, there have been few studies of competitive gamers playing complete games over low-end (less than 150 milliseconds) network latency. Competitive game players are of particular interest since they motivate innovations in reducing low-end network latency through hardware or software solutions.

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This paper presents the results from a user study that measures the impact of network latency on experienced first-person shooter game players. Users were screened for their skill at the esports FPS game *Counter-strike: Global Offensive (CS:GO)* [17], obtaining a pool of 25 qualified participants. Users played rounds of CS:GO with controlled amounts of network latency, both with and without latency compensation techniques provided by the game.

Analysis of the results shows reducing network latency by 100 milliseconds results in a 2 percent better accuracy and 2 more points per minute. The latter translates to about an extra kill per minute – significant since a single kill can create a huge advantage in a competitive game. In addition, this same latency reduction results in an improvement in the quality of experience (QoE) for the game, reducing frustration and annoyance and improving responsiveness by about 0.7 on a 5-point scale.

The rest of this paper is organized as follows: Section II describes previous work on network latency and games related to this paper; Section III describes our methodology, including CS:GO setup and user study design and execution; Section IV analyzes the results from the user study; Section V mentions some limitations of our methods; and Section VI summarizes our conclusions and presents possible future work.

II. Related work

Counter-strike Global Offensive's (CS:GO) [17] is frequently used in computer game research. Frostling-Henningsson [18] finds Counter-strike players are foremost motivated by social reasons, even for gamers that are also motivated by competition and challenge. Lux et al. [19] use opponent kills to anchor CS:GO match summaries and Makarov et al. [20] find ranking CS:GO players based on their team impact is useful for predicting winners.

For network latency and FPS games, Armitage et al. [9] estimate the latency tolerance threshold for Quake 3 to be about 150-180 ms. Dick et al. [21] show players find 150 ms acceptable for Counter-strike and Unreal Tournament 2003 (UT2003). Quax et al. [8] find UT2003 players suffer with latency and jitter as low as 100 ms. Amin et al. [10] demonstrate player experience determines latency sensitivity for Call of Duty, with competitive gamers more adept at compensating for impaired network conditions. For other game genres, Fritsch et al. [5] find players of the role-playing game Everquest 2 can tolerate hundreds of milliseconds of network latency. Hoßfeld et al. [6] show players of the casual game Minecraft are insensitive to network latencies of up to 1 second. Sheldon et al. [4] find some aspects of play in the real-time strategy game Warcraft 3 are not affected by up to a second of network latency. While beneficial, these works typically studied higher latencies than those in our paper (and higher than usually experienced by competitive game players), and do not identify nor isolate the game's latency compensation techniques as does our work.

Latency compensation techniques seek to mitigate the effects of latency on players [16]. Savery et al. [22] find that the lack of latency compensation degrades both score and shooting accuracy in an FPS game. Le finds that synchronization can significantly improve game fairness in deadline-based network games [23]. Lee and Chang et al. [13] show time warp in CS:GO can improve accuracy by 2-4%. While such works are helpful in understanding the effects of latency compensation techniques, they do not necessarily fit competitive player performance, where skill, latency sensitivity and a desire to win may impact the effects of latency.

III. Methodology

To investigate how network latency affects competitive First-Person Shooter (FPS) players, we configured a client-server system with a competitive FPS game, added controlled amounts of network latency, recruited players for a user study, and measured player performance and quality of experience.

Our user study was conducted in a dedicated, on-campus computer lab using a client-server architecture shown in Figure 1. The server hosts the game and is connected via high-speed LAN to the client. The client and server are Alienware PCs with Intel i7-4790K CPUs @4 GHz with 16 GB RAM and an Intel(R) HD 4600 graphics card. The client is equipped with a gaming mouse and high-refresh rate monitor so as to minimize local system latency. The client has a 24.5" Lenovo LCD monitor with 1920x1080 pixels at 240 Hz and a G502 laser mouse with 12k DPI, 300 IPS, and a 1 KHz polling rate. The client runs Ubuntu 20.04 LTS, with Linux kernel version 5.4 and the server runs Windows 10. Both server and client run *Counter-strike Global Offensive (CS:GO)* (version 10.15.2020). Users were given wired Apple airpods for audio.

The base system latency was measured with a 1000 frame/s camera (a Casio EX-ZR100) setup to capture the moment a user presses the mouse button and the resulting screen output. By manually examining the video frames, the frame time when the mouse is clicked is subtracted from the frame time the result is visible, giving the base system latency. This measurement method was done 10 times on our client, yielding an average base latency of 24.6 milliseconds, with a standard deviation of 3.4 milliseconds.

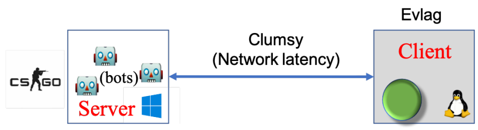

Fig. 1. CS:GO computer configuration

In order to test the effects of network latencies, additional latency was added equally to the server uplink and downlink using Clumsy,[1] a network filtering tool based on the WinDivert library. The total network latency added to the client was one of 25, 50, 100, or 150 milliseconds. The added network latency is in addition to the base system latency. Thus, the user always experiences 24.6 milliseconds of base system latency from the client computer and actions sent to the server have the additional network latency added to them. For example, the minimum network condition we test is 25 milliseconds. With this condition, the player has a base latency of 24.6 milliseconds at the client and an additional 25 milliseconds of network latency for messages sent to the server. We do not have results with 0 ms network latency – such a condition is only for LAN games, not a typical network game over the Internet.

During our experiments, we gathered ping times from the client collected 5 times every second for every player for every round of game play. The network latency observed by these ping values closely matches the intended added latency (over 99% of values are within 1 millisecond of what is intended). Variations to this are within normal system variations observed by ping with no added network latency and are indistinguishable from the latency variation caused by the LAN itself. The LAN latency was less than 1 ms.

TABLE I
Weapon attributes

Weapon	Mode	Fire rate	Clip	Reload	Damage	Accuracy
AK-47	Automatic	600 per min	30	2.43 s	36	21.74 m

While CS:GO matches often include team strategy, the focus of this study is on the effects of network latency on individual player tactics. As such, a death match free-for-all game mode (no teams) was chosen. Thus, each round had open combat for the user and 20 AI-controlled bots, where everyone fought everyone and the goal was to kill as many opponents as possible. The bot difficulty level was set to 3 (hard) out of 4.

There was no upper limit on player score – the game terminated after a 3.5 minutes.

[1] https://jagt.github.io/clumsy/

TABLE II
SUBJECTIVE QUESTIONS PER ROUND

	Rate:	Source
Q1	The quality of the round	Stadia [24]
Q2	The responsiveness of the round	Long [15]
Q3	Your annoyance with the unresponsiveness	GEQ [25]
Q4	The inconsistency of the round	Custom
Q5	Your annoyance with the inconsistency	GEQ [25]
Q6	How capable and effective you felt	PENS [26]
Q7	How fun the round was	GEQ [25]
Q8	Your frustration in the round	iGEQ [25]
Q9	How much your performance was due to you	Attribution [27]

Players were equipped with only one weapon at a time – the AK-47 (the most popular automatic rifle) [28], with specifications as in Table I, and unlimited ammunition.

To maximize combat time compared to wandering, the third smallest [29], and most popular [30] map "Mirage" was used. The user and the bots spawned at random locations on the map that were not currently in view of anyone else.

CS:GO includes a server configuration option for the time warp latency compensation technique [16]. With time warp, the server resolves a shot based on the timestamp when the player fires instead of when the server receives the event. Time warp is enabled by default, but can be disabled. CS:GO has another latency compensation technique called interpolation – where the player position is smoothed out based on past positions – that cannot be disabled.

The CS:GO settings were pre-configured at the server with the experiment controlled by scripts on the client – this meant when starting the study, users immediately joined and launched into the game, bypassing normal game lobbies and weapon selection phases.

The IRB-approved user study was conducted during the COVID pandemic, so everyone wore masks and respected social distancing requirements. Upon completion of each user's study, we carefully sanitized the keyboard, mouse and earphones.

A user study proctor was available for questions and trouble-shooting during the experiment.

Users first did a custom reaction-time test written in Javascript and launched via a Chrome Web browser. In the test, users waited for a screen color change then clicked the mouse as quickly as possible, doing this 10 times.

Users played a practice round without any added network latency to get familiar with the map and game mode. This data was not analyzed. Users then played additional 3.5 minute rounds of CS:GO, each round with a different network latency (25, 50, 100, or 150 milliseconds) and with latency compensation either on or off, randomly shuffled.

After each round, users filled out a subjective survey consisting of nine questions on a discrete 5-point Likert scale about the game experience in the preceding round. The abbreviated questions are shown in Table II. The complete questions and answers are available on our website.[2]

After completing the survey, the next round would commence when the user was ready.

After completing all the game rounds, users were given a questionnaire with additional demographics questions.

Study participants were solicited via University email lists. Interested participants first filled out a screener questionnaire to ensure appropriate CS:GO experience (at least 100 hours). Users were rewarded with a $10 USD Amazon gift card upon completion of the study.

TABLE III
DEMOGRAPHICS

Users	Age (yrs)	Gender
25	20.8 (3.0)	25 male, 0 female

FPS Self-rating	CS:GO Self-rating	FPS Hours	CS:GO Hours	Reaction-time (ms)
4.4 (0.7)	4.6 (0.5)	2436 (3866)	832 (703)	205 (24)

IV. ANALYSIS

This section first summarizes participant demographics (Section IV-A), then the effects of network latency: on player performance (Section IV-B), with and without latency compensation (Section IV-C), and Quality of Experience (Section IV-D).

A. Demographics

Twenty-Five (25) users were screened to participate in the user study out of 128 initial responses. Table III summarizes the participant demographics. FPS self-rating and CS:GO self-rating are on a five-point scale, 1 (low) to 5 (high). For age, FPS self-rating, CS:GO self-rating, CS:GO hours played, and reaction times, the mean values are given with standard deviations in parentheses. Ages ranged from 17-29 years old, typical of a University subject pool. All participants were male – while disappointed there were no female participants, we note esports players are mostly males, especially for FPS games [31]. User self-ratings as FPS and CS:GO gamers both skewed towards "high" (mean 4.4 and 4.6 out of 5, respectively). Half of the users played 10 or more hours of computer games per week.

Figures 2, 3 and 4 depict boxplot distributions for FPS hours played, CS:GO hours played and reaction times, respectively. Each box depicts quartiles and median for the distribution. The whiskers span from the minimum to the maximum. The black pluses shows the mean values. Most users played from 500-2250 hours of FPS games and from 100-1100 hours of CS:GO. Reaction times were mostly fast – most between 195 and 220 ms – typical of experienced computer game players [32] and about 80 ms faster than the average reaction time collected by the human benchmark site [33].

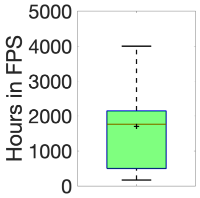

Fig. 2. FPS hours

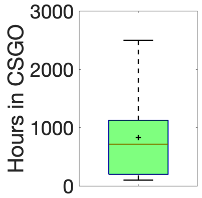

Fig. 3. CS:GO hours

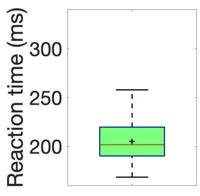

Fig. 4. Reaction times

B. Player Performance

1) Accuracy: Figure 5 depicts weapon accuracy versus network latency on the x axis (the 25 ms system latency is not included). The right y axis is the weapon accuracy (percent) and the left y axis is the percent increase from the 150 ms latency condition. For example, an accuracy of 15 percent at 150 ms of latency compared to an accuracy of 20 percent at 25 ms of latency would be a 5 percent improvement on the left y axis. The circles are the means for all users for that latency condition, bounded by 95% confidence intervals. The dashed line shows a linear regression for the mean values. The regression fits the mean values well, with an R^2 of 0.93 and $p = .04$. As a take-away, a decrease in network latency by 100 ms improves accuracy by an average of about 2 percent.

2) Score: Figure 6 depicts player score versus latency. The axes and points are as in Figure 5, but the data is the score ($2 \times kills + assists$) per minute instead of accuracy. The linear regression fits the mean values well, with an R^2 of 0.96 and $p = .002$. As a take-away, a decrease in latency by 100 ms improves player score by 2 points per minute of gameplay. For reference, often less than a single point in a game separates the scores of top CS:GO players.

3) Effect Size: An effect size provides a measure of the magnitude of difference – in our case, the difference when reducing network latency to the 25 ms base condition. We compare performance with latency to this base condition by independent, 2-tailed t tests ($\alpha = 0.05$) with a Bonferroni correction and compute the Cohen's d effect sizes. The Cohen's d effect size assesses the differences in means in relation to the pooled standard deviation. Generally small effect sizes are anything under 0.2, medium is 0.2 to 0.5, large 0.5 to 0.8, and very large above 0.8. The results are shown in Table IV. From the table, while only the 150 ms condition is significant, this is likely due to the sample size and player variation. For both accuracy and score, there is a small effect when reducing latency from 50 ms to 25 ms, a medium effect for 100 ms to 25 ms and a large effect for 150 ms to 25 ms.

C. Latency Compensation

CS:GO by default has latency compensation on (Time Warp [16]), but it can be explicitly turned off. Figure 7 and Figure 8 depict accuracy and score, respectively, comparing latency compensation on and off. The axes and points are as in Figures 5 and 6, with the blue lines denoting latency compensation on and the red off. The results of the linear regressions are provided in Table V, with slope units of percent per millisecond for accuracy and point per millisecond for score. The p values all indicate statistical significance. From the table and figures, there is an observable benefit to using latency compensation for both score and accuracy. As take-aways, 1) accuracy degrades slightly faster with network latency for compensation off than for compensation on, 2) latency compensation improves accuracy by about 19 percent, and 3) latency compensation improves score by about 1.5 points per minute.

D. Quality of Experience

Quality of Experience (QoE) was assessed from user responses to 9 survey questions filled out at the end of each round. Responses are on a discrete 5-point scale. For the analysis, we rearranged the answers for question 3, 5 and 8 so for all questions, 1 is low (worse) and a 5 is high (better). Table VI shows linear regression parameters fitting the means for each question. From the table, QoE degrades with latency for all questions – the linear regressions fit the mean ratings well for all questions, with R^2 values from 0.901 to 0.999.

[2]https://web.cs.wpi.edu/~claypool/papers/csgo-net-21/

TABLE IV
SIGNIFICANCE AND COHEN'S D EFFECT SIZE (COMPARED TO 25 MS)

	Accuracy			Score		
Latency (ms)	t(22)	p	Effect	t(22)	p	Effect
50	0.750	.460	0.15	0.515	.611	0.10
100	1.196	.244	0.24	2.353	.027	0.47
150	4.623	**<.001**	0.92	3.142	**.004**	0.63

TABLE V
LINEAR REGRESSION FOR PERFORMANCE

Metric	Compensation	y-intercept	Slope	R^2	p
Accuracy	On	21.45	-0.022	0.93	**.011**
Accuracy	Off	19.42	-0.037	0.98	**.037**
Score	On	15.92	-0.018	0.96	**.023**
Score	Off	14.59	-0.020	0.95	**.024**

TABLE VI
LINEAR REGRESSION FOR QOE QUESTIONS

Question	y-intercept	Slope	R^2	p
Q1	4.66	-0.008	0.997	**.001**
Q2	4.71	-0.009	0.997	**.001**
Q3	4.27	-0.007	0.987	**.006**
Q4	4.36	-0.006	0.996	**.002**
Q5	4.40	-0.009	0.999	**.004**
Q6	4.29	-0.005	0.901	.051
Q7	4.31	-0.006	0.993	**.004**
Q8	4.00	-0.006	0.955	**.023**
Q9	4.21	-0.005	0.905	**.049**
Combined	4.36	-0.007	0.994	**.003**

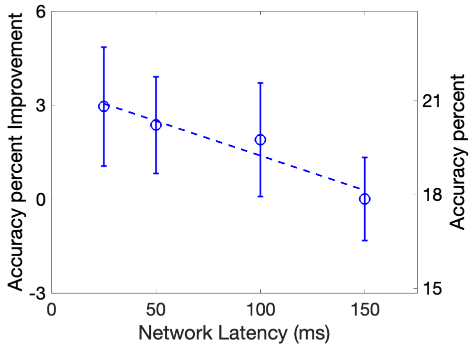

Fig. 5. Accuracy (means with 95% confidence intervals)

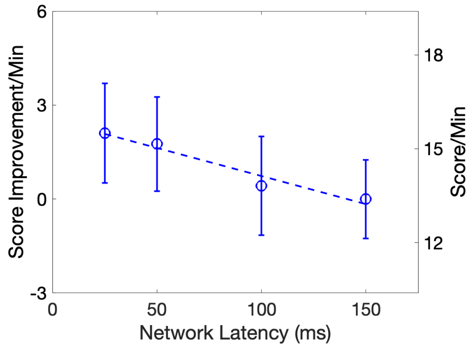

Fig. 6. Score (means with 95% confidence intervals)

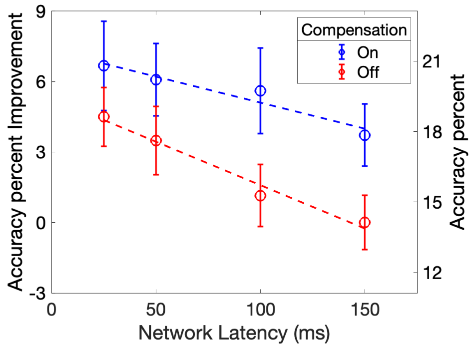

Fig. 7. Accuracy – latency compensation (means with 95% ci)

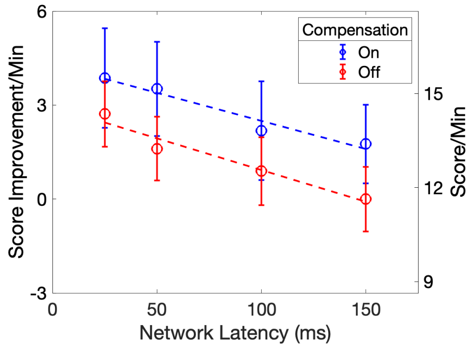

Fig. 8. Score – latency compensation (means with 95% ci)

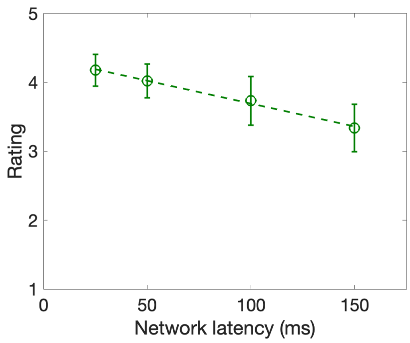

Fig. 9. QoE – combined questions (means with 95% ci)

All values are statistically significant except for question 6 (capable and effective).

For an overall measure of QoE, we compute the overall mean rating (i.e., weighting all questions equally). Figure 9 depicts the results. The x axis is the network latency in milliseconds and the y axis is the rating. The circles are the means for all users for that latency condition, bounded by 95% confidence intervals. The dashed line is a linear regression fit through the mean values. The linear regression fits the means well, with R^2 0.99 and $p = .003$. A one-way between subjects ANOVA shows a significant effect of latency on combined QoE rating at the 0.05 significance level for the four conditions, $F(3, 96) = 5.85$, $p < .001$. As a take-away, a decrease in latency by 100 ms improves QoE by 0.7 points on a 5-point scale.

V. Limitations

Our user study intentionally focuses on the effects of latency on individual player performance. However, as noted in Section III, CS:GO is often a team game, where groups of players (typically 5 per team in esports) work together to defeat the opposing team.

As noted in Section IV-A, our study is skewed towards males (no females participated). While this may reflect the gender breakdown of FPS games today, the results may not be indicative of female performance in competitive FPS games.

Our study intentionally isolated CS:GO play to a single weapon type only – the most popular [28] AK-47 rifle – whereas players typically can choose from a variety of weapons with different firing rates, magazine capacities and damages inflicted.

Most CS:GO games use only human players and not AI-controlled bots, as in our study. However, the relative effects should be similar since latency affects aiming and shooting.

VI. Conclusions

Many gamers seek faster network connections, but how much low-end network latencies benefit competitive players is not well-known. Understanding the impact of network latencies may help better inform gamers about network connections and motivate developers and researchers to devise systems to mitigate latency for games and game-like applications.

We study the effects of latency on competitive First-Person Shooter (FPS) game players. We setup a testbed for *Counter-strike: Global Offensive (CS:GO)* [17] – a popular FPS game used in esports – with four levels of network latency (25, 50, 100 and 150 milliseconds). Twenty-five (25) highly-experienced CS:GO players participated in a user study, each playing 8 rounds of CS:GO with 4 different latency conditions both with and without latency compensation. In total, the study provides over 10 hours of gameplay with objective player performance data (accuracy and score) via logs and subjective opinion data (Quality of Experience – QoE) via surveys.

Analysis of the results shows that across the range of network latencies studied, player performance and quality of experience both improve linearly as latencies decrease from 150 ms to 25 ms. Specifically, player accuracy at 25 ms is about 3% higher than player accuracy at 150 ms, and scores are 17% higher over the same range, an equivalent of about 1 additional kill or 2 additional assists per minute of gameplay. Over this same range, latency compensation improves player accuracy by about 3-4% and score per minute by about 1.5 points. From 150 ms to 25 ms, Quality of Experience (QoE) increases by about 25%, with the QoE at 150 ms being about 3.3 (on a 5 point scale) and the QoE at 25 ms being about a point better at 4.2.

Future work may investigate additional aspects of latency and FPS games, including a broader range of player skills (i.e., non-expert gamers), player versus player (rather than versus bots), and other weapon types (e.g., shotguns). Possible extensions also include more latency compensation techniques and different input and output devices – e.g., game controllers, TVs, touchscreens, and virtual reality.

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