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ABSTRACT

Latency can degrade the performance and quality of experience for online games. While the effects of latency have been studied, what is less well known are the limits for perception and tolerance that players have for online games. This paper presents the results of a survey analyzing latency perceptions for over 240 users and their more than 550 games. Generally, users claim they notice latencies as low as 85 milliseconds, but can tolerate about 600 milliseconds of latency. These values vary considerably from individual to individual and from genre to genre. Users find network issues relatively infrequent, but when they do occur, users feel it has a big impact on competitive games.

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1 INTRODUCTION

Computer games are one of the most popular sources of entertainment in the world, with an expected 2.7 billion gamers in 2021, up from 1.8 billion in 2014 [5]. In the U.S., gamers comprise 66 percent of the general population, up from 58 percent in 2013 [6]. With the growth and penetration of the Internet and the spread of powerful mobile devices, computer games are increasingly online, connecting players competitively and socially in interactive worlds [19].

Online games must deal with local latency from the player's computing device as well as network latencies. When playing online, game states and actions from one player's game world must to be transmitted across the network to a server and other players. This extra delay can manifest in a less responsive game world or, in the case of game state prediction, less consistent world views across players.

There have been numerous studies of the effects of latency on game players, often clustering work based on genre – e.g., First Person Shooter [1, 2, 17], Massively Multiplayer Online [4, 12], Real-Time Strategy [7], and Sports [14, 16]. And there are established methods to game systems deploy to compensate for network delays in traditional online games [3, 13], such as system-level treatments (e.g., network packet priorities), delay compensation algorithms (e.g., dead reckoning, sticky targets, aim dragging) and even game designs that can mitigate perceived delay (e.g., deferred avatar response, geometric scaling).

What is not well-understood is how latency is currently perceived by players for the games they play. For example, it is not known what player's think the minimum noticeable latencies nor what they feel are the maximum tolerable latencies. The effects of latency on player performance are often dependent upon the genre [8] or player perspective [10], but whether these results align with player perceptions is not widely know. Prior surveys have looked at player perceptions of the network for online games [15, 18], but have not directly ascertained the effects of latency, or have examined players' perception of latency, but only for a small set of games in a few genres [11]. Moreover, past surveys are all about 10 years old and older and so may not reflect player perceptions regarding modern games on today's computing systems and networks.

This work presents the results from a widely-distributed survey regarding online games played today, ascertaining player perceptions of minimal and maximum tolerable latencies for each game. Additional information queried concerns the number and kind of devices played on, the network connections for those devices and the frequency and severity of network degradations on online games. The survey was sent to various university mailing lists, circulated among

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colleagues, and posted to online communities in an effort to reach as broad an audience as possible.

Over 400 people responded to the survey, with over 240 providing sufficient data for analysis. While most participants were from the United States, gamers from 11 different countries in total were represented. The 240+ users provided perceptions of the impact of networking and latency for the over 550 online games they played, 164 of them unique.

Analysis of the results shows: Most people play on more than one gaming device per week, with laptop and desktop computers being the most common. Most people play 2 or more different online games about 5-8 hours per week total, connected via a wired Ethernet or WiFi as opposed to mobile. Our clustering of online games into genres based on the type of player interactivity shows first person shooters, exploration and competition games are the most popular. Overall, the average minimum latency users report as noticeable is about 85 milliseconds and the average maximum latency users reported as tolerable is about 600 milliseconds. These latency limits vary considerably by genre, with first person shooters being perceived as the most sensitive to latency, but with all genres having an average minimum noticeable latency below 100 milliseconds. Users generally find network problems infrequent, but when there are network issues, competitive games suffer the most while exploration or turn-based games, not so much.

The rest of this paper is organized as follows: Section 2 describes related work in the form of other surveys of online gamers, Section 3 details our survey and distribution methodology, Section 4 presents the aggregate data, Section 5 analyzes the results, and Section 6 summarizes our conclusions and presents possible future work.

2 RELATED WORK

Oliveira and Henderson [15] present results from a survey of gamers to glean what users think of the Internet and its impact on their game playing experience. The survey included 23 questions, most in the form of a 7 point Likert scale and was advertised on several online gaming mailing lists. Responses from 335 users provided a range of responses, but users' opinions on the perception of the network and delay are most relevant to our work. Most of the surveyed users attribute disruptions in their gameplay to the network, which was said to be annoying. Latency was generally a factor in users' choices of online game servers. Our work is similar in the general scope of the survey, but we ask specific questions about latency values and tie them directly to the games the users reported playing.

Dick et al. [11] analyze different factors affecting players' perceptions and performances in online games, including a survey of players' views on network latencies for a variety of games. Their survey contained questions on users' experiences, computer hardware, and Internet connections. In addition, their survey asked for the latency limits for very good, playable and annoying classifications of gameplay. These values were requested for 12 specific games, 9 of which were first person shooters. The survey was distributed through the Internet by using game forums and mailing lists to reach a large number of online game players. Responses from 309 users provided data on gaming experience and play, but most relevant to our work, gave data on latency limits: between 70.5 and 93.2 milliseconds with an average of 80.7 milliseconds. The lower limit was the same for nearly all games. There was no clear differentiation between first person shooters and the real time strategy game or the sports game. Our work provides for a broader set of survey questions to gather user opinions on the wider range of online games played today than the first person-centric set of games the studied by Dick et al.

Tseng et al. [18] present an Internet survey designed to understand how players perceive latency and its causes. They deploy a 33 question survey with questions from four main categories: player demographics, perceptions of latency, reactions towards latency, and perceived solutions. They advertised the survey on a bulletin-board system in Taiwan and, as an incentive, paid each respondent 50 PTT dollars (about $0.05 USD). Responses from 229 users showed most players noticed latency, if occasionally, and when they did it was intermittent, lasting a few seconds. Most players thought latency influenced their gameplay, even causing some to quit their online game. While similar to our work, their survey did not gather information on the games played so cannot relate the latency experience to the game genre, unlike our work.

3 METHODOLOGY

To assess players' perceptions of latency for online games, we employ the following methodology:

(1) Create a survey (Section 3).
(2) Solicit survey participation via mailing lists and online forums (Section 3).
(3) Analyze the results (Section 4 and Section 5).

Survey Questions

We created a Qualtrics[1] survey with the following questions (with possible answers shown in parentheses):

(1) How old are you? (Numeric entry)
(2) Gender? (M, F, Other, Prefer not to say)
(3) Rate your ability as an online gamer. (1-low to 5-high)
(4) On average, how many hours do you play games per week? (0-1 h, 2-4 h, 5-8 h, 9-16 h, 17+ h)

[1] https://www.qualtrics.com/

(5) Select all devices you play on each week. (laptop, desktop, console, hand-held console, mobile phone, tablet, VR, other)
(6) On average, how many different online games do you play per week? (1, 2, 3, 4, 5+)

For each game (indicated by question #6), the following questions were triggered:

(A) Name the online game you play the (1st, 2nd, 3rd, ...) most each week. (Free text)
(B) How do you connect to the Internet when you play this game? (WiFi, Wired, Mobile)
(C) What is the *minimum* network latency/lag in milliseconds you can notice when playing this game (give us your best guess). (Numeric entry)
(D) What is the *maximum* network latency/lag in milliseconds you can tolerate when playing this game (give us your best guess). (Numeric entry)
(E) Rate your confidence in your answer. (1-low to 5-high)
(F) How fast paced is this game? (1-low to 5-high)
(G) How often are there network problems? (1-low to 5-high)
(H) When there is latency/lag, how much does it affect your performance? (1-low to 5-high)

Solicitation

After approval by the University Institute Review Board (IRB),[2] a solicitation email with a link to the survey was distributed via University mailing lists:

- University-wide faculty and staff mailing list
- Faculty and staff in the Computer Science (CS) department
- Undergraduate and graduate students in the Interactive Media and Game Development (IMGD) program and the CS department
- Students enrolled in IMGD courses
- Related game and software research groups

In addition, solicitation was done via the authors' direct contacts and social media accounts:

- Reddit: `r/TakeMySurvey`, `r/SampleSize`, `r/gaming`
- Discord: `IGDA WPI`
- Sina Weibo, Facebook, Tumbler (personal pages)
- Friends and family
- Colleagues

4 RESULTS

Table 1 lists the number of participants obtained via the survey. Over 400 responded by visiting the Qualtrics link. Of those, 247 completed the survey. Manual inspection of those that did not complete the survey provide an additional 13 users that had enough information to allow comparison with other users. From the 260 participants, 17 reported 0 as the number of online games they reported per week. Thus, the final count of participants analyzed for this study is 243. All subsequent analysis in this report is from this group of 243 users, unless otherwise noted.

Table 1: Number of participants.

Total number of participants	401
Number of participants with complete data	247
Number of participants with enough game data	260
Number of participants used in analysis	243

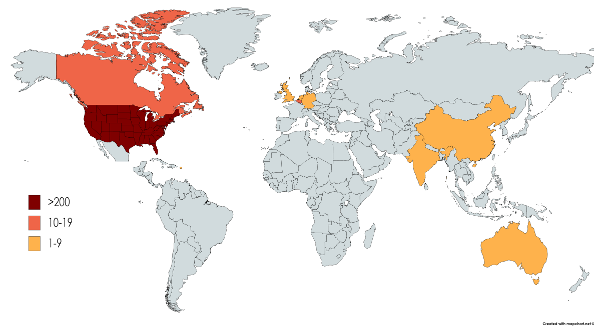

Figure 1: Distribution of participants around the world.

Figure 1 depicts the global distribution of our survey participants by country, determined by IP address. The vast majority (220) of the participants are from the United States with the next highest number of participants coming Belgium and Canada. The full list of countries represented by at least one participant includes: Australia, Belgium, Canada, China, Germany, Hong Kong, India, Netherlands, Puerto Rico, United Kingdom, and United States.

Figure 2 depicts the distribution of United States participants across states, again determined by IP address. The majority of the participants are from Massachusetts, the location of the authors' university, with New Jersey, New York, Connecticut and Georgia all having more than 10 participants. In total, 24 out of the 50 U.S. states are represented by at least 1 participant.

Figure 3 shows the age distribution of the participants. The x-axis is the age in years, binned into 5-year intervals, and the y-axis is the count of people in each bin. The oldest participant is 75 years old, while the youngest is 12. Most participants are between the 18 and 30 years old, perhaps owing to the university-centric forums used for soliciting participants.

[2]https://www.wpi.edu/research/resources/compliance/institutional-review-board

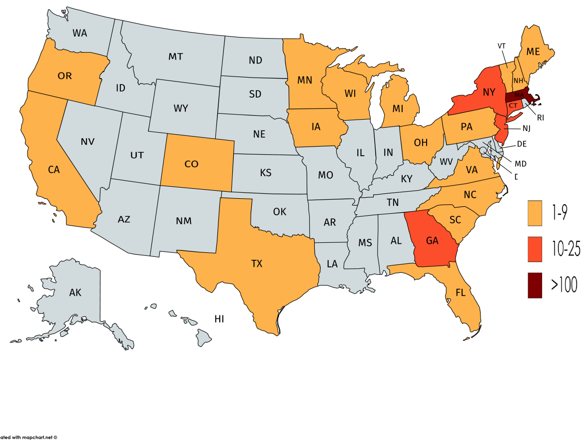

Figure 2: Distribution of participants in the United States.

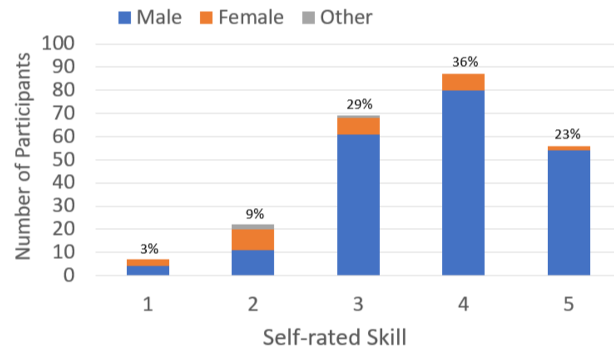

Figure 4: Self-rating as a Gamer.

Table 2: Demographic summary.

N	Age	Gender	Gamer	Games/wk
243	24.5 (8.1)	210 ♂, 28 ♀, 5 ?	3.7 (1.0)	2.4 (1.10)

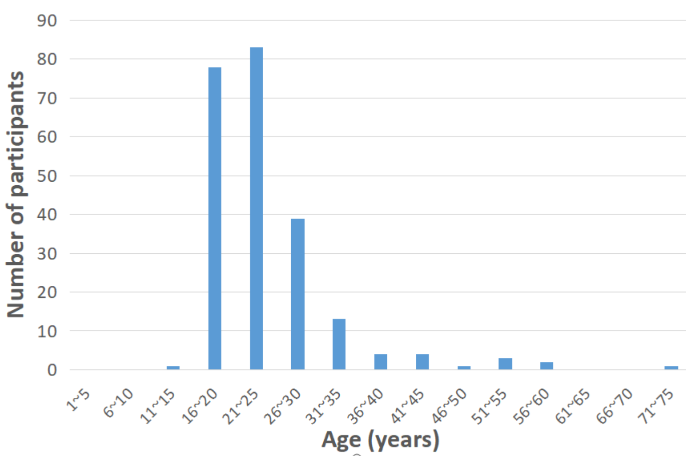

Figure 3: Age.

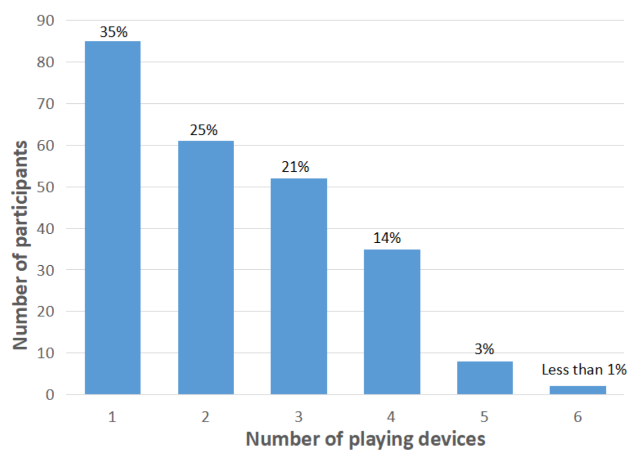

Figure 5: Devices played on per week.

Figure 4 depicts the distribution of participants' self-rating scores as gamers, from 1-low to 5-high. The x-axis is the self-rated score, and the y-axis is number of participants. The bars are stacked, with blue denoting males, orange females and gray other. Overall, the distribution is skewed towards a high self-rating of gamer ability, with few participants rating themselves a 1 or 2, and a mode of 4.

Table 2 provides a summary of the participants' demographics, with the columns as follows: "N" denotes the number of participants; "Age" is the mean age in years, with the standard deviation in parentheses; "Gender" gives a breakdown of males, females or not specified; "Gamer" is the mean self-rating as a gamer (1-low to 5-high), with the standard deviation in parentheses; and "Games/wk" is the mean number of online games the participants play per week, with the standard deviation in parentheses.

Figure 5 depicts the distribution of different devices the participants reported they played on each week. The x-axis is the number of devices and the y-axis is the number of participants. While about a third of participants only play games on one device each week, most play games on two or more devices each week and 15% play on 4+ devices each week.

Figure 6 shows a breakdown of the game devices reported used by the survey participants. The x-axis is the device and the y-axis is the participant count. It can be seen that laptop, desktop and console are the most popular types. There still

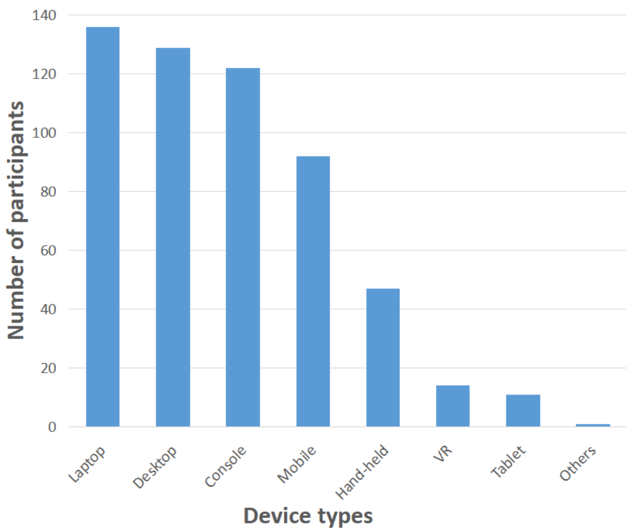

Figure 6: Device types used.

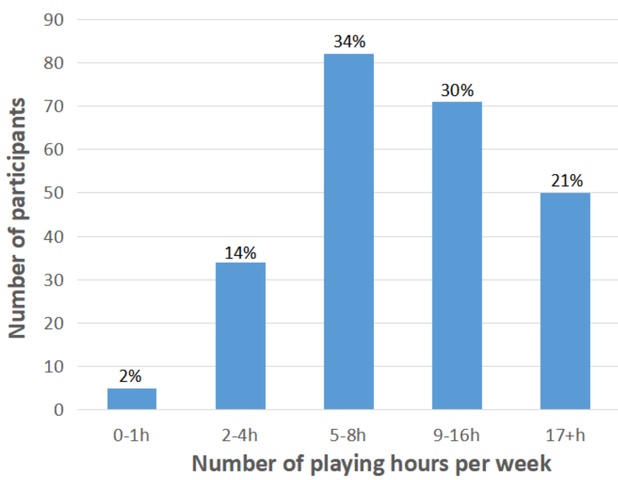

Figure 7: Number of hours played per week.

many users would choose mobile-phone and hand-held console as playing devices. But only a few participants would play games on VR or tablet.

Figure 7 depicts the distribution of participant play time per week. The x-axis is the hours, in bins that double in size left to right, and the y-axis is the participant count. The response mode is 5-8 hours per week, but right-skewed in that about half of the participants reported playing 9 or more hours per week.

Figure 8 shows the distribution of unique online games participants reported playing per week. The x-axis is the number of online games and the y-axis is the participant

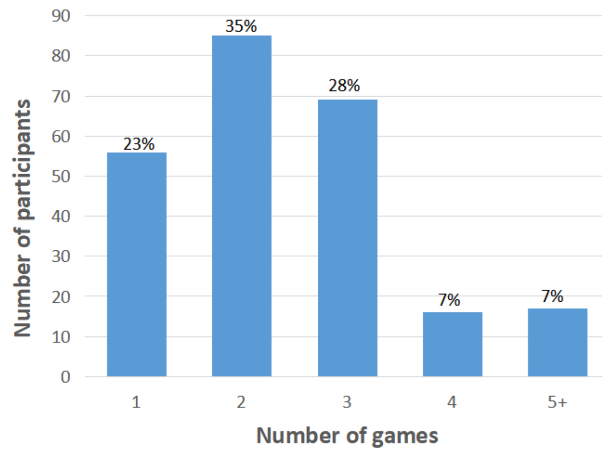

Figure 8: Number of online games played per week.

Table 3: Connection Types

Connection	Count	Percent
WiFi	254	44.9
Wired	226	39.9
Mobile	24	4.2
WiFi & Wired	48	8.5
WiFi & Mobile	8	1.4
WiFi, Wired & Mobile	6	1.0

count. The mode response is 2, but most users play between 1 and 3 games per week.

Table 3 depicts the number and the percentage of games played over WiFi, Wired, Mobile and combinations thereof. Most participants indicated they play online games about equally on WiFi or wired (not both) with only a minority indicating mobile.

5 ANALYSIS

Games

The 243 participants reported playing 567 different online games, total. Manual cleanup of game names (e.g., cleaning up typos and abbreviations) left a total of 164 unique games, with different versions of the game being counted separately whenever possible (e.g., Civilization IV and Civilization V count as two games). The top 10 games the participants reported playing are listed in Table 4. About 100 games were played by a single participant.

Figure 9 depicts the rank order popularity of the games played by the participants. The x-axis is the rank order, high to low, and the y-axis is the count of participants that played each game. Generally, the rank order of games played follows

Table 4: Top 10 Games.

Game	Count
League of Legends	54
Apex Legends	35
Minecraft	30
Overwatch	29
Counter-Strike: Global Offensive (CSGO)	23
Call of Duty (CoD)	15
Rainbow Six Siege	13
Fortnite	11
Super Smash Brothers	10
PlayerUnknown's Battlegrounds (PUBG)	10

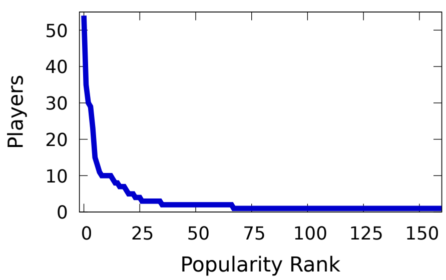

Figure 9: Rank order popularity of games.

a Zipfian trend in that the probability of an observation is inversely proportional to its rank.

Genres

Given the size of this game pool (164 total), and the fact that most games (over 100) have only one player, before analyzing the perception of latency we categorize games by genre.

Unfortunately, there are nearly as many genres used to describe games as we have games. Wikipedia[3] includes almost 70 different game genres. However, many of the differences in genres are not meaningful in terms of the effects of delay on the game and other genres are so broad as to not provide for sufficient game differentiation so as to better understand latency.

Hence, we break down games into genres that have: 1) a sufficient number of games in each genre, and 2) groupings with similar pacing and intensity of player interactions with the game world. To assign games to genres, we used the following methodology:

(1) Two authors assigned each game to a genre, doing half the list of games each.
(2) For consistency, two different authors repeated the same analysis. There was moderate agreement between the individuals, with a Cohen's kappa score = 0.50.
(3) Differences were discussed and agreed upon. The resulting list was 39 different genres.
(4) From these genres, the authors discussed the common player interactions for each and distilled the list to 7 final genres. The genres and their definitions are listed in Table 5.
(5) Two people assigned games to these new 7 genres.
(6) For consistency, two different authors repeated the same analysis. There was strong agreement between the individuals, with a Cohen's kappa score = 0.89.
(7) The final list of games and their corresponding genres is available online.[4]

Table 5: Genres and their definitions.

Genre	Definition
Competition	Primary player interaction is time sensitive
Competition and Exploration	Substantial elements of competition and exploration
Exploration	Primary player interaction is time insensitive
First (and Third) Person Shooter	Primary player interaction navigation and shooting
Racing	Primary interaction time-sensitive navigation
Real-Time Strategy	Primary player interaction strategic, not tactical
Turn-Based	Players take turns, each 1+ seconds
Other	Games not in any of the above categories

In our final analysis, we determined that 10 of the 11 games in the Other genre are not, in fact, online games. These games are removed from further analysis in this paper.

Figure 10 depicts the distribution of online games among the final 7 genres. The x-axis is the game genre (First Person Shooter, Exploration, Competition, Competition and Exploration, Turn-based, Real-Time Strategy, Racing and Other) and the y-axis is the count. There are almost equal numbers of games in the First Person Shooter, Exploration and Competition Genres which make up over 75% of all games.

[3]https://en.wikipedia.org/wiki/List_of_video_game_genres

[4]https://web.cs.wpi.edu/~claypool/papers/lag-survey/

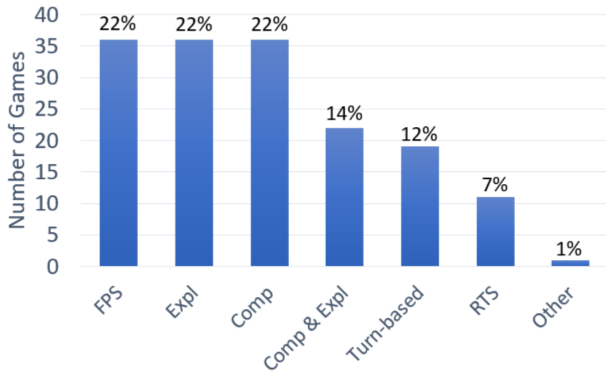

Figure 10: Distribution of game genres.

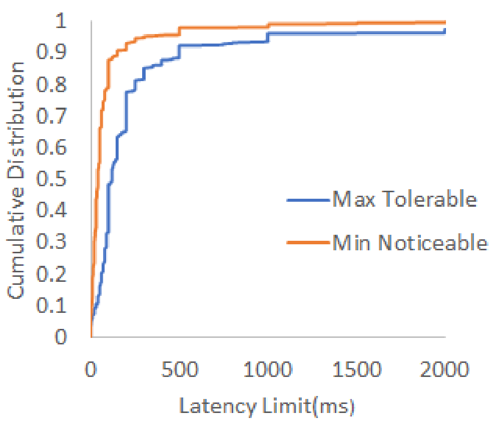

Figure 11: Minimum noticeable and maximum tolerable latencies.

Given that there are only 3 games in the Racing genre and 1 game in Other genre, these genres are removed from all subsequent graphs that group games by genre. The 4 games are still included in analysis that considers all game data.

Latency

Figure 11 depicts cumulative distribution functions of the latency limits as indicated by the participants across all games. The x-axis is the latency in milliseconds and the y-axis is the cumulative distribution. There is one line shown for each limit: minimum noticeable latency (orange) and maximum tolerable latency (blue). The maximum tolerable latency reported was 60,000 milliseconds, but the graph is scaled to 2000 milliseconds for readability. Table 6 depicts summary statistics for the same data and also includes the participant's self-rated confidence in their answer.

From the figure and table, the minimum noticeable latency is about 50 milliseconds and the maximum tolerable latency

Table 6: Latency summary statistics.

	Median	Mean	SD
Minimum Latency	40 ms	86.3 ms	195.7 ms
Maximum Latency	120 ms	608.0 ms	4190.7 ms
Confidence in Answer	3 (of 5)	3.3	1.3

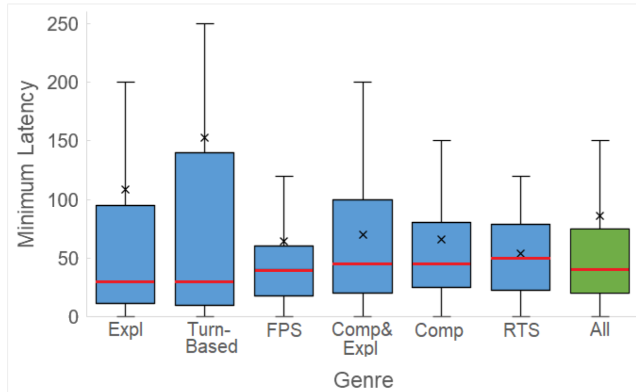

Figure 12: Minimum noticeable latency by genre.

about 125 milliseconds. However, there is considerable variation across responses, with the low limits (noticeable and tolerable) near 0 and the high limits several seconds (noticeable) up to a minute (tolerable).

Figure 12 shows boxplots of the minimum noticeable latency grouped by genre, sorted in ascending order of median value. Exploration (Expl) has the lowest median noticeable latency and Real Time Strategy (RTS) has the highest. However, in general, the median values are similar regardless of genre. First Person Shooters (FPS) have the lowest spread (inter-quartile range) of any genre.

Figure 13 shows boxplots of the maximum tolerable latency grouped by genre, sorted low to high by median value. First Person Shooters (FPS) and Exploration have the lowest maximum tolerable latencies, but the latter has a large spread and much higher mean than most other genres. The median values here vary more than the minimum noticeable latencies, with FPS medians around 100 milliseconds and Turn-Based medians around 200 milliseconds.

Pacing

Figure 14 shows the distribution of the pacing online games as reported by the participants. The x-axis is the response to the question "how fast paced is this game" (1-low to 5-high) and the y-axis is the frequency. The distribution is right-skewed, with a mode of 5, mean of 3.66 and median of 4.

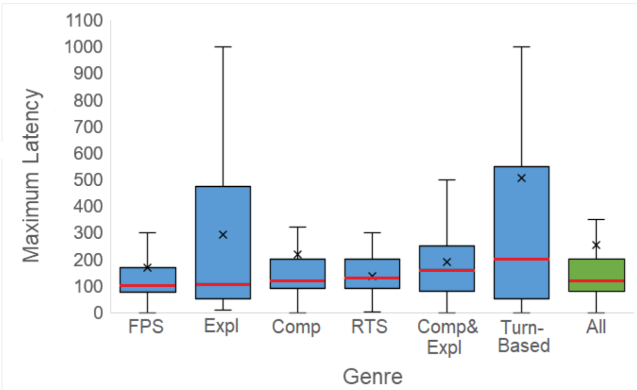

Figure 13: Maximum tolerable latency by genre.

Table 7: Minimum Latency summary statistics (units are milliseconds).

Genre	Mean	SD	Median	IQR
FPS	64.45	162.42	45	80
Exploration	108	288.94	50	56.25
Competition	65.99	79.57	45	54.75
Real Time Strategy	54.1	34.06	50	56.25
Comp. & Expl.	70.09	82.04	45	80
Turn-Based	152.6	266.27	65.99	54.75

Table 8: Maximum Latency summary statistics (units are milliseconds).

Genre	Mean	SD	Median	IQR
FPS	167.1	272.75	100	85
Exploration	430.38	1148.21	110	415
Competition	924.13	5936	120	110.75
Real Time Strategy	137.42	77.94	130	110
Comp. & Expl.	180.69	161.5	162.5	170
Turn-Based	504	835.05	200	500

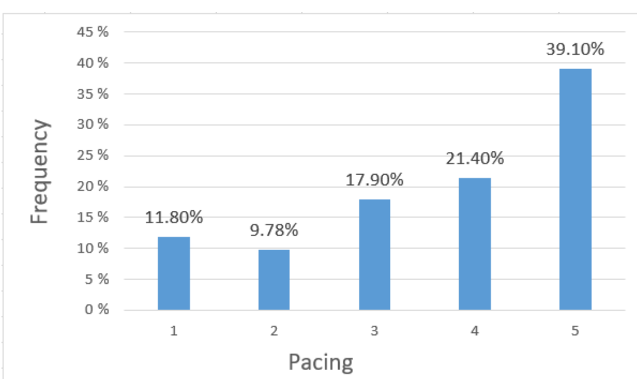

Figure 14: Distribution of game pacing.

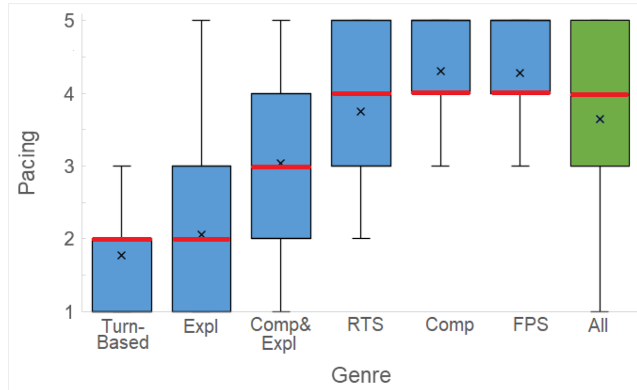

Figure 15: Game pacing by genre.

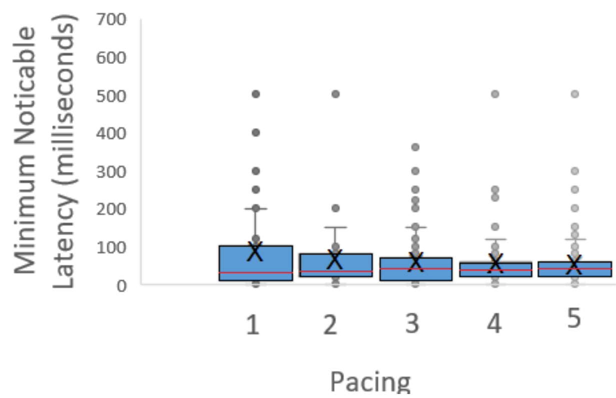

Figure 16: Minimum noticeable latency versus pacing.

Figure 15 shows boxplots of the game pacing grouped by genre, sorted low to high by median value. Turn-Based games have the lowest median pacing score, while First Person Shooter (FPS) and Competition games have the highest. Exploration games have the highest spread of pacing values, possibly due to the wide variety of games in this genre.

Figures 16 and Figures 17 show boxplots of the minimum noticeable latency and maximum tolerable latency, respectively, for games at each pacing level. Generally, there is an inverse relationship between latency limits and pacing, with the highest paced games deemed to have the lowest noticeable and lowest tolerable latencies. The lower paced games (pacing 1 and pacing 2) have the largest spread, too. 24 games did not have a rating for pacing, and thus were removed from these plots.

Network Problems

Figure 18 depicts the distribution of the frequency of network problems when playing online games as reported by the participants. The x-axis is the answer to the question "How often are there network problems" (1-low to 5-high) and the

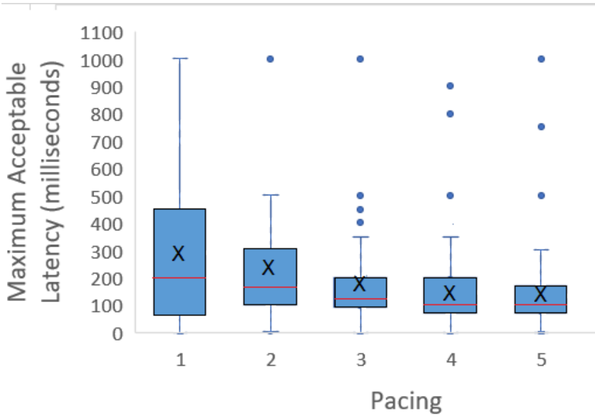

Figure 17: Maximum tolerable latency versus pacing.

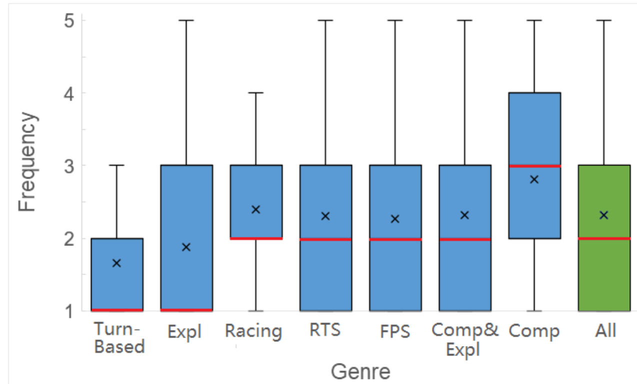

Figure 19: Frequency of network problems by genre

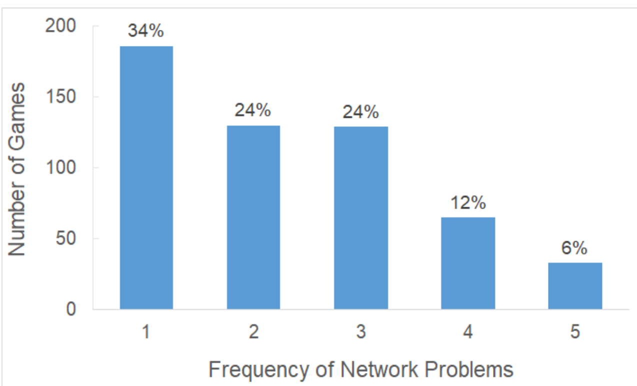

Figure 18: Frequency of network problems.

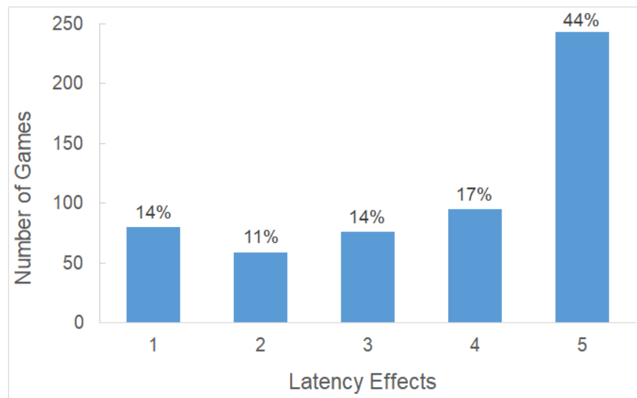

Figure 20: Latency effects on performance.

y-axis is the frequency. The distribution is left-skewed, with network problems relatively infrequent (1 and 2 make up over half of the distribution) and fewer than 10% of games having the most frequent (5) problems. The mean network problem frequency is 2.31 with a standard deviation of 1.23.

Figure 19 shows boxplots of the frequency of network problems grouped by genre, sorted low to high by median value. Turn-Based and Exploration games suffer from network problems the least and Competition games the most. Generally, game genres that are more time sensitive and interactive suffer from network problems more than games that are relatively time insensitive.

Figure 20 depicts the distribution of responses to the question "When there is latency/lag, how much does it affect your performance?" (1-low to 5-high). Although Figure 18 shows network problems to be infrequent, when they do happen, Figure 20 indicates the effects are large. The mode, 5-high, makes up over half of all responses. The median is 4, with a mean of 3.63 and a standard deviation of 1.48. In total, more than 60% of participants thought they were greatly affected by latency in online games (values of 4 and 5), similar to the percentage of users that attributed networking problems to the main reason for abandoning a game from previous survey results [15].

Figure 21 shows shows boxplots of the affects of latency grouped by genre, sorted low to high by median value. Competition and First Person Shooter (FPS) games are most affected with means and medians above 4, while Turn-Based and Exploration games the least, with means and medians about 2. This latency perception fits previous work [9] that suggests first person perspective games, such as FPS games, than games in the third person perspective, typical of most Exploration and Turn-Based games.

6 CONCLUSION

The popularity of computer games has continued to grow and the depth and penetration of networking has allowed computer games to increasingly connect players online, providing geographically-dispersed players ways of interacting in real-time in a wide-variety of game worlds. A challenge

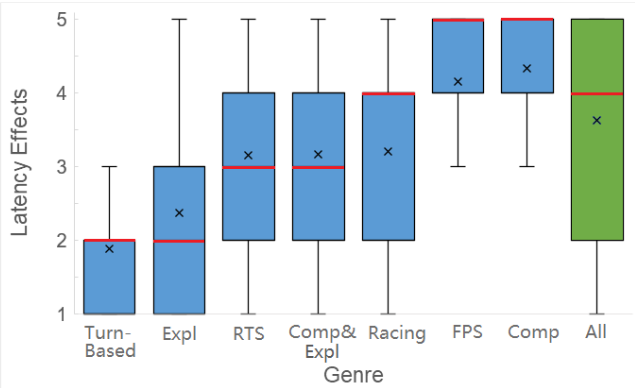

Figure 21: Latency effects on performance by genre.

all such online games must overcome is that of network latency that can reduce the response time of player input to be realized in the game world and/or increase inconsistency of the view of the world across players. Networking and game technologies have been developed and deployed to reduce the impact of network latencies, but the extent to which today's players perceive latencies is relatively unknown.

This paper presents results from a widely-distributed survey of players and the online games they play, with specific questions regarding the noticeable and tolerable limits of latency and the frequency and severity of network problems. Responses from over 240 users provide data on over 550 online games from 7 different game genres. Overall, the minimum noticeable latency is about 50 milliseconds across all games with a maximum tolerable latency of about 125 milliseconds. However, there is considerable variation across games and game genres, with median limits about 2x higher for turn-based games than for more time-sensitive interactive games, limits that also correlate with the perceived pacing of a game. Network problems are relatively infrequent, but when they do occur the effects of latency are severe.

Future work includes: 1) additional surveys that may ascertain more details on the kinds of effects latency has on games and game genres and specific player actions, 2) user studies to measure the effects of latency on specific games and game genres, and 3) experiments ascertaining the benefits of different latency compensation techniques and their appropriateness for different genres.

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