The Effects of Frame Rate and Resolution on Users Playing First Person Shooter Games

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The rates and resolutions for frames rendered in a computer game directly impact the player performance, influencing both the overall game playability and the game's enjoyability. Insights into the effects of frame rates and resolutions can guide users in their choice for game settings and new hardware purchases, and inform system designers in their development of new hardware, especially for embedded devices that often must make tradeoffs between resolution and frame rate. While there have been studies detailing the effects of frame rate and resolution on streaming video and other multimedia applications, to the best of our knowledge, there have been no studies quantifying the effects of frame rate and resolution on user performance for computer games. This paper presents results of a carefully designed user study that measures the impact of frame rate and frame resolution on user performance in a first person shooter game. Contrary to previous results for streaming video, frame rate has a marked impact on both player performance and game enjoyment while resolution has little impact on performance and some impact on enjoyment.

1. INTRODUCTION

Today, computer games continue to spur innovation in the computing industry, driving the design of new desktop hardware to support the latest game innovations as well as more powerful mobile and hand-held devices to allow ubiquitous game playing. Factors key to gaming performance and demand new innovations are the frame rate and the frame resolution, both of which often need to be limited by the graphics card or the computer game software. Generally, for smoother gameplay a higher frame rate is better than a lower frame rate and for better looking game images a higher resolution is better than a lower resolution. However, only the top-end computer systems can play the latest computer games at the highest frame resolutions and fastest frame rates. Older devices, or devices with limited display capabilities such as hand-helds and other mobile gaming devices, must sacrifice either frame rate or frame resolution or both in order to run the latest games. In fact, there is often a tradeoff between frame resolution and frame rate, with higher resolutions resulting in lower frame rates while lower resolutions enable higher frame rates. PC gamers will often tune the display options for their games in an ad-hoc fashion until the game "feels" right. Console gamers and hand-held gamers typically do not have such an option, but instead rely upon the settings the designers chose when building the game and gaming platform.

There have been numerous studies[1–7] that have examined the effects of frame rate and frame resolution on users passively watching streaming video. These studies have found that a decrease in frame resolution corresponds to a decrease in user satisfaction, while a decrease in frame rate does not decrease user satisfaction as much. However, watching video, even during a video-conference, does not have the same interaction requirements, in terms of the required response time, as do some other interactive media applications.

There are some, albeit fewer, studies[8–11] that have examined the effects of frame rate and frame resolution on users actively engaged in an interactive media environment. These studies have generally found that user performance suffers under extremely low frame rates (under 4 frames per second), while frame rates as low as 4 or 5 can support acceptable performance. Frame resolution can affect performance, but is not as directly correlated to performance as it is for users passively watching video.

However, despite the wide-spread popularity of computer games, to the best of our knowledge, there is no quantitative understanding of the effects of frame rate and frame resolution on the overall playability of computer games. Computer games typically run on platforms with a range of processing and display capabilities, where a single game title may be released on PC, console and hand-held devices simultaneously. Even games released only for PCs must be effective over

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a considerable range of processing power and graphics card capabilities. This diversity of game hardware results in the same game being played at different frame rates and frame resolutions. A quantitative understanding of the effects of frame rate and resolution on game playability is therefore critical for: (1) *gamer players* who need to be able to make informed decisions on computer game machine purchases and for adjustments to game display settings, when appropriate; (2) *hardware developers*, including those designing graphics cards and console devices, to enable better targeting of hardware improvements to aspects of the display that matter; (3) *designers* of small, resource-constrained devices that must ensure that the right level of graphics capabilities are factored into the design decisions of a device.

This paper presents results of a carefully designed user study investigating the effects of frame rate and frame resolution on users playing a first person shooter (FPS) game. A custom map was designed to allow repeated testing of the core aspect of FPS play – aiming and shooting at an opponent. A test harness was developed to first collect demographic data for each user, and then cycle through the custom map with different frame rates and frame resolutions, collecting user perceptions each time. Sixty users participated in the study, providing a large enough base for statistical significance for most of the data analyzed. Analysis shows the effects of frame rate and frame resolution to be remarkably different for computer games than for streaming video and other interactive media. In particular, for computer games, frame rate has a pronounced effect on user performance, while resolution does not. Both frame rate and frame resolution, however, impact user perception of game picture quality.

The rest of this paper is organized as follows: Section 2 provides insights into the effects of frame rate and frame resolution and informs our hypotheses; Section 3 describes the custom software and experimental methodology used for our study; Section 4 analyzes the user data obtained; Section 5 describes related work; Section 6 summarizes our conclusions; and Section 7 presents possible future work.

2. HYPOTHESES

First person shooters (FPS) are games in which a user interacts with the game world through the eyes of a virtual character (the “first person”) and fires weapons (the “shooter”) in an attempt to destroy other virtual characters that are controlled by either other human players or a computer (the latter are called *bots*).

Figure 1 depicts frames captured from a first person shooter (Quake III) showing an opponent jumping down from the top of a cement block to the floor. The vertical frames on the left show the series of frames the player would see if the game was played at 60 frames per second (fps). The adjacent columns proceeding to the right show the frames the player would see if the game was played at 30 fps, 15 fps, 7 fps and 3 fps, respectively. Notice that as the frame rate decreases, the ability to precisely track the opponent also decreases. For example, at 15 fps, the player would see the opponent at the top of the block in frame 4 and then, approximately 50 milliseconds later, the opponent would appear nearly at the floor in frame 7. If the player were to target and shoot at the opponent anywhere in these 50 milliseconds, the shot would fire where the opponent was presumed to be located, at the top of the block. However, as shown by frames 5 and 6 which are not displayed to the player at 15 frames per second, the opponent would be moving off the block and towards the floor. Anything but a wild shot would likely miss. This effect is exacerbated at 7 frames per second where the observed time between the top of the block in frame 1 and the opponent reaching the floor in frame 8 is about 120 milliseconds, and at 3 frames per second the player gets a visual update of the opponent’s location only about every 300 milliseconds.

This example showing the movement of an opponent is a common occurrence in most first person shooters since a moving opponent is much more difficult to hit, providing an incentive for players to dodge their opponents. Thus, the inability to accurately track, aim and shoot an opponent is likely to be prevalent at all reduced frame rates. This insight informs our first hypothesis:

HYPOTHESIS 1. *Frame rate has a significant impact on user performance in first person shooters.*

Figure 2 depicts screenshots of a first person shooter showing an opponent across a chasm, with Figure 2(a) showing the game played at a resolution of $640x480$ and Figure 2(b) showing the game played at $320x240$. Notice the level of detail in Figure 2(a) is much greater than that in Figure 2(b). However, for the purposes of targeting, the opponent is visible in both frames thus allowing the player to aim and fire effectively even at a resolution where the opponent is rendered in only a few pixels.

This insight informs our second hypothesis:

HYPOTHESIS 2. *Frame resolution does not have a significant impact on player performance in first person shooters.*

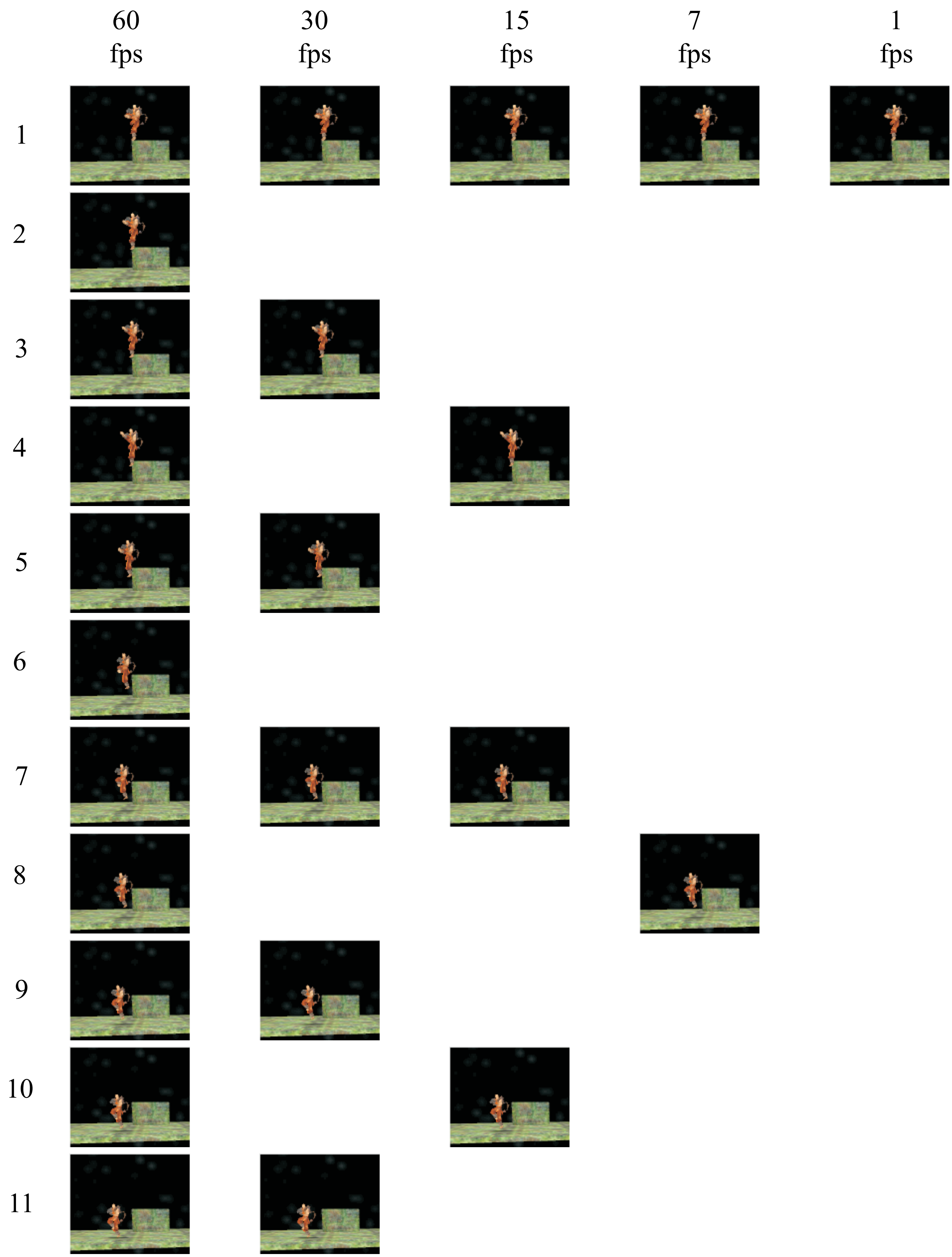
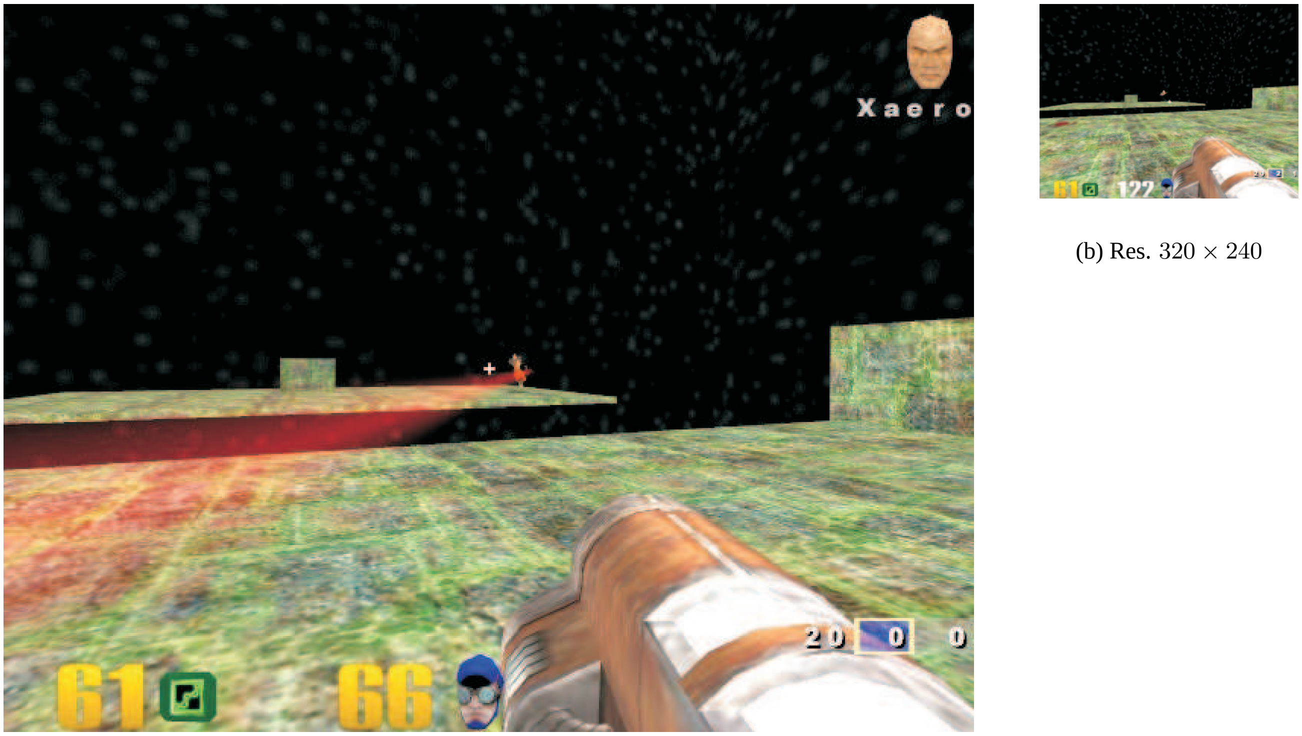


Figure 1. Illustration of Frame Rate. The columns indicate frames that would be displayed at (from left to right) 60, 30, 15, 7 and 3 frames per second.



(a) Res. 640×480

(b) Res. 320×240

Figure 2. Illustration of Frame Resolution.

Frame rate and frame resolution do not only affect player performance, as measured by their ability to hit their opponent or avoid being hit themselves, but also affect how "good" a game looks. Using studies of perceived quality for video[1,3,4,7] as guidelines, it can be assumed higher frame rates makes games look smoother, while higher frame resolutions make games look sharper. The fact that both frame rate and frame resolution have a significant impact on how good video looks to the viewer is the basis of our third hypothesis:

HYPOTHESIS 3. *Frame rate and resolution both have a significant impact on perceived picture quality in first person shooters.*

The experiments designed to test and evaluate the above hypotheses are described in the next section.

3. METHODOLOGY

A first person shooter (FPS) game was chosen for the study because of the popularity of the FPS genre, especially for online game play. FPS games also require intense player interaction with time-critical decisions such as where to aim and when to shoot. Impairment to the display quality can cost virtual lives. Other computer game genres, such as 3rd person fighting games, real-time strategy games and puzzle games may have less time-critical real-time interactions and are left as future work.

The FPS game selected for the experiments was *Quake III Arena*,* a first person shooter developed by id Software and published by Activision. There were several factors that led to this choice. First, while Quake III Arena may be considered "old" (released in December 1999), it is still a fairly popular game† and is still representative of current FPS games in terms of perspective, weapon choices and gameplay. Second, for a seamless experimental environment it was essential to

*http://www.idsoftware.com/games/quake/quake3-arena/

†A periodic sampling of GameSpy finds around 700 Quake III servers running on a typical weekday afternoon

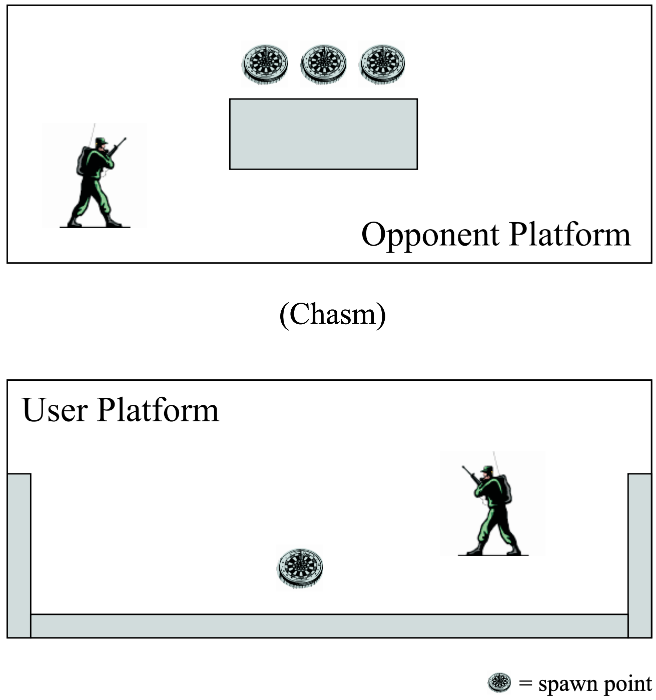


Figure 3. Top View of Custom Map.

control the frame rate and frame resolution at which the game was played via console commands. Quake III both allows a game to be started with a initial frame rate and frame resolution from the command line, as well as allows switching of the display parameters through an interactive shell environment. Third, the relatively short time required to load Quake III makes it possible for a user to play numerous Quake III games with different settings and without significant startup delays between games. This allows for a more thorough user study exploring the frame rate and frame resolution parameters, for the same amount of user time.

3.1. Map

A custom Quake III map was created to allow repeated testing of the effects of frame rate and frame resolution in a short amount of time. Figure 3 shows a top-level view of the custom map created for the experiments using *GtkRadiant* (v1.3.7) - a freely available stand-alone map editor. Since the goal of the experiments is to measure the shooting accuracy of the player under different frame rates and frame resolutions, the map was designed to: (1) Minimize the uncontrollable effects of other players. Although Quake III games are often played against other human opponents, in order to minimize the number of parameters outside of our control, users were instead pitted against a computer controlled opponent, called a *bot*. The bot used in the map is Xaero. (2) Minimize movement. The map contains two platforms divided by a chasm that cannot be jumped by either the player or the bot.[‡] This de-emphasizes the movement component of the game and enables the player to instead focus on the aiming and shooting aspects; (3) Maximize aiming and shooting opportunities. With the exception of a single small wall that blocks the bot's spawn point (to ensure that a player cannot spawn camp and pick off the bot right away), there are no walls or other obstacles that can be used as cover. This ensures that the bot is always in the line of sight of the player. Similarly, on the player's platform there is no cover, although the player's platform does have back and side walls to prevent accidental deaths due to falls off the platform. (4) Minimize the effects of lighting. Ample light sources ensure that dimness from poor lighting does not effect the performance of the player. The background is a dark sky filled with many stars, contrasting well with the more brightly colored bot, the user's target. (5) Stabilize the number of shots required per kill. Higher scores (recorded by the number of kills) allow more fine-grained resolution in user performance. To achieve this, the bot level is set to the lowest difficulty level (level 1), and the *Railgun* is the only

[‡]While an accidental jump or a fall into the chasm results in a death, these deaths were discarded during analysis.

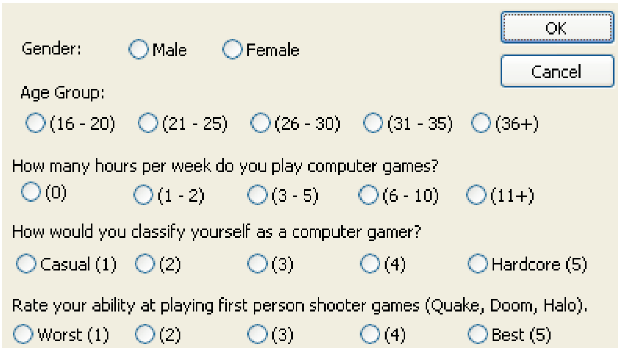


Figure 4. Screenshot of the User Demographics Interface.

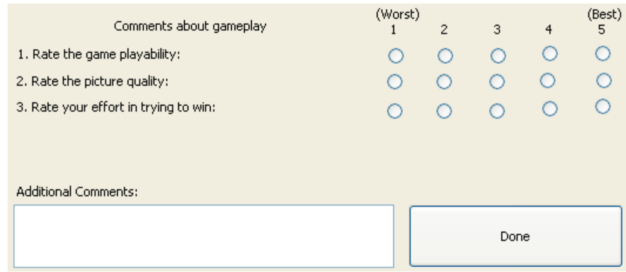


Figure 5. Screenshot of the User Comments Interface.

weapon available for both the player and bot. This combination allows a one-hit kill for a level 1 bot. No other weapons can be picked up by the player during the course of the game. In addition, the Railgun has a 2-second firing delay (i.e. it cannot be fired continuously), ensuring the player must actually aim and then shoot.

3.2. Test Harness

The test harness comprised of three primary components: (1) a configuration file used to start Quake III with different combinations of frame rate and frame resolution; (2) a client program that managed the flow of the game sessions and captured the qualitative user comments at the end of each game; and (3) a server side program that captured the statistics (deaths and kills), for each game.

Configuration. The configuration file was pre-set to invoke Quake III with 16 different combinations of 5 frame rates and 3 frame resolutions for the main experiment run, as well as one configuration with the highest frame rate (80 frames per second) and the highest resolution (1024×768). The highest frame rate and resolution setting was used to prime the users prior to commencement of the main experiment runs. For the main experiment runs, the five frame rates were 3, 7, 15, 30 and 60 fps, while the 3 frame resolutions were 640×480, 512×384, and 320×240. The frame rates were selected to correspond to the range of frame rates previously studied for streaming video and other interactive media applications (see Section 5), and also to the frame rates that appear on many game devices during normal game play. The frame resolutions were selected as representatives of resolutions used for many PC and console games down to the upper-end resolutions available in hand-held devices. While the highest frame rate and resolution was the first game played by each user, all subsequent configuration combinations were presented to the user in random order to mitigate any recency effects due to the order of the display settings.

Client Program. A Client program was used to control the flow of the game session and to gather and record user demographics as well as user comments on the quality of the game play. User demographics were collected prior to the start of the actual experiment runs, and included gender, age group, number of hours per week of computer game play, self-rating as a gamer, and self-rating on skill level in first person shooter games. Figure 4 shows a screenshot of the actual Client interface used to gather the user demographics. The Client then invoked each command of the configuration file, allowed it to run for 30 seconds, and then killed the process – resulting in the user playing a specific configuration of Quake III for 30 seconds. At the end of each 30 second game, users were prompted to rate the session's playability, picture quality and the effort expended in aiming and shooting the bot. In addition, users could provide free-form comments if desired. Figure 5 shows a screenshot of the actual Client interface used to record the user comments at the end of each 30 second game.

Statistics Collector. User performance in terms of the kills and deaths was obtained from the Quake III server logs, while the user demographics and comment data was captured in a log produced by the Client. Users were tracked by a unique user number, but user identities were otherwise anonymized.

3.3. User Solicitation and Demographics

User participants for the experiments were widely solicited over a 2-week period using a range of enticements that included: (1) a raffle for three $50 gift certificates, (2) extra credit for courses, and (3) refreshments for participants.

A total of 64 users took part in the study, but data from 4 of the users was removed because they ended the Client prematurely. All subsequent analysis is on the remaining 60 users that completed all frame rates and frame resolutions sets in the configuration. Most users were undergraduate computer science students in their late teens and early twenties. A sizeable number of participants (almost 25%) were over the age of 25, most of these being graduate computer science students. Over 65% of the users played over 1 hour of computer games per week, with 25% playing 6 or more hours per week. Nearly half of the users classified themselves as casual gamers, but most classified their skills at first person shooters as moderate. About 20% of the users were female. Of these, only one claimed to be more than a casual gamer, while about 65% of the males classified themselves higher than a casual gamer.

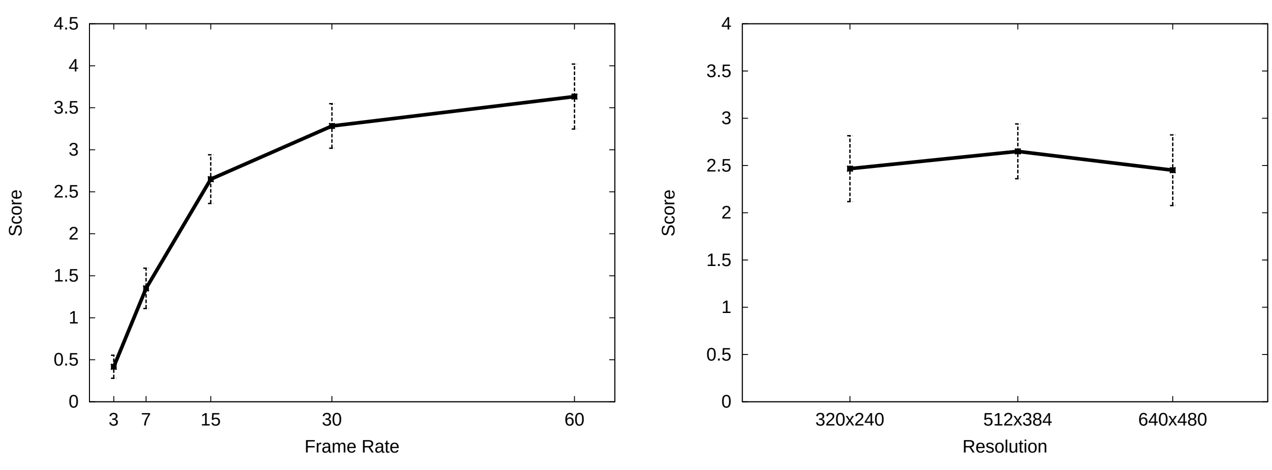
3.4. Experiment Environment

The experiments were conducted in a sectioned room that enabled one person to run through the experiments without being observed by other waiting participants. A separate section (physically separated by a divider) was used as a waiting room. Each run of the experiment (one user) took approximately 10 minutes and participants for the study were accepted on a first-come, first-served basis. All experiments were conducted on a Pentium 4, 2.8 GHz client with 512 MB RAM, an nVidia Geforce 6800GT 256 VRAM graphics card, and a 19” flat screen LCD monitor. A local, dedicated Pentium 4, 1.6 GHz server with 512 MB RAM ran the Quake III server. Both server and client ran Windows XP with service pack 2, while the Quake III version was point release 1.32.

4. ANALYSIS

4.1. User Performance

First, user performance (as determined by the number of times the user killed the bot) is analyzed for the independent variables of frame rate and frame resolution. The number of times the player was shot by the bot was also analyzed, but those results were relatively independent of the frame rate and resolution. The reasoning is that the bot appears to hit the player approximately 1 out of every 10 shots, independent of the player movement, and the bot is certainly not affected by the settings for frame rate or frame resolution. Thus, for all subsequent user performance measurements, the score is shown as determined by the number of times the player shot the bot in the round.



(a) Score versus Frame Rate (512×384 resolution)

(b) Score versus Resolution (15 frames per second)

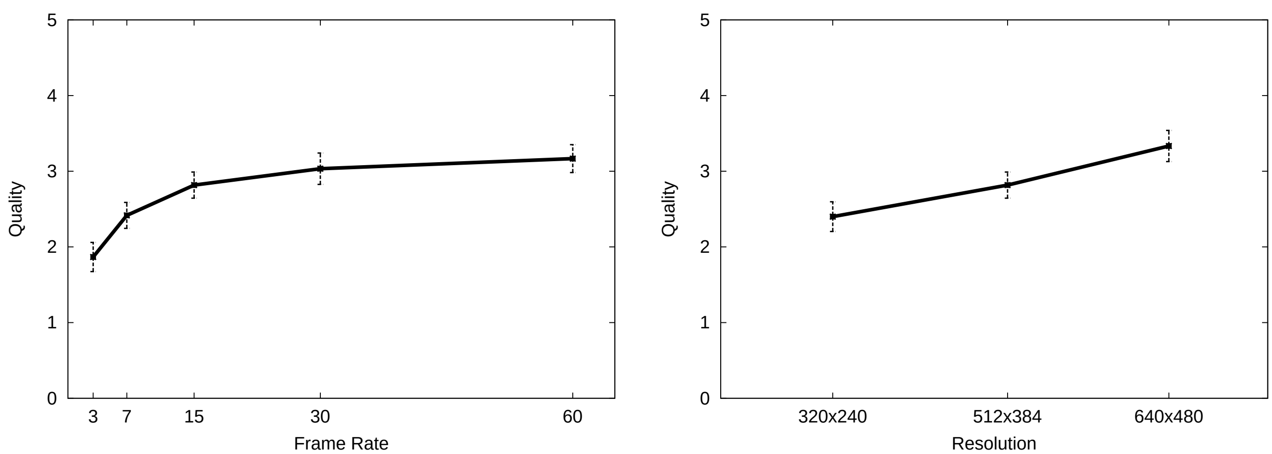
Figure 6. Effects of Frame Rate and Frame Resolution on User Performance

Figure 6(a) depicts the effects of frame rate on user performance. For this graph, the resolution is fixed at 512×384 to make the results clear while the independent variable of frame rate ranges from 3 to 60. Each data point represents the mean score achieved by all players, shown with a 95% confidence interval. Visually, the effect of frame rate on user performance is clear – there is a logarithmic decrease in user performance with a decrease in frame rate. Statistically, only the confidence intervals for 30 and 60 frames per second overlap and an ANOVA test shows a significant difference between the five different levels of frame rate, F(4,295)=64.96, $p<0.001$. Similar results were obtained for resolutions of 320×240 and 640×480.

Figure 6(b) depicts the effects of frame resolution on user performance. For this graph, the frame rate is fixed at 15 frames per second while the independent variable of frame resolution ranges across 320×240, 512×384, and 640×480. Each data point represents the mean score achieved by all players, shown with a 95% confidence interval. The data points are connected with a line since the x-axis points are plotted using the square pixels ($X \times Y$) of resolution. Visually, there appears to be little effect of frame resolution on user performance, with the mean user performance being consistent across all resolutions. In fact, the 95% confidence intervals for all resolutions overlap the means, and an ANOVA test shows the difference for the three resolutions is not significant, F(2,177)=0.290, p=0.01. Similar results were obtained for frame rates of 3, 7, 30 and 60.

4.2. User Perception

Performance, as determined by how well players can aim and shoot, does not necessarily determine how appealing the game looks to users. For example, a game may be quite playable with smooth, blocky graphics but it might not be visually appealing at all. So, next, the effects of frame rate and frame resolution, as perceived by the users, are analyzed.



(a) Quality versus Frame Rate (512×384 resolution)

(b) Quality versus Resolution (15 frames per second)

Figure 7. Effects of Frame Rate and Frame Resolution on Perceived Quality

Figure 7(a) depicts the effects of frame rate on players' perceived quality of the pictures. As above, the resolution is fixed at 512×384, with the mean scores for all players shown with 95% confidence intervals. Visually, the effect of frame rate on perceived quality is clear, but less pronounced, than the effect of frame rate on user performance. Statistically, the confidence intervals for 15, 30 and 60 frames per second overlap, but an ANOVA test shows a significant difference between the five different levels of frame rate, F(4,295)=21.64, $p<0.001$. Similar results were obtained for resolutions of 320×240 and 640×480.

Figure 7(b) depicts the effects of resolution on perceived quality, with frame rates fixed at 15 fps and mean scores shown with 95% confidence intervals. Visually, the effect of frame rate on perceived quality appears linear with square pixels, a more pronounced relationship than the logarithmic trend shown in Figure 7(a) for frame rate. Statistically, the confidence intervals do not overlap and an ANOVA test shows a significant difference between the three resolutions, F(2,177)=16.0, $p<0.01$. Similar results were obtained for 3, 7, 30 and 60 frames per second.

5. RELATED WORK

Work related to this study is broken into two general categories: (1) studies with *active users* that examine the impact of various visual degradations on performance; and (2) studies with *passive users* that explore the visual quality of video as it is being watched. The studies with active users are more relevant for our work since our user studies involve players actively playing a first-person shooter game.

5.1. Active Users

Swartz and Wallace[10] examine the effects of frame rate and frame resolution on trained users tasked with identifying, tracking and designating targets by unmanned aerial vehicles. The users tasks were accomplished by watching a short video clip in the first study and flying a vehicle in a simulator in the second study. The independent variables were frame rates of 2, 4 and 7.5 frames per second (fps) and resolutions of 2, 8 and 12 T.V. lines. While the effects of frame rate were statistically significant, there was minimal difference between performance of 4 or 7.5 frames per second and the authors suggest 4 fps is enough for acceptable performance. Resolution had only marginal effects overall on task performance although the effects on image quality ratings were significant.

Smets and Overbeeke[9] explore the trade-off between frame rate, resolution and interactivity for users solving simple spatial puzzles with their hands. Digital cameras capturing the users hands and puzzle were fed through a computer that modified the resolution and then fed the image to a head-mounted display the user wore. The amount of interactivity was controlled by the location of the camera, either head-mounted or fixed. The independent variables were resolutions of 768×576, 36×30 and 18×15 and frame rates of 25 and 5, controlled by the user of a stroboscopic light. Frame rate was not a statistically significant factor in performance while the main effects of resolution were statistically significant. Although their analysis included generally appropriate statistical tests (ANOVA), they had only four users making the generality of their results suspect.

Massimo and Sheridan[8] studied the performance of tele-operation with varying force of feedback, task difficulty and frame rates. Six users, all graduate students from MIT, remotely operated a mechanical arm, using it to complete a puzzle where pegs were placed in holes. In one study, users observed the puzzle via a remotely operated video link with video frame rates of 3, 5 and 30 frames per second, all with a resolution of 512×256 pixels. The effects of frame rate on user performance (the time to complete the puzzle) were found to be statistically significant, with a large change in performance from 3 to 5 frames per second and a smaller change in performance from 5 to 30 frames per second. Interestingly, the presence of force feedback, not commonly available in computer games, was able to make up for any deficiencies in performance at 3 frames per second. Although they claimed their results confirm early research, the small set of users in their study (6) calls into question the generality of their results.

These studies are significant in that they suggest users can tolerate low frame rates and still achieve acceptable performance, while low resolutions can sometimes have a negative impact on performance. Our study differs primarily in that there is a larger group of users, interacting with a virtual environment over a wider range of frame rates and resolutions available in today's interactive gaming environments.

5.2. Passive Users

There have been numerous studies of users reacting to passive computer-based video.

McCarthy et al.[3] examine the fraction of time sports videos at varying frame rates and resolutions was acceptable to users in the context of streaming to small screen devices, such as mobile phones. Users watched sporting clips in which the frame rate and/or frame resolution were gradually degraded until the users indicated the quality was unacceptable. Contrary to earlier findings, the authors find users prefer higher resolutions to higher frame rates, and find frame rates as low as 6 frames per second are acceptable 80% of the time.

Apteker et al.[1] study the effects of frame rates on the watch-ability of videos. Users watched and rated eight videos with varying spatial and temporal characteristics, at 5, 10 and 15 frames per second on a display of 160×120 pixels. The effects of frame rate on the watch-ability of the videos was significant but the effects of the lowest frame rate, 5, did not result in a marked decrease in watch-ability for all videos.

Ghineas and Thomas[2] look at the effects of frame rate on the ability of users to understand the content of video clips. Users observed videos selected from various categories at 5, 15 and 25 frames per second and answered questions pertaining to their content. Analysis found that even the lowest frame rates (5 fps) did not result in any significant loss in information content.

Tripathi and Claypool[4] study the impact of frame rate and resolution on videos with different content, specifically high-motion videos and low-motion videos. Users watched and rated the perceived quality of several short video clips degraded by either a reduced frame rate or a reduced frame resolution. The authors find that the effects of decreasing the frame rate and resolution depends upon the motion content, with high-motion videos being degraded more with a decrease in frame rate and low-motion videos being degraded more with a decrease in resolution.

These studies are significant in that they show that at least for some videos, users can tolerate video displayed at low frame rates and that users generally prefer higher resolutions.

6. CONCLUSIONS

The growth of computer games and the diversity of technology to support these games brings an increasing need for a better understanding of the impact of frame rate and frame resolution on game players. This paper presents analysis from a user study designed to measure the effects of frame rate and frame resolution on users playing a first person shooter game. Sixty users participated in the study, providing user performance data and user perception data over a range of frame rates and frame resolutions commonly studied for video streaming and inclusive of frame rates and resolutions in many computer game platforms.

Analysis of the performance results shows that for the ranges tested, frame rate has a larger impact on performance than frame resolution. Moreover, a suitable frame rate, in particular, is critical for adequate game performance. Frame rates as low as 3 fps and even 7 fps are almost un-playable as users cannot adequately target opponents. In fact, there are performance benefits for user play up through 60 fps, where a frame rate of 60 fps provides a 7-fold increase in performance over a frame rate of 3 fps. Conversely, frame resolution has little effect on user performance. Users are able to effectively target opponents even at low resolutions, doing as well at 320×240 as they do at 640×480.

Analysis of the quality results shows that for the game images as perceived by the users, both frame rate and frame resolution are important. The effect of frame rate on perceived quality has an effect similar to, if less pronounced, the effect of frame rate on performance, with less of a difference in perceptual quality for the higher frame rates. Interestingly, the effects of frame resolution have a prominent effect on perceived quality, with the perceived quality increasing linearly with the square pixels of frame resolution.

The overall results are dramatically different than those obtained for previous research that assessed the effects of frame rate and frame resolution for streaming video. Those studies concluded resolution mattered more for performance than did frame rate, and frame rates as low as 7 and perhaps even 3 fps were acceptable. For first person shooter video games, the converse is true. Frame rate has a major impact on user performance, while resolution does not statistically impact performance. This contrast suggests there may be challenges in designing devices that can effectively support both computer games and streaming multimedia as the quality of service (QoS) for computer games appears to be significantly different than for other forms of multimedia.

7. FUTURE

The results presented in this paper were obtained by user studies performed for a particular map played under varying frame rates and frame resolutions. An immediate extension of the work could explore the consistency of results under other aspects of first person shooter games such as different maps, light versus dark backgrounds and different types of guns. Future work could also include further studies to determine the consistency of the results across gender or aged groups. Moreover, while it is hoped that the results obtained in this study generalize to other computer game genres, the specific genre tested, first person shooters, has numerous differences from other genres. Future work could include a study similar to the one presented in this paper for real-time strategy games, 3D action games, or sports games.

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