Effects of 3D Audio and Video in Video Games

Interactive Qualifying Project Report

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Abstract

Our study was carried out in order to improve our understanding of the relationship between 3D audio and video, and user experience in video games. In order to determine the best way to attempt to measure these effects, we researched several methods of 3D video and 3D audio delivery. We decided to use two different games to gauge the effectiveness of 3D video, Mario Kart 7 and Crysis 2. Due to a small sample size, we were unable to conclude strongly in either way about many of the factors we believed that 3D video and audio would effect, but were able to see an increase in enjoyment and perceived ability from our surveys.

Table of Contents

Table of Figures

Table of Tables

1 Introduction

The video game industry started off simply with basic games such as pong. Since then video games have come a long way. As time went on and the public's interest in games grew, the graphics, realism, usability and general level of technology involved in the production of video games grew. The idea of an immersive environment, in which the participant is able to see, hear, and perhaps even smell or feel a virtual environment has existed for many years in fiction. It is not surprising to see that video games would eventually seek to become closer to that ideal of perfect immersion.

One of the first attempts to produce 3D video games was by Nintendo. Nintendo's first foray into 3D was in the form of a 3D add-on to the Famicom, known as the Famicom 3D System. It used shutter glasses technology to simulate a 3D environment but was limited in its uses as few games were developed to make use of it. In addition, the system was never released outside of Japan (Varias). The first fully 3D gaming system was the Nintendo Virtual Boy, released in 1995. The Virtual Boy projected a different image to each eyepiece to create the sense of 3D in its games. Selling only 770,000 consoles (Snow 2), the Virtual Boy left the market less than a year after its introduction (Boyer).

Furthermore, Nintendo continued to experiment in 3D technology in their games even after the failure of the Virtual Boy. For example, one planned feature of the Nintendo Gamecube system was actually the ability to support 3D games (Goldman). Gamecube systems came built enabled for 3D but the actual implementation of this technology never happened. Nintendo would then wait until the 3DS to once again fully commit to supporting 3D games on a gaming system.

In more recent years, the advance in other types of 3D video producing technology and the falling cost of consumer electronics allowed for 3D video games to once again begin showing up. Until the Nintendo 3DS was released, the vast majority of these games were released on PC, with the 3D being an option that could be enabled or disabled at will. With Nintendo's release of a new, modern 3D focused handheld console, the question of 3D's place among video games has once again moved to the front. This becomes especially so as games become more and more realistic in visual fidelity.

The cost of 3D technology is rapidly decreasing due to the improvement of manufacturing processes and engineering techniques. 3D television has rapidly dropped in price (White), but is only now starting to see increased adoption, and even then the percentage of 3D capable TVs remains at two percent (Nakashima). The 3DS is a fairly popular system, especially in Japan ("Consolidated Sales"), but there has been no evidence as to whether the 3D technology plays any part in its adoption and not just other factors such as the brand recognition behind popular series such as Mario.

One major concern associated with the use of 3D video technology is the possible unpleasant aftereffects with some technologies. In theaters, a ten percent of the population experiences unpleasant headaches or eyestrain after lengthy exposure to 3D video ("Ten Percent of Population"). The demand on our eyes to focus on the screen and simultaneously adjust to the distance of the content can cause disorientation and lead to discomfort ("Does 3D Harm Your Eyes?"). It is advertised in one of the games we used for this study, Crysis 2, to take modest breaks every hour or so of playtime and to prevent small children from using 3D mode. While this is done for preventative health reasons, there is currently no evidence to suggest that 3D effects impair eyesight development or cause other forms of permanent damage ("Does 3D Harm Your Eyes?").

Advances in the realm of 3D audio systems have also been made throughout the 1900s. Until the late 1940s, monaural audio was the de facto sound producing technology (Wadham). Mono sound consisted of all sound being transmitted through a single audio channel. This means that no matter where a listener is in relation to the speaker, the sound will still sound the same. An innovation that was perhaps most famously utilized in Disney's monumental film *Fantasia* was stereophonic audio (Artner). Stereo audio would combine the sound output of multiple channels in order to produce a more realistic representation of sound. The method for producing stereo audio involves the separation of audio signals to two independent channels. This separation of sounds can produce the illusion of hearing sounds from different points in space and simulate a real world sound experience ("Sound Systems”).

Starting in the 1970s, Dolby Laboratories reintroduced stereo surround sound after abandonment by theaters due to high costs. Dolby Stereo improved the quality of the earlier 4 channel stereo sound significantly. Its most famous use was in the renowned film *Star Wars* (Miller). Following Dolby Stereo was Dolby SR, an upgrade to Dolby Stereo, and then Dolby Digital Surround, which used digital rather than analog audio encoding and introduced additional audio channels (Miller).

2 Background

In order to construct our experiment in such a way that we would be able to properly analyze and distinguish the differences that 3D audio and 3D video would bring, we began by researching the different methods that are used in order to generate these effects. In addition, we decided to use Mario Kart 7 and Crysis 2 for the games to be played by the subjects.

2.1 3D Audio Methods

Methods used to produce spatialized (3D) audio include the Head Related Transfer Function, which characterizes how a sound from a specific point in space will make it to the ear. The function is determined experimentally by recording a sound from a human ear as it is emitted from several different points in a given space (Tonnesen).

Another technique for 3D audio is known as stereo widening. Stereo widening changes the phase relationship between the two channels of a stereo signal. Taken to the extreme, (180 degrees) it will cancel any information that was in the center of the image. This adds separation to the signal, usually combined with reverberation to control perceived distance from the source (Thornton).

X.0 and X.1 (e.g., 5.1) spatialized audio can be approximated using surround sound which is implemented with either a set of speakers, the number determined by the 'X', or with a headset that is capable of simulating the position of virtual speakers to achieve multiple angles of sound travel. Surround sound (SS) can be produced by mixing the sounds from left and right channel speakers to create different balances as an illusion of position, or a system can have audio sent to the different speakers/simulated speakers based on information about the source of a sound effect in regards to the "player's location." Headset-based SS is the only one that can be reliably used in gaming because of the number of uncontrollable variables such as speaker position and room insulation (Beal).

Monaural cues are a method of producing the illusion of distance and position by manipulating the balance and intensity of a sound. In order to simulate position, two channels must be used. Monaural cues use our own brain's ability to judge position and distance by the volume of sounds, the miniscule time difference between receiving the sound in each ear, and the sound itself. For example, a soft sound would be judged as right next to us if it had to soft tone of a whisper. Because monaural cues use two speakers (headphones) to provide these effects, it does not necessarily provide the ability to distinguish between sounds that are above and behind, as an example.

2.2 3D Video Methods

3D Anaglyph uses superimposed red and blue images of the regular 2D screen, with local center offset from the original image center depending on their 'distance' from the viewer. Red/Blue filter glasses are used to prevent the eye from seeing the color from that side's filter, creating the illusion of the image coming out of the screen. This is one of the most familiar versions of 3D, as it is very cheap to produce and the glasses used require nothing more special than coloring in order to function. Some example games that use this are Minecraft (Sturdevant) and Sly 3 (Eldred), however in modern games, it is used as an afterthought rather than a feature (Edwards). This method of producing 3D video was also used for the film Spy Kids 3-D (Zone).

Another technique that is used is called active shutter. The active shutter technique utilizes glasses that rapidly alternate which eye is allowed to see at a rate that is nearly impossible for the human eye to detect, thus giving the illusion of 3D imaging (Beal). This method is used for NVidia 3D Vision ("3D Vision Pro"). This uses a couple of systems working together to function. In order to provide 60 frames per second to each eye, the screen itself actually runs at 120 fps, so each eye can receive 60 fps separately. (Edwards) An infrared base sends synchronization data to the glasses to allow them to match with the display. The glasses themselves block off one eye and then the other in an alternating pattern, lining up with the refresh rate of the display as seen in Figure 1.

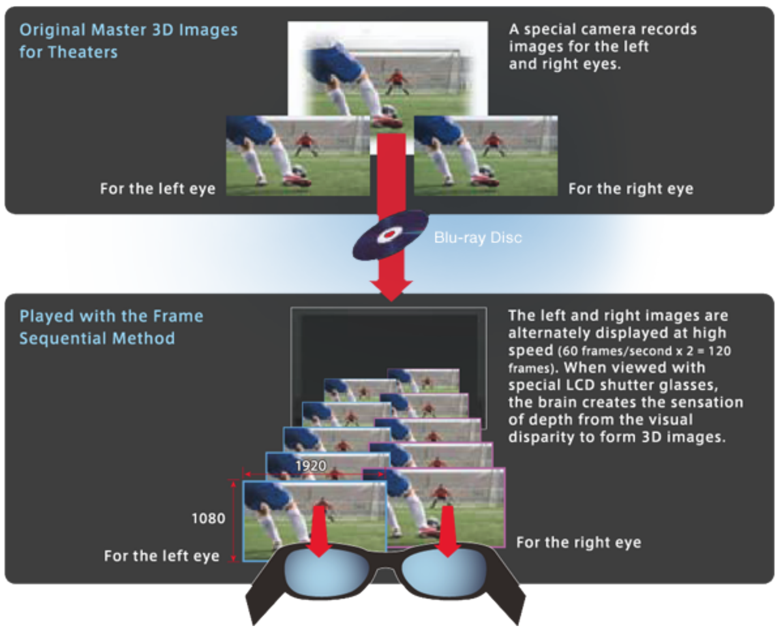

Figure 1: Active Shutter

http://phys.org/news173082582.html

Autostereoscopic imagery is what is commonly referred to as “glasses-free 3D”. Autostereoscopic systems come generally in two types, but there are more methods that exist and/or are in development. Holographic technology like that hypothesized with Star Trek’s holodeck would be a type of autostereoscopic effect. Parallax Barrier, Lenticular Arrays, and Volumetric Display are three types of autostereoscopic imagery (“How 3D Without Glasses Works?”).

Parallax barriers and lenticular prints both use alternating strips of an image, but each use a different method to deliver this as a 3D effect. Two images are imposed on the same sheet in narrow alternating strips. In parallax barrier technology, the screen blocks one of the two strips. The Nintendo 3DS uses the parallax barrier method to provide this type of effect. In lenticular prints, the screen uses narrow lenses to bend the strips. The background methods of displaying alternating strips of images in an alternating pattern remains the same as with the parallax barrier, however, instead of using strips of blocking material to guide each eye to see only the strips it is supposed to, lenticular arrays use curved lenses to bend the light from each strip such that it reaches the correct eye (Figure 2) (Sexton).

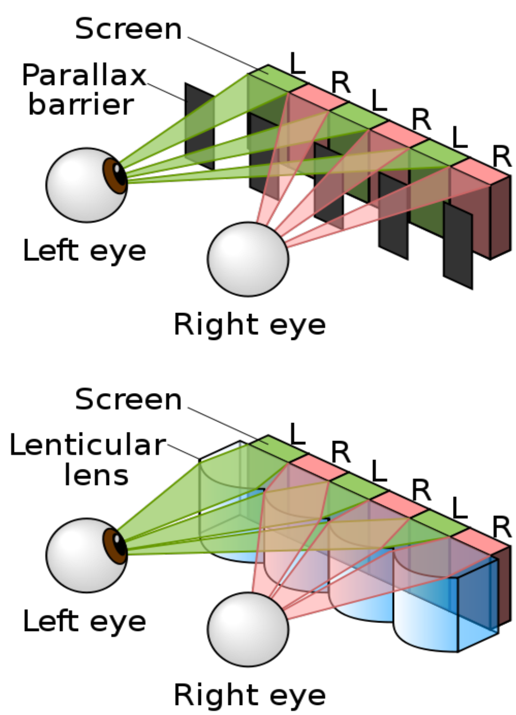

Figure 2: Parallax Barrier vs. Lenticular Array

http://en.wikipedia.org/wiki/File:Parallax_barrier_vs_lenticular_screen.svg

Volumetric displays use some mechanism to display points of light as 3D pixels (voxels). Because they also do not require the use of 3D glasses to see properly, they count as a subclass of autostereoscopy. There are different techniques for achieving this, such as multiple display planes stacked up, and rotating panel displays, where a rotating panel sweeps out a volume.

Other systems use laser light on plasma to generate the voxels. Volumetric displays are not, however, used in gaming systems and are not likely to appear in one anytime in the near future (Lebreton).

The Head-mounted Display method involves the user wearing a helmet or specialized glasses that display separate images to each eye, making the brain able to perceive 3D images. A primitive version of this technology was used in the Nintendo Virtual Boy ("Virtual Boy Is Born"). Groups such as the US military use head-mounted displays, for training and simulation, in part because they allow an exceptional level of immersion and breaking away from the outside world while being worn (Melzer). A more modern example of a head-mounted display in the video game realm is the Oculus Rift, a multi-platform HMD that is similar in form factor to a pair of ski-goggles ("About Oculus VR"). The Nintendo Virtual Boy (Figure 3) (1995) and the Oculus Rift (Figure 4) (2012) give us an idea of how the design of head-mounted 3D systems has changed over the years.

Figure 3: Nintendo Virtual Boy

http://en.wikipedia.org/wiki/File:Virtual-Boy-Set.png,

Figure 4: Oculus Rift

http://www.kickstarter.com/projects/1523379957/oculus-rift-step-into-the-game

The Polarizing Display method creates two images that are projected superimposed onto the same screen or displayed through different polarizing filters to each eye, usually with glasses (Kaiser). This is most commonly done with orthogonal polarizing filters, but a technology exists that generates polarized light in circles of opposite handedness and has the glasses convert it into linear polarized light. This circular method allows the wearer to perceive 3D images from different head orientations, whereas orthogonal polarizing filters require the user keep his head still in a precise position or else he/she will experience discomfort and be unable to properly fuse the images.

Monocular cues are used in almost all modern video games as a way to provide a sense of depth and distance without requiring the use of more expensive methods of producing 3D images. While monocular cues are not in themselves 3D, they allow us to give such a semblance in games so that the gamer is capable of approximating the distance and direction of objects in the game world. There are several different types of monaural cues that are used.

1. Motion Parallax - When someone moves, the apparent relative motion of several stationary objects against a background gives clues about their relative distance (Ferris SH).
2. Motion Depth - Apparent object size of objects in motion is used to judge distance.
3. Relative Size - If the size of an object known to be the same as another this information can be used to determine the distance using size relative to each other.
4. Aerial perspective – Objects that are a great distance away have darker lighting and lower color saturation (O'Shea RP).
5. Accommodation - The sensation of the eye focusing on faraway objects can provide depth clues.
6. Occlusion - Blocking the sight of objects by others is also a clue that provides information about relative distance (Gillam B) (Schacter).
7. Curvilinear perspective - Due to the shape of the eye, shapes appear to bend around peripheral vision. The degree of distortion helps position one in 3D space.
8. Texture gradient - Faraway objects look less detailed than closer up counterparts.
9. Lighting and Shading - Information about shadows and relative lighting gives a lot of information about viewing angle and relative size and positioning of objects (Lipton).

2.3 Games

Released on December 4, 2011 (“Mario Kart 7”), Mario Kart 7 is the most recent game in the Mario Kart series, which consists of racing games starring many of Mario’s most iconic characters. In most game modes, players race against each other for the best place in several races. Mario Kart 7 was chosen, however, largely due to the presence of a Time Trials mode, which greatly limits the number of variables that need to be considered, including power-ups and other players. Figure 5 shows an image of Mario in the middle of a race.

Figure 5: Mario Kart 7

http://nintendo3ds.wikia.com/wiki/File:Mario_Kart_screenshot_5.png

Crysis 2, in contrast, is a “highly realistic” first-person shooter that takes place in a science fiction setting. Highly realistic refers to games that have a high standard of graphical fidelity and attempt to emulate the real world with their art assets (“Crysis 2”). The goal of each mission is to make it from the start of each level to the end by any means necessary. Crysis 2 was chosen for a number of reasons. It has some of the best 3D graphics of any 3D game and was a game that we had easy access to. In addition, it is a modern first-person shooter that, despite this, was not quite as linear as many other modern first-person shooters in that a player has a significant amount of choice when it comes to how they choose to move through a level. Figure 6 and Figure 7 each show a scene from gameplay, the screen from Figure 7 is part of the area that players are in for this experiment.

Figure 6: Crysis 2 Gameplay

http://gamingbolt.com/wp-content/uploads/2011/03/Crysis-2-SP.jpg

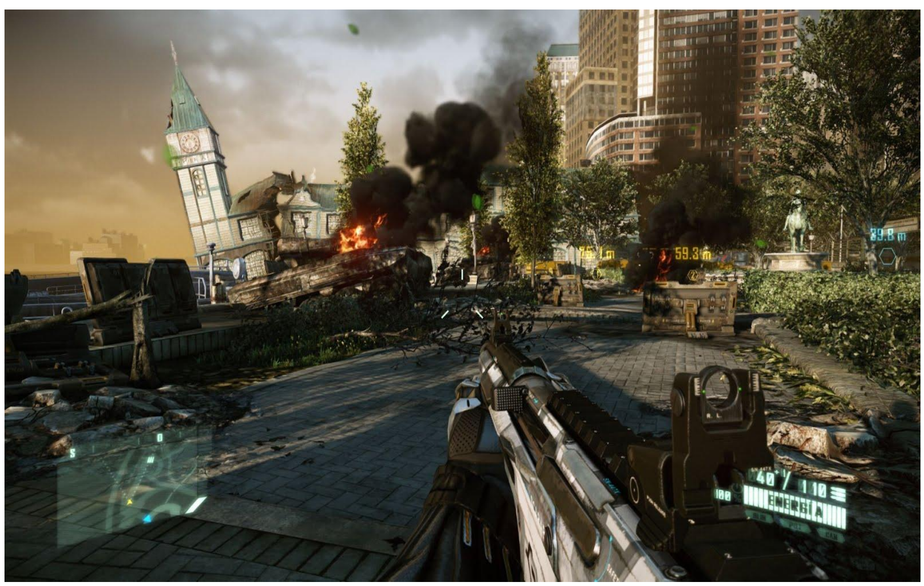

Figure 7: Crysis 2 Gameplay

http://www.hdtvperu.com/recordings/Crysis2%202011-03-24%2022-40-40-91.png

3 Problem Statement

Our study seeks to determine the effects that 3D audio and 3D video have on a person's experiences in the medium of video games. In order to determine this, we decided to investigate the effects that 3D audio and 3D video have on one's enjoyment and performance.

3.1 Purpose

The question that this study seeks to answer is whether or not 3D Audio and 3D Video will improve a subject's performance and/or enjoyment in the game. To improve our ability to determine the effect and any mechanism associated with it, we used two video games, Mario Kart 7 for the Nintendo 3DS and Crysis 2 for the PC. For Mario Kart 7, 3D Video was obtained using the 3DS's parallax barrier. For Crysis 2, 3D Video was achieved using stereoscopic 3D with NVidia 3D Vision and surround sound audio was simulated using a Logitech G930 Surround Sound Headset. This would allow us to study both 3D audio and 3D video, as well as allow us to see if the method of delivery for the 3D video would have any relation to the results.

Mario Kart 7 and the 3DS were chosen for a variety of practical reasons. The 3DS shows a relatively new type of 3D not previously seen in consumer devices, autostereoscopy using a parallax barrier. Mario Kart 7 has a variety of useful performance metrics, including a time trial mode that removes most luck variation from the game and time down to milliseconds. The 3D aspect of it may help avoid obstacles and gauge depth on slanted pathways. The Crysis series is, on the other hand, well known for pioneering advancements in graphics technology. It also captures 3D more completely using shutter glass technology and so was a good candidate for analyzing holistic enjoyment of the 3D experience.

3.2 Hypothesis

Going into the study, we held four hypotheses about our results.

1. The use of 3D Video during gaming will increase a subject's performance during play.
2. The use of 3D Video during gaming will increase a subject's enjoyment during play.
3. The use of 3D Audio during gaming will increase a subject's performance during play.
4. The use of 3D Audio during gaming will increase a subject's enjoyment during play.

3.3 Justification

3D Video gives the subject more advanced perception of their virtual environment by providing the viewer's eyes with actual binocular cues such as stereopsis instead of simply emulating the effect using artistic perspective. This increased perception, therefore, should theoretically improve a subject's ability to detect objects in the virtual world, including enemies and other obstacles. Naturally, improved detection of hostile objects will allow a subject to better avoid and/or neutralize such objects, granting them greater ease in achieving the game's objective. Furthermore, the extra realistic nature of 3D video compared to standard video should give subjects a greater sense of immersion within the game's universe. This greater immersion will enhance a subject's enjoyment of the game experience.

Like 3D Video, 3D Audio grants the subject enhanced awareness of his or her surroundings in the virtual game world. For example, 3D surround sound can allow a subject to better determine the relative origin point of a sound coming from the game world. This enhanced awareness can allow subjects to better determine the location of threats in the game, such as enemies, and react more effectively to counteract them. Moreover, the extra realism in 3D audio combined with its the extra realism provided by the improved localization of sounds in space, should theoretically improve a subject's enjoyment of the game. A similar increase in immersion as in 3D Video combined with the more pleasing audio quality provides increased enjoyment of the game.

4 Empirical Design

In any study, it is necessary to take into account as many variables as possible and, when able, control for them in order to reduce the number of possible confounding factors. Additionally, it is necessary to prepare a complete plan of how the experiment itself is to be carried out in order to control for any changes that could have occurred as a result of different investigators or inattentiveness.

4.1 Controls

For in Mario Kart 7, Airship Fortress, Bowser's Castle, and Rainbow Road were chosen as the three courses to be played in time trial mode. These courses were among the more difficult of the game's tracks and had many obstacles for the subject to avoid. We hoped that the additional obstacles, especially the bullet bills shooting (Figure 8) out of the screen in Airship Fortress, would highlight the differences in performance from 2D to 3D. In addition, Airship Fortress, while containing numerous obstacles, had very few ways to cause the subject to go out of bounds, making it ideal for a first course choice as subjects have an opportunity to get acquainted with the controls and general gameplay.

Figure 8: Airship Fortress

http://www.gamexplain.com/article-628-1321928808-mario-kart-7-retro-tracks-whats-new-and-whats-changed.html

Traditionally, Mario as a player character in competitive Nintendo games is the most balanced character and the default choice for most beginners ("Mario"). To provide a level ground for all subjects, Mario was chosen as the player character to be used in this study.

Mario Kart 7 in competitive play is a rather chaotic and unpredictable game. Powerful and unpredictable power-ups combined with the rubber-band A.I. provide for a poor environment for testing performance, as these factors would affect any performance metrics measured, including lap times, in a way that cannot be properly accounted for. For this reason, Time Trials mode was chosen for this study, rather than the standard Grand Prix or Versus modes. Time Trials mode removes all obtainable power-ups and other players from the game, leaving the subject with nothing but three speed boost power-ups and a static course to navigate. In the absence of other competing players in the Mario Kart 7 Time Trials mode, the only metric that represents a subject's overall performance in the course is the total time taken to complete the 3 laps. Without the randomness resulting from other players and obtainable power-ups, the time is a very accurate metric for performance measurements.

For Crysis 2, there were fewer factors to control for. The level was chosen for its status as the tutorial level of the game. In this level, many of the basic controls of the game are explained to the subject. In addition, the level is among the most straightforward in the game, with only a few basic enemies in most places. These factors make this level an excellent place for subjects of all skill levels to start. In order to give all subjects the same chance, the game difficulty was set to the lowest (Easy) setting.

Additionally, there were some factors that needed to be controlled for in the case of every test subject, whether they played Crysis 2 or Mario Kart 7. All subjects were self-selected from the WPI Psychology Student Participant pool. The subjects were not aware of the nature of the study until they arrived at the registered time to participate. This allowed us to prevent a predisposition towards or against the subject matter.

4.2 Independent Variables/Uncontrollable Factors

Due to the nature of Crysis 2, one of the only uncontrollable and immeasurable variables within the game itself is the randomness attributed to the enemy's artificial intelligence. The AI reacts to the player's actions but also has predefined movements that it performs when the player is not interacting with it. This makes it impossible to control the behavior of the enemies in the game.

There is also a randomness attributed to the types of weapons dropped by enemies. For example, a weapon dropped by an enemy may have a scope attached to it, improving the player's accuracy, while the weapon dropped by the same enemy in a different play-through may not.

Though it may sound obvious, the individual skill of a player can make a huge difference in the player's ability to complete the objective efficiently. Additionally, players unfamiliar with the game or genre of the game may experience additional challenge or become frustrated with the game, affecting their experience.

4.3 Dependent Variables

Falls in Mario Kart 7 represent an important performance metric. A fall is defined as an instance in which a subject falls out of bounds in a track and needs to be returned in bounds automatically. This metric is important separately as a fall can represent a perceptual misjudgment by the subject, which is something that can be affected by a shift from 2D to 3D visuals.

The number of deaths of a subject in Crysis 2 represents a large failure on the subject's part to avoid damage by enemies. The fact that 3D visuals can help in the detecting and tracking of such enemies makes this an important performance metric that may be influenced by 3D.

The number of enemies the player kills in Crysis 2 depends on both how well they do while playing, on how many times they die (and must therefore reset to a previous checkpoint), and on how they choose to approach the area. A player who focuses on stealth, for instance, will have substantially fewer kills than one who charges in and shoots at anything that moves. It is entirely possible to reach the objective without killing any enemies. Being able to defeat more enemies with fewer deaths represents a greater performance by the player, which is something that can possibly be affected by 3D.

For both Mario Kart 7 and Crysis 2, the amount of time it takes for a player to complete their objective depends on a number of factors, including the number of deaths/falls that they experience in their play session. Since the number of failures by the player (deaths/falls) is reflected in the time taken to complete the objective, time is just as important a metric to measure.

4.4 Methodology

In this study subjects were asked to play either a section of gameplay in Crysis 2 or three time trial races in Mario Kart 7. Subjects were drawn from the WPI Psychology Student Participant Pool as volunteers. Subjects playing Crysis 2 were divided into four groups, forming a grid of whether the subject played with surround sound and whether the subject plays 3D first. Mario Kart 7 subjects were divided into 2 groups, based on whether they started by playing in 3D (Table 1 and Table 2).

Table 1: Crysis 2 Experiment Groups

Crysis 2	**3D Video First**	**2D Video First**
Surround Sound	Group A1	Group A2
Stereo Sound	Group A3	Group A4

Table 2: Mario Kart 7 Experiment Groups

Mario Kart 7	**3D Video First**	**2D Video First**
	Group B1	Group B2

Each subject had their playing recorded with a camcorder and answered a number of surveys, including demographics, a comparative survey, and a survey of enjoyment after each playthrough.

The Experimental Procedure followed the following steps.

1 The subjects were read an introduction to give them an overview of what they would be asked to perform. (Appendix A)
2 Each subject was read the Informed Consent form and asked to sign it. They were given a copy to keep. (Appendix B)
3 The subject was read the instructions for the test and provided with a small card that contains a list of the controls for the game, so that they would understand how to play.
4 The set of levels/checkpoints that the subject was asked to play were explained to them at this time.
5 The recording device used to capture performance was turned on.
6 After this, the subject started play.
7 Once the subject has finished, they were asked a few questions in Likert scale form about their experience. (Appendix C)
8 The subject was given a brief (5 to 10-minute) break.
9 The subject performed steps 4-6 again, switching into 3D video if they weren't already in it, or 2D video if they were in 3D.
10 The subject filled out a comparative survey, and, in the case of playing Crysis 2, an additional section on subject immersion. (Appendix D/E)
11 Finally, the subject filled out a demographics survey. (Appendix F)

The video recordings of each subject's playing were looked through independently by two investigators after all testing has been completed in order to ensure that nothing is overlooked or misrepresented. The data will be recorded and corroborated. Each of the two games will have a different set of data collected. In the case of Mario Kart 7, data on time taken, number of times falling off the track will be recorded. For Crysis 2, the subject's time to completion, number of kills and their type, and number of deaths were taken for analysis.

4.5 Statistical Analysis

In order to appropriately analyze the data collected from our test we chose a set of statistical tests that would allow us to work with small data sizes and still draw a reasonably strong conclusion in the case of there being an indication of difference. These tests were selected because they lack the common assumption of data normality and are strongly sensitivity to small differences.

The Wilcoxon signed-rank test measures whether there exists a difference in medians between matched pairs or one sample and a hypothetical value. We are comparing the 2D and 3D performance metrics against each other and the questionnaire data against a neutral median of two. This median was obtained by converting our questions, which were asked using Likert scales, to a number between one and five inclusive.

The Mann-Whitney test measures whether there exists a difference in medians for independent samples. It combines and ranks the data from the two samples and calculates a statistic on the difference between the sums of their ranks. Due to our small sample size, we were unable to compute any results for this test's intended subject pools (stereo audio and surround sound).

Descriptive statistics such as mean, median and interquartile range were calculated for the samples in order to improve our understanding of and ability to analyze the data for interesting properties not otherwise apparent.

4.6 Resources

Most equipment was sourced from WPI or was owned by a researcher. The Logitech G930 headset was used to provide a good surround sound audio experience. A wired and weighted mouse was used to ensure precision when playing Crysis 2. The NVidia 3D vision set was used as a mature shutter glass 3D technology implementation to show 3D effects in Crysis 2. We used a Canon ZR800 camera, provided by WPI, for recording gameplay. All testing was done in WPI's library tech suites in order to prevent influence by interruptions.

5 Data Report

The subject pools for our test were small; there were 12 people who played Mario Kart 7, and 10 people who played Crysis 2. Of those who played Mario, one of them had part of the race data lost due to an error with recording, reducing the number of data-providing test subjects to 11. Of the Crysis subjects, 4 failed to complete the pre-designated objective within the 20-minute time limit that was imposed.

5.1 Statistics for Mario Kart 7

The following demographic information was collected about the subjects of Mario Kart 7. The survey data itself is included in Appendix G. There were twelve subjects participating in this section of the study. Seven of the subjects were Male. The average age of subjects was 19 years and nine months and the median was 19 years and six months. The oldest subject was 21 and the youngest was 18. Eight subjects reported playing 2 or fewer hours of video games per week. Nine subjects reported playing video games on a weekly basis. Only three of subjects reported playing racing games weekly, and none reported playing more than 2 hours per week. Of those who reported playing video games, only one did not play FPS games on a weekly basis. Ten of the subjects have watched a 3D movie before, however, only 3 of the subjects claim to have played a 3D video game. None of the subjects reported owning a device capable of 3D graphics. Seven of the subjects reported suffering physical discomfort from 3D video. None of the subjects indicated discomfort due to playing the game in 3D.

A W-value is obtained with the sum of the signs of each entry multiplied by their rank. This W-value allows us to determine p-value of our sample result being anomalous data. In Table 3, we have a comparison of the results from the intersession surveys for Mario Kart 7. We see high p-values for both of the questions, indicating that it is unlikely that there was any significant difference between the results for 2D and 3D video.

Table 3: Mario Kart 7 Intersession Survey

Mario Kart 7 Intersession Survey	Survey Results for 2D	Survey Results for 3D	Comparative Results (3D – 2D)
I enjoyed playing the/these levels.	m = 3.50 s.d. = 0.456	m = 4.25 s.d. = 0.829	m = 0.75 s.d. = 0.628 W = 8 p = 0.40
I felt that I performed well in this/these levels.	m = 3.96 s.d. = 0.628	m = 3.71 s.d. = 0.900	m = -0.25 s.d. = 0.629 W = 21 p = 0.24

The comparative survey (Table 4), where the subjects were asked specifically about the effects they felt the 3D video had on them, lacked the paired data that is usually used for the Wilcoxon test, so we chose to compare each set of answers against a null hypothesis of neutral answers. Additionally, we computed data on the median and quartiles in order to better display our results. The results we see from Table 4 indicate that the difference from the null hypothesis is unlikely in the case of perceived ability to perceive distance and direction, satisfaction and likelihood to choose 3D racing games in the future. However, we find that there is fairly good reason to believe that people will find the 3D video to reduce their ability to react to incoming obstacles ($p = 0.026$).

Table 4: Mario Kart 7 Comparative Survey

Mario Kart 7 Survey results for subject's experience playing in 3D and 2D.	Mean	Standard Deviation	Interquartile Range	Wilcoxon signed-rank test results
I found the 3D video effects to improve my ability to react to incoming obstacles.	2.33	0.943	1st = 2.00 Med = 2.00 3rd = 3.00	W = 75 p = 0.026
My ability to perceive distance/direction in the game was improved by the 3D video.	2.92	1.256	1st = 2.00 Med = 3.00 3rd = 4.00	W = 105 p = 0.97
My satisfaction with playing the game was improved by the 3D video.	2.75	1.254	1st = 1.81 Med = 3.00 3rd = 3.81	W = 81 p = 0.72
After playing this game, I would be more likely to choose 3D Racing video games.	2.69	1.287	1st = 2.81 Med = 3.00 3rd = 4.00	W = 105 p = 0.97

Table 5 shows us the time data from each track ran by the subjects, as well as values for total time taken. Additionally, Figure 9 shows us that there is little difference in the average time taken to complete the track for 2D and 3D. We calculated p-values exceeding .20 for each of the time comparisons, and in each case, found that the standard deviation of the paired differences to be greater than the mean difference in time.

Table 5: Track time data for Mario Kart 7

Track Times for Mario Kart 7	Results for 2D	Results for 3D	Comparative Results (3D – 2D)
Airship Fortress	m = 165.89 s s.d. = 7.947 s	m = 170.83 s s.d. = 8.658 s	m = 4.94 s s.d. = 9.065 s W = 109.5 p = 0.28
Bowser's Castle	m = 194.26 s s.d. = 10.095 s	m = 195.83 s s.d. = 12.117 s	m = 1.58 s s.d. = 13.043 s W = 125 p = 0.95
Rainbow Road	m = 157.25 s s.d. = 12.967 s	m = 159.23 s s.d. = 14.712 s	m = 1.98 s s.d. = 11.032 s W = 143 p = 0.71
Total	m = 518.62 s s.d. = 24.534 s	m = 526.99 s s.d. = 26.281 s	m = 8.37 s s.d. = 20.301 s W = 111 p = 0.32

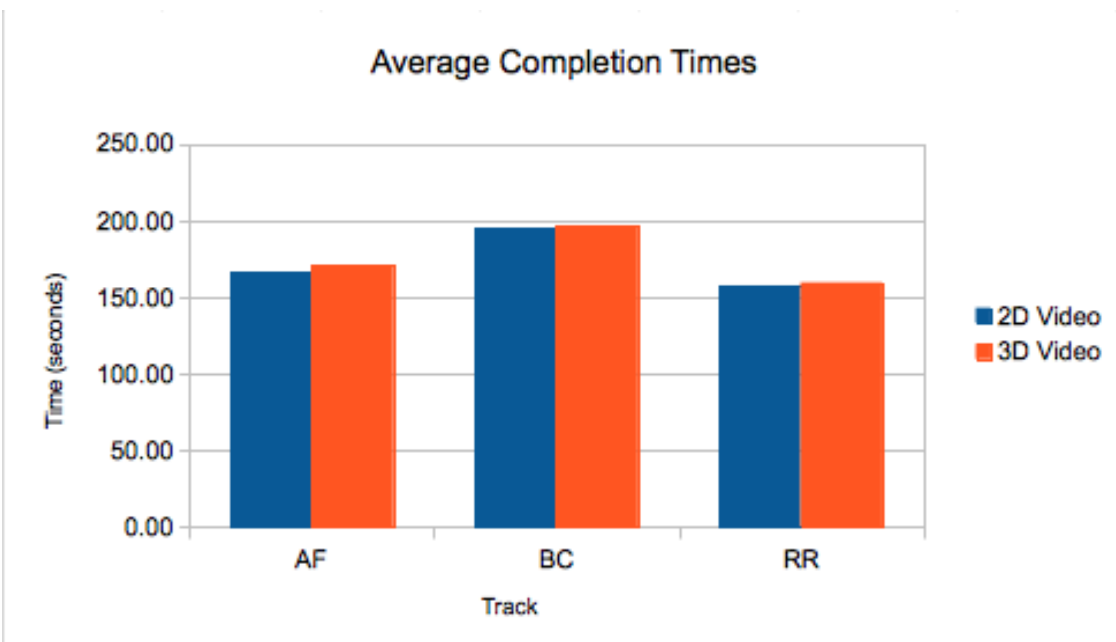

Figure 9: Average completion time by track (Mario Kart 7)

Table 6: Track death data for Mario Kart 7

Track Deaths for Mario Kart 7	Results for 2D	Results for 3D	Comparative Results (3D – 2D)
Airship Fortress	m = 0.00 s.d. = 0.000	m = 0.27 s.d. = 0.445	m = 0.27 s.d. = 0.445 W = 6 p = 0.10
Bowser's Castle	m = 2.00 s.d. = 0.445	m = 2.09 s.d. = 1.311	m = 0.091 s.d. = 1.443 W = 80.5 p = 0.69
Rainbow Road	m = 1.92 s.d. = 1.279	m = 2.58 s.d. = 1.801	m = 0.67 s.d. = 1.491 W = 31.5 p = 0.22
Total	m = 4.00 s.d. = 1.348	m = 5.09 s.d. = 1.781	m = 1.09 s.d. = 1.881 W = 68.5 p = 0.14

Table 6 provides the figures for how many times a player fell off of the track during play. Like with the time data, we find p-values too large to reject the null hypothesis as well as standard deviations greater in magnitude than the mean differences.

5.2 Statistics for Crysis 2

The following demographic information was collected about the subjects of Crysis 2. The survey data itself is included in Appendix G. There were ten subjects that participated in the Crysis 2 side of the study. Seven of the subjects were Male. The average age of subjects was 20 years and one month and the median was 20 years. The oldest subject was 22 and the youngest was 19. Nine of the subjects reported playing video games on a weekly basis. Four subjects reported playing 6 or more hours of video games per week. Six subjects reported playing first person shooter games weekly. All of the subjects have watched a 3D movie before. Four of the subjects reported to have played a 3D video game; the same four subjects claim to own a device capable of 3D graphics. Only one of the subjects claimed to suffer physical discomfort from 3D video. None of the subjects indicated discomfort due to playing the game in 3D.

Once again, the Wilcoxon test was used to compare survey data from the playthrough surveys (Table 7). There is no evidence, given the high p values, to reject the null hypothesis for either of these questions. The following questions were designed to evaluate a subject's experience during play with questions about how they felt playing in 3D affected them.

Table 7: Crysis 2 Intersession Survey

Crysis 2 Intersession Survey	Survey Results for 2D	Survey Results for 3D	Comparative Results (3D – 2D)
I enjoyed playing the/these levels.	m = 4.30 s.d. = 0.458	m = 4.45 s.d. = 0.470	m = 0.15 s.d. = 0.071 W = 34 p = 0.57
I felt that I performed well in this/these levels.	m = 3.70 s.d. = 0.900	m = 3.50 s.d. = 0.890	m = -0.20 s.d. = 1.054 W = 64 p = 0.68

Table 8 contains the first page of the Crysis 2 survey, the comparative part. Additionally, charts of the responses to three of the questions (Figure 10, Figure 11 and Figure 12) show the distribution of responses to those questions. The one question that was skipped from these four was the one asking whether the subject would be more likely to choose 3D First Person Shooter games in the future. This was done because it was the only question of the four to not have a statistically significant or near significant result.

Table 8: Crysis 2 Experience Survey

Crysis 2 Survey results for subject's experience playing in 3D and 2D.	Mean	Standard Deviation	Interquartile Range	Wilcoxon signed-rank test results
I found the 3D video effects to improve my ability to react to incoming obstacles.	3.48	0.965	1^{st} = 3.00 Med = 4.00 3^{rd} = 4.00	W = 52 p = 0.059
My ability to perceive distance/direction in the game was improved by the 3D video.	4.00	0.447	1^{st} = 4.00 Med = 4.00 3^{rd} = 4.00	W = 45 $p < 0.001$
My satisfaction with playing the game was improved by the 3D video.	3.93	0.949	1^{st} = 3.25 Med = 4.00 3^{rd} = 4.81	W = 44 $p < 0.01$
After playing this game, I would be more likely to choose 3D FPS video games.	3.35	1.001	1^{st} = 2.25 Med = 3.75 3^{rd} = 4.00	W = 72 p = 0.25

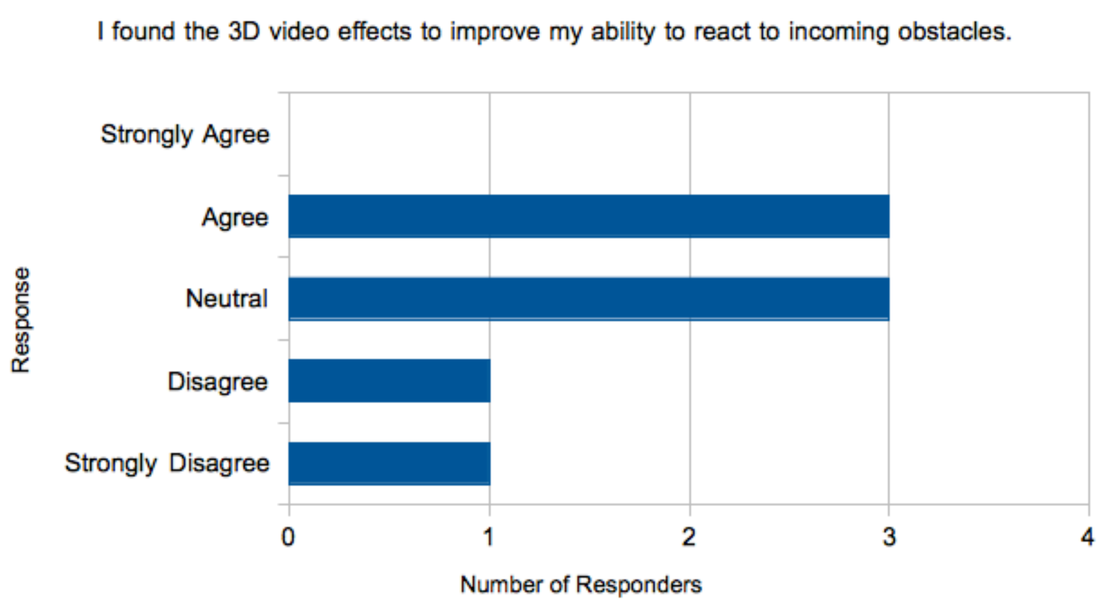

Figure 10: Crysis 2 "ability to react"

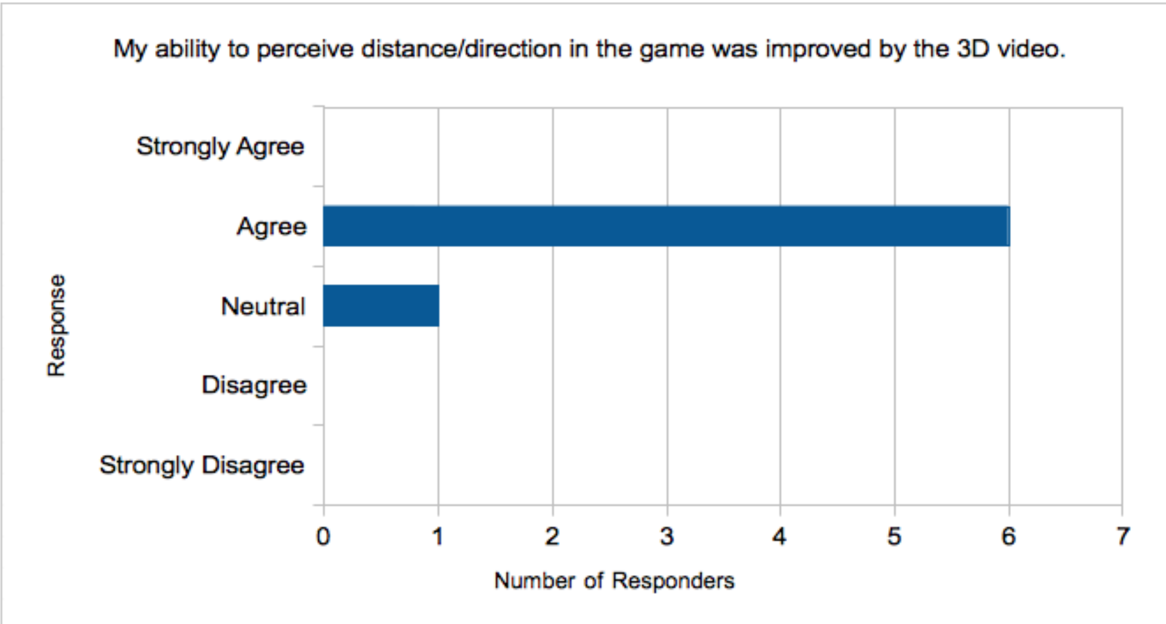

Figure 11: Crysis 2 "percieve distance/direction"

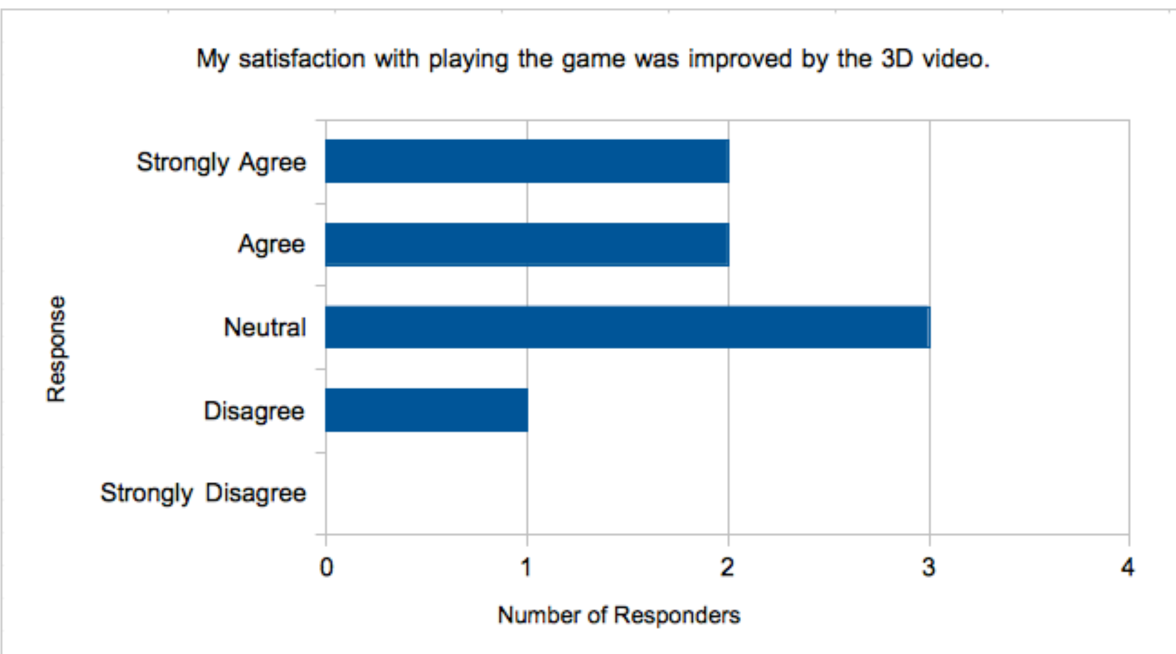

Figure 12: Crysis 2 "satisfaction with playing"

Our findings show a very strong probability that subjects felt that they experienced an increase in their ability to perceive distance and/or direction while playing Crysis 2 with stereoscopic 3D ($p < 0.001$). We also found that subjects were more satisfied while playing in 3D ($p < 0.01$). For both the question of improving reactions and likelihood of choosing 3D First Person Shooters, we were unable to reject the null hypothesis. Additionally, we observed a trend in the answers to the question of ability to react to incoming obstacles towards "slightly agree".

Table 9: Crysis 2 Immersion Survey

Crysis 2 Immersion survey results	Mean	Standard Deviation	Interquartile Range	Wilcoxon signed-rank test results
How aware were you of the real world surrounding while navigating in the game?	3.50	1.025	1st = 2.50 Med = 4.00 3rd = 4.00	W = 85 p = 0.14
How real did the game world seem to you?	3.88	0.700	1st = 3.19 Med = 4.00 3rd = 4.00	W = 28 p < 0.001
How much did your experience seem consistent with your real world experience?	3.10	0.940	1st = 2.75 Med = 3.00 3rd = 3.75	W = 39 p = 1.00
I did not feel present in the game.	1.90	0.300	1st = 2.00 Med = 2.00 3rd = 2.00	W = 55 p < 0.001
The game seemed more realistic than the real world.	2.10	0.539	1st = 2.00 Med = 2.00 3rd = 2.00	W = 36 p < 0.001
I was not aware of my real environment.	3.60	0.917	1st = 3.00 Med = 3.50 3rd = 4.00	W = 42 p = 0.12
In the game world I had a sense of "being there".	3.95	0.150	1st = 4.00 Med = 4.00 3rd = 4.00	W = 55 p < 0.001
Somehow I felt that the game world surrounded me.	3.50	0.671	1st = 3.00 Med = 4.00 3rd = 4.00	W = 35 p < 0.01

Table 9 reports the results from the immersion side of the Crysis 2 survey. We found that subjects felt that the game world felt “fairly real” with a strong degree of certainty ($p < 0.001$). We see a strong probability that subjects felt present in the game world while they were playing ($p < 0.001$). Additionally, there is strong evidence to suggest that subjects did not feel the game world to be more realistic than the real world ($p < 0.001$), but had a sense of “being there” ($p < 0.001$) and felt that the game world surrounded them ($p < 0.01$). We are unable to reject the null hypothesis of whether or not subjects were aware of their real environment.

Table 10: Crysis 2 gameplay data

Gameplay data for Crysis 2	Results for 2D	Results for 3D	Comparative Results (3D – 2D)
Time of Completion (if completed)	m = 667.33 s s.d. = 207.065 s	m = 556.33 s s.d. = 103.996 s	m = -111.00 s s.d. = 203.737 s W = 34 p = 0.48
Total Kills	m = 11.50 s.d. = 7.487	m = 11.50 s.d. = 7.966	m = 0.00 s.d. = 5.285 W = 67 p = 0.93
Lives Used	m = 2.30 s.d. = 1.952	m = 2.40 s.d. = 2.800	m = 0.10 s.d. = 1.375 W = 16.5 p = 0.80
Kills per Life	m = 6.72 s.d. = 5.592	m = 6.82 s.d. = 3.156	m = 0.10 s.d. = 3.817 W = 79 p = 0.60

The p-values reported in Table 10 indicate that there is no evidence demonstrating any difference in kills, deaths, or time taken between 3D and 2D Crysis groups.

5.3 Analysis and Interpretation

We observed a number of trends and statistically significant results among the data collected from our surveys. Unfortunately, we lacked sufficient data to make significant comments on whether or not players actually did better or worse when 3D video was on. Additionally, we lacked enough data to even generate a p-value for the performance or enjoyment differences between subjects who were given stereo audio and those given surround sound.

We observe that on average, subjects who played Mario Kart 7 were slightly faster when playing in 2D than in 3D. From the survey results, our own personal experiences, and comments from some of the subjects, we believe that while the Nintendo 3DS does provide a better concept of depth than a non-3D system, the difference between how it presents 3D images and how people actually see makes it more difficult in a high-speed situation like a race. Additionally, a negative confounding factor may be that the 3DS requires the person to be in a very specific position so as to see the 3D video effects without any double-vision. While we did not find strong evidence to reject the null hypothesis on three of the four comparative survey questions (Appendix D), responses were mostly on the low end of the scale, and there is reasonable belief that subjects felt that their ability to detect obstacles was reduced while using 3D video. As such, we believe it is plausible that subjects overall feel that they perform and are able to react worse while using 3D.

While with Mario Kart 7 we see a vague leaning against the usefulness of 3D both in terms of enjoyment and in performance, Crysis 2 appears to give the opposite impression. Unfortunately, we obtained a similar level of inability to reject the null hypothesis in the case of any of our performance metrics, so we are unable to say that 3D video either aids or hinders the performance of the subjects. Our findings show that subjects felt strongly present in the game world while playing, but also felt that the game world was less real than the real world. We also saw that subjects felt a moderate sense of "being there" while playing, and that the game world somewhat surrounded them. From this we are led to believe that subjects were immersed in the game to a fair degree. Because we did not ask these questions of immersion after each playthrough of the stage, we cannot be certain of whether the 3D video effects were the specific cause of these results, but we feel that it is worth further investigation to gain a better understanding of how 3D video in games such as Crysis 2 affect our immersion in the game. Additionally, while subjects who played Mario Kart 7 appeared to find perhaps a slight detriment from playing in 3D when comparing it to 2D, we see that the subjects who played Crysis 2 generally felt more satisfied, and felt that 3D video helped them in play. From this, we believe that there is merit in looking into this for the purposes of a larger, more thorough study of the effects of 3D video in such games.

6 Weaknesses

The types of metrics collected are probably the most important design flaw. In Mario Kart 7, harmful collisions with obstacles were not recorded unless they resulted in a fall, despite the fact that any harmful collision would represent a perceptual failure by the subject. Such failures should theoretically be affected by a shift from 2D to 3D and thus should have been recorded. We were, however, most interested in the total performance of subjects and any significant difference between 2D and 3D should be reflected in the final time. If 3D ends up having separate harmful and beneficial effects on performance, it would be impossible to differentiate between them because they would be masked in the total effect. Moreover, we should have had a document explaining all of the advanced controls, as a few of the subjects used more obscure techniques that were not explained (such as accelerating at the right time after coming back from a fall to get a speed boost).

In Crysis, our performance metrics could be confounded by the fact that people simply play games differently. For example, some of our subjects attempted to rush through the level while others hunted down every remaining enemy before moving on to the next section. In addition, subjects did significantly better the second time they played, regardless of whether it was 3D or 2D. If, on average, 3D has a beneficial effect on subject skill it should still be apparent in the calculated statistics using total time, kills and deaths, but the large amount of variance would require many more samples to reach a significant conclusion.

Generally, we could have asked the immersion questions after both 2D and 3D game segments to compare differences in immersion instead of exclusively at the end. As we have it, we can only compare whether people enjoyed/were immersed in the game as a whole.

Our subjects were entirely drawn from WPI students and not the general community. While there is little reason to suspect that there would be any significant difference in the physiological or psychological effects of 3D stereoscopic display at WPI than the world at large, it does mean that our statistically significant results may be impossible to generalize to a broad scale.

A theoretical problem with measuring "fun" and performance through survey data is the possibility of conflating the subjects' expectations with their actual enjoyment. It is reasonable to expect that some subjects may perceive improvements merely due to novelty or an expectation of a logical relationship. For instance, it did appear that subjects thought they did better on 3D even when it was overwhelmingly obvious that they did not. We attempted to correct for this effect by additionally collecting objective metrics, but if any effect is present we could not conclusively detect it using our limited subject pool. Another issue with participant self-selection is that participants with a serious aversion to stereoscopic video would likely not sign up for the study and the effect of this significant minority on the overall adoption, acceptance and enjoyment of 3D technology would be masked and it would be difficult to make a cost-benefit assessment of different 3D technologies ("Ten Percent of Population").

Our study was limited in scope and would not be able to detect with good certainty whether there are differences between the 3DS' autostereoscopy and shutter glass 3D. This is because we used two different game genres and platforms, which could confound the data. We would optimally need to use the same game on different platforms and ensure that the 3D is used comparably well and often in both games. If it is shown that both racing and FPS games share an effect, it would strengthen our ability to interpret the data in this way, however.

There are a number of changes in the design of this experiment that we would suggest for any researcher who is interested in replicating or expanding upon our results. The first of these is, of course, to obtain a larger sample size. Due to time constraints, we were only able to test with 22 subjects between Crysis 2 and Mario Kart 7. Thanks to this small number, we were entirely unable to do any comparative analysis related to the use of surround sound audio.

If a study using the 3DS is done, it is suggested to tether the 3DS device to a stand where it will remain motionless. This makes error-free motion capture more practical and reduces the disruptive effect on the 3D image when the device moves. This would be somewhat less indicative of real-world results, however, as people do not play these devices in such strict conditions and as such could present a different and possibly artificially positive image of parallax barrier 3D.

If a study is performed using Crysis 2, it is suggested to use a more powerful desktop computer instead of a laptop or other mobile device. As lag-free direct screen capture is preferred to error-prone over the shoulder recording, and it is unlikely that a laptop computer will be able to run Crysis 2 at full speed while recording. In addition, the immersion survey should be given after both 2D and 3D in order to measure any difference between 2D and 3D.

7 Conclusions

The question of whether or not 3D video has a positive effect on a player's enjoyment and success during play is an important one, especially when we see a growing presence of the use of 3D video technologies in the video game and other industries. As such, it is meaningful for us to investigate further into these relations for the purpose of deciding whether to include such features in future games, and also the best way to use 3D video technology to augment the video game experience. Additionally, determining the effectiveness of surround sound audio for similar metrics holds a similar position as a question, especially because of how easy it is to obtain a 7.0 surround-sound capable system.

Through our observations and analysis of the data we have found good reason to believe that there exists a positive relation between the use of shutter glass 3D and a subject's enjoyment while playing and the level of immersion that they experience. Because of this relation, we believe that there is merit in running a test similar to this one at some point in the future using a significantly larger subject pool in order to further explore the relation that 3D video has on a player's experience.

Despite the small sample that we ended up with, we were able to obtain some compelling results. We were unfortunately unable to reject the null hypothesis in the case of almost every question and measure in the case of Mario Kart 7. For Crysis, on the other hand, most subjects perceived improvements in their gameplay, although this was not statistically apparent from the actual kills, deaths or time data. The results from the enjoyment survey suggest that given a larger sample size we might get a result indicating an enhanced experience. Further, we saw many strong favorable results from the immersion survey.

There is some indication that different kinds of 3D video technology may have differing effects on performance and enjoyment. The 3D technology used in shutter glasses appears to provide a superior experience despite the substantial cost of supporting this type of display, and further study and engineering cost reductions may reveal that it creates a more immersive and enjoyable game experience. From this, we believe that it may also be worth directly investigating the differences between different methods of delivering 3D video to people to see what methods rate higher than others.

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Appendix A: Introduction Script

"We are studying the effect of surround sound audio and stereoscopic (3D) video on player performance and enjoyment in video games. You will be asked to play one of either Crysis 2 (for the PC) or Mario Kart 7 (for the 3DS). You will be asked to answer a set of survey questions about yourself and your experience in playing the selected game. You will be asked to participate in the game that you are less experienced with if you are experienced in one or either of the games.

After playing the game, you will be asked to fill out a brief survey about gaming history and non-specific personal data (age, gender, etc.). In the study, you will be asked to play either a segment of Crysis 2 or a number of Time Trial races from Mario Kart 7 using both 3D and 2D video. For Crysis 2, your gameplay and voice will be recorded; the recordings will be used to collect performance statistics. A camcorder on a tripod will be used to record footage of the Mario Kart 7 runs in order to collect track statistics. After completing each mode, you will be asked to answer a series of survey questions about your personal experience playing the level(s). A final survey will be administered after the you have finished playing with both modes of visuals to compare the two playthroughs."

Appendix B: Informed Consent

Informed Consent Agreement for Participation in a Research Study

Investigator: Robert W. Lindeman

Contact Information: Tel: 508-831-6712 Email: gogo@wpi.edu

Title of Research Study: 3D Visual and Audio Feedback in Games

Introduction

You are being asked to participate in a research study. Before you agree, however, you must be fully informed about the purpose of the study, the procedures to be followed, and any benefits, risks or discomfort that you may experience as a result of your participation. This form presents information about the study so that you may make a fully informed decision regarding your participation.

Purpose of the study: The purpose of this study is to determine the effect that 3D visuals and audio in video games have on your performance and enjoyment.

Procedures to be followed: You will be given a game to play, either one stage of ***Crysis 2*** or three time trial races in ***Mario Kart 7***. Crysis 2 is a first person shooter game of a highly realistic and graphic nature, in which players control a super-soldier in a near-future version of New York City. Mario Kart 7 is a racing game taking place in a the cartoonish world of the Mario games. You will play through the game twice: once with the 3D effects turned on, and once with them turned off. During this, video and audio recordings of both you playing, and of the screen during your play session will be made. Finally, you will be asked for basic demographic information including age, gender, etc.

Risks to study participants: Possible risks of playing 3D games include headaches, motion sickness, and other symptoms related to rapidly changing images.

Benefits to research participants and others: There are no benefits that you will receive from participating.

Record keeping and confidentiality: Information regarding your experience with the two games will be collected for both 2D and 3D visuals/audio and compared. Only those directly involved in conducting the study will have access to the data directly collected from the study and all records pertaining to it. Data may be reported in scientific publications in aggregate with personally identifying information removed. Records of your participation in this study will be held confidential so far as permitted by law. However, the study investigators, and under certain circumstances, the Worcester Polytechnic Institute Institutional Review Board (WPI IRB) will be able to inspect and have access to confidential data that identify you by name. Any publication or presentation of the data will not identify you.

Compensation or treatment in the event of injury: The risks in taking part in this study are no greater than during normal video game play. You do not give up any of your legal rights by signing this statement.

Cost/Payment: No compensation beyond fulfillment of course activity participation will be provided to you.

For more information about this research or about the rights of research participants, or in case of research-related injury, contact:

IRB Chair (Professor Kent Rissmiller, Tel. 508-831-5019, Email: kjr@wpi.edu)
Univ. Compliance Officer (Michael J. Curley, Tel. 508-831-6919, Email: mjcurley@wpi.edu)
Project Advisor (Robert Lindeman, Tel. 508-831-6712, Email: gogo@wpi.edu)
Proctor (Sam Jaffe, Tel. 207-632-9830, Email: sam.jaffe@wpi.edu)
Proctor (Christian Walker, Tel. 817-901-0647, Email: cgwalker@wpi.edu)
Proctor (Eric Oswald, Tel. 631-258-1127, Email: e_oswald@wpi.edu)

Your participation in this research is voluntary. Your refusal to participate will not result in any penalty to you or any loss of benefits to which you may otherwise be entitled. You may decide to stop participating in the research at any time without penalty or loss of other benefits. The project investigators retain the right to cancel or postpone the experimental procedures at any time they see fit.

By signing below, you acknowledge that you have been informed about and consent to be a participant in the study described above. Make sure that your questions are answered to your satisfaction before signing. You are entitled to retain a copy of this consent agreement.

________________________ Date: ________________
Study Participant Signature

____
Study Participant Name (Please print)

Approved by
WPI IRB 1
12/2/2012 -12/1/2013

________________________________ Date: ________________
Signature of Person who explained this study

Appendix C: Intersession Survey

Intersession Survey #______

Please fill out the following brief survey describing your experience playing this session of the game. You will be asked to complete this survey once for your 3D playthrough, and once for your 2D playthrough. After completing this survey the first time, you will be given a 5-15 minute break, depending on your preference, before playing again in the opposite video setting.

	Strongly Disagree	Disagree	Neutral or No Opinion	Agree	Strongly Agree
I enjoyed playing this/these levels.					
I felt that I performed well in this/these levels					

Appendix D: Mario Kart 7 Comparison Survey

Mario Kart 7 Comparative Survey #_____

Please respond to the following statements with how much you agree or disagree with the following statements about the change in experience between the 3D and 2D playthroughs of Mario Kart and about your overall experience playing the game.

	Strongly Disagree	Disagree	Neutral or No Opinion	Agree	Strongly Agree
My ability to detect and react to incoming obstacles was improved by the 3D video.					
My ability to perceive distance/direction in the game was improved by the 3D video.					
My satisfaction with playing the game was improved by the 3D video.					
After playing this game, I would be more likely to choose 3D racing video games.					

Appendix E: Crysis 2 Comparison/Immersion Survey

Crysis 2 Comparative Survey #_____

Please respond to the following statements with how much you agree or disagree with the following statements about the change in experience between the 3D and 2D playthroughs of Crysis 2 and about your overall experience playing the game. Note that some of the questions have different scales, please take note of these changes while filling out the survey.

	Strongly Disagree	Disagree	Neutral or No Opinion	Agree	Strongly Agree
I found the 3D video effects to improve my ability to detect and react to incoming obstacles.					
My ability to perceive distance/direction in the game was improved by the 3D video.					
My satisfaction with playing the game was improved by the 3D video.					
After playing this game, I would be more likely to choose 3D First Person Shooter video games.					

Crysis 2 Comparative Survey (Continued)

#_____

	Extremely Aware	Fairly Aware	Moderately Aware	Slightly Aware	Not Aware at all
How aware were you of the real world surrounding while navigating in the game? (i.e. sounds, room temp, other people, etc.)?					

	Not Real at all	Fairly Unreal	Somewhat Real	Fairly Real	Incredibly Real
How Real did the game world seem to you?					

	Barely Consistent	Not Very Consistent	Somewhat Consistent	Fairly Consistent	Very Consistent
How much did your experience in the game environment seem consistent with your real world experience?					

	Strongly Disagree	Disagree	Neutral or No Opinion	Agree	Strongly Agree
I did not feel present in the game.					
The game seemed more realistic than the real world.					
I was not aware of my real environment.					
In the game world I had a sense of "being there"					
Somehow I felt that the game world surrounded me.					

Appendix F: Demographics Survey

Demographics Survey #_____

Please fill out the following questions about demographic information so that we may better understand the results of our study.

Please provide your gender

- Male
- Female
- Other
- Decline

How old are you?

How many hours per week do you play video games?

- 0
- 0-2
- 2-6
- 6-10
- 10+

How many hours per week, on average, do you play racing games?

- 0
- 0-2
- 2-6
- 6-10
- 10+

Demographics Survey (Continued) #_____

How many hours per week, on average, do you play First Person Shooter games?

- 0
- 0-2
- 2-6
- 6-10
- 10+

Have you ever seen a 3D movie?

- Yes
- No

Have you ever played a 3D video game?

- Yes
- No

Do you own a device that supports 3D (3DTV, Nintendo 3DS, 3D Computer Monitor)?

- Yes
- No

Does watching 3D video cause you physical discomfort?

- Yes
- No

Appendix G: Gameplay Data

Table 11: Mario Kart 7 2D data

2D raw data	Airship Fortress	Bowser's Castle	Rainbow Road
Subject M1	t = 156.34 s d = 0	t = 196.28 s d = 3	t = 142.60 s d = 1
Subject M2	t = 173.81 s d = 0	t = 192.63 s d = 1	t = 155.08 s d = 2
Subject M3	t = 167.61 s d = 0	t = 189.76 s d = 1	t = 172.90 s d = 3
Subject M4	t = 159.72 s d = 0	t = 197.01 s d = 5	t = 144.13 s d = 2
Subject M5	t = 166.28 s d = 0	t = 198.59 s d = 1	t = 163.44 s d = 3
Subject M6	t = 167.23 s d = 0	t = 197.68 s d = 4	t = 143.84 s d = 1
Subject M7	t = 171.34 s d = 0	t = 205.90 s d = 3	t = 173.32 s d = 1
Subject M8	t = 181.09 s d = 0	t = 210.94 s d = 3	t = 164.28 s d = 2
Subject M9	t = 160.16 s d = 0	t = 192.45 s d = 1	t = 174.36 s d = 4
Subject M10	t = 171.42 s d = 0	t = 184.73 s d = 1	t = 144.85 s d = 1
Subject M11	t = 152.74 s d = 0	t = 170.85 s d = 1	t = 140.15 s d = 1
Subject M12	t = 164.27 s d = 0	t = 197.69 s d = 2	t = 168.05 s d = 2

Table 12: Mario Kart 7 3D data

3D raw data	Airship Fortress	Bowser's Castle	Rainbow Road
Subject M1	t = 162.72 s d = 0	t = 196.87 s d = 3	t = 152.24 s d = 2
Subject M2	t = 165.05 s d = 0	t = 188.77 s d = 0	t = 155.45 s d = 2
Subject M3	t = 178.40 s d = 0	t = 218.57 s d = 3	t = 147.94 s d = 1
Subject M4	t = 155.00 s d = 0	t = 173.81 s d = 2	t = 142.90 d = 2
Subject M5	t = 183.25 s d = 1	t = 202.05 s d = 2	t = 166.18 s d = 3
Subject M6	DATA LOST	DATA LOST	t = 147.12 s d = 1
Subject M7	t = 174.13 s d = 0	t = 207.44 s d = 2	t = 174.88 s d = 4
Subject M8	t = 181.09 s d = 0	t = 209.36 s d = 5	t = 153.54 s d = 2
Subject M9	t = 180.18 s d = 1	t = 184.27 s d = 0	t = 196.12 s d = 8
Subject M10	t = 165.81 s d = 0	t = 190.97 s d = 2	t = 150.44 s d = 2
Subject M11	t = 166.09 s d = 1	t = 189.89 s d = 2	t = 151.58 s d = 2
Subject M12	t = 167.36 s d = 0	t = 192.21 s d = 2	t = 172.33 s d = 2

Table 13: Crysis 2 2D data

2D raw data	Time Taken (s)	Kills with Gun	Kills with grab	Kills with stealth	Lives used (inc. starting)
Subject C1	DNF	8	0	0	1
Subject C2	DNF	20	0	0	6
Subject C3	DNF	7	0	0	3
Subject C4	DNF	24	0	0	6
Subject C5	440	6	1	1	1
Subject C6	1005	8	0	0	1
Subject C7	492	3	0	0	1
Subject C8	787	20	0	2	1
Subject C9	490	0	1	1	1
Subject C10	790	13	0	0	2

Table 14: Crysis 2 3D data

2D raw data	Time Taken (s)	Kills with Gun	Kills with grab	Kills with stealth	Lives used (inc. starting)
Subject C1	DNF	8	0	0	1
Subject C2	DNF	22	6	1	10
Subject C3	DNF	3	0	0	2
Subject C4	DNF	24	0	0	5
Subject C5	570	10	0	1	1
Subject C6	753	7	0	2	1
Subject C7	530	4	1	1	1
Subject C8	423	10	0	2	1
Subject C9	587	4	2	1	1
Subject C10	475	6	0	0	1

Appendix H: Survey Data

Table 15 presents the demographics data recorded from each of the subjects. The columns of the table correspond, in order, to the associated question in the demographics survey in Appendix F. Table 16 provides the responses to the intersession survey, the questions were all asked on a Likert scale as seen in Appendix C. Table 17 provides the responses to the comparative survey using a similar scale as the previous table. Table 18 provides the responses to the Immersion survey questions from Appendix E. Decimal results are estimated.

Table 15: Demographics Data

	Gender	Age	vg/wk	rc/wk	fps/wk	3Dmovie	3Dgame	3Ddevice	Discomfort
M1	M	20	2-6	0	2-6	Y	N	N	N
M2	M	21	2-6	0	2-6	Y	N	N	N
M3	F	21	0	0	0	Y	N	N	N
M4	M	19	6-10	0-2	6-10	Y	Y	N	Y
M5	F	19	0	0	0	Y	N	N	N
M6	M	22	6-10	0	6-10	N	N	N	Y
M7	F	19	0-2	0	0-2	Y	Y	N	Y
M8	F	19	0-2	0-2	0-2	Y	N	N	Y
M9	F	20	0	0	0	Y	N	N	Y
M10	M	20	0-2	0	0-2	Y	Y	N	N
M11	M	18	0-2	0-2	0	N	N	N	Y
M12	M	19	0-2	0	0-2	Y	N	N	Y
C1	F	19	0-2	0	0	Y	Y	Y	N
C2	M	22	0-2	0-2	0	Y	Y	Y	N
C3	F	20	0	0	0	Y	N	N	Y
C4	F	21	2-6	0-2	2-6	Y	N	N	N
C5	M	19	6-10	0-2	0-2	Y	N	N	N
C6	M	20	0-2	0	0	Y	N	N	N
C7	M	19	10	0	2-6	Y	Y	Y	N
C8	M	21	2-6	0-2	2-6	Y	N	N	N
C9	M	21	10	0-2	10	Y	N	N	N
C10	M	19	10	0-2	2-6	Y	Y	Y	N

Table 16: Intersession Survey Data

	I enjoyed playing this/these levels. (3D)	I felt that I performed well in this/these levels. (3D)	I enjoyed playing this/these levels. (2D)	I felt that I performed well in this/these levels. (2D)
M1	4	3	4	4
M2	5	4	5	4
M3	4	4	4	4
M4	4.5	4	4.5	4
M5	5	5	5	5
M6	4.5	4.5	4	4.5
M7	3.5	3.5	4	3.5
M8	4	4	4	3
M9	2	2.5	5	4
M10	4.5	3	4.5	3.5
M11	5	5	5	5
M12	5	2	5	3
C1	4	2	4	3
C2	4.5	4	4	3
C3	4	2	4	3
C4	4	2.5	5	4
C5	5	4	4	5
C6	5	4	4	5
C7	5	4	4	4
C8	4	4	5	4
C9	5	4.5	5	4
C10	4	4	4	2

Table 17: Comparative Survey Data

	I found 3D video to improve my ability to detect and react to incoming obstacles.	My ability to perceive distance/direction in the game was improved by the 3D video.	My satisfaction with playing the game was improved by the 3D video.	After playing this game, I would be more likely to choose 3D fps/racing video games.
M1	2	4	3	2
M2	4	4	5	4
M3	2	2	2	3
M4	2	3	4	4
M5	2	3	4	4
M6	2	2	2	1
M7	2	2	1.25	1.25
M8	4	4	3	3
M9	1	1	1	1
M10	3	4	3.75	4
M11	1	1	1	1
M12	4	5	3	4
C1	4	4	4	2
C2	1.75	4	4.25	4
C3	4	4	3	2
C4	5	5	5	5
C5	4	4	5	4
C6	4	4	5	4
C7	3	4	4	3
C8	2	3	2	2
C9	3	4	3	3.5
C10	4	4	4	4

Table 18: Immersion Survey Data

	How aware	How real	Consistent	Presence	More real	Not aware	Being there	Surrounded
C1	4	3	5	2	1	1	4	4
C2	4	3.75	3	2	3	4	3.5	4
C3	4	4	2	2	3	4	4	2
C4	4	4	3	2	2	2	4	3
C5	2	5	4	2	2	3	4	4
C6	2	5	4	2	2	3	4	4
C7	2	3	2	2	2	2	4	3
C8	4	4	2	2	2	2	4	3
C9	5	4	3	1	2	2	4	4
C10	4	3	3	2	2	3	4	4