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THE EFFECT OF HIGH MONITOR REFRESH RATE ON GAME EXPERIENCE

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ABSTRACT:

Most computer monitors display images at a rate of 60hz or 60 updates per second. Modern gaming-oriented monitors often run at rates of over 100hz, even up to 240hz. In practice this higher refresh rate is most noticeable in the smoothening of fast movements, which are present in many competitive shooter games such as Counter-Strike: Global Offensive (CS:GO).

High refresh rate as a feature in a monitor will increase its price the same way as larger panel size or better image quality. This study aimed to find out if the possible benefits of high refresh rate is worth it for the game experience of PC gamers in general, as it is becoming more affordable. This is a qualitative study which employs observing and semi-structured interviews for data collection and thematic analysis for analysing the collected data. In the practical part the study, a small number of individuals played CS:GO with two refresh rate settings, 60hz and 144hz in a controlled environment. The participants had different levels of experience in PC games which helped in forming codes and themes in the analysis phase in addition to their reactions and answers in the lab.

It was determined that competitive players who possess a certain skill level can benefit from high refresh rate. It can also positively affect the experience of some gamers as a visual effect perceived as smoother movement. For many gamers however, it has negligible or no effect on their experience. High refresh rate is supported by some upcoming gaming consoles and smartphones. This would suggest that high refresh rate will become more mainstream in the future, providing more potential for research in this topic.

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TIIVISTELMÄ:

Suurin osa tietokonenäytöistä toistaa kuvia 60hz taajuudella eli 60 päivitystä sekunnissa. Nykyaikaiset pelikäyttöön suunnatut näytöt voivat usein toistaa kuvia yli 100hz tai jopa 240hz taajuudella. Käytännössä tämä nopeampi virkistystaajuus näkyy sulavampina nopeina liikkeinä, joita on esimerkiksi nopeissa ammuntapeleissä kuten Counter-Strike: Global Offensive (CS:GO).

Nopea virkistystaajuus kasvattaa näytön hintaa siinä missä mikä tahansa muu ominaisuus kuten suurempi näyttöpaneeli tai korkeampi resoluutio. Tämä tutkimus pyrki selvittämään, ovatko nopean virkistystaajuuden mahdolliset hyödyt arvokas ominaisuus yleisesti PC pelaajien pelikokemukselle, koska se on nyt tullut paremmin saavuteltavaksi. Tutkimus on luonteeltaan laadullinen ja se käyttää havainnointia sekä puolistrukturoituja haastatteluja tiedonkeruumenetelminään sekä teema-analyysia analyysimenetelmänään. Käytännönosuudessa pieni ryhmä osallistujia kävi vuorollaan pelaamassa CS:GO -peliä laboratoriotilassa kahdella eri virkistystaajuusasetuksella, 60hz ja 144hz. Osallistujilla oli eroavia määriä kokemusta PC pelaamisesta. Tämän ansiosta he myös reagoivat ja vastasivat haastattelussa eri lailla, mikä auttoi muodostamaan koodeja ja teemoja analyysivaiheessa.

Lopputuloksena todettiin, että kilpailuun keskittyvät pelaajat voivat hyötyä nopeasta virkistystaajuudesta. Se voi myös vaikuttaa positiivisesti joidenkin pelaajien pelikokemukseen liikkeitä sulauttavana visuaalisena efektinä. Monille pelaajille sillä ei kuitenkaan ole juurikaan tai ei lainkaan vaikutusta heidän pelikokemukseensa. Nopea virkistystaajuus on tulossa myös uusiin pelikonsoleihin sekä älypuhelimiin. Ominaisuudesta on siten tulossa enemmän valtavirtaa, mikä avaa uusia tutkimusmahdollisuuksia aiheeseen.

1 INTRODUCTION

The flat screen liquid crystal display (LCD) has become the standard monitor technology for today's desktop computers. LCD's have mostly replaced other monitor technologies such as the bulky cathode ray tube (CRT) and costly plasma displays. The standard refresh rate, how often the image updates on the screen, of LCD monitors has been 60 hertz (hz) or cycles per second. When the refresh rate is high enough, the human eye will perceive smooth motion instead of individual frames on the screen. The refresh rate needs to match or surpass the image output of the computer, referred to as frame rate or frames per second (fps), in order to display all the provided images and to avoid distortions.

In the early 2000's 60fps was considered enough for gaming in general. When describing what frame rate to aim for when developing a game, Fox even states: "*Frame rates faster than 60 fps are not really detectable by the human eye*" (Fox 2005). A higher than 60 fps is now seen as a must for professional gamers in e-sports for fast paced games such as Counter-Strike: Global Offensive (CS:GO) by Valve Software (Appendix 2.). In extreme cases, competitive gamers may seek several hundred frames per second in games that require very fast reaction times such as CS:GO. In order to represent these high frame rates generated by the computer, an equal or higher refresh rate monitor is required. A 60hz monitor for example may only reproduce up to 60fps image output correctly, which is not enough for the needs of hardcore competitive gamers. To counter this, LCD monitors capable of producing images at rates well exceeding 100hz have become more available to the consumer market. Some years ago, these monitors were specifically targeted to hardcore gamers and enthusiasts and commanded a premium pricing. The market situation has now changed as cheapest models of these monitors may now cost less than 200€ in Finland (Gigantti 2019), making them accessible to the average gamer. High refresh rate has changed from a premium feature of gaming enthusiasts to something that any gamer might consider while buying a new monitor. This is also reflected in the current high sales numbers of high refresh rate monitors.

Based on this apparent popularity of high refresh rate, this study aims to assess whether different PC-gamers can improve their game experience with such monitors in some way or if they should look for monitors with a different set of features. These include panel size, colour reproduction, resolution and input lag. Some monitors have a mixture of these features such as higher resolution together with a more modest increase in refresh rate, such as 75hz instead of the usual 60hz (ASUSTek Computer Inc. 2019). At the same time, some high-end high refresh rate monitors targeted for hardcore gamers have pushed the refresh rate to over 200hz (ASUSTek Computer Inc. 2019). It is also possible to find 144hz high refresh rate monitors at the lower end of the price spectrum with often poorer image quality. This study aimed to find out whether high refresh rate affects the gaming experience of different PC-gamers and should they invest in it.

Previously the related topic of frame rates in games has been researched by Claypool & Claypool, who discovered that increases in frame rate from up to 60 frames per second (fps) made players perform more effectively in a shooter game. However, the performance difference between 30 and 60 fps was minimal. In this study the equipment was able to produce more than 60fps/hz, at which point it will have negligible effect on player performance in most cases according to their research. High refresh rate could however positively affect other aspects of gaming than just player performance, such as visual representation, which some players could value.

Instead of focusing solely on player performance, this study is interested in finding out how the overall gaming experience can be affected by high refresh rate. Games are played for many different reasons, or different types of fun as described by Lazarro (Isbister & Schaffer 2008: 318). Visual representation of the game, provided by the monitor, plays a different role for seekers of various types of fun in games. Based on Csíkszentmihályis (1990: 34-40) theory of flow or the optimal experience, Ermi and Mäyrä have described the roles of different types of immersion in games. (Ermi & Mäyrä 2005: 7). Out of these, the audiovisual immersion is most strongly related to monitor refresh rate. Cognitive skills such as perception and attention likely play a major role in the players ability to notice refresh rate changes in games (Calvert 2005: 126-129).

Recently graphics card producer Nvidia Corporation released a commercial article which compared the performance of gamers in battle royale-style games (a fast-paced survival game genre where players collect resources and fight other players) using different computer and monitor setups. Based on the data that company has collected from its customers using their software, Nvidia claims that the players had significantly better kill to death ratios when using 144hz or 240hz refresh rate instead of the standard 60hz. In order to run the games at the required frame rates with high settings, a high-end graphics card was required. (Delgado 2019) These graphics cards are out the of economic reach of many gamers, so they need to turn down the graphics settings in order to run the games at high frame rates required for higher refresh rates.

In addition to desktop gaming, higher than 60hz refresh rates have started to appear in smartphones and they are expected to be supported by next generation gaming consoles (Ivan 2019).

1.1 High refresh rate monitors in PC-gaming

No strict definition exists for the term 'gaming monitor'. However, high refresh rate is seen as an essential feature for one, especially in the 1920x1080 and 2560x1440-pixel resolution monitors. Some of the most popular high refresh rates (over 60hz) in gaming monitors are 144hz and 240hz. (Prosettings.net 2019) TN-panels are common in gaming monitors thanks to their quick response time, but VA- and IPS-panels have also gained popularity recently with their better image quality (Baker 2015).

Monitors with over 60hz refresh rate have been targeted especially for gaming use. They can be found for example in gaming lounges such as Gaming Lounge Helsinki Finland (GLHF 2019). E-sports organizations such as the Finnish Esports Federation (SEUL ry) use them in gaming tournaments and practice sessions which they organise. They view high refresh rate as a must have feature in monitors which can provide a competitive advantage for gamers. A SEUL ry representative commented on the use of high refresh rate monitors:

"Over 120hz or faster monitors are a mandatory and required in every esports tournament. Nobody wants to play with a refresh rate of 60hz in esports events. The same applies to commercial gaming cafes and lounges." (Appendix 2.)

For e-sports use in PC-gaming, high refresh rate monitors are viewed as a necessary tool for competitive performance. Organisations and teams in e-sports also have powerful gaming PC's available, which can run the games at high frame rates. Prosettings.net, a website which analyses the gaming setups of professional gamers, claims that 98% of the over 2500 pro-players they have analysed indeed have hardware that can run e-sport games at 144fps or more. They use enthusiast level graphics cards such Nvidia's GTX 1080 and RTX 2080 series, graphics cards being the most important component for achieving a high frame rate. Pro-players also prefer to play the game on small resolution and low graphical settings, which improve frame rate even further. Prosettings.net considers 144hz refresh as the minimum refresh rate for competitive gamers and that players who switch from 60hz to higher will never want to return to the slower rate. They even recommended that professionals should look to acquire the equipment necessary for 240fps/hz if possible. Of the players they have analysed 48% play with 240hz, 47% with 144hz, 4% with 120-185hz and only 1% with 60hz monitors. (Prosettings.net 2019)

1.2   Popularity of high refresh rate monitors among Finnish retailers

The public top 10 product sales lists were studied from several Finnish retailers in order to determine the popularity of high refresh rate monitors in Finland (Figure 1). 120hz was set as the minimum for such a monitor to be included, so some lower refresh rate gaming-oriented monitors are excluded. The included retailers have a large overall selection of monitors, including ones that do not have a high refresh rate. They also sell other peripherals, components and devices that are specifically targeted for gamers.

High refresh rate monitors among Top 10 monitor models

Fast refresh rate monitors

Jimm's PC Store	8
Gigantti	6
Verkkokauppa.com	7
Multitronic	5
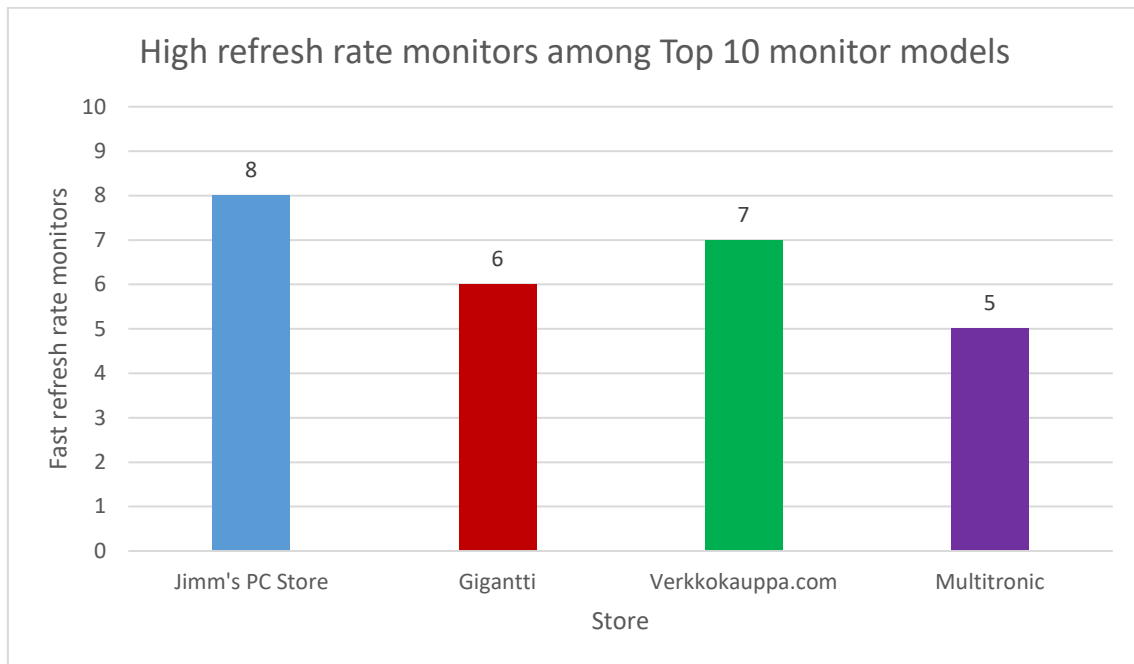
Store

Figure 1 Popularity of high refresh rate monitors among Finnish retailers in May 2019.

PC-enthusiast focused retailer Jimm's PC-Store had eight high refresh rate monitor (FRRM) models in its top ten most sold monitors on 2.5.2019. (Jimm's PC-Store Oy)

Electronics retailer Gigantti had six HRRM models among its ten most sold monitors on 2.5.2019. (Gigantti Oy)

Finland's most popular online store Verkkokauppa.com had seven HRRM models among its ten most popular monitors on 2.5.2019. (Verkkokauppa.com Oyj)

Vaasa based electronics retailer Multitronic had five HRRM models among its ten most popular monitors on 2.5.2019). (Multitronic Oy)

Based on these listings, high refresh rate monitors are very popular among Finnish consumers in 2019. These retailers also have comparably priced monitors that lack the high refresh rate but have other features such as panels with better image quality. It seems that Finnish consumers are interested particularly in high refresh rate when they are

buying a new monitor. This could also be a result of general PC users switching from desktop PC's to laptops and not needing a separate monitor (Holst 2019). PC gaming enthusiasts on the other hand have stayed more on desktop since they tend to have better gaming performance and upgradeability than laptop. When they look for a separate PC-monitor they likely want one made for their specific use, resulting in the popularity of high refresh rate monitors.

1.3   Objectives and limitations of the study

High refresh rate monitors have achieved widespread popularity in professional gaming and they are now also being sold consumers in large quantities. Little academic research exists so far on how they affect the gaming experience of different PC-gamers, despite the popularity of HRRM's. Correspondingly, this study aims to answer the following research question:

"How does high monitor refresh rate affect PC gaming experience?"

The objective of this qualitative study is to examine, how higher than average monitor refresh rates together with a high frame rate in a computer game can have effect on the gaming experience. Most gamers are familiar with low frame rates in games, which can in the worst case make the game almost unplayable. According to Claypool & Claypool, there should be little effect of performance when going above 60fps/hz (Claypool K. & M. Claypool 2007), but the mass opinion of current gamers seems to disagree.

This study focuses on the other end of the spectrum by raising the frame rate and monitor refresh rate from 60 to 144hz/fps. Shooter game enthusiasts especially have sworn in the name of higher refresh rates (Wiltshire 2017), but is it something that can affect the experience of PC-gamers in general? Would they be better off investing in some other feature in a monitor? Should high refresh be marketed to all gamers?

1.4   Research methods

The main data gathering method was to conduct a qualitative experiment, where a small number of participants play a selected game in two sessions with different monitor refresh rate settings and corresponding frame rate. Before the sessions the participants were asked some basic questions regarding their gaming habits. These questions were not directly related to the topic of monitors in order to keep the exact nature of the test hidden for now. After the play session, the participants were interviewed in a semi-structured manner regarding their game experiences with the different refresh rate settings and how they view it themselves. Conversations inside the lab were recorded and analysed as well. The participants were individuals who have at least some previous experience in playing PC-games. This is in order that the sessions proceed without the need to teach the basic controls or gameplay mechanics and can focus more on playing the game itself.

The study will be a qualitative one, as it matches several definitions for such study as listed by Hirsjärvi, Remes and Sajavaara (2009: 164):

1. *The study employs holistic information gathering and the material is gathered from real life situations.*
2. *Individuals are favoured as the instrument for information gathering*
3. *Inductive content analysis is being used. Gathered information is investigated multifacetedly and in detail without the purpose of proving a theory or hypothesis.*
4. *Qualitative research methods, such as thematic interviews and participant observation are used.*
5. *The subjects of the study are selected appropriately, not randomly.*

After the data was collected, it was analysed using thematic analysis. Codes that describe the meaning of significant data excerpts are formed from the dataset. Groups of related codes will form themes that are the core points that can be discerned from the data. The relations between themes will form a thematic map. (Braun & Clarke 2006: 35) The developed themes and thematic map were made to indicate how higher monitor refresh rate affects different PC gamers, how beneficial it might be and whether it is valued.

2 DISPLAY TECHNOLOGIES AND CONCEPTS

This part covers the theoretical background regarding computer display technology and recent trends in computer monitors that are relevant to this study. Frame rate and refresh rate are covered in their own sections, as both these are essential in creating smooth movement on the screen. Special focus is given to gaming monitors, since their features such as high refresh rate tend to differ from monitors made for other use cases. The popularity of high refresh rate gaming monitors in Finland is explored in its own section. Gaming monitors seek to minimise input lag, which is covered in its section. High amount of input lag can make the game feel unresponsive and sluggish. Refresh rate is one way reduce the effect of input lag. The necessity of matching frame and refresh rate is covered in the section covering the screen tearing effect. Elimination of screen tearing is why high refresh monitors exist in the first place.

2.1 Liquid crystal display (LCD) and panel technologies

The twisted-nematic structure that is still used in many LCD's was discovered in early 20th century, but practical display technology was developed in the 1960's. The first commercial LCD's were produced in the early 1970's for use in advertisement boards, calculators and wrist watches. When the early impractical "dynamic scattering effect" technology was replaced with Twisted-Nematic (TN), Field Effect, LCD's started gain much more popularity in the late 1970's. (Castellano 1992: 9-12)

In the early 2000's LCD technology had matured enough that it started to replace older cathode ray tube (CRT) monitors in desktop computing. LCD desktop monitors were much lighter and took less space. The screen was completely flat instead of curved and it had better contrast and sharpness. They could be manufactured in larger sizes while still consuming less power than CRT's. (Flyktman 2002: 901)

TN-panels are still used especially in gaming as they can reach the highest refresh rates, up to 240hz currently. TN also has the best pixel response time, which is also useful for

gaming. Even with all the technological advancements, TN-panels still suffered from limited viewing angles as well as poor colour reproduction. (Schiesser 2019) As a solution to this, Hitachi developed the In-Plane Switching (IPS) technology in 1996. It provided good colour reproduction and viewing angles. These qualities have made IPS-monitors popular with professionals who work with images. (Baker 2015) For a long time IPS-monitors were not used in gaming due to their poor response time and inability to have high refresh rates. These features have recently been incorporated to IPS-monitors specifically targeted for gaming. (Babcock 2019) Vertical-alignment (VA) panels offer a middle ground between TN and IPS panels. They have better contrast than either TN or IPS and better viewing angles than TN. VA panels still tend to lose somewhat in colour reproduction compared to IPS. VA monitors however are much more widely available with high refresh rates than IPS. (Schiesser 2019)

2.2   Frame rate

In personal computers, frame rate or frames per second (fps) depicts the number of images from the virtual environment that the computer can create in one second (Figure 2). Zero frames per second means that no images are being rendered, while 24fps is considered the minimum amount for perceiving a somewhat smooth movement. (Qazi 2019)
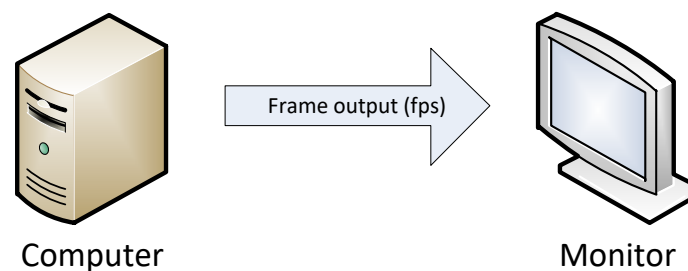

Frame output (fps)

Computer   Monitor

Figure 2 Frame output from the computer to the monitor is indicated in frames per second (fps).

For gaming 60fps is considered as the standard frame rate, though some games on Xbox One and PlayStation 4 are still capped at a maximum rate of 30fps in order to achieve a consistent frame rate (IGN 2019). The frame rate fluctuates depending on the computer hardware and the workload given to it. There is no upper limit on frame rate; a game that requires little processing power can run at a rate of hundreds of FPS on a powerful computer.

Hardware such as central processing units (CPU), graphics cards (GPU) and memory (RAM) affect how a game runs on a given PC, with GPU usually handling most of the load (Qazi 2019). These components vary greatly in their construction and performance and due to this, games often allow the user to adjust the visual settings such as textures and shadows. Lowering them can increase frame rate while raising them will decrease it. Many games will automatically adjust these settings based on the hardware that is present in order to provide a smooth experience without any adjustment from the user. 3rd party settings tweaking guides also exist for many games, which seek the best graphical detail while retaining playable fps.

Frame rate is also used in other visual fields, such as in movie theatres, which employ 24 frames per second rate for depicting movement. Faster frames rates have been experimented on in some movies, such as 2012's Hobbit: An Unexpected Journey, but with little positive results. Audiences are so used to 24fps in cinema that any change would make the experience feel foreign. (Qazi 2019) Since frame rate fluctuates in games, this phenomenon doesn't appear in gaming as users aren't fixed to a given frame rate.

2.3   Refresh rate

Refresh rate depicts the amount of times that the computer display device can update its image in one second (Figure 3). The unit used to depict this cycle rate is hertz (hz). The display will start updating the image from the top, one line of pixels at a time, instead of doing it simultaneously.
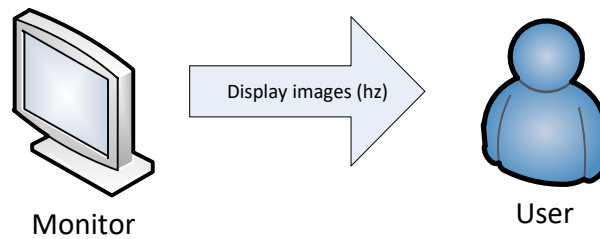
Figure 3 The frequency at which the monitor updates the image is referred to as refresh rate, measured in hertz (hz) or cycles per second.

Most of modern flat screen display devices in computers, tablets and smartphones utilize a 60hz refresh rate. 60hz was chosen as the standard of DC power supply frequency in the US, which was then eventually used in televisions and monitors as well. (Qazi 2019) The human eye can detect flickering at approximately 50hz, so 60hz monitor refresh rate is still above this range. (Ware 2013: 61) Other common monitor refresh rates include 75hz, 120hz, 144hz, 165hz and 240hz. Older cathode ray tube (CRT) displays employed a high refresh rates in order not to cause eye strain, this is not a requirement for LCD's. (Qazi 2019)

If the computer produces 60fps then a 60hz monitor will display each frame correctly. If the computer produces 30fps, the 60hz monitor will have to repeat some frames. If the computer produces 120fps the monitor won't be able to display each provided frame at the correct time. (Qazi 2019) A higher refresh rate means more frames can be displayed by the monitor in the same amount of time passed (Figure 4). Visually this can be detected as smoother movement of objects on the screen, while some individuals may even be able to react to sudden events thanks to faster processing of information. This is the reason higher refresh rates are seen in monitors used in competitive gaming (Appendix 2.).
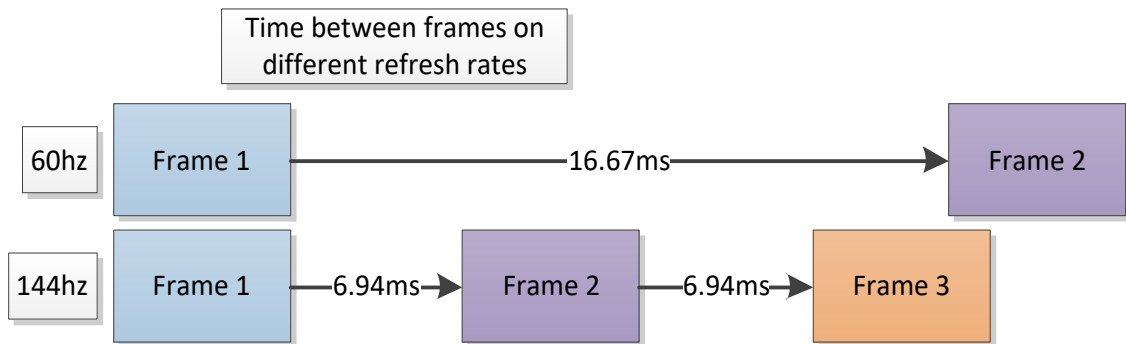
Figure 4 Time between frames on two different refresh rates refresh rates.

2.4 Input lag

Input lag is used to refer to the delay that exists between the user giving an input to a control device and having it displayed on the monitor (Figure 5). Some amount of input lag exists always, but it is usually unnoticeable for most users. Low input lag is important in games which require very quick reactions, as a delay of milliseconds could result for example in the player missing a shot taken at a glimpse sighting of an enemy. (Wilson 2009)
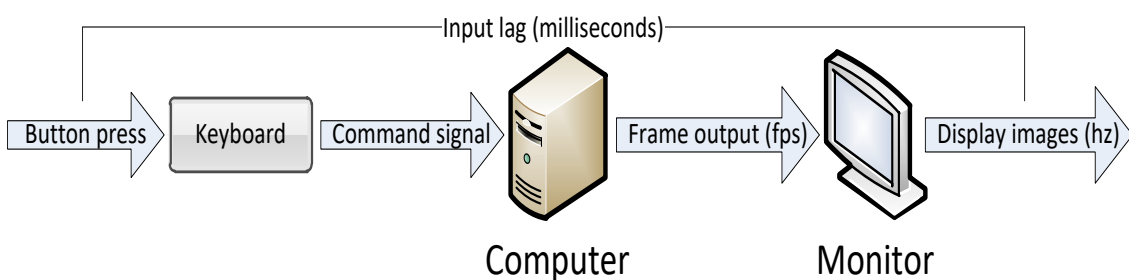
Figure 5 Input lag consists of the delay between user input and the command being displayed on the monitor.

According to Petit (2019), input lag consists of three main factors: controller, game engine and monitor lag. High amounts of input lag can make it frustrating to play games that

require fast movement and precise timing. Gaming targeted peripherals such as monitors, mice and controllers seek having low input lag for this reason.

Monitor input lag (Figure 6) is the aspect of input lag related to this study. Monitors are often marketed with pixel response time-based input lag, measured in milliseconds.
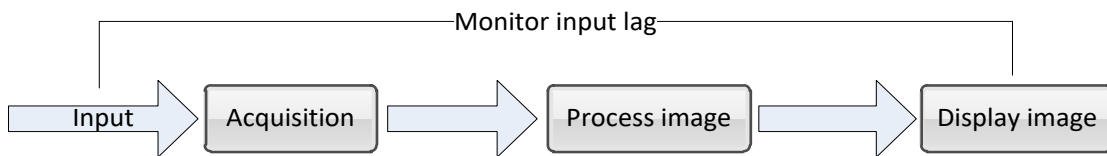
Figure 6 Monitor input lag consists of the time it takes for the monitor to process the signal from the PC to displaying it to the user. (Azzabi 2017)

Monitors with TN panels tend to have the fastest pixel response time with some having less than 1ms delay, which is why they are popular is gaming monitors. Increasing the refresh rate can reduce the effect of monitor input lag. Some gaming monitors even allow the user to increase the refresh above its factory settings, referred to as overclocking, but this can also introduce visual artifacts in extreme cases. (Azzabi 2017)

2.5   Screen tearing effect

Screen tearing is a monitor related graphical distortion where the frame rate output of the computer exceeds the amount images that the monitor can display in the same amount of time (Figure 7). As a result, the monitor may display cut out parts of multiple images simultaneously. This problem can appear especially in games which involve fast movement and run at high frame rates. (TechTerms 2018)
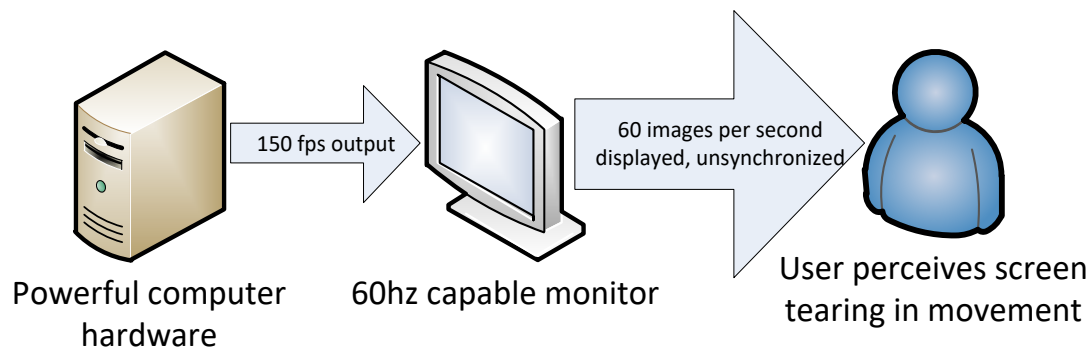
Figure 7 Unsynchronized frame rate and refresh rate can result in screen tearing.

In order to benefit from high frame rates and avoid screen tearing distortions, higher refresh rate monitors are required. For example, if a game runs at 120fps it can be displayed distorted on a 60hz monitor but will be correctly displayed on a 120hz monitor. (Qazi 2019) The problem can be mitigated by enabling a setting called vertical synchronization (VSync). VSync forces the graphics card to provide frames to the monitor in equal number to its refresh rate, essentially forcing the card to wait for the monitor to catch up. The downside of VSync is that it can increase the amount of delay experienced by the user for inputs, such as mouse movement and key presses. Graphics card manufacturers Nvidia and AMD have created their own synchronization technologies, which can reduce the input delay. Fast Sync and Enhanced Sync respectively work by having graphics card render new frames instead of waiting while monitor is still unable to refresh and then providing the latest frame for the monitor to display. The graphics card manufacturers have also created their synchronization solutions for monitors with higher refresh rates, referred to as adaptive sync. Monitors that are equipped with this technology can lower or raise their refresh rate depending on the current frame. Nvidia's G-Sync is a proprietary technology that requires its own module inside the monitor, while AMD's Freesync is royalty-free. (Schiesser 2018)

3   GAME EXPERIENCE

This chapter covers the concept of game experience. The study aims to have different types of gamer participants. One way to distinguish different gamers is to divide them into different categories based on their gaming experience and habits. Competitive gaming has been for years referred to as its own type of sport, e-sport. This has resulted in the formation of professional gamers. The term "PC-gamer" typically refers to someone who mostly plays games on a desktop computer using a computer monitor. Console-gamers play on home consoles such as PlayStation 4 or Xbox One. The console is often located in the living room and is connected to a television instead of a monitor. Those who play mobile and browser games are referred to as casual game players, though many hardcore gamers also play casual games (Kultima & Paavilainen 2007).

3.1   Different types of fun in games

Lazarro (Isbister & Schaffer 2008: 318) describes four different types of fun that players experience in video games (examples in brackets):

1. Hard fun: games based on competition and honing skills (FPS and MOBA games)
2. Easy fun: games centred on story, exploration and roleplaying (adventure and RPG games)
3. Serious fun: games that are played for real life value (physical or mental exercise games)
4. People fun: games with social interaction (MMORPG games)

Games that are centred on hard fun are likely to be affected the most by monitor refresh rate. These games are based on challenging the player and making them master the gameplay mechanics. The ultimate emotion created by good hard fun games is called fiero, where players finally succeed in a task after certain amount of frustration and feel accomplished. (Lazarro 2008: 324-328) Shooter games like Counter-Strike: Global Offensive are good examples of hard fun games. Players of these games often look for

different strategies and tools that can help them overcome the opposition in game. This includes tweaking the game settings and acquiring gaming equipment that can help them succeed in the game. Higher monitor refresh rate could provide hard fun gamers with an advantage by allowing them to react better to events in the game.

Easy fun games are centred on elements such as storytelling and exploration while in social games emphasis is given on communication and co-operation between the players (Lazarro 2008: 330). These types of games are likely less affected by monitor refresh rate, as they tend to be slower paced and don't often require fast reactions from the player. There are exceptions though, such as fighting a challenging boss enemy in RPG games, where higher refresh rate could be momentarily useful. Some players with a keen eye for visual details may also prefer the smoothness of high refresh rate in general.

Serious fun games are played for some beneficial real-life effect such as changing the mood of the user, making them learn something or having them do physical exercise in a dance game. People fun games on the other hand are based on interaction between players and having them form communities. (Lazarro 2008: 334, 339) Some serious and people fun-oriented games could be affected by higher refresh rate. Some of these games are based on simulation and virtual reality and have the user wearing a VR-headset. These games can cause nausea for the player if movement in game doesn't feel natural. This can be mitigated by raising the frame and refresh rate for more responsive output. (Epstein 2019)

3.2   Flow and immersion

Csíkszentmihályi (1990: 34-40) describes flow as the optimal experience, where one can centre their full attention on achieving a goal without having to worry about the disorder and threats that life tends to pose. Computer games seek having the user experience flow while playing, to have them envelop themselves in the game world instead of the one around them. Regarding flow in games, Järvinen, Heliö & Mäyrä (2002: 20-21) state: "*With digital entertainment products, attention is invested both in material sense and*

immaterial sense…there forms a triangle between the player, the game (software code) and the gaming peripherals". Monitor is one of the peripherals required for gaming and plays an important part in forming the flow in the game. A large monitor that provides a good image quality will allow the user to concentrate on the task of gaming, while a poor monitor can make it impossible to achieve a flow experience.

Ermi and Mäyrä have divided the gameplay experience into several different dimensions: sensory immersion, challenge-based immersion and imaginative immersion. Sensory immersion is according to them *"related to the audiovisual execution of games"*. (Ermi & Mäyrä 2005: 7) In desktop PC gaming this visual execution of the game is commonly displayed by the monitor, with devices such as virtual reality headsets remaining a small minority. If the player feels that the monitor is inadequate or not working correctly it could prevent them from being immersed in the game. The refresh rate of a monitor affects the visual presentation of the game, more specifically how movement is portrayed. Some could find the smoother movement more lifelike and responsive. Others could find it weird and "not game like" if they are used to low frame and refresh rate, as it happened when a movie like The Hobbit: An Unexpected Journey was shown in a faster frame rate (Qazi 2019).

Professional gamers have stated high refresh rate can provide them the ability to react faster in games. This would imply that high refresh rate can also affect the challenge-based immersion in games, by making it easier to react correctly to sudden events in the game. (Abstract 2.) The immersion of less experienced gamers is probably less affected in this regard, as their ability to react in the game isn't as honed.

Visual appeal of the game and how it is affected by the monitor refresh rate are the focus in this study. Can the player be more immersed in the game thanks to the visual change provided by the higher refresh rate, or is it irrelevant? Can it provide a stronger immersion for the player by making movements in the game seem smoother and more natural?

3.3   Cognitive skills and games

According to framework of information-processing activities compiled by Calvert, playing games requires the use of **perception, visual attention and representation and memory**. **Perception** is used to acquire information from the environment and is triggered by cues such as movement, pacing of events and visual or sound effects. These direct the **attention** of the player to certain events that happen in the game or a specific location in the game world. Through experience the player can automate their attention, which allows multitasking such as moving fluently in the game while forming a strategy for how to proceed in the next stage. **Representation and memory** are also used by experienced gamers for developing mental maps of the game environment in their mind and how to proceed in them. Through these activities in games, active players have been able to improve their visual-spatial skills. (Calvert 2005: 126-129) These information processing abilities are especially vital in fast-paced competitive games such as CS:GO. The player needs good **perception** in order to react correctly to visual and audio cues such as seeing a glimpse of an enemy far away or hearing their footsteps. At the same time the player needs to put their **attention** to where teammates and enemies are located and then form a strategy for how to proceed. In CS:GO **representation and memory** is demonstrated with actions such as players remembering to check for enemies on top of a crate after turning from a certain corner in familiar map. Professional CS:GO teams practice playing the same map over and over in order to memorize every location and to counter any opposing strategy (van Hulst).

Of the above information processing activities, perception and visual attention are likely affected the most by the refresh rate of the monitor that displays the game. Reception could be affected by providing the player movement and animations that feel more natural and smoother. Attention could be improved by providing the player new information faster through displaying more images in the same amount of time. This could appear in situations such as displaying the movement of an enemy that suddenly appeared at the edge of the screen. Representation and memory are likely not affected, since these activities happen in the mind of the player. Improved visual-spatial skills of the player could affect how they react to high refresh rates compared to those who play less games.

4   MONITOR REFRESH RATE USER EXPERIMENT

In order to determine the effect of high refresh on different gamers, a qualitative study was conducted where a small number of gamer participants would play the same game with the same settings except for the refresh rate. It was important to acquire different types of gamers as they would likely have very different reactions to refresh rate. It was also relevant to find out if they would be interested in using high refresh rate in the future after they were told about the topic. Their reactions to high refresh rate and comments on it and monitor topics would be recorded and then analysed in a thematic analysis as defined by Braun & Clarke (2006: 35) and Guest, MacQueen & Namey (2012: 10).

The analysis will use an exploratory approach, as it is not driven by a hypothesis and is instead centred on observing participants' reaction to refresh rate change and asking them on their views regarding it. New data is created, which is then analysed, coded and formed into themes. (Guest et al 2012: 7)

4.1   Test setting and setup

The study was conducted in June 2019 at the usability laboratory of University of Vaasa. Ten participants took part in the study. They were not told beforehand about the exact topic of the study, but the participants were informed that it involved playing Counter-Strike: Global Offensive and that their personal skill level in the game was not being evaluated. The usability laboratory was selected as it provided a calm setting and was equipped with the necessary hardware.

The data was collected using observation and thematic interviews. The participants entered the lab individually and were first asked some basic questions regarding their gaming habits, such as what types of games they play and how often. After answering the initial questions, the participant would play CS:GO for at least ten minutes at 60hz monitor setting. Once finished, they would switch to another session of the game on same monitor now running at 144hz. With the gameplay sessions finished a semi-constructed

interview on the game sessions and the participants views regarding the topic would commence. The conversation inside the lab was recorded, which proved very useful especially with the participants who noticed a major difference in the refresh rate. They verbally commented on the change almost immediately.

The setup consisted of two computers which were connected to the same monitor (Samsung C32JG50 32"), that could run at 60hz or 144hz refresh rate. One of the computers was a laptop set to run the game at around 60fps at 60hz refresh rate on the monitor and the other was a desktop capable of running the game at around 144fps with the monitor at 144hz. Speakers were connected to the audio connector of the monitor, so the same pair was in use for both computers. Identical pairs of keyboard and mice were plugged to the computers, this was the only noticeable change in physical devices that participants could observe. The game was set to run at low settings on both computers in order to ensure the required 60 or 144 frames per second minimum. Two computers were used in order to remove a pause that would have been present when using only one computer, as the game would have to be closed in order to change the refresh rate.

The game selected for the study was Counter-Strike: Global Offensive (CS:GO), developed and published by Valve software in 2012. It is a team based first-person shooter game originally developed in the late 90's and is one the most popular e-sport games currently. In CS:GO the players are split into two opposing teams; terrorists and counter terrorists. The game has several modes of which the most popular is Bomb defusal, which was also selected for this test. In this mode the terrorists are tasked with planting a C4 explosive carried by one player at a designated bomb site. After the bomb has been planted a 40 second timer will run through after which the bomb explodes and the terrorists win. The Counter-Terrorists can win by defusing the bomb or if the round time ends. Either team can win by eliminating all opposing players, however if the bomb has been planted the Counter-Terrorists still have to defuse it in order to win. Each player earns money through eliminating opponents, achieving objectives and winning or losing rounds. This money is used to buy better weapons and equipment such as defusing kits at the beginning of each round. The game is usually played with other players, but computer bots were used in the test in order to have more consistent matches. The in-game character

is controlled with the keyboard for movement and the mouse for camera and shooting. Strong emphasis in the game is put on mastering the controls, which can be achieved only through practise. Accordingly, the participants in this test could pick the difficulty level of the bots according to their skill, in order to make the game more exiting. Some participants underestimated their skill in the game and wanted slightly more challenging bots for the second match. This change in difficulty did not seem to affect the participants ability to tell the difference between refresh rates.

4.2 Semi-structured interview

Hirsjärvi & Hurme (2006: 47) state that semi-structured interview differs from structured and non-structured interviews by having aspects like the general topic of the interview remain the same for all participants, but details such as the order of questions and the ways they are answered can differ. For conducting a structured interview, the researcher has already investigated the subject to some extent and has formed an interview structure based on their findings. The interview itself is focused on the individual experiences of the participants regarding the subject chosen by interviewer. (Hirsjärvi & Hurme 2006:47)

Semi-structured interview was chosen as the main data collection method as the study participants would have the same experience of playing the game in the lab and then being interviewed regarding it. Each participants' previous experiences in gaming and the one they have in the lab would form a unique entity. They would all be asked the questions found in the interview form, but they were free to answer questions in length and were also asked individual questions based on their answers.

Each interview question in the form had suggested answer types, but the participants could add to each answer with their own perspectives. Questions, such as which age category the participant belonged to, were similar as the ones found in structured interviews. On the other hand, each response to "how important is refresh rate when compared to other monitor features" was different in some way. Questions such as this

one often developed into unstructured interview style conversations in the lab. (Hirsjärvi & Hurme 2006: 47-48)

4.3   Observation

According to Saaranen-Kauppinen and Puusniekka (2006), observation can be used to supplement the data gathering in an interview process. This was the case in this study as well, since it included the participants playing the game with the researcher present. The role of the researcher was largely non-participating, except for providing advice for the participant and having general conversation with them. Relaxed conversation atmosphere was sought in the lab in order to avoid the control effect, where the presence of research affects the participants performance. The observation conducted was somewhat structured in nature even though strict conditions were not laid for it. The focus was on how the participants reacted or did not react to the refresh rate in the game. The observed reactions were how the participants used mouse movement in the game and what kind of comments and remarks they made while playing. (Saaranen-Kauppinen & Puusniekka 2006)

4.4   Thematic analysis

The method for data analysis selected for this study is thematic analysis (TA). TA is only a method for analysing qualitative data instead of being an entire approach of qualitative research, which provides more flexibility in its use. (Braun & Clarke 2012:58) In this method, the dataset that has been gathered using qualitative research methods is thoroughly examined in order to discover datapoints that are intricately related. These datasets are grouped into a label referred to as a code. According to Guest and others, codes should then be compiled into a codebook, which presents the connections that exist between the codes. (Guest et al. 2012: 52) The next level of the analysis is to form themes from groups of codes that are related to the same topic. Themes also tend to have connections between them. Braun and Clarke highlight that the researcher should not lose

touch with what is in the data while forming themes. The themes should reflect what the study participants have said or the phenomena their answers are related to. (Braun & Clarke 2012: 63, 65) While Guest and others highlight the importance of a codebook in their description of applied thematic analysis (Guest et al. 2012:52), Braun & Clarke underline forming a thematic map as end result of the analysis (Braun & Clarke 2012: 65).

According to Braun and Clarke, thematic analysis is interested in finding the commonalities in the data, which reflect how the topic at hand is viewed in general. Codes reflect the common datapoints and codes are used to define each theme. TA is not focused on highlighting all the unique views that are held on the topic. Additionally, only the themes that are related to the current research question should be explored in detail. (Braun & Clarke 2012:57)

Thematic analysis can be conducted with different approaches such as inductive or deductive analysis with experiential or critical orientation. Inductive TA is focused on developing something new from what is in the data itself, while deductive TA pre-existing concepts are used to code the data. Experiential TA is based on describing the experiences and meaning of the participants and data, while critical TA is focused on how the data is influenced by a given theory or existing research. These approaches are often combined in the analysis and the overall consistency of the analysis is placed above adhering to any given approach. This study will use the inductive and experiential approach, as it is based on coding the participants personal experiences on gaming and how they react to refresh rate. (Braun & Clarke 59)

Braun & Clarke (2006: 35) have divided thematic analysis into six phases:

1. *Become familiarized with the data*
2. *Generate initial codes*
3. *Search for themes*
4. *Review themes*
5. *Define and name the themes*
6. *Produce a report*

The analysis starts with the researcher going through the data several times and making notes of any interesting findings. These findings are then formed into the initial codes in the next phase. The codes are continuously redefined as the analysis proceeds. Initial themes can be formed from groups of codes that are clearly related to each other. These themes must be faithful to the data extracts that were formed and relevant to the overall dataset. Next, clear definitions and names are formed for each theme and the end results of the analysis are being formed. These results are then formed into a proper report. (Braun & Clarke 2006: 35)

4.4.1   Codes & coding

After the data has been gathered and read through, codes are formed based on different features that it includes. According to Braun & Clarke codes: *"identify and provide a label for a feature of the data that is potentially relevant to the research question"*. Codes can be used to describe what the participants have said in a direct manner or they can be used to interpret their answers for what they really mean or implicate. The label given to a code can also be used to refer to the participants' answers in a direct way or it can be linked to a larger concept that the researcher has recognized from the data. Often time they are a mix of both. Interpretive codes can be more difficult to identify, but it does not mean they are better than descriptive codes. Braun & Clarke suggest that any item that is potentially important to the research should be coded, as unnecessary codes can later be discarded while the researcher avoids having to go through the data again for missing codes. The codes can be modified during the coding process as new excerpts of it are found in the data. (Braun & Clarke 2012: 61)

4.4.2   Themes

Themes are meanings in the text that often occur repeatedly, but there are also other ways to identify them such as data that was expected but was missing from participants' answers. (Guest et al. 2012: 66). These meanings need to be connected to the current research questions. Repetition by itself does not mean that the meaning is important for the research. (Braun & Clarke 2012: 57). Two major categories of themes exist: structural

topics and content themes. Structural topics are associated with how the research question is being explored and the research is designed, while content themes are meanings in the answers and observations gathered while conducting it. (Braun & Clarke 2012: 61-63)

Initially, a larger group of candidate themes and subthemes based on relevant codes and the relations between these themes can be formed into an early thematic map that can resemble a mind map (Braun & Clarke 2006: 19-20). This early thematic map is refined in two stage: first the themes are compared to the data extracts that form and in the second to the whole dataset. These stages are ensuring that the map truly represents data gathered from the participants. When the thematic map is becoming more refined, the individual themes and their meaning is analysed in more detail. The data that forms a theme will create the ´story´ that it tells. (Braun & Clarke 2006: 20-22)

5   STUDY RESULTS

The purpose of the user study was to gather data on how refresh rate affected their gaming experience. The goal was to gather a dataset using qualitative research methods and to analyse it using thematic analysis in order to answer the research question: *"How does high refresh rate affect PC gaming experience?"*. Based on the collected raw data itself, it could be seen that some forms of answers to the question can be found. Several reactions and answers from individual participants were quite similar, making them more definitive.

The data was gathered in a qualitative study using observation, voice recording and semi-structured interviews. The participant was first asked some basic questions regarding their gaming experience. These more general questions were asked in the beginning, while questions specific to the test and research topic would be asked later, so that the participants would have the gaming experience fresh in mind while answering. The participants would then play the game for two sessions that lasted at least ten minutes each. The researcher was present in the room the whole duration of the test, observing and recording the participants reactions. Lastly, the participants were interviewed regarding the game sessions, importance of visual detail in games and how they viewed high refresh rate monitors for their own use.

Voice recording was started when the participant entered the lab and ended after the last question was discussed in the final interview. During the interviews the participants talked quite openly, but while playing the game many of them stayed mostly silent. They at times asked advice about the controls or quickly commented on funny events in the game. Some crucial comments were recorded from certain participants however, when the refresh rate was changed. In addition to voice recording data, the participants' answers to interview questions were recorded on paper with notes added when necessary. Each question had multiple answer options to serve as a guide, but the participants often had their own personal answers to questions. Each participant was also asked individual

questions based on their previous experiences, how they acted in the game and what they thought of some features that were relevant to their gaming experience.

5.1   Test participants

The study had ten participants who had all played digital games to varying degree during the past year (Table 1). They study or have studied at higher education level in Finland. The participants were unaware of the exact purpose of the test, but knew that it involved playing CS:GO. None of them reported having any major visual impairments that would prevent them from noticing the refresh change for certain. All of them were young adults, of whom two wore glasses while playing the game.

Participant	Age	Played digital games past year
1	26-29	Almost every day
2	26-29	Almost every day
3	22-25	Weekly
4	22-25	Almost every day
5	22-25	Almost every day
6	26-29	Almost every day
7	22-25	Weekly
8	26-29	A few times per month
9	26-29	Weekly
10	30-33	Weekly

Table 1 Age and gaming frequency of the participants.

The participants had at least some form of PC-gaming experience (Figure 8), but some play games mostly with a console. Half of the participants were very active gamers, playing games almost daily, four others weekly and only one more seldomly. Seven of the participants said they play competitive games every week or even daily. Five of them play shooter games such as CS:GO at least weekly, with three having many years of experience in playing CS:GO intensively. The five other participants did not know or

remember some of the controls of the game, so they were instructed on them at times. Nine of the participants knew the basic premises of the game, such as eliminating opponents and arming or defusing the bomb.
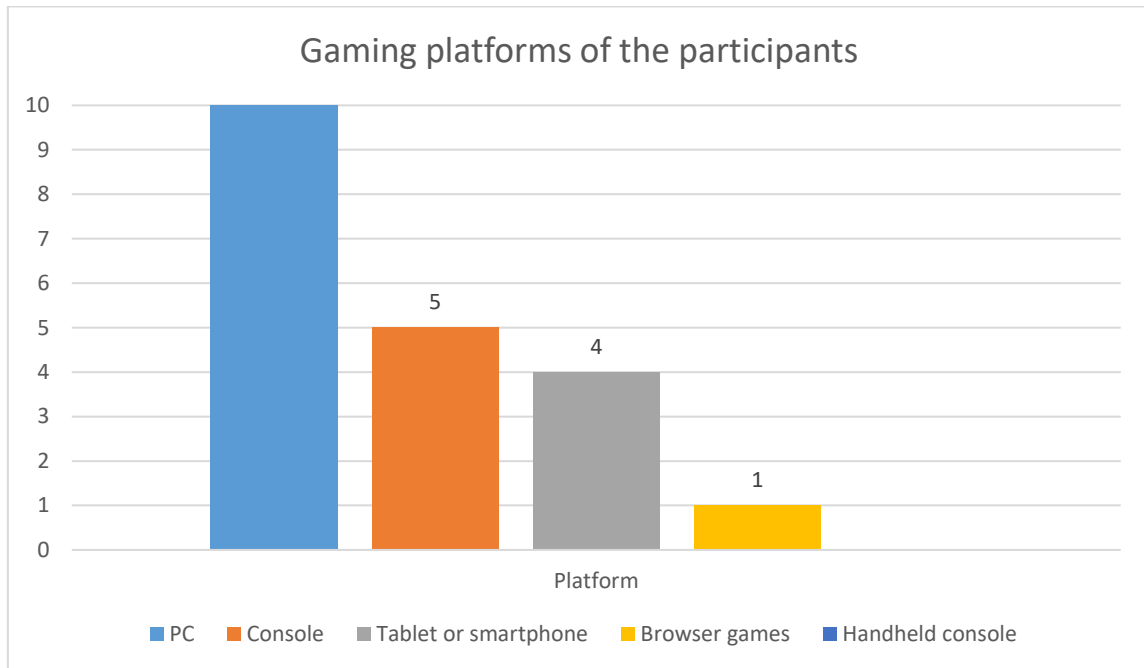
Figure 8 Gaming platforms of the study participants, some participants play on several platforms.

Some of the participants who were experienced in CS:GO were nonetheless able to determine the nature of the study when the refresh rate was changed. Two of the participants had prepared by taking their own mouse with them. They were allowed using them, as it provided them with a more familiar feel of the game than using the provided mouse. Some participants indeed found the provided mouse and keyboard uncomfortable or unresponsive, but this didn't have much impact on their ability to notice differences in refresh rate.

The most common display device for gaming among the participants was a standard refresh rate 60hz computer monitor (Figure 9). Four of them use a television for playing

game. Two participants use both a monitor and a television. Only two participants owned high refresh rate monitors themselves.
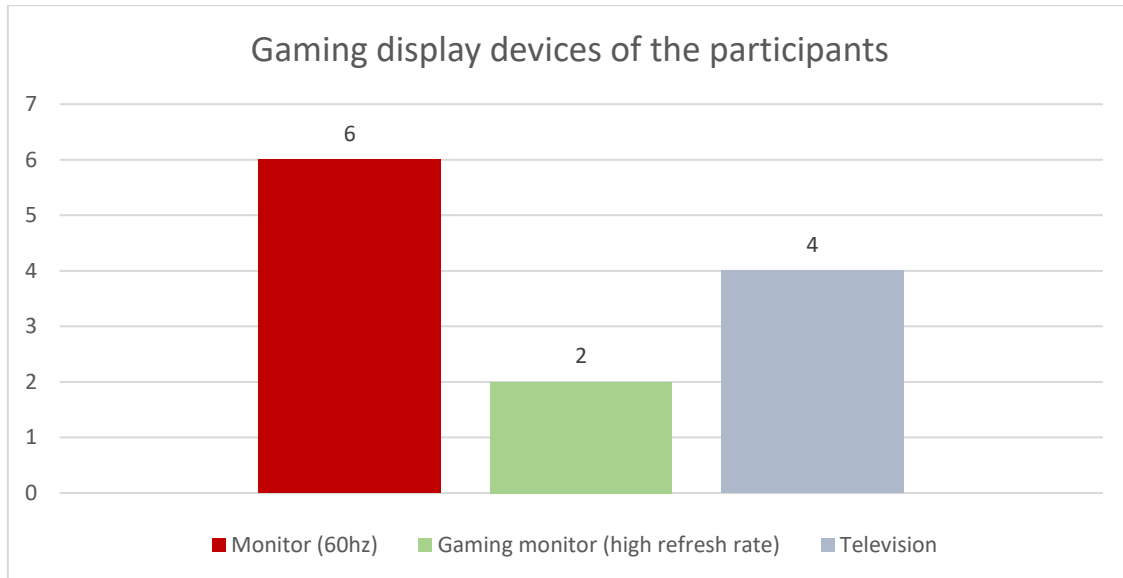
Figure 9 Gaming display devices of the study participants.

Six of the participants considered frame rate as very important and two somewhat important (Figure 10). The exact required frame rate for them varied. Some participants wanted at least 60fps in games, while others were contempt with rate above 30fps while playing. Two participants considered frame rate unimportant in general while gaming.
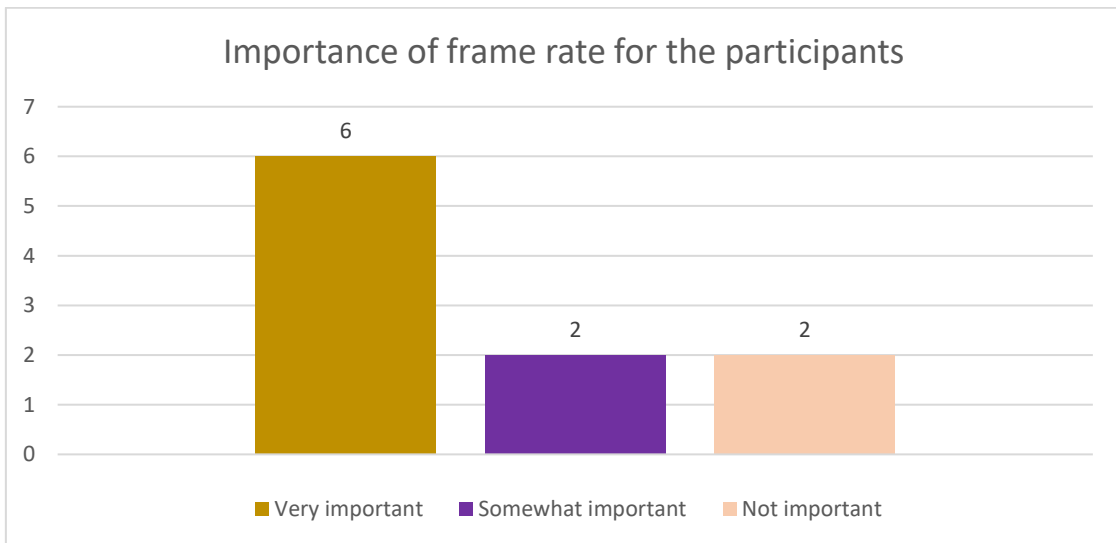
Figure 10 Importance of frame rate for the participants.

5.2   Reactions of the participants to higher refresh rate

The results of the test can be divided into three main categories: participants who didn't notice any difference between the refresh rate settings, those who noticed a minor difference and those who noticed a major difference. Their interview answers reflected their reactions for the most part. Participants who had minor or no reaction saw it as less important at least for their personal use. Those who had a significant reaction saw refresh rate as more important or even vital for a good game experience.

Four of the participants reported a major difference between the gaming sessions where they first played with 60hz and then 144hz refresh rate. Three of them described some form of minor difference and three others noticed no difference at all (Table 2).

No difference detected	Minor or uncertain of difference	Major difference detected
3/10	3/10	4/10

Table 2 Reaction of the study participants to change in refresh rate from 60hz to 144hz.

All of those that noticed some level of difference between the settings said that game felt better in some way on 144hz than 60hz, but its overall effect on their game experience varied. None of the participants felt that 144hz made their experience worse, though some were completely unaffected by it.

1. Participants who noticed no difference

Three of the participants said they did not notice any difference in the feel of the game between play sessions. Two of them game mostly on PlayStation 4, while having also some PC-gaming experience and the remaining one mostly with PC. This PC-focused player had also spent a bit of time in CS:GO and was familiar with most of its basic controls and gameplay features. The two PlayStation 4 gamers knew the gameplay goals of CS:GO, but did not know all of the controls. These three participants focused on trying out different weapons and ways of moving in the game, instead of observing its visual aspects in detail. They are active gamers but aren't particularly focused in shooter games. Their preferred genres included role-playing, strategy and adventure games. They play games actively: two almost daily and one every week.

> Participant who mostly plays with a PlayStation 4: *"No, I didn't really notice any difference."*

> PC-gamer: *"No, I didn't really notice any difference… No, it [refresh rate] doesn't affect [my immersion]. I play mostly RPG's, so graphics and colour reproduction are more important for me."*

These three participants had no previous experience with high refresh rate monitors, though they were aware of their existence to some extent. All three had good general understanding of computer technology. They were generally more interested in better resolution and image quality in monitors or televisions used for gaming over higher refresh rate. Consequently, they had no interest in acquiring high refresh rate monitors. Some other aspects of gaming monitors may still interest them such as higher resolution or a curved panel. They currently use 60hz televisions or monitors for gaming and were contempt with them.

Frame rate in games was a familiar concept to these three participants, but they stated they do not require high rates to have a good experience. Two of them stated they prefer 60fps over lower frame rates such 30fps. One console-oriented participant said they don't often notice a difference between 30fps and 60fps that much. If given the chance to choose between better graphical details or high frame/refresh rate, they would choose graphical detail. The PC-gamer summarized his requirement for frame rate:

> *"As long as it's at least 60fps, that it [the game] runs smoothly. I don't need something like 300fps like CS:GO pros… Yeah, it [30fps] is pretty clunky."*

The games that they play can be competitive, but tend to be less movement and reflex based than the likes of CS:GO. In these games a high refresh rate monitor won't provide them with much of an advantage even if they could notice it. The console gamers won't have to worry about lacking any competitive edge in the first place, as current consoles tend to be capped at 60fps. Even though high refresh rate monitors did not appeal to these participants, they want to keep their gaming setup reasonably up to date. They want to play new titles with somewhat high level of graphical detail. They might not be competitive oriented gamers but at the same time they are not occasional gamers either. Two of them play games daily and one every week, making them very active gamers, who are nonetheless unaffected by high refresh rate.

2. Participants who noticed a minor difference

Three participants stated they felt like there was a small difference between the sessions, where 144hz refresh rate might have been a bit better or smoother. However, it made little practical difference for their game experience. One participant, who mostly plays with a desktop PC, did mention smoother mouse movement but remained uncertain of its effect:

PC-gamer: *"Yeah, the second match was better."*
Interviewer: *"Can you describe how?"*
PC-gamer: *"Not really, the mouse felt like it was moving more smoothly."*

Their current gaming activity varied: one plays almost every day, one every week and the last more seldomly. Competitive gaming was not their main interest in general, so high refresh rate is less important for them than graphical detail or story in games. They were not interested in investing a lot of money in their gaming setup, so long as it could run their preferred games on acceptable settings. Even though these participants could tell there was some difference, it wasn't enough to make them interested in acquiring high refresh monitors. One of them uses a laptop for occasional PC-gaming and is not interested in acquiring a separate monitor. A desktop PC-gamer, who uses a 60hz monitor, did not consider refresh rate as an important factor for their own use:

> *"For me the important criteria would be price, [panel] size and then the other things…bigger resolution would go before 144hz."*

Those who did have a desktop computer were not interested in refresh rates, as they would rarely benefit from it in the games that they play. They are mostly contempt with a general-purpose 60hz monitor, if it provides acceptable image quality. High refresh rate is a nice-to-have feature for them at best, but it's unlikely they end up using it any time soon.

The data gathered from these participants who noticed some difference in refresh rates was not as concise, since they weren't so certain of what the difference was, or how to describe it. Factors such as the participants becoming more accustomed to the game in the second session likely had an effect, as one participant commented:

> Interviewer: *"So you noticed some small difference in the game?"*
> Participant: *"Yeah, but it might have been more to do with that the first match was kind of like warmup."*

3. Participants who noticed a major difference

The four participants who reported a major difference between the settings were experienced PC-gamers, all of whom also have experience in CS:GO. They play fast paced shooter games like CS:GO at least every week if not almost daily, though two of

them were on a break from the game. They noticed the difference in refresh rate right away as the session changed and considered the 144hz setting much smoother and enjoyable. The movement and reaction speed of these four participants in the game was very quick, which pronounced the effect of frame and refresh rate for them. Two of them already own FRR monitors and were clearly uncomfortable with the slower than what they are used to 60hz setting. They felt it was distracting and hindering their performance in the game. For the two other experienced gamers the higher refresh rate also greatly affected their game experience and they too said it was much smoother even though they don't own such a monitor themselves. In the opinion of these four, smooth movement in games such as CS:GO is much more important in general than high graphical detail. The word ´smooth´ was specifically mentioned by all of them when describing 144hz refresh rate.

> Experienced CS:GO player on the difference between refresh rates: *"Quite a big difference…When you move the mouse it's [movement in game] much smoother. The first match made me want to puke."*

> Another experienced CS:GO player had a similar opinion: *"It's so much smoother… I could tell the difference in hertz right away."*

These participants were well informed of high refresh rate monitors and their effects. Some of them already own a high refresh rate monitor, but the ones who didn't also had similar reactions and answers. Those who did not own one had tried out high refresh rate before and were interested in acquiring such a monitor in the future when they would be updating their setup. The four participants also felt that a good mouse and to a lesser extent keyboard were also needed for a smooth gaming experience. Playing a familiar game such as CS:GO with a different computer setup was somewhat uncomfortable for them. In order to make the game feel more familiar, the experienced players adjusted some of the game settings like the crosshair and key bindings to what they were used to.

One participant, who has experience in CS:GO and has had a chance to try out high refresh rate before, but doesn't own such a monitor, commented right after changing to the second session:

> *"Ok, I think this [the study] is about me noticing graphics settings or 144hz."*

> After moving around in the game for a few seconds: *"Yeah it's 144hz, could tell the difference right away."*

For two of these participants who are experienced in fast paced competitive games, high refresh rate was an important if not decisive factor when choosing a monitor. They believed that those who already have such a monitor cannot think of switching back to lower refresh rate as it has major negative effect on their gaming experience. They said that they have become more sensitive in noticing frame and refresh rate changes and drop in these can affect their performance in competitive games that require fast reaction times. The two of them were willing to sacrifice graphical detail in games to at least some extent in order to ensure smooth frame rates. Fast pixel response time and low input lag are also important for them in a monitor. Other features such as image quality, aren't as important for of them at least when they are mostly playing CS:GO. These two participants didn't have very powerful PC hardware, but they can still run games such CS:GO on high enough frame rates for their monitors. They prefer to also play CS:GO on lower resolutions, which aids with the frame rate.

Two other participants, who noticed a large difference between the refresh rates, were looking for a new gaming monitor at the time. Both of them had experience in fast shooter games such CS:GO. They had tried out high refresh rate before, but do not own such a monitor yet, despite being PC-building enthusiasts to some extent. One commented enthusiastically on 144hz refresh rate after the game sessions:

> *"The whole game [2nd] I was thinking: I have to go buy one [144hz monitor], why am I still using 60hz."*

In addition to high refresh rate, these PC enthusiast participants also want their monitor to have good image quality and higher than Full HD resolution. Visual detail in games like CS:GO was not important for them, but they play also games where graphics are in bigger role. They were willing to invest more in a new monitor than other participants.

5.3   Overview of the results

All four participants, who noticed a large difference between the refresh rates, stated that higher refresh rate made them more immersed in the game especially by providing smoother movement (Figure 11). Two of them, who already own a FRR monitor, were clearly distracted from the game when playing at 60hz. Two of those who observed a more minor difference said that refresh rate had some effect on how immersed they were. Four participants said refresh rate had no real effect on their immersion, only one of them noticed a minor difference between the settings.
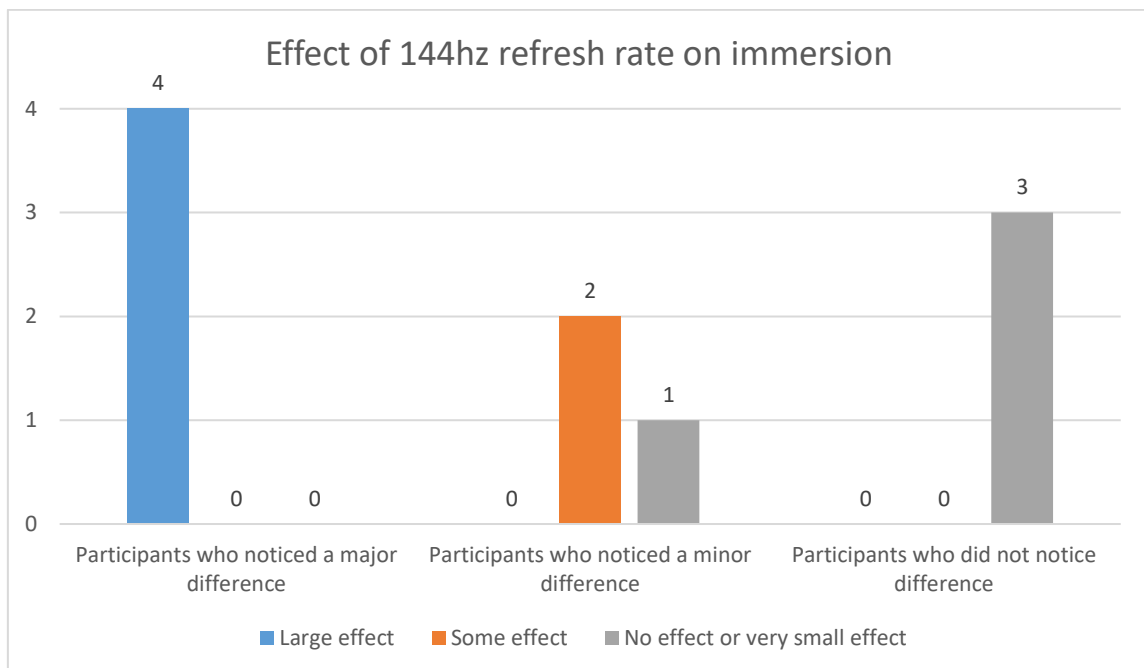
Figure 11 Effect of 144hz refresh rate on the participants immersion in the game.

Three of the participants, who could tell a large difference between the refresh rate settings, also ranked high refresh rate as the most important feature for their preferred gaming display device (Figure 12). One who noticed a large difference and one who noticed a more minor one thought it was an important feature, but they also greatly valued some other features in a monitor such as resolution or image quality.
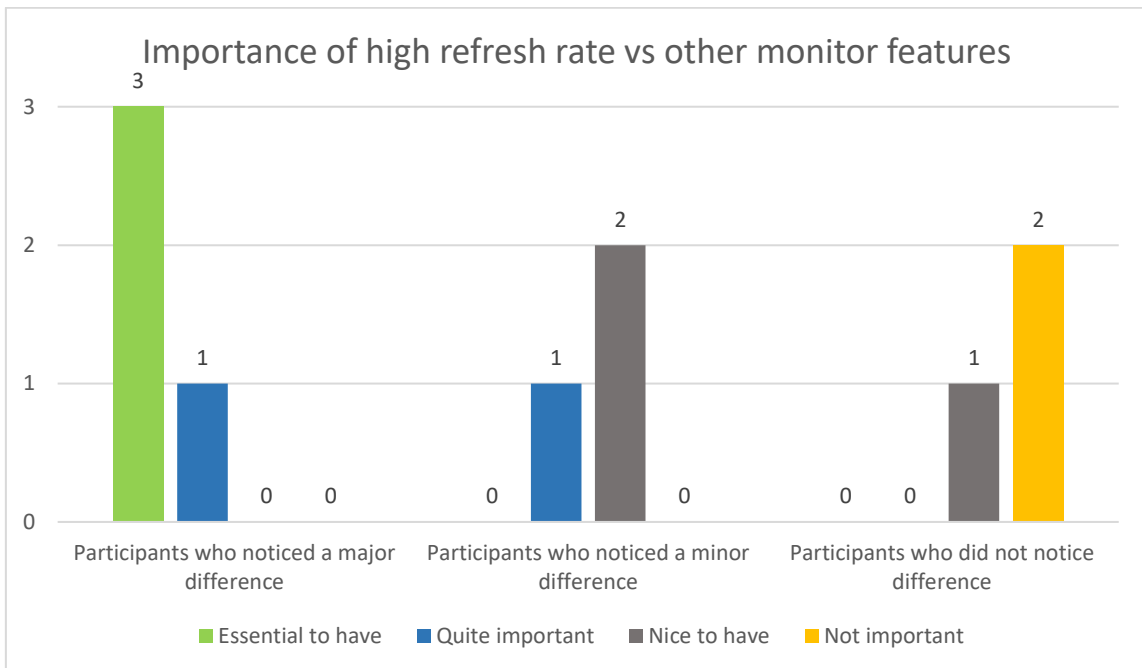
Figure 12 Importance of high refresh rate for the participants versus other monitor features.

Two participants who noticed a minor difference and one who didn't notice any thought that high refresh rate is a feature that could be nice to have in a display device that they use, but they wouldn't invest in it particularly. Two participants who didn't notice any refresh rate difference saw higher refresh as unimportant when compared to other monitor features such as resolution or image quality.

For nine of the participants a reasonable price of a monitor model would be the most important factor when choosing one for their use case. Only one was willing to pay more premium for an extended set of features including high refresh rate, high resolution, large panel and G-sync compatibility. Of the eight participants who did not already own a HRR monitor, two were planning to buy one in the future.

6   THEMATIC ANALYSIS OF THE DATA

The analysis started by transcribing the conversations recordings of each study participant and the relevant notes to form a proper dataset. Codes were formed from the dataset as they were identified and later expanded if other data excerpts presented new details relating to them. The codes group into a few general topics. These codes were used to form themes as described by Braun & Clarke (2006: 10). The prevalence of codes was not the only factor in forming themes, more emphasis was given to its importance concerning the research topic.

6.1   Codes

In thematic analysis, codes are used to give a label for excerpts of collected data that are related to the research question (Braun & Clarke 2012: 61), as discussed earlier in section 4.4.1. The codes that were developed from the data in this study were divided into four different categories based on their topic.

6.1.1   Gaming habits

This group of codes describes the individual gaming habits of the participants. Each participant described their habits a bit differently, but some general similarities could be recognized in some of their answers. These included general experience in gaming, gaming platform (PC or console) and what types of games they prefer.

Code: **Experience in gaming**

This code reflects the amount of gaming experience that the participants have accumulated throughout their lives. Though the participants reported to have some level of experience in playing digital games, the amount of experience varied greatly. Those who noticed a major difference (participants 4, 5, 9 and 10) between the refresh rates were all very active gamers. Participant 5 answered regarding how much he plays games: "Too

much, almost every day.". However, the three participants (1, 2 and 3) who didn't notice any difference were all active gamers too, while one participant (8) who doesn't currently play much games was able to tell some difference between the refresh rates. Gaming experience then by itself doesn't ensure that refresh rate would be important for the player, but it would seem to aid in noticing it.

Code: **Gaming Platform**

This code was based on the platform that the participants use for gaming. The distinction between the participants was whether they play on consoles or the PC. Current gaming consoles are limited to 60fps so their users are unable to use high refresh rate monitors. Overall the participants seemed to quite set on one platform and were unlikely to change in the future.

Five of the participants were used to playing on consoles, though they also have at least some PC gaming experience. Participant 1 stated: "I'm used to playing on consoles." Participant 2 was also PlayStation focused: "Really mostly just PlayStation, a bit with PC." Participants 3, 7 and 8 also have also played quite a bit on a console, though 3 and 7 now mostly play with a PC. Participants 1, 2 and 8 were more used to playing games using a controller instead of the PC mouse and keyboard combination.

The five other participants play games almost solely on PC. Participant 4: "Only PC." Participant 10: "PC master race only." Participants 5, 6 and 9 also play mostly with a PC. They are used to playing games with a mouse and a keyboard.

Code: **Gameplay element preference**

A major distinction between the gaming habits of the participants was what types of games they prefer to play. Many participants had several favorite types of games. The participants' preferred game types also reflected on their reaction to refresh rate and how they value it. Those who appreciated high refresh rate the most were also competitive type of gamers, though some other competitive gamers didn't see it as important.

Participants 1, 3, 5, 6, 7 and 9 mentioned that they play strategy games. Individual games mentioned included Total War and Starcraft 2. Strategy games are less likely to benefit from higher refresh rate monitors, though games like Starcraft 2 do require fast reactions from the player and quick movement of the mouse. These games are based on the hard fun-element, discussed in chapter 3.1, of challenging players, but the challenge is in forming a strategy instead of reactions or input control.

Participants 1, 2, 3, 7 and 8 mentioned they like games where there is exploration, role-playing and a strong story element. These are features of easy fun games, as discussed in chapter 3.1, though some hard fun-elements can also be present. Mentioned games included titles such as The Witcher 3 by participant 3 and The Elders Scrolls 5: Skyrim by participant 7. None of these participants noticed a major difference between the refresh rate settings.

Seven of the participants (1, 2, 4, 5, 6, 9 and 10) said they play competitive games against other players at least weekly. Participants 1 and 2 did not mention what competitive games specifically, while participant 6 plays competitive strategy games. Participants 4, 5, 9 and 10 said they play or have played competitive shooter games extensively. These four participants prefer hard fun-types of games, where honing skills and succeeding in competitions provides feeling of accomplishment. Participants 4 and 10 stated they currently play a lot of CS:GO, while 5 and 9 were focusing on different types of competitive games at the moment. These four were also the participants who noticed a major difference between the refresh rate settings.

6.1.2   Cognitive capabilities of the player

This group consisted of codes that were related to cognitive aspects of gaming, which were discussed in chapter 3.3. The data excerpts that formed these codes came mostly from observing the participants for any physical or verbal reactions to the change in refresh rate while they played the game.

Code: **Perception**

The participants had clearly different reactions (or lack thereof) to perceiving the change in refresh rate.

Participants 1, 2 and 8 had little or no experience in games like CS:GO on PC and had difficulties with tasks such as recognizing which characters were allies or enemies. While 1 and 2 perceived no difference in refresh rate, 8 was able to perceive it in a similar way as more experienced players.

Participants 3, 6 and 7 had some experience in CS:GO, but were still occupied with re-memorizing controls, weapons and maps of the game. They perceived little (6 and 7) or no (3) difference between the refresh rates.

Five of the participants described verbally how they were able to perceive the difference in refresh rate and some even demonstrated it in game with rapid mouse movement. Participants 4, 5, 9 and 10, who all had a lot of experience in CS:GO, noticed the difference in refresh quickly by moving the mouse around rapidly. Through experience with the game they were able to tell apart small differences in movement smoothness. Participant 8 showed no reactions to higher refresh rate while playing the game but described it similarly as the other four in the interview afterwards.

Code: **Attention**

The participants attention while playing the game clearly varied based on their previous experience in CS:GO or similar games. Lesser experience meant that the player was occupied with figuring out controls and other basics of the game, while more experienced players were able to divide their attention on multiple aspects of the game at the same time.

Participants 4, 5, 9 and 10 had experience in CS:GO and were able focus their attention on multiple tasks at the same time. These included keeping track of how the game was

proceeding and where each game character was in addition to controlling their own movement. By knowing how a game should feel like to play, they are able to take note of a detail like the change in refresh rate.

Participants 3, 6 and 7 had some experience in CS:GO or similar shooter games, but their attention was still mostly occupied by concentration on their own movement and reminding themselves of the game mechanics.

Participants 1, 2 and 8 were new to the game and were largely occupied by learning the basics instead of paying attention to details such as refresh rate. Participant 8 was still able to notice a difference in the refresh similarly to more experienced players.

6.1.3   Settings and devices in gaming

This group focuses on how the participants viewed graphical settings, frame rate or smoothness of the game and hardware required to run games. None of the participants owned a top of the line PC gaming setup, which meant that they would have to make compromises between good graphical detail and high frame rate if they were to play games demanding a lot of computing power.

Code**: Graphical settings preference**

Nine of the participants stated that a game in general should have a certain level of graphical detail for them to enjoy it. Instead of just having a lot of graphical details, the participants often implied that a game should also "look good" in its overall visual design. Participants 8 and 10 said that good graphics played a vital part on their enjoyment of most games. Only participant 5 said that graphics don't matter to him at all. Participants 4 and 10 did also mention that graphics were much less important in certain games like CS:GO, which are focused on competition instead of creating a fantasy world or telling a story.

Code: **Preferred frame rate**

The participants' views on what frame rate they required differed based on kind of games they liked to play and how perceptive to frame rate they are.

Participants 1, 3 and 8 said that 60fps is enough for them. They stated they can tell the difference between games that run at 30 or 60fps.

Participants 2, 6 and 7 said that it didn't matter for them if the game was running at 30 or 60 fps. They have played some games at 60fps, but it didn't have effect on their gaming experience compared to lower frame rate running games.

Participants 4 and 5 preferred having more than 60fps in games, since they already own FRR monitors capable of displaying images at those rates. Higher than 60fps was also preferred by participants 9 and 10 though they currently have 60hz monitors. Overall, the competitive oriented participants 4, 5, 9 and 10 highlighted that any game they play needs to run smoothly for them to enjoy it. Frame dips below 60fps would feel very distracting for them.

Code: **Gaming setup**

The participants described having differing gaming equipment such as hardware like PC's or consoles and peripherals such monitors or controlling devices. They also had differing levels of enthusiasm and ability to invest in their gaming setup. The participants were young adults with limited possibilities to spend money, so they tend to buy new equipment only when it's necessary to keep playing the games they prefer.

Participants 1, 3, 4, 5, 6, 7, 9 and 10 stated they have some form of desktop PC for gaming setup. 4 and 5 already own FRR monitors have other peripherals such as mice and headphones specifically for gaming. Participants 3, 4, 5, 6, 7, 9 and 10 mentioned their PC was at least a few years old, with only 9 and 10 planning to update soon.

Participants 1 and 2 play mostly on the console using a television as the display device, so monitors aren't very appealing for their gaming purposes. Participant 8 uses a laptop PC for occasional gaming and has previously used a console, so a monitor isn't very necessary for her either.

6.1.4   Opinion on high refresh rate

Refresh doesn't matter

Participants 1, 2 thought that high refresh rate wouldn't matter at all overall when it comes to their own gaming experience. If the game would run at about 60fps they were contempt with a 60hz monitor or television.

Refresh rate has little effect

Participants 3,6 and 7 stated that even if they were able to tell some form of difference, it doesn't affect their gaming experience in practice. Participant 8 stated that refresh rate would be important in games like CS:GO, but the games she currently plays wouldn't really benefit from it.

Refresh rate is very important

Participants 4, 5, 9 and 10 viewed refresh rate as an important feature that significantly affects their gaming experience. While playing at 144hz, 4 and 5 commented how it felt the same as playing on their own computer setup with a similar monitor. They would recommend the feature to other gamers and said they could notice the smoothness it provides even in desktop use. Participants 9 and 10 said they were interested in acquiring FRR monitors after trying out the different settings in the study.

6.2   Initial themes

Four themes were initially formed from a mix of codes of different code groups. The focus was on the third (searching for themes) and fourth (reviewing themes) phases of thematic analysis as described by Braun & Clarke (2006: 35).

6.2.1   Sensitivity to frame rate and refresh rate changes

High frame and refresh rates aren't useful as features to a player who is unable to consistently detect them while playing a game. Some individuals can detect the difference without having experience in a game.

In this study three active gamers were unable to notice any difference between 60 and 144hz. Three participants, who are also active gamers, stated they have trouble noticing or that they don't care about the difference between 30 and 60fps. On the other hand, those who were able to tell the difference between 60 and 144hz did so almost immediately after starting to play. It seems that a gamer needs to "train" their eyes to notice changes in refresh rate at higher levels, but those who have done so are able to tell the difference very quickly. One way to do this training is play fast paced games with a lot of mouse movement, which is what these participants had done.

Codes for this theme: Experience in gaming, Perception, Frame rate preference

6.2.2   Competitiveness

E-sports titles such CS:GO is a good example of a game where every competitive advantage such as smooth character movement matters and elements such the game world and story building through visual appearance play minor roles. High refresh is not just a visually pleasing detail for the most competitive and experienced players, but also a tool they require for maximum performance. Just like enthusiasts and professionals in any other sport, these players are more willing to invest money in this tool than the average gamer.

Players of non-competitive games on the other hand can benefit from high refresh rate mainly as a visually appealing feature, if they are able to notice it. Story based single-player games can have moments which require precise and fast reactions from the player while allowing players to attempt them again with little consequence from failure.

Codes for this theme: Preferred gameplay element, Gaming setup, Refresh rate is very important

6.2.3 Refresh rate vs graphical detail

High refresh rate requires a fast frame rate, which can only be reached by lowering the graphical details of games in the case of most PC-gamers. A choice needs be made between frame rate and graphical detail, as they both require computing power. If the player doesn't notice much difference in the game from 60hz/fps onwards, they have no reason to lower the settings. On the flip side, if the player values smooth movement and cares less for graphical detail, high refresh rate becomes the prevalent feature. Two participants in this study, the ones who own HRR monitors, did consider smoothness as more important than graphics in all circumstances while gaming.

Codes for this theme: Graphical settings preference, Gaming setup, Refresh rate doesn't matter, Refresh rate has little effect, Refresh rate is very important

6.2.4 Willingness to spend on gaming

Young adults, who formed the demographic of this study, tend to be in a tight economic situation. Any purchase worth hundreds of euros would have to be considered carefully by them. Investing in high refresh rate doesn't only include buying a monitor but also requires powerful PC hardware unless one only plays less-demanding games at low graphical settings. Currently the only gaming platform to take advantage of high refresh rate is PC, which has a higher entry cost than consoles. The situation may change when next-generation consoles enter the market in 2020. These new platforms will likely support higher than 60fps frame rates, as this has been a growing trend in gaming. New

smartphone models such Google's Pixel 4 have been equipped with high refresh rate screens, which have been appreciated by tech aficionados (Ismail 2019). These new devices might be an easier way to access high refresh rate for those who play less on the PC.

Codes for this theme: Competitiveness, Gaming setup,

6.3   Final developed themes as answers to the research question

After further analysis, the contents of the four initial themes were condensed into three final themes (Figure 13). These three themes form the two different ways that high refresh rate can affect gaming experience, which was the research question. This was the fifth phase of thematic analysis, defining and naming of themes, as described by Braun & Clarke (2006: 35).
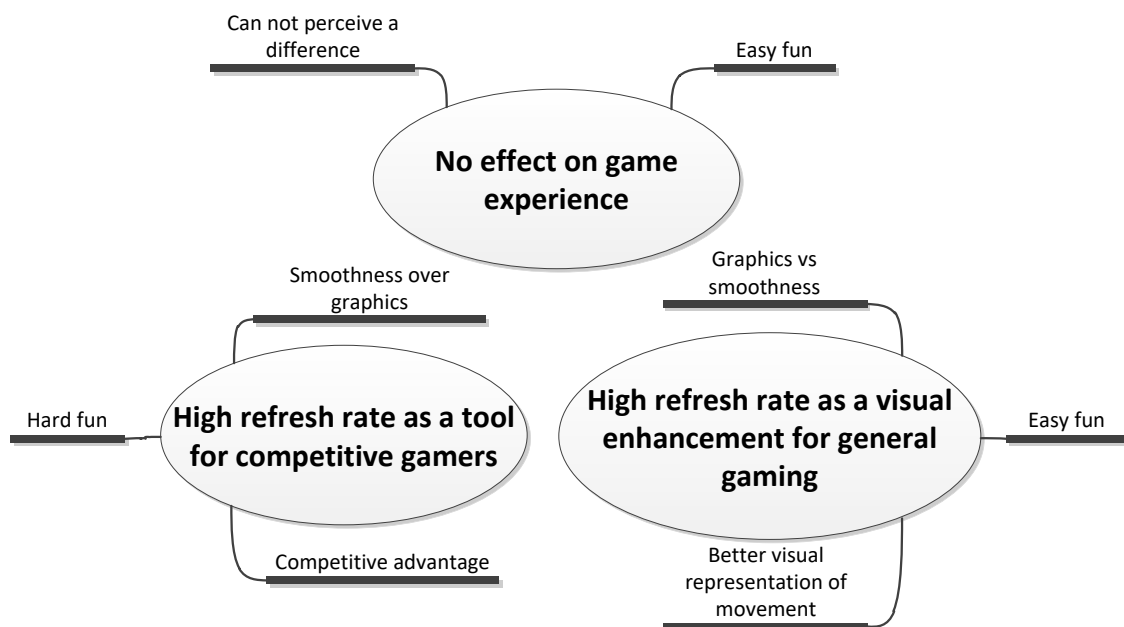
Figure 13 Importance of high refresh rate for the participants versus other monitor features.

6.3.1   No effect on gaming experience

The first developed theme includes gamers, whose game experience was not affected at all by high refresh rate. Gamers who mostly play non-hard-fun centered games, which have less reaction time requirements or competition, can be unable to perceive any difference between refresh above 60hz. Given enough time they could probably train their eyes to spot the visual difference, but high refresh rate would still have little effect on their experience.

Three participants in this study were unable to notice any difference between 60hz and 144hz despite being very active gamers. They were interested in games with impressive visuals, good stories and diverse gameplay mechanics instead of extreme responsiveness or smoothness. According to these participants, a monitor can have still a positive effect on their game experience by having a higher resolution, better colour reproduction or a larger panel.

6.3.2   High refresh rate as a visual enhancement for general gaming

For more varied types of gamers, who aren't solely focused on competition, high refresh rate has different effects on game experience. Some gamers can notice a difference in smoothness when moving in a game with a monitor refresh rate greater than 60hz. Anything past around 100hz is unnecessary for the game experience of most gamers, as by this point the visual difference is hard to discern and many games won't run at fast enough frame rate in the first place on average PC hardware. In order to reach the high frame rates, the game would have to be run on lower graphical settings. This has a bigger effect on the game experience of gamers who prefer the easy fun elements such as exploration in games instead of hard fun which focuses on competition and challenge.

Unlike gaming console, PC's aren't designed with gaming as the sole main function. PC's are used for other purposes as well such as multimedia and office work. High refresh rate is not useful in these tasks while features such as color reproduction, good viewing angles and higher resolution can be vital. These features, including high refresh rate, can be found in a single monitor but such models are quite expensive. If the user can perceive

some difference between refresh rates, high refresh rate still might not be among the most important monitor features for them.

6.3.3 High refresh rate as a tool for competitive gamers

High refresh rate has the most impact on the game experience of hard fun seeking gamers, who play competitive fast paced games. The four participants in this study, who were most affected by high refresh rate, were focused on hard fun games that are challenging and competitive. Competitive oriented gamers can or will learn to notice the smoothness while playing using high refresh rate. For the most competitive gamers high refresh rate can be considered a necessity as it provides an advantage when certain skill level is reached. Necessity means that the price of a gaming monitor and hardware can be justified by these gamers. Additionally, the prices of HRRM's have been decreasing, so buying a monitor only for gaming and another monitor for work is a possibility.

To take competitive advantage of high refresh rate, the player needs to possess certain level of experience in the game and they need to train their reflexes. If the player can't react quickly to events in the game the refresh rate won't aid them. Even a competitive gamer may need some time to train their eyes in order to take note of higher refresh rate. Once they are accustomed to it, when going back to a slower refresh rate they can discern the difference more easily. As previous research by Claypool & Claypool pointed out, player performance in games will not increase much after higher 30fps. Only the most competitive gamers truly need high refresh rate, while for others it's a visual feature with its own set of requirements needed to display it. The player needs to have powerful enough computer hardware to run the game at the necessary high frame rates. This often means turning down the graphical settings, which competitive gamers don't mind as much since e-sports games do not focus on graphics in any case.

E-sports games tend run at high frame rates even on average PC hardware, so they can benefit from the highest refresh rate monitors such those capable of 165hz or 240hz. E-sports players also look for other peripherals to their specific needs such as gaming mice and headphones, so a high refresh rate monitor will appeal to them too. While 240hz

monitors are still somewhat expensive, lower refresh rate monitors like 144hz are becoming quite affordable. Extreme refresh rate monitors such as 240hz models are limited to only gaming in their use case, as TN-panels make them unsuitable for visual work.

7 DISCUSSION AND CONCLUSIONS

This chapter will include reflections on its results and comparisons to previous research, how the study proceeded, recommendations for groups interested in this study and how future research could be conducted on this topic.

Even if some of the less competitive gamers can notice a small difference, many of them are more immersed in the game through graphical detail, gameplay elements or story telling than high movement responsiveness. High refresh rate is something they don't mind having, but other monitor features and especially price play a much bigger role when they choose their monitor. That is if they even need one, since they might be fine with using a laptop screen or television for gaming.

The study came together well in the end from my perspective. The biggest fear of failure was that the lab environment would create completely inconclusive results or that participants wouldn't really react in any way to the change in refresh rate. This was not the case, as with only ten participants very different reactions were observed. Some immediately reacting to the change in refresh rate and were excited about, while others had a more limited or no reaction. Interviews with participants indicated that refresh rate is valued differently by gamers of various types.

In the end, the study was successful in providing at least a partial answer to its research question: *"How does high refresh affect gaming experience?"*. It can affect the visual experience of the game and the competitive aspect of the game or it might not affect the experience at all, depending on the individual gamer.

Refresh rate can affect the game experience of those who play fast paced shooter games in two ways, or it might have no effect at all. If the player is experienced in the game and has fast reflexes, they might see an improvement in their performance. The second effect is more indirect in nature. If the player feels that the game is smoother while being displayed on higher refresh rate, it can improve their visual experience of the game.

7.1 Implications to consumers and monitor manufacturers

For consumers interested in improving their competitive gaming experience, high refresh can provide a noticeably smoother experience in games that include fast movement and even provide an opportunity for improving their individual performance. For gamers who are not interested in competing and do not perceive much difference between 30 and 60fps, high refresh monitors of 144hz or higher will provide little to no enhancement in gaming experience. Many new big budget games, such as Shadow of the Tomb Raider, will not run at high frame rates on average PC gaming hardware (Purslow 2018), making high refresh rate a moot feature. Instead, they may wish to invest in monitor features that provide improvements that are easier to detect. These include higher resolution or simply a bigger screen size. As with most other purchase decision, it is best to try out different monitors before settling on one that provides the features one has deemed useful.

For monitor manufacturers, this study would point out that gamers demand different types of monitors based on their personal preferences. The market for high refresh rate monitors of 144hz or higher targeted for competitive shooter games has been filled with different models. There are also monitor models that provide a mix of features such as good colour reproduction with IPS panel, higher resolution such as 2560x1440 pixels and more modest increase in refresh rate to 75hz. Few of these are marketed as gaming monitors, even though they would seem to have the features desired by many less competitive oriented gamers. Other peripherals, such as mice, have been even expanded for different kinds of gaming such as strategy, multiplayer online battle arena (MOBA) and shooter games. It could be beneficial to target not the hard-fun types of gamers with models, but easy-, serious- and people-fun seekers as well.

7.2 Limitations

Looking back at the data collection process, some aspects of it could have certainly been conducted more thoroughly. The sample size of ten participants was just on the verge of being enough, around twenty participants would have been preferable as processing the

data turned out not the be as time consuming with a semi-structured interview. On the interview questions more emphasis could have been put on how the participants are able to tell visual details in the game. The possibility that the participants had trained their eyes for fast paced gaming was not explored, nor was the condition of their eyesight.

While analysing the data, it was clear that some codes were weaker than others as they were based on only one or two data excerpts. This was due to having only ten participants in the study. With a larger group it may have been possible to make these codes more certain or they could have been dropped if they still only appeared infrequently. The data on those who noticed a large difference in the refresh rate and those who saw none was more conclusive in nature. The responses of those who reported a minor difference could have been affected by several factors such as being more comfortable with the game in the second session or just presuming that the second setting must have been better somehow. This portion of the dataset was not so solid as a result.

7.3   Further research possibilities

This was a qualitative study, in which ten participants were interviewed about how they personally experienced and thought about high refresh rate. In order to have more data on the subject, a quantitative study could be conducted with more resources. Such research could be used to test the hypothesis that high refresh rate has an impact on the performance of gamers and not just how they perceive it themselves.

This test centred on two refresh rates only: 60hz and 144hz. These are two popular refresh rates, but there are many others available as well. It would be interesting to see whether gamers are affected by even higher refresh rates such 165hz or 240hz.

High refresh rate is rapidly gaining popularity in different gaming fields. A future focus for a study could be on the effects of high refresh rate on console or mobile devices as it becomes more prevalent there. There already several smartphone models that support higher than 60hz refresh rate and it is likely that next generation gaming consoles do so

as well. Refresh rate plays an important part in creating a comfortable experience while using a VR headset. This could be another topic of refresh rate research.

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APPENDICES

APPENDIX 1. Survey questions before the gaming sessions.

Age

- 18-21
- 22-25
- 26-29
- 30-33
- 34-37
- 38-41
- 42-45
- 46-49
- 50-53
- 54 or older

How often have you played digital games during the past year?

- Almost every day
- Weekly
- A few times in a month
- Only seldomly
- Not at all

On what platforms do you play games on?

- PC (e.g. Windows, Linux) / Mac
- Home consoles (e.g. PlayStation, Xbox, Wii)
- Handheld gaming devices (e.g. Nintendo 3ds, PlayStation Vita)
- Mobile devices (e.g. Smartphones, tablets)
- Browser games (e.g. Facebook games)

How often have you played competitive multiplayer games during the past year?

- Almost every day

- Weekly
- A few times in a month
- Only seldomly
- Not at all

How often have you played first or third person shooter games during the past year?

- Almost every day
- Weekly
- A few times in a month
- Only seldomly
- Not at all

APPENDIX 2. Interview questions after gaming sessions.

1. If you are PC, Mac or home console gamer, what display device do you use for gaming?

   - General purpose computer monitor(s)
   - Gaming monitor(s)
   - Television

2. How important is the visual appeal and graphics of a computer game to you?

   - Not important at all
   - Not that important
   - Somewhat important
   - Very important

4. Do you like to adjust the graphical settings to your liking in games?

   - Yes, in most games
   - Yes, in some games
   - No, I know how but don't really care about them
   - No, I don't really know how

5. Do you know what frame rate is in games? If so, how important is it to you?

   - I don't know what it is
   - I know what it is, but it's not important to me
   - I know what it is and it's somewhat important to me
   - I know what it is and it's very important to me

6. How interested are you in keeping your gaming devices and hardware up to date?

   - I like to update them frequently
   - I have reasonably up-to-date hardware and devices
   - I upgrade only when it is necessary in order to keep playing at all
   - I'm not interested in new devices or hardware

8. Did you notice any change in the feel of the game between the sessions

- Yes, a lot.
- Somewhat
- Not that much.
- Not at all.

9. Did the refresh rate of the monitor have an effect on how immersed you were in the game?

- Yes, a lot.
- Somewhat
- Not that much.
- Not at all.

10. How important is refresh rate compared to other monitor features when you are looking for a monitor?

- Essential
- Quite important
- Somewhat important
- It is a "nice to have" -feature
- Doesn't matter at all

APPENDIX 3. Interview of SEUL ry representative.

1. **In your experience, how common are fast refresh rate monitors (120hz or faster) in esports tournaments?**

Over 120hz or faster monitors are a mandatory and required in every esports tournament. Nobody wants to play with a refresh rate of 60hz in esports events. The same applies to commercial gaming cafes and lounges.

2. **Does fast refresh rate provide an advantage for its user?**

Yes it does, for example when turning a character in first person shooter games the refresh rate gives a player an advantage when the monitor displays the changing picture more often.

3. **Is fast refresh more or less important than other features in a monitor, such as resolution or panel size?**

It seems to be the most important thing when buying a gaming monitor. Panel size and resolution are less important.

4. **Would you recommend fast refresh rate monitors for gamers in esports?**

Absolutely. I would also recommend high quality IPS-panel with NVIDIA G-sync or similar features for players because of better details in game.

5. **Do you think that these monitors are useful for inexperienced gamers?**

Yes. Using a monitor with a high refresh rate makes the game look smooth, so there is also a visual benefit compared to a normal 60hz monitor.

6. **Are there certain types of games that you would recommend a fast refresh rate for?**

Definitely any game with three dimensional landscape and high quality graphics. In esports It's a necessity, especially in first person shooters.

APPENDIX 4. Letter for test participants.

You are taking part in the data collection phase for my master's thesis. Due to the nature of my research topic, I can't reveal you the purpose of my research just yet. Don't worry, I'll let you know everything at the end of your visit.

First, I'll ask you some simple questions about your gaming habits.

After that your task is to play the game in two sessions, feel free to chat with me or ask any questions (other than the research topic) that come to your mind! Your performance in the game is not the focus in the sessions.

Finally, I'll interview you a bit about the gaming sessions. Your personal information is not being asked.

During your visit our conversations will be recorded, but these recordings will not be made public and they will be deleted by 30th September 2019 at the latest. I might quote something that you have said in my thesis anonymously such as [Experienced PC-gamer participant: "I prefer fast-paced games".].

Thank you very much for participating!

-Juho Huhti