Perspectives, Frame Rates and Resolutions: It's all in the Game

Mark Claypool
Interactive Media and Game Development
Worcester Polytechnic Institute
Worcester, MA, 01609, USA
claypool@cs.wpi.edu

Kajal Claypool
Weather Sensing Group
MIT Lincoln Laboratory
Lexington, MA, 02420, USA
claypool@ll.mit.edu

ABSTRACT

Hardware and platform limitations restrict the display settings for most computer games, forcing a tradeoff between frame rate and resolution to achieve acceptable performance. Previous work has explored the effects of frame rate and/or resolution on a variety of multimedia applications, but most of these are less interactive than typical computer games. Previous work within the context of computer games has concentrated primarily on user actions for specific environments, such as combat in a first-person shooter game. This paper provides a detailed study of the effects of frame rate and resolution on discrete, canonical actions common to many games, *shooting* and *navigation*. The study uses a novel *perspective* based classification defined by the position of the camera relative to the user and the visual change in object sizes relative to the camera, to further refine the findings across a broad spectrum of game genres. A custom game with levels that combine actions and perspectives and measures user performance with different display settings provides the core for the user study experiments. Analysis for over 25 users shows that frame rate has a much greater impact on user performance than does resolution across all game perspectives and gameplay actions. Both frame rate and resolution impact user opinion on playability and quality. These insights into the effects of frame rates and resolution on user performance and opinions can guide game players in their choice for game settings and new hardware purchases, and inform system designers in their development of new hardware.

1. INTRODUCTION

Computer games continue to drive innovation in multimedia, spurring the design of new desktop hardware to support the latest game innovations and pushing the envelope on increasingly powerful mobile and hand-held devices that enable ubiquitous game play.

Frame rate and resolution are key factors that determine game performance. In general, a higher frame rate affords smoother gameplay than a lower frame rate and a higher resolution provides better game images than a lower resolution. Both frame rate and resolution can be limited by underpowered hardware (graphics cards or processors) or by the computer game software. Typically, only the top-end computer systems can play the latest computer games at the highest resolutions and fastest frame rates. Older computer systems, or platforms with limited display capabilities such as hand-held gaming devices, must sacrifice frame rate and/or resolution in order to play the newest games. In fact, there is typically a direct tradeoff between resolution and frame rate, with higher resolutions resulting in lower frame rates and lower resolutions enabling higher frame rates. Players with PCs will often adjust the display options in an ad-hoc fashion until the game "feels" right. Players with game consoles and hand-held devices typically do not have such an option, but instead hope the display settings chosen by the designers that built the game and platform are adequate.

Numerous studies [1, 10, 12, 20, 22, 24, 25] have examined the relationship between frame rate and resolution and perceived quality for users passively watching streaming video. In general, these studies found that lower resolutions tend to lower user satisfaction, while lower frame rates do not negatively impact user satisfaction as much. However, watching video, even in a video-conference, does not have the same interactivity requirements as most computer games. Fewer studies [12, 14, 15, 16, 18, 23] have examined the relationship between frame rate and resolution on users interacting in a multimedia environment. These studies have generally found that user performance degrades at extremely low frame rates (under 4 frames per second), while for some tasks frame rates as low as 5 frames per second can still provide adequate performance. Resolution is generally not as directly correlated to performance as it is for users passively watching video, but can still impact performance. The few known studies [3, 5] that examined the effects of frame rate and resolution on users playing games show pronounced differences compared with other multimedia studies. Specifically, for games, frame rate significantly impacts user performance, while resolution does not. Both frame rate and resolution do however impact the perception of game picture quality. However, even these studies are limited in scope in that they apply only to the narrow game genre of first-person shooters, neglecting many other games and game genres.

In spite of the wide-spread popularity of games, a quantitative understanding of the interplay between frame rate and resolution, and user-level actions across the breadth of games and game genres is missing. We hypothesize that the impact of frame rate and resolution varies depending upon the action required by the game. Specifically, we hypothesize: 1) the fundamental action of shooting requires the user to react to game events in a short amount of time and is greatly impacted by frame rate; in contrast, 2) the fundamental action of navigating is more forgiving of delayed or inaccurate user response, hence is less impacted by frame rate; 3) resolution, while important for improving the appearance of a game, has relatively little impact on performance; and 4) hypotheses 1-3 hold across different game genres categorized by the perspective as identified by the camera angle and by the visual size of objects in relationship to the camera.

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To evaluate our hypotheses, this paper presents results of a carefully designed user study investigating the effects of frame rate and resolution on different user actions. Unlike in previous studies where user performance was tied to a specific game action and game genre, our approach allows generalization to many computer games using: 1) a novel, carefully-crafted classification of games based on *perspective*; and 2) identification and isolation of fundamental gameplay *actions*. The study uses a custom-built game with levels corresponding to a distinct combination of action and game perspective. A test harness collects demographic data for each user, then iterates through the custom game levels with different frame rates and resolutions, gathering performance metrics and user perceptions for each level.

Twenty-seven users participated in the study, providing a user base large enough to show statistical significance for most of the data analyzed. Analysis shows the effects of frame rate and 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 significant effect on objective measures of user performance and subjective measures of playability and quality. Additionally, across different game actions, frame rate has a slightly more pronounced effect on shooting than on navigation. Moreover, the perspective afforded to the user determines the performance degradation and perceived quality at low frame rates. Resolution has little impact on performance, regardless of action or perspective, but has modest impact on perceived quality.

The rest of this paper is organized as follows: Section 2 introduces the canonical actions common to most games and presents a categorization of games based on perspectives; Section 3 presents the overall methodology applied for conducting the study; Section 4 provides the results and analyzes the data; Section 5 discusses our work in the context of other related work; and Section 6 highlights the main contributions and summarizes the conclusions.

2. ACTIONS AND PERSPECTIVES

2.1 Gameplay Actions

Many player actions in real-time (as opposed to turn-based) games fall into one of two broad categories: *navigating* or *shooting*. Navigating is defined as the task of moving an avatar across a terrain from a start location to a destination location. Examples of navigating include moving an avatar forward, rotating, or side-stepping. Shooting is defined as the task of identifying (sighting), aiming and then launching a projectile at the target. Examples of shooting include firing a gun at a clay pigeon, throwing a basketball through a hoop, and casting a fireball spell at an enemy target.

These actions vary along two primary axes, *deadline* and *precision*. Deadline is the time required to complete the action – the length of time it takes to achieve the final outcome intended by the player. For example, for a shooting action, the deadline is the time it takes for the player to sight an target in the cross-hairs and to fire the weapon. Precision is the degree of accuracy required to successfully complete the action. For example, the precision of a shooting action is dependent on the size of the target.

Shooting and navigating actions have disparate deadline and precision requirements. For example, shooting generally has relatively high precision and tight deadline requirements, meaning the player has to place the gun cross-hairs exactly on the enemy target to hit and the action must be carried out immediately or the enemy may move. Navigating, on the other hand, requires high precision but has a relatively looser deadline than typical shooting actions – the precise location determines if a player's avatar is an exposed target, while navigating from one location to another takes a long time, on the order of seconds. Deadline and precision together define the interaction requirements for the gameplay actions.

2.2 Game Perspectives

Previous work has studied the effects of frame rate and resolution on specific game actions for individual games [4, 3] and for specific genres [5]. However, to the best of our knowledge, there has been no systematic comparison of these effects across different games and game genres. This paper compares the effects of frame rate and resolution for fundamental gameplay actions across a diverse set of games based on a novel, generalized, *perspective*-based classification.

This paper defines *game perspective* as: (1) the placement of the camera with respect to the avatar in the game world, and (2) the visual change in object sizes relative to the position of the camera. Based on this definition, many computer games can be classified as one of three types:

1. **First-person Linear Perspective.** In the first-person linear perspective, the camera location is synonymous with the avatar's eyes and the game world objects appear smaller and closer together the farther they are from the camera location giving the illusion of a 3-dimensional world in a 2-dimensional space. Examples of games with a first-person linear perspective include *Doom*, *Half-Life*, *Need for Speed* and *Flight Simulator*. For the rest of the paper, the first-person linear perspective is referred to as the first-person perspective.
2. **Third-person Linear Perspective.** In the third-person linear perspective, the camera is placed at some point around the avatar, and the size and clustering of game objects varies with distance from the camera providing a 3-dimensional feel to the game. Examples of games with a third-person linear perspective include *World of Warcraft*, *Madden NFL*, and *Tomb Raider*.
3. **Third-person Isometric Perspective.** In the third-person isometric perspective, the camera is placed at some point around the avatar, but the size and clustering of game objects does *not* vary with distance from the camera, thus projecting a 2-dimensional world on a 2-dimensional space. Examples of games with a third-person isometric perspective include *Diablo*, *Super Mario World*, and *Starcraft*.

3. APPROACH

3.1 Game Development

A custom game with six parallel starting levels was designed and implemented to allow repeated testing of the effects of frame rate and resolution for each game action (navigation and shooting) in isolation, under the three different game perspectives (first-person, third-person linear, and third-person isometric). The game was developed using Game Maker v6[1], with stock art taken from Game Maker and select video games. Variables such as firing and movement rates in each level were normalized to ensure a fair comparison across the levels and, hence, across the different perspectives.

Third-person Isometric Perspective. Two levels specific to the navigation and shooting actions in third-person isometric perspective were created. Both levels used a square room with a basic grass texture and a small brick wall that served as the bounds of the room. No walls or obstacles were placed in the room to ensure that avatar actions were not especially restricted. The avatar, represented by a *Mario Kart* sprite, had a range of motion in eight directions: left, right, up, down and along the diagonals, using the arrow keys. No

[1] http://www.gamemaker.nl/

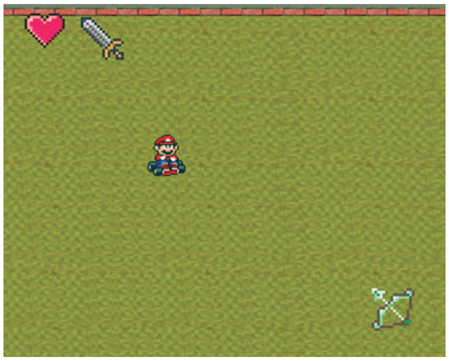


Figure 1: Shooting Level for Third-person Isometric Perspective.

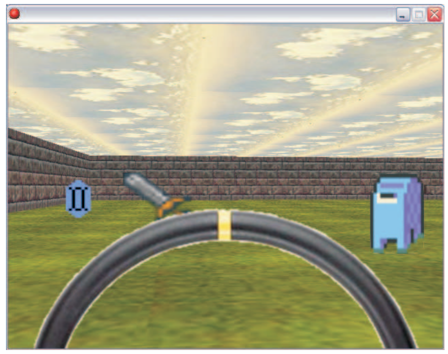


Figure 2: Shooting Level for First-person (Linear) Perspective.

Figure 3: Shooting Level for Third-person Linear Perspective.

forward progress was allowed after the avatar hit a wall. To give the user the illusion of movement the sprite bobbed up and down by a small degree to simulate the effect of a car bouncing.

The navigation level required the user to correctly identify a sword object out of five other dummy objects. The size for all object sprites was set to 32x32 pixels, and the *sword* object was always placed at the same distance from the avatar to ensure consistency in the difficulty of the navigation action. The dummy objects were placed at random throughout the room. On successful collection of the sword, all objects were randomly re-positioned for the next iteration (again, the sword was placed at the same distance from the avatar). Performance for this level was measured by the number of sword objects collected in a fixed time.

The shooting level required the user to find and shoot an enemy sprite. The enemy sprite, represented by another *Mario Kart* sprite, was set to continuously move and change direction upon collision with the wall. Shooting required the user to target the enemy by facing the avatar in line with the enemy and firing using the spacebar. To encourage the user to aim before firing, rapid firing was disabled by having a 500 msec minimum time-delay between shots. Performance for this level was measured by the number of hits times accuracy, where accuracy $=$ hits $\div$ total shots fired. Figure 1 shows a screenshot of the third-person isometric shooting level.

First-person Linear Perspective. Two levels specific to the navigation and shooting actions in first-person linear perspective were created. Both levels used a square room, similar to the third-person isometric perspective levels. In addition, the room was enhanced with a floor and ceiling to provide a three-dimensional feel. A steering wheel was used to represent the view through the eyes of the avatar, in lieu of the *Mario Kart* avatar used in the third-person isometric perspective. The room view was restricted to the line of sight of the avatar, and the steering wheel was rotated slightly when the avatar turned during movement.

The navigation and shooting levels were designed similarly to the third-person isometric navigation and shooting levels respectively, with correspondingly identical performance metrics. Figure 2 shows a screenshot of the first-person shooting level.

Third-person Linear Perspective. Two levels specific to the navigation and shooting actions in the third-person linear perspective were created similarly to those for the other perspectives. A rear view of a *Mario Kart* avatar was used in lieu of the steering wheel from the first-person perspective and collision detection was used to bounce the avatar off the walls and detect collision with objects. In all other regards these levels were identical to those designed for the other perspectives. Figure 3 shows a screenshot of the shooting level in the third-person linear perspective.

Normalization. All levels were normalized based on the first-person navigation and shooting levels. In particular, for each level the room size was set such that it took four seconds to travel from one end of the room to the other, and the time taken to turn around in a full circle was set to two seconds. For navigating, the time taken to traverse in a straight line from the avatar to the sword object was set to one second for all levels. For shooting, the time-delay between bullets was set to 500 msec.

3.2 Test Harness

The test harness, implemented in Visual Basic, managed: user demographics, user preparation, game sessions, qualitative user comments, the flow of the game sessions, user demographic information, and qualitative user comments. The harness also included a built-in mechanism to capture and record user performance data for each game level.

User demographics were gathered in advance of each experimental run conducted by the user, and included gender, age group, number of hours per week of computer game play, self-rating as a gamer, and an optional email address. Figure 4 shows a screenshot of the interface used to gather the user demographics.

User preparation was facilitated by a brief screen that informed the participants on the length of each game level (15 seconds), and two dummy tests, one each for the navigational and shooting levels, respectively, that provided user with basic experience with the game. Each dummy test supplied a set of instructions on the avatar controls for the level (navigation or shooting) prior to launching the game level at the highest frame rate (30 frames per second) and resolution (1280X1024 pixels). No user performance data was collected for these dummy tests.

The test harness invoked each game level for a total of thirty six game sessions. Game sessions for each perspective (twelve game sessions) – first-person (linear), third-person linear, third-person isometric – were executed sequentially with randomly selected levels, shooting or navigation, at varying frame rates and resolutions. The selection of the levels, frame rates and resolutions was randomized to minimize any coincidental effects from a particular pattern of display settings. Each game session was run for fifteen seconds, and user performance was recorded at the end of each session.

Users were presented with a brief questionnaire at the end of each game session. This questionnaire recorded qualitative information on the playability and the picture quality of the game session. Figure 5 shows a screenshot of the qualitative interface.

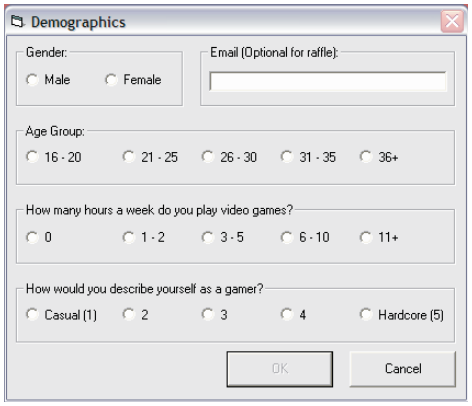


Figure 4: Screen Shot of Demographics Interface.

Figure 5: Screen Shot of User Opinions Interface.

3.3 Experiment Environment

The experiments were conducted in a campus computer lab, with Dell Precision 380 Pentium D 3.0 GHz Dual Core computers with a Dell 1907 Flat Panel displays. Each computer had 2 GB of RAM and a default resolution of 1280x1024 pixels. Users were kept at least one computer apart to reduce distraction from adjacent people. Each complete run of one user through all game levels took approximately 15 minutes.

3.4 User Solicitation

Participants for the user study were solicited through flyers posted around campus, oral announcements in courses, and through email to various student groups. Volunteers were enticed with: (1) raffles for $25 Best Buy gift certificates, and (2) extra credit for select academic courses.

4. RESULTS

4.1 Demographics

In total, the study was under-taken by 27 users, most undergraduates in the computer science (CS) department. As is typical of CS undergraduates, most (89%) users were male, and the majority (74%) between the ages of 16-25 years. The users over 25 years old were primarily graduate students in CS. Most (60%) users claimed they played 6 or more hours of computer games per week, and this time generally correlated with user performance. About a quarter of the users rated themselves as casual gamers, while about half rated themselves as hardcore or almost hardcore.

The average score was computed for each action and each perspective. For the navigating action, user score was the number of correct items collected in the 15 second game time. For the shooting action, user score was the number of successful hits multiplied by the accuracy (hits ÷ shots taken).

Figure 6(a) depicts the average score versus hours played for shooting and Figure 6(b) depicts the average score versus hours played for navigating. From the Figures, the scores for users that play games 3 or more hours per week are higher than the scores for users that play games 2 or fewer hours per week. This trend holds for both shooting and navigating and is especially pronounced for the third-person isometric perspective.

4.2 Navigating

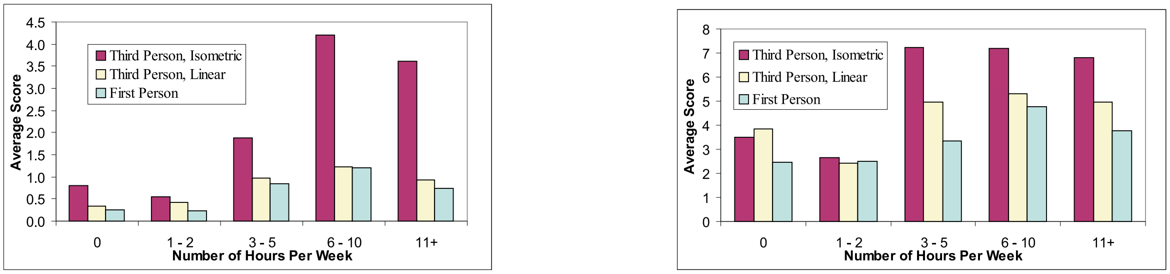
User performance (score) was analyzed for the navigating action for the independent variable of frame rate. Figure 7 depicts the results. The x-axis is the frames per second, and the y-axis is the user score. The three data sets are for the third-person isometric, third-person linear and first-person perspectives. The data points are the average scores, shown with 90% confidence intervals. The three trend lines are distinct, suggesting navigating is easier in the third-person isometric perspective than in the third-person linear or first-person perspectives. The overlap in confidence intervals for the third-person linear and first-person perspectives suggests that navigating is similarly difficult for these perspectives. For third-person linear and first-person, there is a clear increase in performance as the frame rate increases, with separation in the confidence intervals at 7 frames per second and 30 frames per second. However, for third-person isometric, the trend line is relatively flat and the confidence intervals overlap, suggesting frame rate does not affect action difficulty for this perspective.

User performance for the navigating action was analyzed for the independent variable of resolution, depicted in Figure 8. The y-axis and data sets are the same as for Figure 7. The three trend lines are again distinct, with some overlap in the third-person linear and first-person perspectives. Equally significant, the trend lines are predominantly flat, with overlap in confidence intervals for 1280x1204 and 800x600 resolutions for each data set. This suggests there is no benefit to user performance for different resolutions.

4.3 Shooting

User performance (score) for the shooting action was analyzed for the independent variable of frame rate. Figure 9 depicts the results. The x-axis is the frames per second, and the y-axis is the user score. The three data sets are for the third person isometric, third-person linear and first-person perspectives. The data points are the average scores, shown with 90% confidence intervals. The scores for third-person isometric are generally higher than the other two perspectives and the confidence intervals do not overlap. This is likely because the full-field of vision afforded by the third-person isometric perspective makes it easier to locate the target. The trend lines (and confidence intervals) for the first-person and third-person linear perspectives overlap, suggesting comparable difficulty in the shooting action at all frame rates. Notably, there is a marked "knee" in the curves for all three trendlines at 15 frames per second. Performance drops dramatically (by nearly one unit) below this rate and only increases modestly (about 1/2 unit) above this rate. In particular, at 7 frames per second, users were nearly unable to hit the target in first-person and third-person linear perspectives, but could still play reasonably well in the third-person isometric perspective.

User performance for the shooting action was also analyzed for the independent variable of resolution, depicted in Figure 10. The y-axis and data sets are the same as for Figure 9. The third-person isometric line is again distinct, with extensive overlap in third-person linear and first-person perspectives. Also, the trend lines are nearly flat, with overlap in confidence intervals for 1280x1204 and 800x600 resolutions for each data set. As for the navigating



(a) Shooting (b) Navigating

Figure 6: Score versus Hours Played.

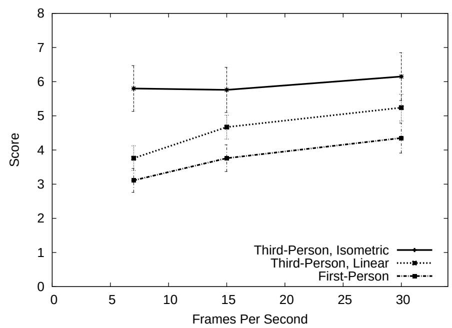


Figure 7: Navigating Score versus Frames per Second.

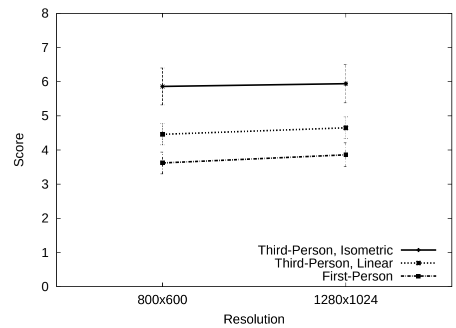


Figure 8: Navigating Score versus Resolution.

action, this suggests that there is no benefit to user performance for different resolutions.

It is notable that the confidence intervals for the third-person isometric perspective are considerably larger than the confidence intervals for the other two perspectives (not shown). The range of scores in Figure 6 suggests that time spent playing per week may account for this disparity in confidence interval sizes.

4.4 Player Perception

Performance, as determined by how well users can shoot and navigate, does not necessarily determine how appealing a game looks or how playable it feels. For example, a game may be quite playable with smooth, blocky graphics but it might not be visually appealing at all. Or, a game may not feel playable with jerky playout, even if a user is able to achieve an acceptable score. So, the effects of frame rate and resolution on the perception of the users was analyzed. User opinions on the playability and picture quality (see Figure 5) were gathered on a 5 point scale for each perspective and action. Since the primary effect of reduced frame rate is to reduce playability and the primary effect of reduced resolution is to reduce quality, only the playability versus frame rate and quality versus resolution analysis is shown in Figure 11. The y-axes are user ratings (1 being low to 5 being high) and the x-axes are either the frame rates or the resolutions. The user rating averages are shown with 90% confidence intervals.

Figure 11(a) and Figure 11(c) depict the effects of frame rate on playability for shooting and navigating, respectively. The playability rating trends are similar to those for performance in that there is a definite “knee” in the trendlines at 15 frames per second. However, while user performance in the third person isometric perspective is higher than user performance in other perspectives, user ratings of playability are similar across the different perspectives. The one exception, seen at the left of Figure 11(c), is that playability of navigating in third-person isometric perspective is clearly higher at 7 frames per second than playability for other perspectives.

Figure 11(b) and Figure 11(d) depict the effects of resolution on quality for shooting and navigating, respectively. The quality rating trends are similar to those for performance in that the trendlines are predominantly flat. There is a slight upward slope as resolution increases from 800x600 to 1280x1024 pixels, but the confidence intervals overlap making the difference statistically insignificant.

5. RELATED WORK

Perspective. Rouse [17] defined and compared first-person and third-person perspectives in video games. He explained the key differences between the two perspectives, and discussed the advantages of one perspective over another with various examples.

Troy et al. [21] performed experiments to determine if tasks involving relative positioning and orientation of objects are better suited for display in 2D or 3D. It was concluded that strictly 3D displays are ineffective for both positioning and orienting objects unless there were additional features such as lighting, shadows, and a quality viewing angle. In general, users performed faster in the 3D display, but made significantly more errors.

Yang and Olson [6] compared how the first-person and the third-person perspectives affected two actions: searching through a world and targeting an object. Third-person searching was found to be much faster than first-person searching, but first-person was found to be more effective for targeting.

Schuemie [9] studied the effects of two perspectives, first-person and third-person, in a Virtual Reality Exposure Therapy (VRET) system to determine how it impacted the performance of the therapist. Their results suggested a first-person perspective was best for navigating while a third-person perspective may have been better for a more precise task such as positioning a target.

Note that the results in Yang and Olson [6] and Schuemie’s study [9] seem contradictory. However, in Schuemie’s study participants

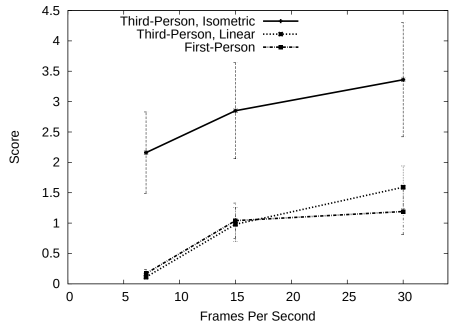


Figure 9: Shooting Score versus Frame Rate.

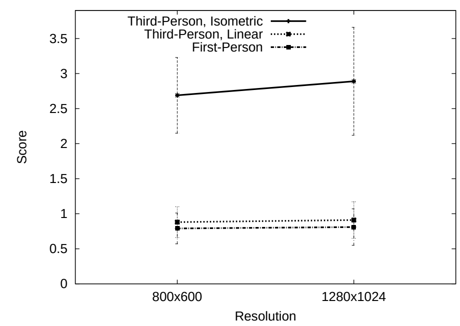


Figure 10: Shooting Score versus Resolution.

navigated an environment and placed a target as opposed to actually identifying and shooting as in Yang and Olson's study.

Our study expands upon definitions provided by Rouse [17], and explores their effect through user studies. The positioning, targeting, and orientation actions defined by Rouse are related to the navigating and shooting actions in our study. Contrary to all these studies, our study adds the third-person linear perspective and varies display settings (frame rate and resolution) when measuring user performance.

Resolution. Smets and Overbeeke [18] explored the trade-off between resolution, frame rate, and interactivity for users solving simple spatial puzzles with their hands. Digital cameras showing the users hands and puzzle were fed through a computer that modified the resolution and then fed the image to a head-mounted display worn by the users. The amount of interactivity was controlled by the location of the camera, either head-mounted or fixed, to the side of the puzzles. The independent variables were resolutions of 768×576, 36×30 and 18×15, with frame rates of 25 and 5 fps controlled by 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, they had only four users making the generality of their results suspect.

Tripathi and Claypool [20] studied the impact of 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 a reduced frame rate or a reduced resolution. The authors found that the effects of decreasing the resolution depended upon the motion content, with low-motion videos appearing more degraded with a decrease in resolution than high-motion videos.

Claypool et al. [4] hypothesized that resolution impacts user performance in first-person shooters when identifying distant or camouflaged objects. Users were tested in a first-perspective game for shooting and navigating over a range of resolutions. Overall, resolution had no statistical impact on user performance, except when the object being identified was too distant to be rendered.

Polys et al. [13] studied the effects of increased display size on navigating and spatial comparison in 3D. Study with a virtual biological cell with different view ports concluded that in general, changing the software field of view for smaller screens had no effect, but on larger screens there was an increase in user accuracy.

Ni et al. [14] studied how larger display sizes and higher resolutions affect 3D navigation. Users were asked to find various objects in a virtual art museum, using low and high resolutions, and small and large screen sizes. Overall, it was found that participants using higher resolutions on larger screens found the desired object faster.

These studies were significant in that they show resolution has a modest effect on performance and more significant impact on quality. Our study differs primarily in that our user base is substantially larger than many of the studies, the amount of interaction in games is significantly higher than in the other tested environments, and a wider range of conditions are tested, appropriate for today's interactive gaming environments.

FrameRate. Swartz and Wallace [19] examined the effects of frame rate and resolution on skilled users tasked with identifying, tracking and designating targets using unmanned aerial vehicles. The independent variables were frame rates of 2, 4 and 7.5 frames per second (fps) and resolutions of 2, 8 and 12 lines on the television set. While the effects of frame rate were statistically significant, there was minimal difference between performance of 4 or 7.5 fps and the authors suggested 4 fps was enough for acceptable performance. Resolution had only marginal effects on task performance although the effects on image quality ratings were significant.

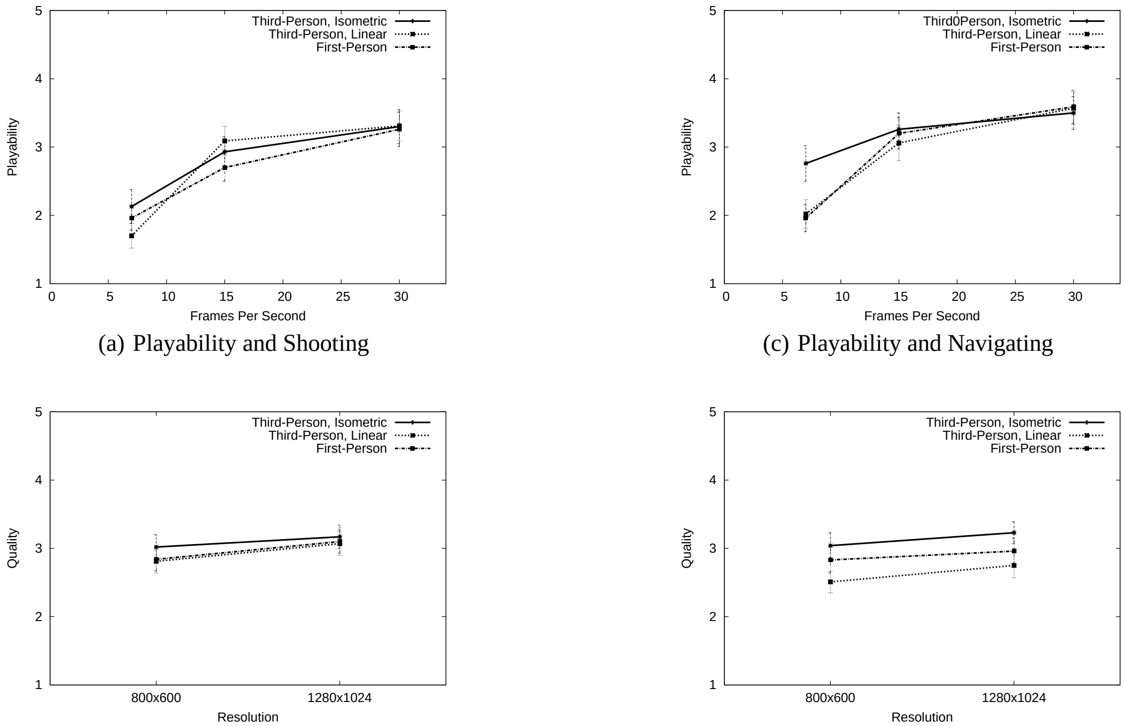
Massimo and Sheridan [11] studied the performance of tele--operation with varying force of feedback, task difficulty and frame rates. The effects of frame rate on user performance (the time to complete the puzzle) were found to be statistically significant. Interestingly, the presence of force feedback, not commonly available in computer games, was able to make up for any deficiencies in performance at low frame rates.

McCarthy et al. [12] examined the percentage 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 sport videos in which the frame rate and/or frame resolution were gradually degraded until the users indicated the quality was not acceptable. Contrary to earlier findings, the authors found users preferred higher resolutions to higher frame rates, and found frame rates as low as 6 frames per second were acceptable 80% of the time.

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

Johnson and Caird [7] examined the degree to which users could recognize sign language over degraded frame rates. Forty-eight users were trained in sign language and then watched videos of sign language gestures at 1, 5, 15 and 30 fps. Analysis of the data included ANOVA tests and showed participants were able to learn to recognize signs even at the lowest frame rates.

Bryson [2] examined the effects of delay and frame rate on the



(a) Playability and Shooting

(c) Playability and Navigating

(b) Quality and Shooting

(d) Quality and Navigating

Figure 11: Subjective Opinions on Quality and Playability.

ability to track an object on the screen. Two types of tracking were studied: pursuit tracking where an object was followed on the screen with a pointer and pursuit tracking where a pointer was moved from one location to another. Users used a custom application that measured accuracy and time for tracking tasks. The author suggested that low frame rates quantitatively impact performance similarly to delay. However, only two users participated in the study so the conclusions may not be statistically valid.

Reddy [8] examined the importance of frame rate on user performance in virtual games. Users were shown a 3D world where the camera moved about the fixation point and the user determined whether they had moved left or right of that point, shown at frame rates ranging from 2 up to 15 frames per second. It was concluded that decreasing frame rates decreases performance.

These studies are significant in that they suggest users can tolerate low frame rates and still achieve acceptable performance for some interactive media tasks. As for resolution, our study has more users, a wider range of frame rates and deals with more interactive games.

6. CONCLUSION

A computer game will often run simultaneously on platforms with varying processing and display capabilities, such as a PC, game console and hand-held game device. Even games created only for PCs must support a considerable range of processing and graphics capabilities. This diversity of game hardware means the same game is often played at different frame rates and resolutions. An understanding of the effects of frame rate and resolution on the players of the game is critical for: (1) game players to enable informed decisions on game platform purchases and for adjustments to display settings, when appropriate; (2) hardware developers, including graphics cards and console designers, to allow focus on display hardware improvements that matter; and (3) designers of resource-constrained devices to provide information to enable the right level of graphics capabilities for effective game support.

This paper presents a first-of-its-kind study of the effects of frame rate and resolution on the most prevalent game actions, *shooting* and *navigating*, across the common game perspectives, *first-person*, *third-person linear* and *third-person isometric*. The analysis shows that frame rate has a much greater impact on user performance than does resolution. This trend holds for all game perspectives and user actions. In general, user performance shows a marked drop in performance below 15 frames per second with a modest increase from 15 to 30 frames per second. Specifically, the slope of degradation is more pronounced for the more precise, impending shooting action, dropping sharply for frame rates below 15 frames per second, than for the less precise, more delay-resilient navigating action. User performance is not affected by resolutions from 800x600, a low-end computer setting, up to 1280x1024, a higher-end setting.

Users perform the best in the third-person isometric perspective for both shooting and navigating, regardless of frame rate and resolution. The third-person isometric perspective affords the user a broader view of the game level, allowing the user more rapid identification of the object to find or shoot, while in the first-person and third-person linear perspective, the user can only see what is in front of the avatar making it more difficult to target an object that appears behind the field of view. Users perform somewhat better in third-person linear than in first-person for navigating, perhaps because the third-person perspective provides a clearer indication of collisions between the avatar and walls and objects.

Analysis of the subjective opinions on playability shows a trend for user playability ratings versus frame rate similar to that for performance versus frame rate, while analysis of quality shows a trend for user picture quality ratings versus resolution similar to that for performance and resolution. However, the user ratings show a slight upward trend as resolution increases from 800x600 to 1280x1024 pixels.

The overall results presented in this paper, while re-affirming some of the results presented in [3, 5], are dramatically different from those obtained for previous research that assessed the effects of frame rate and resolution for streaming video and interactive multimedia applications. Those studies concluded that resolution was a bigger factor for performance than was frame rate. Moreover, frame rates as low as 7 and perhaps even 4 frames per second were acceptable to users. Across the board, for games, the converse is true – frame rate significantly impacts 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. Furthermore, the effects of frame rate on user performance vary with the precision and the delay-resilience of the game action (*i.e.* shooting versus navigating), and with the perspective used by the game. This suggests that game designers need to make informed decisions that weigh in the impact of perspective and the actions during game design to provide a better gaming experience for its users. Future work could examine the tradeoff between frame rate and resolution on processing time for current game hardware, or the effects of extremely low resolutions for, say, mobile devices.

7. REFERENCES

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