# Cascading Impact of Lag on User Experience in Cooperative Multiplayer Games

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## ABSTRACT

Playing cooperative games should be fun for everyone involved. Part of having fun in games is being able to perform well, be immersed, and stay engaged [18, 30, 31]. These indicators of experience are part of a game player's Quality of Experience (QoE).

One of the primary causes of QoE degradation in online games is *lag*, a general term for communication delay and loss due to poor network conditions [7, 10, 12, 33, 34, 42]. Current lag mitigation strategies are constructed using the assumption that when evaluating the QoE of a player only that player's network conditions impact their QoE [5].

We have designed an experimental framework to study the effects of lag on a group of players by measuring a gamut of subjective and objective QoE metrics. Our results indicate that the change in QoE of one player due to their lag has a cascading effect on the QoE of the other players.

Understanding a player's QoE as a cascade function that includes other users' network conditions provides a more complete understanding of the impact of lag in cooperative multiplayer games. This has the potential to improve lag mitigation strategies for multiplayer games and other group applications.

## 1. INTRODUCTION

Playing cooperative games should be fun for everyone involved. Part of having fun in games is being able to perform well, be immersed, and stay engaged [18, 30, 31]. These indicators of experience are part of a game player's Quality of Experience (QoE). Previous research has shown that a high QoE in a game makes it more likely that players will play the game longer which translates into increased profit for the game developer.

One of the primary causes of QoE degradation in online games is *lag*, a general term for communication delay and loss due to poor network conditions [7, 10, 12, 33, 34, 42]. Game developers and academic researchers both operate with the assumption that for any given individual in a group, that individual's QoE is affected only by their own network condition and not the network conditions of the other group members [5, 7, 9, 10, 12, 32, 35, 37, 42, 43]. Current lag mitigation strategies are constructed using this assumption [5]. We show that this assumption is not always correct.

We have designed an experimental framework to study the effects of lag on a group of players by measuring a gamut of subjective and objective QoE metrics. Using this framework, we have studied player interactions in controlled group sessions with Mass Effect 3, an online cooperative multiplayer third person shooter (TPS) type game. Our results indicate that the change in QoE of one player due to their lag has a cascading effect on the QoE of the other players.

Understanding a player's QoE as a cascade function that includes other users' network conditions provides a more complete understanding of the impact of lag in cooperative multiplayer games. This has the potential to improve lag mitigation strategies for multiplayer games and other group applications. These strategies may include networking techniques such as prioritizing data center traffic for lagged users using $D^3$, DCTCP, or similar protocols [3, 38]. Other strategies might include improved player behavior prediction, better server processing behavior, and improved time warp responses.

The rest of this paper is organized as follows. Section 2 describe previous research related to user QoE in networked applications. In Section 3 we described background on QoE and collaborative applications. Section 4 described the methodology of our study and Section 5 presents its results. Finally, we conclude in Section 6.

## 2. RELATED WORK

The effect of network latency and packet loss on the experience of a single user is well studied. Previous research shows that high latency, high jitter, and moderate loss negatively impact the experience of a single user [4, 5, 6, 12, 14, 19, 24, 25, 32]. The effects of high latency and high jitter are most apparent when they occur together [6, 27].

Some types of online games have been shown to be more sensitive to lag than other types [4, 5, 28]. In particular, First (and Third) Person Shooters tend to be the most sensitive. This is because they require the user to respond quickly to input while directly controlling a single character.

The QoE of players in a multiplayer games has been previously tested in four general ways. These ways are simulations of user interactions through artificial intelligence (AI) *bots* in competitive tasks, observational studies in real-world applications, in applications developed for the specific research, and as by-products of studies interested in single individuals' QoE [8, 9, 11, 16, 20, 21, 26, 27, 33, 41]. These previous studies focused on the QoE of players with lag, but did not directly examine the QoE of group members with no lag.

## 3. BACKGROUND

In this section we describe properties of collaborative applications, how QoE can be quantified in such applications, and an overview of current lag mitigation techniques.

## 3.1 Cooperative Application

This study examined QoE during matches of Mass Effect 3, a popular video game available on both PCs and console game systems [2]. This game features a team of players who cooperate to defeat computer-controlled enemies. Mass Effect 3 uses a peer-to-peer (p2p) matchmaking system so no central server is directly involved in the game matches.

There are several features of Mass Effect 3 which make it ideal for cooperative gaming research. It encourages cooperation between players but does not require it for the game goals to be reached. The game mode choice allows the exact same game character avatars, level map, and enemy distribution to be chosen. In addition, Mass Effect 3 provides a scoring system where each player gets an individual score at the end of a match, allowing for an objective performance measure.

Mass Effect 3 encourages cooperation through a two part combination attack system. In this system, one player can use a power which will mark an enemy as the first step. When a second player uses a matching power on the marked enemy, a larger amount of damage is done than without the marking process. This combination attack is a highly effective play strategy, but not the only means of overcoming the computer controlled enemies.

## 3.2 QoE Defined

Quality of Experience is a way to represent a player's emotional, cognitive, and behavioral responses to a specific system [13, 22, 39]. QoE is multi-dimensional and represents the player's total experience. The dimensions which are most important are dependent on the system studied. In this study the systems analyzed are matches in a popular multiplayer game, Mass Effect 3 [2].

The QoE dimensions which are important in a multiplayer cooperative game are Concentration, Enjoyment, Sense of Being, Performance Gains, and Exploratory Behaviors. Each of these categories can be quantified through subjective and objective metrics associated with them, as described below.

Understanding the QoE a player has during a session with an application requires the measurement of multiple metrics[13, 39, 42]. The QoE measures examined were Concentration, Enjoyment, Sense of Being, Performance Gains, and Exploratory Behaviors. For all measures a high rating equates to a positive contribution to QoE and a low rating equates to a negative contribution to QoE. Each measure has both objective and subjective metrics associated with it.

Metrics were recorded using three tools. An EEG device was used to record the players' brain activity while playing the game. A keylogger was used to record command input during each match. Surveys were used to record players' self reported experiences. A record of each players' Score was taken after each match.

When measuring QoE dimensions objectively and subjectively, the measurements taken are by definition quantifying different aspects of the dimension. Because of the difference between a player's perception and reality, certain ways of measuring the dimensions may show a strong signal in either the subjective or objective metric but not in the other. This is seen in previous work where the correlations between examined metrics tend to vary greatly [13, 23, 39]

## 3.3 QoE Measures

Concentration is a measure of a player's ability to focus on the game. When a player is focused completely on a task, then the Concentration measure is high. The subjective metric for Concentration is a survey question asking the player to rate how Engaging the match was. A high Engaging rating indicates as high level of Concentration. The objective metric Concentration is an Attention rating gathered by the EEG device [1]. When a player has a high level of Attention then their Concentration measure is high. The device used categorizes Attention into five levels: Low, Somewhat Low, Normal, Somewhat High, High [1].

Enjoyment is a measure of a player's feelings of happiness during a match. A survey question asking the player to rate how Enjoyable the match was is used as the subjective metric for Enjoyment, with a high player rating meaning high Enjoyment. The objective metric for Enjoyment was Time Dilation which was established through a survey question asking the player to indicate if the match felt shorter, longer, or about the same length of time compared to other matches. When a player indicates that a match was shorter than usual when it was not indicates that the player had a high Enjoyment. If the player indicates that a match was longer than usual when it was not then they have a low Enjoyment for that match.

Sense of Being is a measure of a player's feeling of being part of the actual game world. When the player has a suspension of disbelief and the feeling that the character they control is a direct representation of themselves within the game world then the Sense of Being is high. The subjective metric for Sense of Being is a survey question asking the player to rate how Immersive they found the match to be. If the player finds the match to be highly Immersive then their Sense of Being is high. The objective metric for Sense of Being is a Calmness rating gathered by the EEG device, called Meditation by the device developers [1]. This Calmness rating is an indicator of what is commonly considered a feeling of "oneness" or being "in the zone." When the Calmness rating is high then Sense of Being is high.

Performance Gains is a measure of the player's ability to become better at tasks implicit to the game. A survey question asking the player to rate the match's contribution to skill Improvement is used as a subjective metric for Performance Gains. If the player feels the match contributed to Improvement, then Performance Gains are high. A second question asking the player to rate Impairment when controlling their character is used as a subjective metric as well. When the player feels that their control was suffering Impairment then their Performance Gains are low. The objective metric for Performance Gains is the Match Score, which is based on the player's actual ability to score hits and perform cooperative tasks within the game. A high Match Score indicates that the player experienced Performance Gains during that match, with higher Match Score indicating higher Performance Gains.

Exploratory Behaviors is a measure of the player actively learning about the game environment. This learning can be related to the physical layout of the game world as well as more subtle elements such as underlying rules controlling computer controlled enemy behaviors. The subjective metric for Exploratory Behaviors is a survey question asking whether the player tried a New Play Style in the match. A player trying a New Play Style indicates positive Exploratory Behaviors. The objective metric for Exploratory

Behaviors is provided by analyzing the keylog for the match and determining the nature of control inputs. When control inputs indicate a rise or decline in specific behaviors, such as use of special powers, the player has explored new ways to play the game.

## 3.4 Lag Mitigation

Several lag mitigation techniques are in current use [5]. These techniques are intended to reduce the impact of lag on a player's QoE during a gaming session. The following lag mitigation techniques are the most frequently used for online games.

Behavior Prediction algorithms are used to adjust the game state to predicted states before user input is received. The game server attempts to predict the player's behavior in order to send the most appropriate state updates to that player. This reduces the information which needs to be sent as state information which does not directly impact the player or objects in view of the player does not need to be transmitted. The client machine attempts to predict enemy behavior in order to place the enemies in the correct locations before getting confirmation from the server. This allows the game to appear to be continuous despite the inherent periodicity in state update information.

Two different Time Manipulation approaches are used. Time Delay is a method where the latency to all players in a group is measured and then artificial latency is added to the information flow to players who do not have the worst natural latency. This is an attempt to provide a mathematical level playing field for all players. Time Warp is a technique where the server applies client input based on the timestamp of the input, rather than the arrival timestamp of the input information. This allows the client computer to accept input that does not have to be forecast into the future game state but can be applied to the game state the player is experiencing.

Information transmission techniques are also used to reduce the apparent impact of lag. Data Compression algorithms are used to reduce the size of information packets. This allows for effectively higher bandwidth and room for information redundancy strategies.

Game servers prefer to use UDP for information communication. This reduces the latency caused by TCP retransmission and allows for bursts of information without the need for a ramp-up period. When UDP is not available, TCP is used instead.

Finally, Visual Trickery can be used to mitigate the impact of lag. This can include using Behavior Prediction models to present the game state in probabilistic states. It can also include things such as ignoring state update information that does not impact the player, such as changes in terrain or precise location of area effects.

# 4. METHODOLOGY

We developed a methodology based on previous work in Sociology and Computer Science to study QoE in a cooperative group application [30, 39, 40, 42]. This methodology consists of taking both subjective and objective measurements during periods of play. In order to study the real world impact of lag, human participants were used in an application that benefited from cooperation but does not strictly require cooperation for the players to succeed in reaching the game's goals.

Table 1: Studied Factor Sets

| Set Number | Location | Latency | Jitter | Loss |
|---|---|---|---|---|
| 0 | Same Room | 0ms | ±0ms | 0% |
| 1 | Same City | 60ms | ±30ms | 1% |
| 2 | Same State | 120ms | ±60ms | 2% |
| 3 | Same Country | 180ms | ±90ms | 3% |

Four factor sets of lag were emulated for one of the players. QoE was measured during each game session using both subjective and objective metrics. All measurements were compared for correlation using the Pearson product-moment correlation coefficient between the lagged player and unlagged players. When a change in a metric for the lagged player correlates to a change in the same metric for unlagged players, that impact is considered to have cascaded because it travels beyond the player directly affected and onto the unlagged players.

A questionnaire given after each match was used to record player-reported metrics. In addition to questions directly related to metrics of QoE, users were also asked whether they attributed any loss of enjoyment to network degradation. During play a wearable EEG and a keylogger were used to record objective metrics.

A total of 160 experimental matches were played. Each participant participated in at least 12 but no more than 20 matches. The participants were paired in permutations that ensured no same pair was together for more than 8 matches. Each participant experienced each factor set approximately an equal number of times, and at each set was experienced at least 2 times.

## 4.1 Emulated Network Conditions

In order to investigate the impact of lag on cooperative game players, network conditions to one player was emulated. The network condition factor sets sets were based on common network conditions based on the geographical distances between players [15]. These sets include representative lag for a user located in the same room, city, state, and country as the other group members [17, 29, 36].

Latency, jitter, and packet loss were combined into representative sets for ease of experimentation. These are studied in combined groups to represent realistic conditions and reduce the total number of experimental episodes needed. Each of the are the round-trip totals. In the case of Jitter, transmissions in each direction had half of the listed value applied according to a normal distribution.

## 4.2 Experiment

A set of self-selected volunteers formed the pool of players studied. This pool comprised a set of individuals from the local community, both students and non-students, of both genders and with an age range of approximately 18-30 years.

Before research began, a briefing for all players was held. At this briefing the players were informed of the general nature of the study, including that the network conditions to one or more computers may be changed artificially at some point in the study.

During the research episodes players were co-located on adjacent computers, allowing for free verbal communication during the experiment as is common during normal online

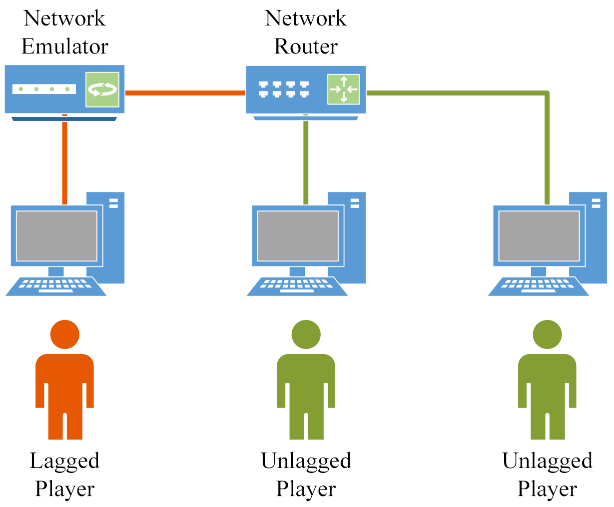


Figure 1: Experiment Setup

play. The player responsible for setting up a two-part combination attack was an expert player. The other two players in each match used characters that can perform the second step in the combination attack. This expert player was the only player lag was applied to, and was the same individual for all tests in order to allow for a standard comparison. One of the unlagged players was selected at random as the match host.

## 5. RESULTS

We examined the cascading impact of lag by adjusting the level of network performance on the path to the game server for only a single member of the group while taking QoE measurements for all group members. These measurements were taken from all group members within a popular real world collaborative application.

The collected data show that the QoE of a player is impacted by the decreased network conditions of other players. This is counter to previous assumption that a player's QoE is only impacted by their own network conditions [5, 9, 12]. Additionally the data show that when examining the cascading impact of lag, the correlations between objective and subjective metrics may not be the same for the unlagged players as they are for the lagged player.

### *5.0.1 Impact on Lagged Player*

In our study, we see that the QoE of the lagged player is affected by lag in the same manner seen in previous work. As the lag becomes worse, the lagged player's QoE metrics become lower.

### *5.0.2 Cascading Impact on Unlagged Players*

Table 2 shows each QoE metric's level and strength of correlation between the lagged player's degradation of QoE due to lag and that of the other players in the group. The $r^2$ value estimates the fraction of the variance in the unlagged players' responses that is explained by the values in lagged player's responses. A high $r^2$ value indicates a strong correlation between the two variables. The p-value is a test of statistical significance. A p-value below 0.05 typically indicates that it is likely the correlation is not due to random

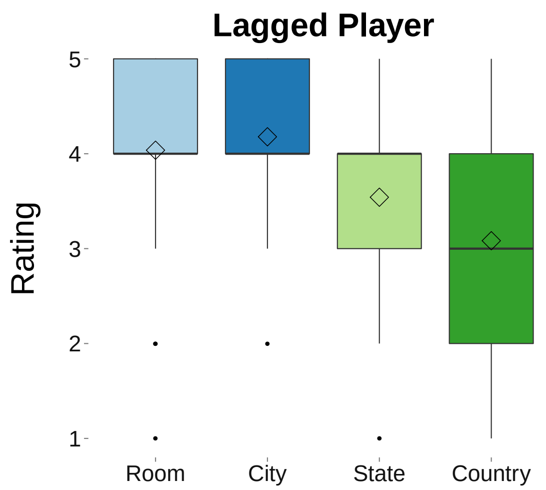


Figure 2: Lagged Player Engaging

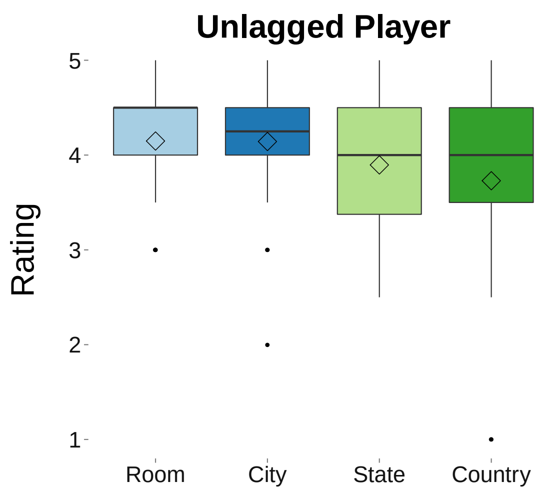


Figure 3: Unlagged Player Engaging

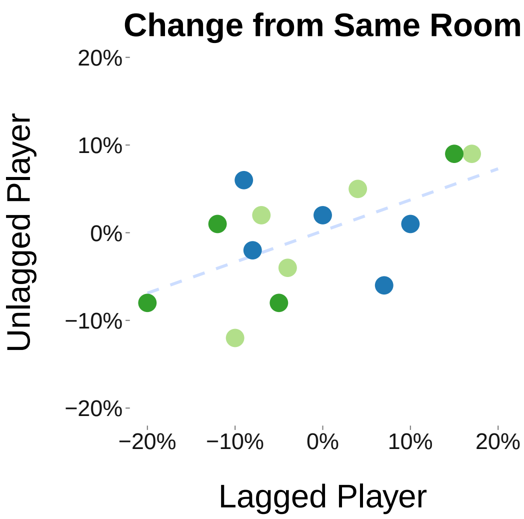


Figure 4: Ratings for Engaging

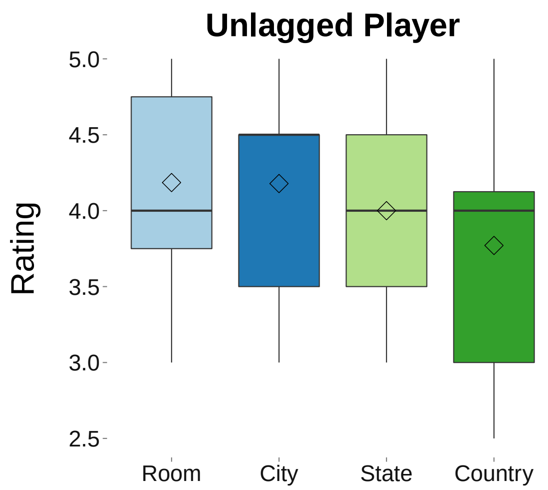


Figure 6: Unlagged Player Enjoyable

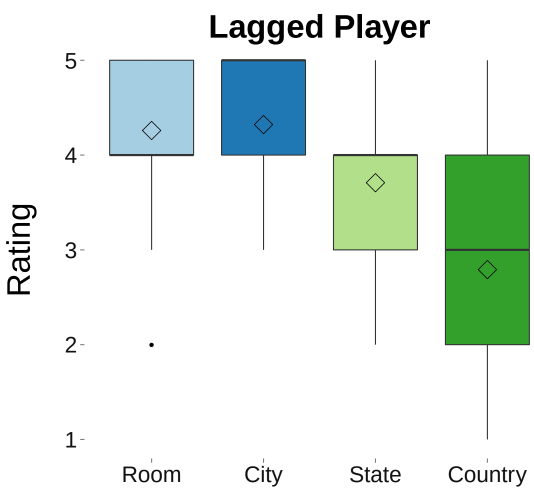


Figure 5: Lagged Player Enjoyable

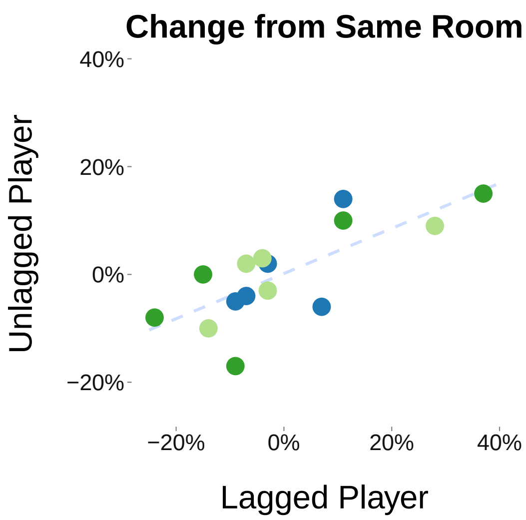


Figure 7: Ratings for Enjoyable

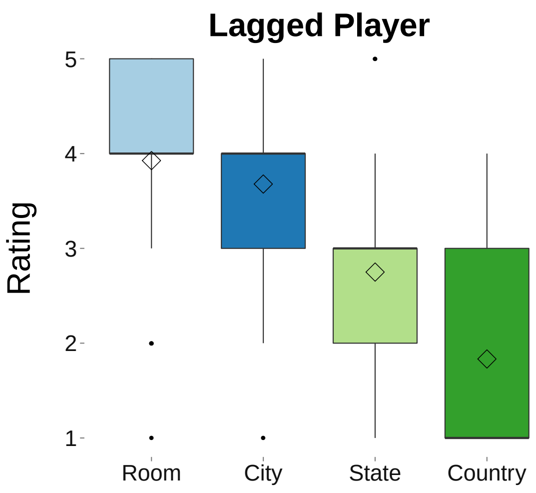


Figure 8: Lagged Player Immersive

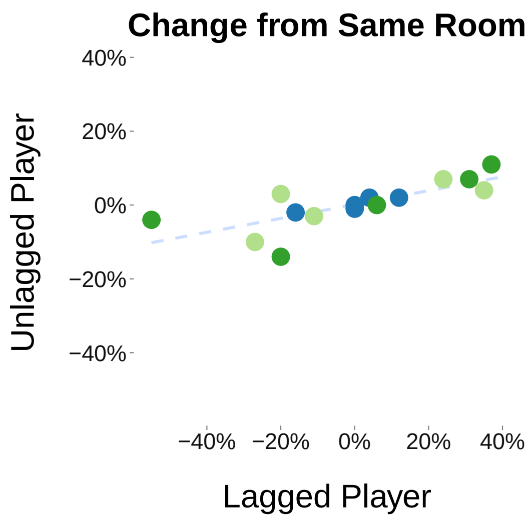


Figure 10: Ratings for Immersive

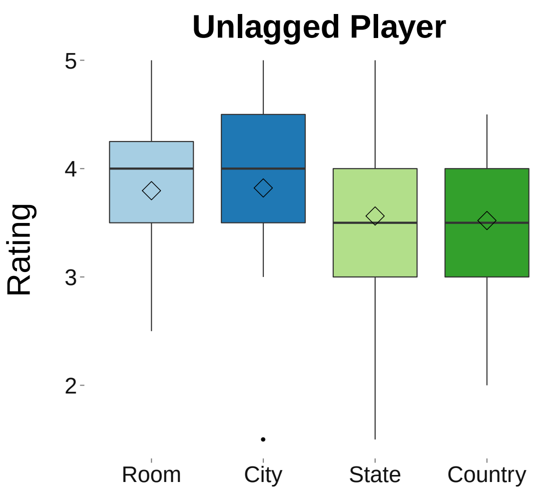


Figure 9: Unlagged Player Immersive

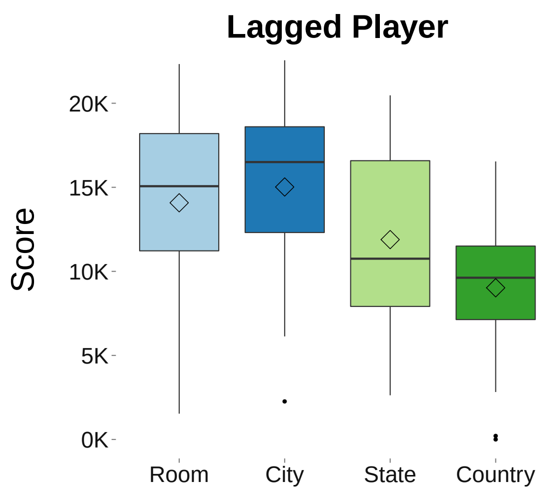


Figure 11: Lagged Player Match Score

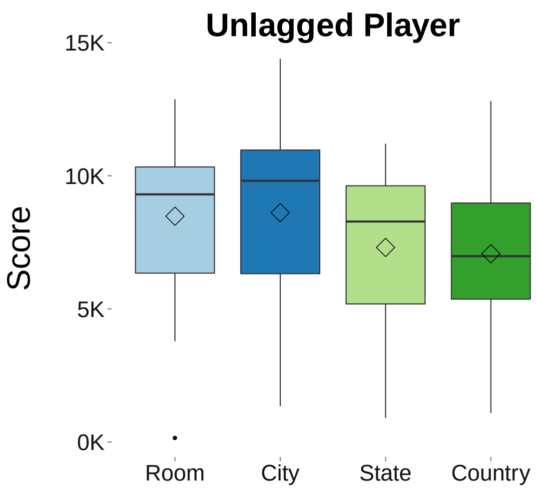


Figure 12: Unlagged Player Match Score

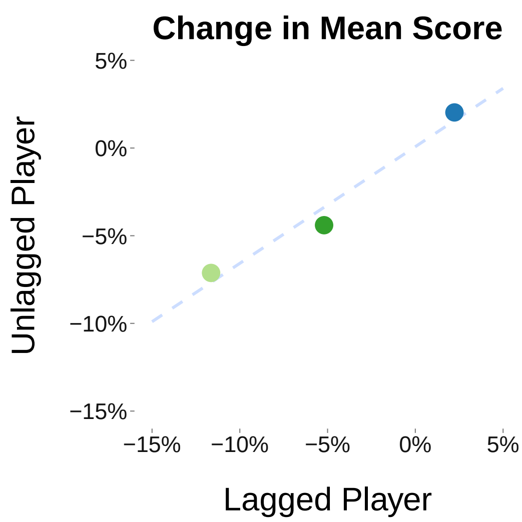


Figure 13: Change in Mean Score

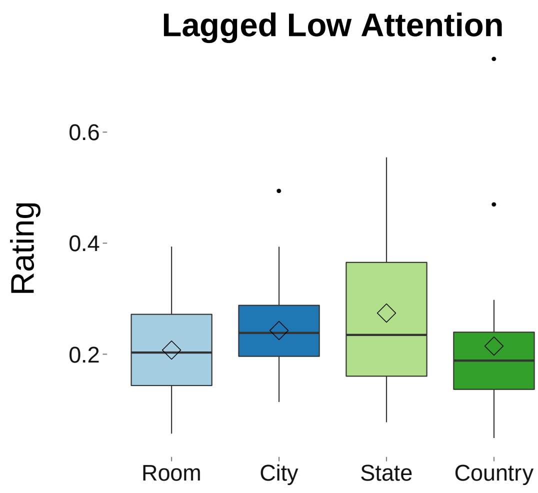


Figure 14: Lagged Player Attention Below Normal

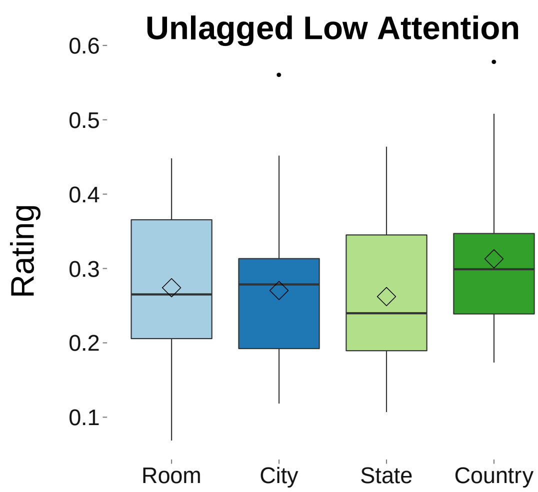


Figure 15: Unlagged Player Attention Below Normal

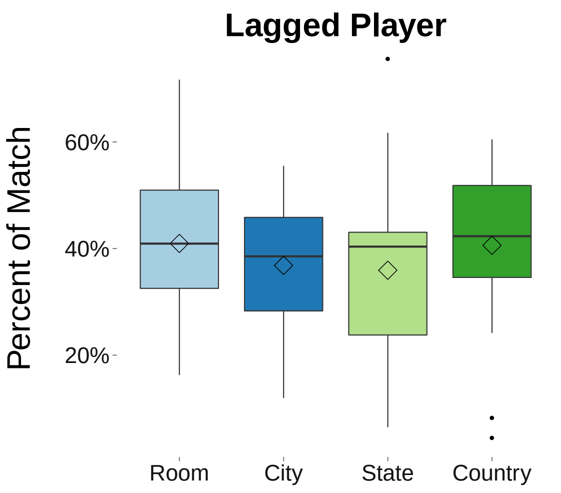


Figure 16: Lagged Player Attention Above Normal

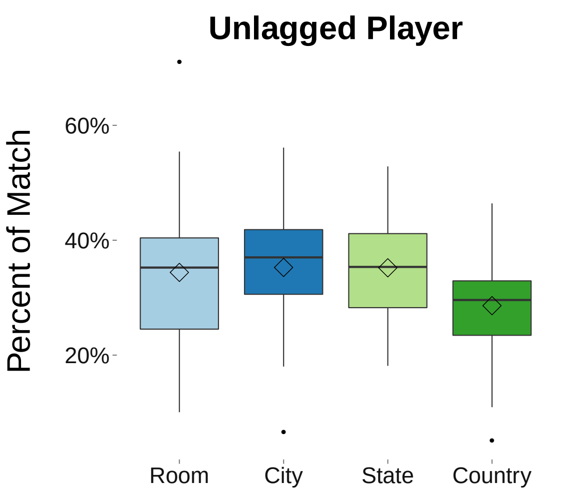


Figure 17: Unlagged Player Attention Above Normal

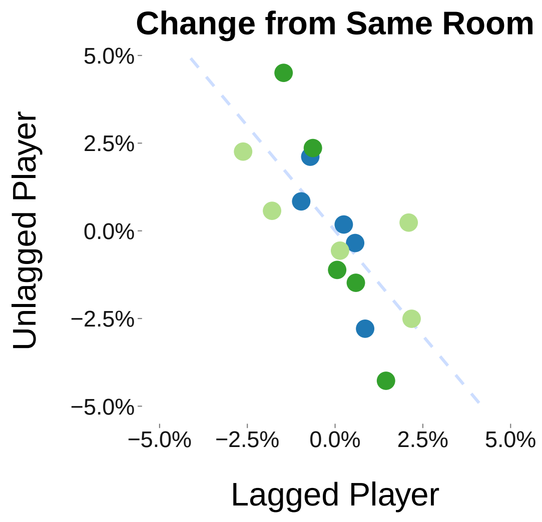


Figure 18: Change in Time of Attention Above Normal

Table 2: Correlations of Change in QoE Metrics

| QoE Metric | Correlation ($r^2$) | p-value |
|---|---|---|
| Engaging | $\approx 0.38$ | $< .015$ |
| Attention | $\approx 0.52$ | $< .003$ |
| Enjoyable | $\approx 0.56$ | $< .002$ |
| Immersive | $\approx 0.56$ | $< .002$ |
| Match Score | $\approx 0.62$ | $< .001$ |

chance. All of our p-values are below 0.015 which indicates that the correlations are statistically significant.

For the metrics of Engaging, Enjoyable, Immersive, and Match Score, we now know that in general as the measured QoE metric decreases for the lagged player, the same metric will decrease for all players in the group. In the case of Attention, the unlagged players showed an increase when the lagged player showed a decrease.

The Ratings for Engaging, Enjoyable and Immersive are shown in scatterplots in Figures 4- 10 representing change in response. All changes are relative to the Same Room factor set (Set 0). The values are the change in percentage of times that the rating was given during each emulated lag set. As the emulated lag becomes worse, the changes in ratings becomes more extreme.

Attention is scored at five levels, allowing for a plot that functions in the same manner as the subjectively rated plots.

The correlation values for Match Score are for raw scores over all matches. Because the Match Score is not categorized in the same manner as the rest of the metrics, its correlation overall is a more appropriate measurement.

## 5.1 Inability to Attribute QoE Decrease to Lag

Figures 19 and 20 show the players rating the amount of impact network conditions had on their Enjoyment, with a rating of 5 indicating no impact. While the lagged player's responses correlated to the lag, the unlagged players' responses did not correlate to the level of lag. This indicates that the unlagged players were not able to correctly attribute their decrease in QoE to changes in the amount of lag.

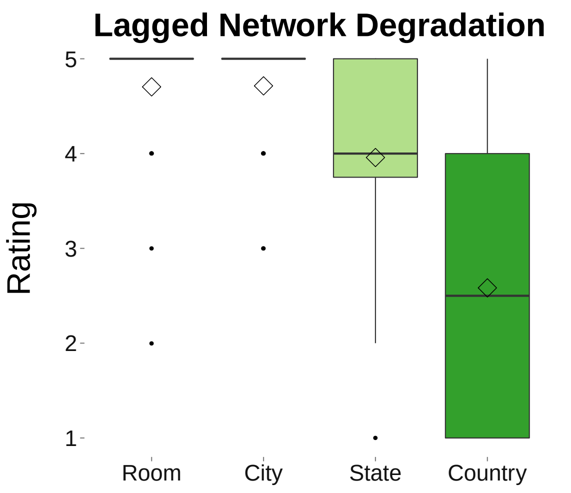


Figure 19: Lagged Player Network Degradation

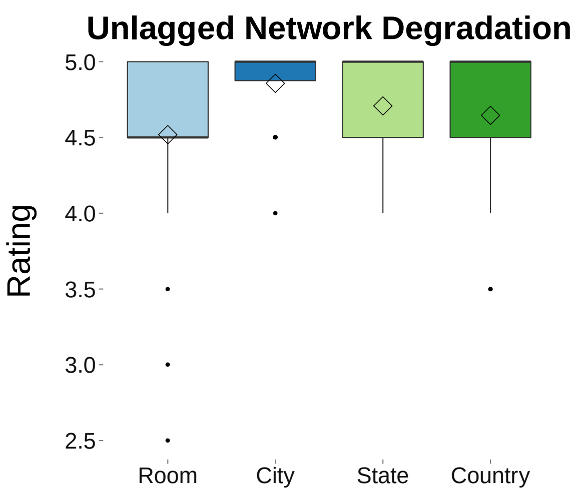


Figure 20: Unlagged Player Network Degradation

# 6. CONCLUSIONS

The lag of just one player can cause a cascading impact on the QoE of other players. This is counter to previous assumptions that only a player's own lag impacted their QoE. Understanding the cascading impact provides additional information when designing cooperative online games.

For our subjective measures, this impact is negative for both the lagged and unlagged players. In the case of Score, there is a slight increase in this metric for Performance Gains when there is a slight amount of lag. This is seen in previous research as well and bears further analysis in future work [5]. Measured Attention levels, both Above and Below Normal did not behave in the same manner as other metrics. Because there is a dearth in research using brainwave measured levels of Attention, future work must be done to understand why this metric behaves thusly.

When asked to rate the amount of QoE degradation caused by network issues, the unlagged players were not able to correctly attribute degradation to the lag present. This indicates that when analyzing the QoE of a cooperative multiplayer game, a user's report stating that network conditions are acceptable may not reflect reality.

Having a group member lag decreases the experience for everyone, but understanding that lag has a cascading impact opens many new areas of systems research and application development. Current lag mitigation techniques are not sufficient when dealing with this cascading impact and may actually be decreasing the overall QoE of the players. Some new techniques may include prioritizing game requests of only the lagged users in data centers using mechanisms such as $D^3$ or DCTCP can improve application usability for all users [3, 38]. It may also be possible to modify current techniques to address this cascading impact.

# 7. REFERENCES


[1] Neurosky's esense meters and detection of mental state. white paper, September 2009.
[2] Bioware accolades. `http://masseffect.bioware.com/about/accolades/`, February 2013.
[3] M. Alizadeh, A. Greenberg, D. A. Maltz, J. Padhye, P. Patel, B. Prabhakar, S. Sengupta, and M. Sridharan. Data center tcp (dctcp). In *SIGCOMM 2010 conference*, August 2010.
[4] G. Armitage. An experimental estimation of latency sensitivity in multiplayer Quake 3. In *International Conference on Networks*, 2003.
[5] G. Armitage, M. Claypool, P. Branch, J. Wiley, G. Armitage, and M. Claypool. *Networking and Online Games - Understanding and Engineering Multiplayer Internet Games*. John Wiley & Sons Ltd, June 2006.
[6] T. Beigbeder, R. Coughlan, C. Lusher, J. Plunkett, E. Agu, and M. Claypool. The effects of loss and latency on user performance in unreal tournament 2003®. In *SIGCOMM workshop on Network and system support for games*, August 2004.
[7] Y. W. Bernier. Latency compensating methods in client/server in-game protocol design and optimization. In *Game Developers Conference*, 2001.
[8] A. Beznosyk, P. Quax, K. Coninx, and W. Lamotte. Influence of network delay and jitter on cooperation in multiplayer games. In *Virtual Reality Continuum and Its Applications in Industry (VRCAI)*, December 2011.
[9] M. Bredel and M. Fidler. A measurement study regarding quality of service and its impact on multiplayer online games. In *Workshop on Network and Systems Support for Games*, November 2010.
[10] J. Brun, F. Safaei, and P. Boustead. Managing latency and

fairness in networked games. *Communications of the ACM*, 49:46–51, 2006.

[11] Y.-C. Chang, K.-T. Chen, C.-C. Wu, C.-J. Ho, and C.-L. Lei. Online game qoe evaluation using paired comparisons. *Proceedings of IEEE CQR 2010*, 2010.

[12] K.-T. Chen, P. Huang, and C.-L. Lei. Effect of network quality on player departure behavior in online games. *Parallel Distributed Systems*, 20:593–606, May 2009.

[13] P. Chen and M. El Zarki. Perceptual view inconsistency: an objective evaluation framework for online game quality of experience (qoe). In *Proceedings of the 10th Annual Workshop on Network and Systems Support for Games*, page 2. IEEE Press, 2011.

[14] M. Claypool and K. Claypool. Latency and player actions in online games. *Communications of the ACM*, 49:40–45, November 2006.

[15] W. Feng and W. Feng. On the geographic distribution of on-line game servers and players. In *Proceedings of the 2nd workshop on Network and system support for games*, pages 173–179. ACM, 2003.

[16] T. Fritsch, H. Ritter, and J. Schiller. The effect of latency and network limitations on MMORPGs: a field study of Everquest 2. In *SIGCOMM workshop on Network and system support for games*, October 2005.

[17] O. Goga and R. Teixeira. Speed measurements of residential Internet access. In *Passive and Active Measurement*, January 2012.

[18] R. Hirota and S. Kuribayash. Evaluation of fairness in multiplayer network games. In *Pacific Rim Conference on Communications, Computers and Signal Processing (PacRim)*. August, 2011.

[19] T. Jehaes, D. De Vleeschauwer, T. Coppens, B. Van Doorselaer, E. Deckers, W. Naudts, K. Spruyt, and R. Smets. Access network delay in networked games. In *Proceedings of the 2nd workshop on Network and system support for games*, 2003.

[20] A. Kaiser, D. Maggiorini, N. Achir, and K. Boussetta. On the objective evaluation of real-time networked games. In *Global Telecommunications Conference*, November 2009.

[21] K. Karadimitriou and M. Roussou. Studying player experience in a collaborative embodied interaction game. In *Games and Virtual Worlds for Serious Applications*, 2011.

[22] F. Kuipers, R. Kooij, D. De Vleeschauwer, and K. Brunnström. Techniques for measuring quality of experience. *Wired/Wireless Internet Communications*, pages 216–227, 2010.

[23] F. Levillain, J. Orero, M. Rifqi, and B. Bouchon-Meunier. Characterizing player's experience from physiological signals using fuzzy decision trees. In *Computational Intelligence and Games (CIG), 2010 IEEE Symposium on*, pages 75–82. IEEE, 2010.

[24] C. Ly, C.-H. Hsu, and M. Hefeeda. Irs: A detour routing system to improve quality of online games. *IEEE Transactions on Multimedia*, 13:733–747, 2011.

[25] J. Nichols and M. Claypool. The effects of latency on online madden nfl football. In *Proceedings of the 14th international workshop on Network and operating systems support for digital audio and video*, pages 146–151. ACM, 2004.

[26] W. Palant, C. Griwodz, and P. Halvorsen. Consistency requirements in multiplayer online games. In *SIGCOMM workshop on Network and system support for games*, October 2006.

[27] K. S. Park and R. V. Kenyon. Effects of network characteristics on human performance in a collaborative virtual environmnet. In *IEEE Virtual Reality*, March 1999.

[28] J. Pellegrino and C. Dovrolis. Bandwidth requirement and state consistency in three multiplayer game architectures. In *Proceedings of the 2nd workshop on Network and system support for games*, pages 52–59. ACM, 2003.

[29] A. Petlund, P. Halvorsen, P. F. Hansen, T. Lindgren, R. Casais, and C. Griwodz. Network traffic from anarchy online: analysis, statistics and applications: a server-side traffic trace. In *Proceedings of the 3rd Multimedia Systems Conference*, 2012.

[30] M. Seif El-Nasr, B. Aghabeigi, D. Milam, M. Erfani, B. Lameman, H. Maygoli, and S. Mah. Understanding and evaluating cooperative games. In *International conference on Human factors in computing systems*, April 2010.

[31] C. Shen and D. Williams. Unpacking time online: Connecting internet and massively multiplayer online game use with psychosocial well-being. *Communication Research*, 38:123–149, 2011.

[32] J. Smed, H. Niinisalo, and H. Hakonen. Realizing the bullet time effect in multiplayer games with local perception filters. *Computer Networks*, 49:27–37, 2005.

[33] M. Suznjevic, O. Dobrijevic, and M. Matijasevic. MMORPG player actions: Network performance, session patterns and latency requirements analysis. *Multimedia Tools and Applications*, 45:191–214, October 2009.

[34] P. Tarng, K. Chen, and P. Huang. On prophesying online gamer departure. In *Network and Systems Support for Games (NetGames)*, November 2009.

[35] P.-H. Tseng, N.-C. Wang, R.-M. Lin, and K.-T. Chen. On the battle between lag and online gamers. In *Communications Quality and Reliability*, 2011.

[36] X. Wang, T. Kwon, Y. Choi, M. Chen, and Y. Zhang. Characterizing the gaming traffic of world of warcraft: From game scenarios to network access technologies. *IEEE Network*, 26:27–34, 2012.

[37] S. D. Webb, S. Soh, and J. L. Trahan. Secure referee selection for fair and responsive peer-to-peer gaming. *Simulation*, 85:608–618, 2009.

[38] C. Wilson, H. Ballani, T. Karagiannis, and A. Rowtron. Better never than late: meeting deadlines in datacenter networks. In *SIGCOMM Computer Communication Review*, August 2011.

[39] W. Wu, A. Arefin, R. Rivas, K. Nahrstedt, R. Sheppard, and Z. Yang. Quality of experience in distributed interactive multimedia environments: toward a theoretical framework. In *International conference on Multimedia*, October 2009.

[40] N. Yankelovich, J. Kaplan, J. Provino, M. Wessler, and J. M. DiMicco. Improving audio conferencing: are two ears better than one? In *Proceedings of the 2006 20th anniversary conference on Computer supported cooperative work*, 2006.

[41] T. Yasui, Y. Ishibashi, and T. Ikedo. Influences of network latency and packet loss on consistency in networked racing games. In *SIGCOMM workshop on Network and system support for games*, October 2005.

[42] S. Zander and G. Armitage. Empirically measuring the qos sensitivity of interactive online game players. In *Australian Telecommunications Networks & Applications Conference*, 2004.

[43] S. Zander, I. Leeder, and G. Armitage. Achieving fairness in multiplayer network games through automated latency balancing. In *ACM SIGCHI International Conference on Advances in computer entertainment technology*, 2005.