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# The Effects of Network Latency on Counter-strike: Global Offensive Players

Xiaokun Xu, Shengmei Liu, and Mark Claypool
Worcester Polytechnic Institute
Worcester, MA, USA
xxu11, sliu7, claypool @wpi.edu

***Abstract*—Players of first-person shooter (FPS) games, such as *Counter-strike: Global Offensive* (CS:GO), seek low latencies in order to play well and have fun. Even network latencies as small as 10 milliseconds may decrease accuracy, score, and Quality of Experience (QoE), degredations that may be exacerbated for some weapons. This paper presents results from 40+ person user study that measures the impact of network latencies on players for the FPS game CS:GO. We setup a testbed where participants played 20+ rounds of CS:GO with controlled amounts of network latency with either a mid-range, rapid fire, high-precision weapon (an AK-47 assault rifle) or a close-range, slow fire, lower-precision weapon (a Nova shotgun). Analysis of the results shows even network latencies under 100 milliseconds degrade player performance (accuracy and score), avatar movements, and QoE, with the impact on player performance more pronounced for the assault rifle compared to the shotgun.**

## I. Introduction

Computer games are one of the most popular forms of entertainment in the world, with global sales increasing at an annual rate of 10% or more. FPS games are particularly popular – *Counter-strike: Global Offensive (CS:GO)* (Valve, 2012), the next generation of the popular FPS game Counter-Strike, consistently has a tremendous online population [1]. CS:GO has more than 750,000 daily players with frequent regional and international tournaments, supporting both casual and professional esports players with significant prize pools.

Prior work has shown even modest amounts of latency can impact game player performance and Quality of Experience (QoE), especially for FPS games. However, most previous work has not teased out the impact of latency on different types of weapons. Our past work [2] posits that the effects of latency depend upon characteristics of player game actions, such as the precision required to hit a target with a weapon in a FPS game. Weapons in CS:GO can vary from long-range, rapid-fire and precise for a gun such as an assault rifle to short-range, slow-fire and fairly imprecise for a shotgun. Furthermore, most previous work studies higher-end network latencies (e.g., as high as 150 milliseconds or more) which is not common among today's competitive gamers. In fact, new networking technology providers can deliver client-server latencies under 10 milliseconds, which may be appealing to competitive gamers. How much such ultra-low network latencies might benefit CS:GO players is not yet known.

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This paper presents the results from a user study that measures the impact of network latency on CS:GO players, with a focus on low-end network latencies and weapons with contrasting characteristics (e.g., precision). Potential participants were screened for their skill at FPS games, in general, and CS:GO specifically, obtaining a pool of 42 qualified participants. Participants each played 22 rounds of CS:GO, half with an assault rifle (an AK-47) and half with a shotgun (a Nova) in a custom game system setup that let us control the amount of network latency and record player performance.

Analysis of the results shows that for CS:GO:

1) Even network latencies under 100 milliseconds matter for player performance and player QoE. Player performance can degrade by up to 15% when network latencies go from 0 milliseconds (i.e., a LAN game) to 100 milliseconds (common for players at home). Network latency also decreases avatar movements which means less dodging to avoid being shot and less re-positioning to make a shot. Player QoE tends to follow player performance, with subjective ratings of game quality decreasing an average of about 0.7 points (on a 5-point scale) for each 100 milliseconds of network latency.
2) The impact of network latency on player performance depends upon the weapon characteristics. For an assault rifle (e.g., an AK-17), latency degrades accuracy by 15% and 2 points per minute for each 100 ms of network latency. The latter translates to about an extra kill per minute – significant since a single kill can create a huge advantage in a competitive game. But for a shotgun (e.g., a Nova), network latency has far less impact on performance, about 1/3rd as much as for an assault rifle. The effects of network latency on avatar movement and QoE are independent of weapon type, however.

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

## II. Related work

This section provides an overview of prior research work on latency related to our paper: Counter-strike: FPS games

(Section II-A), other games (Section II-B), and latency compensation techniques (Section II-C).

### A. FPS Games

Lee and Chang [3] analyze the impacts of lag on FPS games with experiments using CS:GO. They find latency can affect player shooting accuracy and degrade player performance. Quax et al. [4] show for players of UT2003 that latency and latency jitter under 100 ms degrades player performance and QoE. Amin et al [5] show player experience defines and determines the sensitivity to latency for the FPS game Call of Duty, with competitive gamers more adept at compensating for impaired conditions. Gutwin et al. [6] find even modest latencies can cause significant and substantial degradation in performance for FPS games. Dick et al. [7] analyse different factors affecting players' perception and performance in multiplayer games and conclude that latency impacts subjective users perception in FPS games.

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 effects of latency on individual weapons, as we do in our paper.

### B. Other Games

For other game genres, Howard et al. [8] indicate that for online cooperative games, a player can be affected by a teammate's latency due to cascading effects on the game outcome. Pantel and Wolf [9] show latencies of about 100 ms can affect car racing games. Matthias et al. [10] evaluate DOTA 2 in a crowd-sourced user study and show latency degrades player performance. Hohlfeld et al. [11] find players of the casual game Minecraft are insensitive to network latencies of up to 1 second. Fritsch et al. [12] observe players of the role-playing game Everquest 2 can tolerate hundreds of milliseconds of network latency. Sheldon et al. [13] find some aspects of play in the real-time strategy game Warcraft 3 are not affected by up to a second of network latency. Kojic et al. [14] indicate the network latency for an exergame in VR impacts the perception of lag for the opponent, even if they are not delayed. Schmidt et al. [15] assert that game genre itself (e.g., a FPS game) is not effective for classifying the sensitivity of a game to latency and that game pace matters more.

While useful for comparative purposes, these works generally pertain to games that are less sensitive to latency than FPS games, such as CS:GO – the focus of our study.

### C. Latency Compensation

There are numerous software techniques designed to compensate for the effects of latency on game players [16], [17]. Techniques common to FPS games include: self-prediction where the client predicts game state based on player input before getting confirmation from the server; extrapolation (e.g., dead reckoning) and interpolation where a client predicts states for objects controlled by the server or other players based on past state; and time warp where the server rolls back the game state to when the player action occurred on the client, applies the action, then rolls the game state forward to the current time.

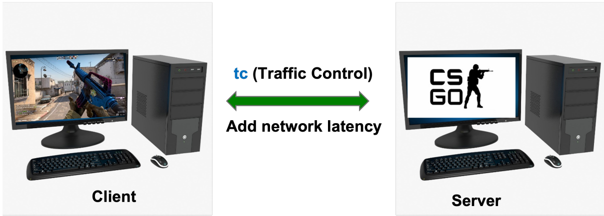


Fig. 1. CS:GO computer configuration.

Lee and Chang [3] evaluate how interpolation in CS:GO improves player accuracy, and their follow-on work [18] suggests keeping latencies below 250 milliseconds when using CS:GO latency compensation. Our previous work [19] evaluates latency compensation for CS:GO, showing it can significantly improve player performance with latency.

While latency compensation is important to combat the effects of network latency, previous work does not evaluate very low latencies or FPS weapon types as in our paper. We use the built-in latency compensation techniques deployed by CS:GO (and most FPS games) – self-prediction, time warp and interpolation.

## III. Methodology

To evaluate the effects of network latency on *Counter-strike: Global Offensive* (*CS:GO*) we setup a client-server testbed for the user study, added controlled amounts of network latency, recruited students to participate in the user study, gathered user data, and analyzed the data for player performance and QoE.

Figure 1 depicts the general setup for our user study testbed. The user study was conducted in a dedicated, on-campus computer lab using a client-server architecture. The server hosts the game and is connected via high-speed LAN to the client. The server PC is an Alienware with an 4-core Intel i7-4790K CPU @4 GHz with 16 GB RAM. The client PC is configured for playing games, with specifications and peripherals typical of a gaming setup. The client has an 4-core Intel i7-4790K CPU @4 GHz with 16 GB of RAM and an NVIDIA GeForce GTX 1080 graphics card. The mouse is a Logitech G502 12k DPI with a 1000 Hz polling rate. The client PC has two monitors – 1 monitor is for the user-study surveys via a Chrome browser (see below) and another monitor is for CS:GO. The CS:GO monitor is designed for gaming, a 25" Lenovo Legion, 1920x1080 pixels displayed at 16:9 and 240 Hz, with AMD FreeSync and a 1 ms response time. Both server and client PCs run CS:GO (version 10.15.2020) on Ubuntu 20.04 LTS, with Linux kernel version 5.4. The PCs connects to a Raspberry Pi 4 configured to act as a network router. The Pi has a 5 GHz 64-bit quad-core CPU with 8 GB of RAM and runs Ubuntu 20.04 LTS with Linux kernel version 5.4 with `tc` [20] to add network latency. Users were given a wired headset for game audio.

TABLE I
TESTBED PERFORMANCE.

| Metric | Statistic |
|---|---|
| frame rate (f/s) | mean: 120.3 (9.6)<br>median: 120<br>min: 95, max 144 |
| local latency (ms) | mean: 17.7 (2.3)<br>median: 17.5<br>min: 15, max: 21 |

We assessed the baseline performance for our testbed for key game parameters: a) in-game frame rate, and b) local latency for the time between local input until the monitor shows the resultant output. The client directly connects to the server via a Gb/s switch, so network round-trip time from the client to the server is lower than 1 millisecond.

Table I depicts the results, reporting mean, median, minimum and maximum. For the mean, the standard deviation is given in parentheses. For frame rate, we measured 5 minutes of CS:GO gameplay using FRAPs [21]. From the results, the recorded frame rate is high and stable, typically desired by gamers. For local latency, we used a 1000 f/s camera (a Casio EX-ZR100) to capture the moment that a user presses the mouse button and the resulting screen output. We inspect the video frame-by-frame to get the time ($t_1$) when the mouse was clicked and the time ($t_2$) when the result was visible. The local latency is then $t_2 - t_1$. We repeated the test 10 times and took the average as the local latency. From the table, the local latency is low, as is typically desired by gamers.

Figure 2 depicts the user study procedure for our study, approved by our Institutional Review Board.

- Potential participants were screened for CS:GO experience to reduce learning effects.
- Selected participants arrived individually at our laboratory at a pre-arranged time and signed a consent form.
- Participants sat at the client PC and adjusted the chair position and height so as to be comfortable.
- The study began with a brief demographic survey.
- The participant then played rounds of CS:GO while our script added a fixed amount of network latency.
- After each round, the participant did a short QoE survey, then repeated the previous step with a different, shuffled latency.
- The participant played 22 rounds, taking just under 60 minutes total. They received $15 remuneration.
- Lastly, we collected game data logs and sanitized and reset the equipment for the next participant.

The QoE survey given at the end of each round was a Mean Opinion Score (MOS) question “Rate the quality of the previous round” on a discrete 5-point Likert scale about the game experience in the preceding round.

Additional latency was added equally to the server uplink and downlink on the router using the Traffic Control [20] Linux utility that has the ability to configure the kernel packet scheduler. The added network round-trip latencies were **0**, **12.5**, **25**, **50** and **100** milliseconds, presented in shuffled order.

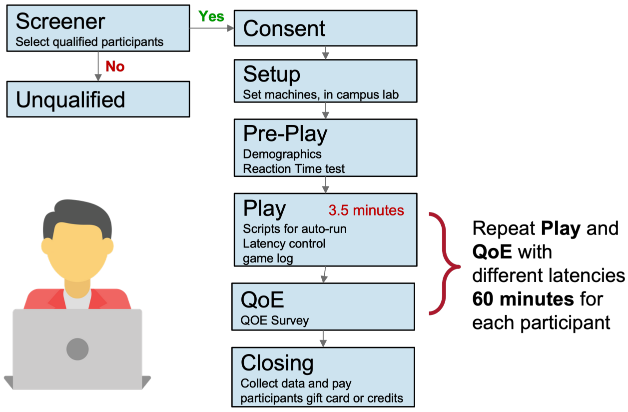


Fig. 2. User study procedure.

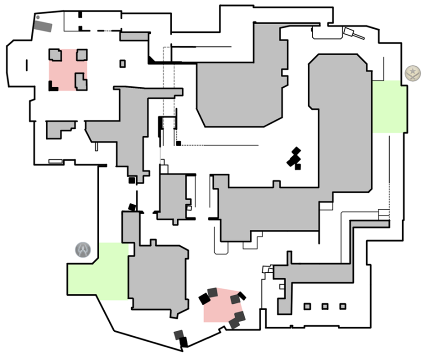

Fig. 3. User study CS:GO map – Mirage.

The objective measures of performance were obtained from the game logs, collected 5 times per second for every player for every round of game play.

TABLE II
WEAPON ATTRIBUTES.

| Weapon | Mode | Fire rate | Clip | Reload | Damage | Accuracy |
|---|---|---|---|---|---|---|
| AK-47 | Automatic | 600/min | 30 | 2.43 s | 36 | 21.74 m |
| Nova | Shotgun | 68/min | 8 | 1.8 s | 26/pellet, 234/shot | 3.2 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. Each round had open combat for the user and 20 AI-controlled players (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.

To assess the effects of network latency on different weapons, the experiment contained 2 parts – 11 rounds with an AK-47 (the most popular automatic rifle) [22] and another 11 rounds with a Nova (the most popular shotgun) [22]. The weapons' specifications are given in Table II. The order of the weapons was shuffled and randomized for all all test scenarios. Players were equipped with only one weapon at a time and had unlimited ammunition.

To maximize combat time compared to wandering around the map, the third smallest [23] and most popular [24] map "Mirage" was used, shown in Figure 3. The user and the bots spawned at random locations on the map that were not currently in view of anyone else.

CS:GO includes time warp latency compensation and interpolation by default. With time warp [16], the server resolves a shot based on the timestamp when the player fires instead of when the server receives the event. With interpolation, the player's actual position is predicted so as to smooth avatar navigation.

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

## IV. Analysis

This section first summarizes participant demographics (Section IV-A), then the effects of network latency on: player performance (Section IV-B) and QoE (Section IV-C).

### A. Demographics

Forty-two (42) students participated in the user study. Table III presents the participant demographics, means with standard deviations in parentheses. The participants were mostly male, with the sample likely skewed by the larger fraction of males (65%) at our university. The average age was 20, typical of our university undergraduates. All participants had experience with FPS games. The participants' average total time spent playing CS:GO was about 2100 hours. The average self-rating for FPS games was 3.8 and the average CS:GO self-rating was 3.3, both on a 5 point scale (1-low to 5-high).

TABLE III
Participant demographic information.

| Users | Age (yrs) | Gender | FPS Self-rating | CS:GO Self-rating | CS:GO Hours |
|---|---|---|---|---|---|
| 42 | 20 (2.0) | 37 ♂ 5 ♀ | 3.8 (1.1) | 3.3 (1.2) | 2109 (703) |

### B. Player Performance

*1) Accuracy:* Figure 4 depicts weapon accuracy on the y-axis (shots hit divided by shots fired) versus network latency on the x axis. The circles are the means for all users for that latency condition, bounded by 95% confidence intervals. The blue dashed line shows a linear regression for the mean values of the AK-47 (an assault rifle) and the red dashed line shows a linear regression for the mean values of the Nova (a shotgun). For the Nova shotgun, if any of the 26 pellets fired per shot hit the opponent, it is considered a 'hit'. Table IV gives the linear regression parameters. Based on the statistical significance and $R^2$ values (and visually), the regression fits the mean values well for the AK-47, with an $R^2$ of 0.83 and $p = 0.03$, and only moderately for the Nova, with $R^2$ of 0.56 and $p = 0.15$. As a take-away, an increase in network latency by 100 milliseconds degrades AK-47 assault rifle accuracy by 15%, with negligible impact on Nova shotgun accuracy for the same latency range.

TABLE IV
Linear regression for accuracy (units are percent).

| Weapon | y-intercept | Slope | $R^2$ | p |
|---|---|---|---|---|
| AK-47 | 0.23 | -0.0003 | 0.83 | **0.03** |
| Nova | 0.20 | -0.0001 | 0.56 | 0.15 |

TABLE V
Linear regression for score (units are points).

| Weapon | y-intercept | Slope | $R^2$ | p |
|---|---|---|---|---|
| AK-47 | 15.8 | -0.016 | 0.88 | **0.019** |
| Nova | 14.9 | -0.003 | 0.18 | 0.48 |

*2) Score:* Figure 5 depicts player score versus latency. The axes and points are as in Figure 4, but the data is the score $(2 \times kills + assists)$ per minute instead of accuracy. Table V gives the linear regression parameters. The regression fits the mean values well for the AK-47, with an $R^2$ of 0.88 and $p = 0.02$, but less well for the Nova, with an $R^2$ of 0.18 and $p = 0.48$. As a take-away, an increase in network latency by 100 milliseconds degrades AK-47 assault rifle score by 12%, with negligible impact on the Nova shotgun score for the same latency range.

*3) Movement:* Figure 6 depicts player movement versus latency, inferred by the total length of time that any of the `WASD` keys were held down per minute. The axes and points are as in Figure 4, but the data is the movement total. When using the Nova shotgun, players move about 20% more, likely because the weapon's shorter effective range means a player must be positioned much closer to an opponent to shoot them. Both linear regressions fit the mean values well, with an $R^2$ of 0.59 and $p = 0.13$ for the AK-47 and an $R^2$ of 0.85 and $p = 0.03$ for the Nova. Overall, network latency decreases player avatar movements. This, in turn, suggests it shortens survival times since a player has a harder time avoiding being shot and a harder time moving into position to shoot opponents. The effect of latency on movement is slightly greater for the Nova shotgun than for the AK-47 assault rifle.

### C. QoE

QoE was assessed by a subjective, 5-point survey question at the end of each round (1-low to 5-high). Figure 7 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

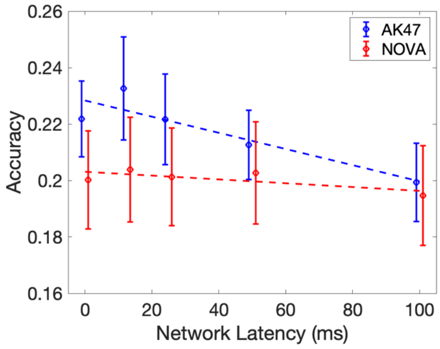


Fig. 4. Accuracy (means with 95% confidence intervals).

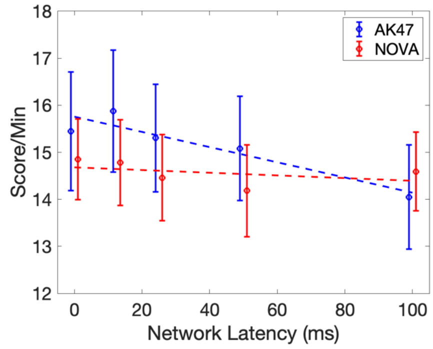


Fig. 5. Score (means with 95% confidence intervals).

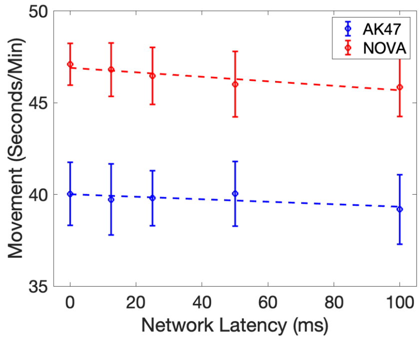


Fig. 6. Movement (means with 95% confidence intervals).

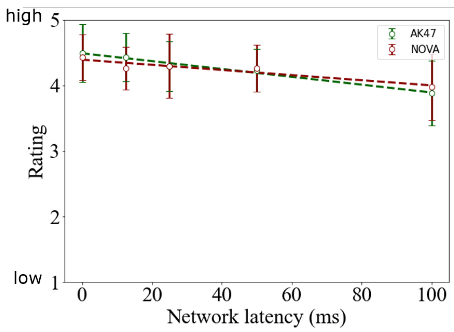


Fig. 7. QoE (means with 95% confidence intervals).

users for that latency condition, bounded by 95% confidence intervals. The green dashed line is a linear regression fit through the mean values for the AK-47 assault rifle and the dark red dashed line is for the Nova shotgun. Table VI gives the linear regression parameters. Both regressions fit the means well, with little visual difference between QoE degradation for the AK-47 compared to the Nova. As a take-away, latency degrades player QoE by 0.5 points on a 5-point scale for each 100 ms, and the degradation is similar for both weapons.

TABLE VI
LINEAR REGRESSION FOR QOE (UNITS ARE POINTS, 5 POINT SCALE).

| Weapon | y-intercept | Slope | $R^2$ | p |
|---|---|---|---|---|
| AK-47 | 4.6 | -0.006 | 0.98 | $<$**0.001** |
| Nova | 4.4 | -0.004 | 0.88 | **0.018** |

## V. LIMITATIONS

Only 5 of the participants in our study were female, and the rest were male. This is fairly representative of our sample pool, but that is because our university has considerably more males than females. More importantly, our results may not represent the performance of female players in CS:GO. Similarly, our participants are young and, while again representative of our sample pool, span a considerably narrower range compared to CS:GO players overall.

Our user study intentionally assess the effects of latency on individual player performance. However, CS:GO is often a team game, where groups of players (typically 5 per team) work together to defeat the opposing team. The impact of latency on CS:GO team efforts, perhaps even team strategies, was not assessed.

Serious game players often customize the software settings on their computers and games to suit their personal play preferences. For example, players may alter the mouse sensitivity or change the graphics resolution from the system defaults. These custom changes presumably improve the specific player's experience and may improve their performance. However, we did not allow any personal changes to the computer or game settings since such customizations create a difference in test conditions between users.

CS:GO games normally have only human players and not AI-controlled bots, so absolute player performance numbers may differ for human versus human games. However, the relative effects of network latency should be similar since the AI-controlled avatars move with the same game physics as do human-controlled avatars, with the primary differences in aiming and firing speeds, impacting player deaths only, not accuracy nor score (kills, assists).

## VI. Conclusions

Network latency has been shown to degrade player performance for many games by making it take longer for a game action at a client to be updated by the Internet game server. While the effects of network latency have been studied for many games, in general, and for FPS games, specifically, what is not known is the impact of low-levels of network latency and latency impact differences based on weapon type. Understanding the effects of latency on a game, and for an FPS game, understanding the effects of latency based on weapon, is important for: a) players to adjust playstyles appropriately (e.g., to choose an appropriate weapon) or to decide to upgrade their system (e.g., get a low-latency network connection), and b) developers in order to deploy latency compensation techniques when appropriate and motivate engineering that might decrease network latency.

This paper presents results of a forty-two (42) person user study that evaluates the effects of latency on players of the popular FPS game *Counter-strike: Global Offensive (CS:GO)* (Valve, 2012). We setup a testbed that controls network latency, collecting objective data (from game logs recording player actions and performance) and subjective data (QoE, via post-round surveys). Each of the 42 participants played a customized game mode of CS:GO for about 1 hour total, experiencing 11 different network latency conditions, with network round-trip times ranging from 0 to 100 milliseconds.

Analysis of the results shows player performance – encompassed by accuracy, score and movement – is significantly impacted by network latency. As a take-away, an additional 100 milliseconds of network latency reduces both score and accuracy by about 15% for the AK-17 assault rifle. However, the impact of latency on score and accuracy is less pronounced for the Nova shotgun. For player movement actions, latency has similar effects for both the assault rifle and shotgun. With 100 milliseconds of network latency, QoE degrades by about 11%, from a high of 4.5 (on a 5 point scale) down a half a point to about 4.0 at 100 milliseconds.

Future work could explore the effects of latency on other weapon types common to FPS games, such as a sniper rifle, pistol or hand-held weapon, such as a knife. Another alternative plan could use our methodology on other games (e.g., the FPS game Valorant), or even other game genres and game platforms, such as cloud-based game streaming systems (e.g., Google Stadia). In both cases, there is also merit in additional study on the effects of latency compensation [16] – e.g., time warp or extrapolation.

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