Comparing Aiming Methods In Virtual Reality

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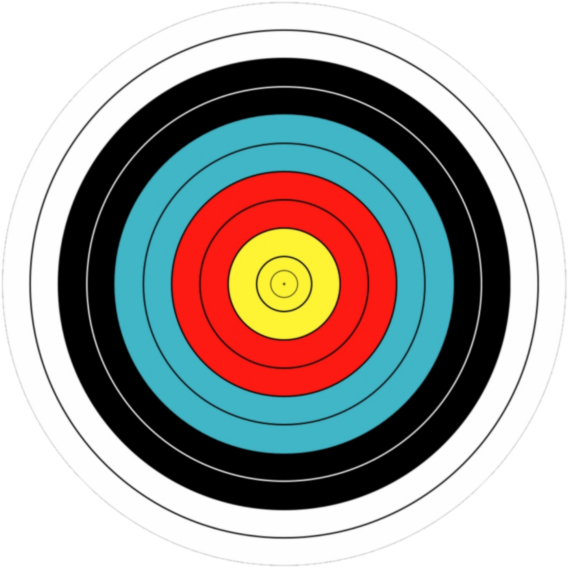


Game & Media Technology

Department of Computer Science
Utrecht University
Netherlands
February 2021

1 Introduction

Video games are an interactive medium. While the worlds portrayed in video games may be fantastical, the interactions are usually based on real-world interactions. Early video games were limited by technology, so simple interactions such as jumping and shooting were implemented. One of the earliest examples of shooting was duck hunt, released in 1984 (see image below).

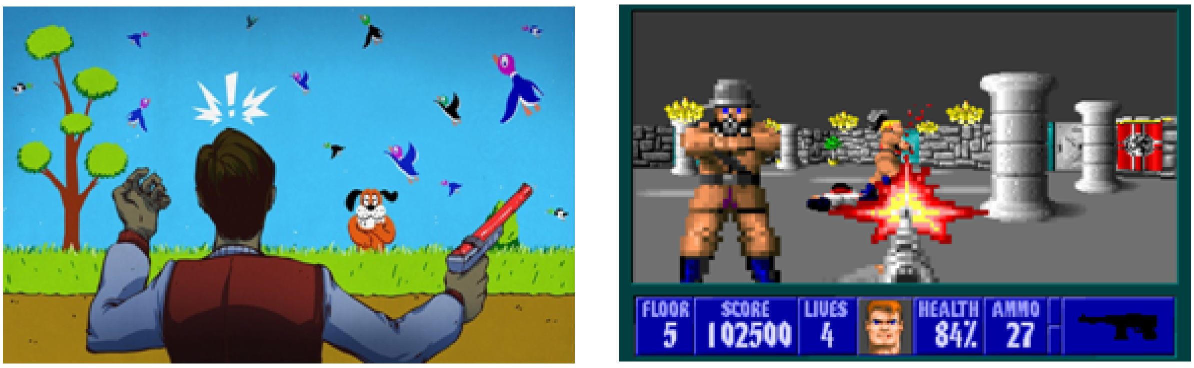


Figure 1: Duck Hunt, played with a gun peripheral. Wolfenstein 3D, played with keyboard & Mouse.

By pointing the gun peripheral at the screen, the Nintendo game was able to determine 2D-coordinates on the screen, allowing the player to aim and shoot ducks. This genre of games is known as light-gun games. Since the main way of interacting with the world is through the gun controller, movement through the world was often automatic, as if on rails. For this reason, another name for these games is rail shooters. While for home consoles, Light-gun games never reached a huge popularity, light-gun games remained a staple in arcade halls across the decades. Following the huge commercial success of the Nintendo Wii (2007), the motion controls were able to revive the Light-gun game genre for home consoles once again. Metroid Prime 3 (2007) allowed for a light-gun like controller in one hand, while navigating the environment with the other. Following the release of the HTC Vive wand controllers and the Oculus Touch controllers in 2016, even more Light-gun type shooting games were released, such as Robo Recall (2017) and Space Pirate Trainer (2017).

Figure 2: Robo Recall, played with Oculus Touch. Space Pirate Trainer, played with Oculus Touch.

Meanwhile, other games started experimenting with walking around an environment and shooting enemies using a keyboard & mouse. This genre came to be known as the first-person shooter (FPS). Two of the earliest first-person shooters were Wolfenstein 3D released in 1992 (pictured above) and Doom, which released in 1993. In these games, you took control of a character as if looking through their eyes, making your way through a pseudo-3D maze-like environment. In 1998, Valve released Half-life. This was one of the most influential games which featured a strong story and non-enemy characters. It was also one of the first games which introduced interacting with objects which followed physics (for example, stacking boxes on a seesaw to reach a high platform). In 2000, Bungie released Halo on the Xbox, which was met with huge success. Trading a keyboard & mouse control for a controller, Halo popularised playing FPS on a console by making fire fights slower, and adding aim assist. Aim assist slightly bends the bullets to hit the target, or subtly slow down a crosshair when it moves over a target. It is still considered one of the best FPS series to date. A large factor of the popularity of first-person shooters is the online multiplayer, where playing against other players makes the replay value almost infinite. Some players like to play one competitive FPS game for months on end. FPS game franchises such as Call of Duty have multiple studios pumping out a new game every year. There were other interesting ways of shooting, such as making a finger-gun with your hands, and having a depth camera track it to shoot. The Gunstringer (2011) for the Xbox 360 Kinect was such a game. Lacking a trigger button, the player fired the gun by jerking the finger-gun backwards, simulating the recoil of the gun. While this game was functional, it suffered from accuracy issues, and this way of shooting did not take off.

First-person shooters remain one of the most popular genres in video games. New technologies such as a Head-Mounted Display such as the Oculus Quest allow for new innovations within the genre. Using an HMD, a player is able to look around the virtual space using his or her own head, instead of relying on a mouse or joystick. Many FPS games have a crosshair in the middle of the screen. When the look direction is tied your aim direction, this design makes the most sense. VR shooters don't have this restriction, and perhaps a decoupled design might have some advantages, such as a greater sense of immersion, or greater situational awareness. VR shooters allow for a blending of the Light-gun shooter genre and the FPS genre. Using a head-mounted display, the player is no longer required to face a certain display, as it is mounted on their head.

For this thesis we will be using an Oculus Quest headset with an Oculus touch controller. Both the headset and controllers have sensors that measure their orientation, and using infrared cameras on the headset, as well as the infrared lights emitted from the controller, the Oculus Quest system is able to determine the position of the controller in relation to the headset. The headset also uses these external camera's and computer vision to determine the position of the headset itself. This allows for six degrees of freedom without needing external camera's. The six degrees of freedom refer to the three spatial dimensions X, Y and Z, as rotating around the X, Y and Z axis, also known as Rolling, Pitching, and Yawing. The movements are all one to one, e.g. moving your head 90° to the left will turn the virtual camera 90° as well. In each of the following three aiming methods, moving the headset will move the virtual camera. Determining the aim direction is where the three methods are different from each other.

Figure 3: Oculus Quest with Oculus Touch controllers.

There are several ways of interacting with the world in VR shooter games. When sitting behind a desk, aiming with a computer mouse can be used. The mouse is the preferred way to aim in traditional desktop shooter games. To translate this way of pointing to a situation where your head movement controls the camera movement, a hybrid approach is required. The head movement controls the camera movement, while the mouse allows for precise adjustment Gun. This aiming method will be called *Aiming with Mouse.*

Figure 4: Aiming with a mouse. Moving the mouse left will rotate the gun left.

Another way of aiming would be simply to look at your target and press the fire button. This means that the aim direction is in the middle of the screen, and as soon as the user looks at a target, he/she can press the fire button. This method has the advantage of having a very low bar to entry. While getting good at aiming with a mouse requires time and practice, looking at things is what we have been doing since we were born. This aiming method will be called *Aiming with Head*.

Figure 5: Aiming with Head. the gun and camera are controller by the head movement.

Since we are simulating a shooting gallery, actually holding something in your hands to aim could add to the sense of immersion. Since the motion controller is tracked separately from the VR headset, it can move independently from the view direction. This could have a positive effect on the speed to find a target. However, since the motion controller is tracking the hand of a human being, this will inevitably move around the controller, making it harder to hold your gun steady and hit a target consistently. This aiming method will be called *Aiming with Gun*.

Figure 6: Aiming with Gun. Moving the Oculus Touch will move and rotate the gun.

All of the three aiming methods are used in commercial VR games. This would suggest that VR developers see some merit in these methods. There are other methods very similar to the aiming with gun method, such as using two guns at the same time, or having a physical bar holding two controllers in place, simulating a rifle. Another is to use a depth camera to track a hand in a finger-gun configuration. While this method can be fun, figuring out when the gun should fire remains a problem, as well as accuracy and immersion. Compared to these alternatives, Motion controller that acts as a gun seems to be the best way to test this category of aiming, since it is the easiest to learn, and you only have a limited amount of time for each method to get familiar with.

Figure 7: Protube VR with a recoil stock. the stock has electrical motors simulating recoil.

The goal of this thesis is to find the best aiming methods for VR shooters by comparing them in terms of performance, gameplay experience, and immersion. Furthermore, it would be interesting to know if some aiming methods might excel in certain gameplay situations. Certain methods might excel in hitting faraway targets, while others might be better suited to hit a moving target consistently. While one method may lack in performance, it might be very immersive and compelling to play this way. To find out which aiming method is the best, we will use a virtual shooting gallery, testing with real people. The best aiming method for VR shooting can be defined as the one who scores the highest in all the things that we would find desirable. While testing, we can measure and record the following for each method: How fast did you find new targets? How consistent did you hit them, and how many times did you miss? Did the method feel fun to play, and were you immersed into the experience using this method? The targets will consist of both close, medium and faraway targets, as well as both stationary and moving ones. If aiming methods score similarly on performance, it would suggest they are a fair match when played in a multiplayer setting. This could be useful information for Multiplayer VR shooter developers. If a method excels at hitting faraway targets, the method could be considered for sniper games. If a method excels at hitting medium and close targets, this method would probably excel in a zombie VR shooter. Some methods might excel in feeling good to play, while not being the best at performance. A developer might decide to go with that method, and adjust the difficulty accordingly. In summation, the goal of this thesis is to find the best aiming method for VR shooters. The information gained from comparing these three aiming methods might help to design better VR shooters with the right aiming method for the right game.

2 Previous Work

Similar studies regarding performance when trying to hit a target have been done before. In as early as 1954, Paul Fitts [3] studied human aimed movement. His focus was to determine human factors when it came to precision tasks. His work helped to improve aviation safety, as well as lay the groundwork for modern mathematical models of human motion. He proposed a metric to quantify the difficulty of a target selection task. Fitts's Index of Difficulty is defined as:

$$ID = \log_2 \frac{2D}{W} \tag{1}$$

Where D is defined as the distance to the target, and W is the width defined as the width of the target along the axis of motion. Note that when the target is a circle, the width is the same regardless of the axis of motion. If the width of the target is small, the margin for error is smaller, making it a more difficult task. Distance to the target has a large influence on difficulty as well, since the precision required is higher when moving a cursor quickly over a larger distance. Taking movement time into consideration, Fitts defined an Index of Performance (IP) defined as:

$$IP = \frac{ID}{MT} \tag{2}$$

Where MT is Movement Time in seconds, and ID is Index of Difficulty in bits. IP is then measured in bits per second. The extra time factor makes it possible to distinguish between the difficulty of slow, deliberate pointing, and fast twitch skill. If someone is both accurate and fast, the index of performance will reflect that. These two equations can be combined into the following:

$$MT = a + b * ID = a + b * \log_2 \frac{2D}{W} \tag{3}$$

Where:

- MT is the average time to complete the movement.
- a and b are the constants that depend on the choice of input device.
- ID is the index of difficulty.
- D is the distance from the starting point to the centre of the target.
- W is the width of the target along the axis of motion.

Since a low movement time MT is considered good performance, the value of the b parameter can be used as a metric to compare pointing devices. To calculate this parameter a regression analysis can be applied. In other words, if under the same circumstances of distance to the target (D) and target width W, if we see a difference of movement time (MT) between aiming methods, this must mean that one aiming method is better over the other. This way of analysing data has shortcomings. For example, if a user is aggressive in his/her shooting style, the movement time may be small, but the number of misses might be very high. That is why missed targets is also a factor to consider. Similar studies [2][5][7] use both movement time and error rate to quantify the performance of their test subjects. In terms of performance, a traditional keyboard and mouse setup with a monitor scores very high [5]. However, in terms of immersion, this traditional setup scores lower [6]. The HMD covers the user's entire field of vision, helping with the illusion of being in the virtual world. There are many other differences between a monitor and an HMD, such resolution, pixel density, distance between the user's eye and the screen, all of which have a possible effect on performance. As this difference in performance between desktop shooting and VR shooting is already established, the focus of this research will be focused on different aiming methods while wearing the same HMD.

In the previous work, there seems to be no studies where the participants are tested on consistency. Spawning a new target as soon as the previous one is hit is consistent with a shooter game where the enemies are humanlike. Some shooters have enemies in them that are more bullet-spongy. These enemies are often giant monsters with specific body parts where the player deals more damage if they can hit those targets consistently. There might be some merit in comparing how consistent the different aiming methods allow the players to hit the same target. Comparing consistency between aiming methods might prove difficult. Most shooters simulate the physicality of shooting a gun by introducing recoil, or a slight jolt to the player's aim. This makes it more difficult to hit a target consistently. How much recoil should be added to the different aiming methods, if at all? Holding your mouse still, versus your neck, versus your motion controller are different challenges. Experimental tweaking of recoil is required to find a fair balance.

Using an HMD such as the Oculus Rift on participants does have a drawback, and that is cyber-sickness. Depending on the person, using a VR headset can make people feel sick or uneasy to the point where they cannot continue the experiment. Extra care needs to be taken when designing and conducting the experiment to account for this. The focus of this research is on aiming and accuracy. Vection, the perception of self-motion in the absence of any physical movement, is one of the main contributors to cyber-sickness [1]. By having the participants remain stationary, The movements they make in real life matches closely what they see in VR. This should prevent Vection, and reduce the amount of cyber-sickness the participants experience. The study done by Martell et al. [5] compared control schemes with each other. The two best scoring VR control schemes of that study are *Aiming with Head* and *Aiming with Mouse.*The other VR control scheme in that study, referred to as *Coupled*, had both the head and mouse control the look direction, with the crosshair in the centre of the screen. While this method scored lower on the aiming tasks, which this thesis will be focusing on, it did score better in the movement and jumping tasks. Players did like this method the least, which is an important factor to consider. According to a qualitative study done by Haywood and Cairns (2005) mentioned in [4], they found that immersion has the following features:

- Lack of awareness of time.
- Loss of awareness of the real world.
- Involvement and a sense of being in the task environment.

If we want to find out which aiming method is the most immersive, forming questions that ask about these traits could be a decent way of determining immersion, instead of just asking participants directly about how immersed they felt. Furthermore, in the paper by Jennett et al. [4] they describe three distinct levels of immersion.

Engagement is the lowest level, and is reached once a player has learned the controls, and knows how to play the game.

Engrossment is the second level of immersion. When the game is put together in such a way that a player's emotions were directly affected by the game, and that the controls become "invisible". The player is no longer thinking about the controls, and begins to lose track of time. The player is also less aware of their surroundings.

Total Immersion is the highest level of immersion. The player feels a sense of presence, being cut off from reality that the game is all that mattered. Total immersion required the highest level of attention, and was more rare and fleeting than engagement or engrossment, which were much more common in their experiments.

There are a number of conclusions we can draw from the previous work done in this field. Early work provides us with formulas that quantify the difficulty of the pointing tasks. This allows us to assign scores accordingly. Previous papers measure hits and misses, but do not measure consistency (hitting the same target in a row) or target acquisition (the speed at which a new target is found). Furthermore, the number of participants is quite low. Increasing the number of participants adds validity to our results, and measuring consistency and target acquisition will give us a more complete picture of the differences between aiming methods. The previous work by Jennett et al. [4] provides us with a way of measuring immersion. The challenges with cyber-sickness that the previous work describes gives us insight into what causes it, and how to design the experiment around it to avoid it as much as possible. Armed with the lessons of the previous work, we are better equipped to tackle the objectives described in the next section.

3 Objectives

The goal of this thesis is to find the best aiming method for VR shooters. So, the global research question is:

GRQ: What is the best aiming method for VR shooters?

This question can be subdivided according to what the “best” is for VR shooters. A hypothetical best method would score high in immersion, gameplay experience, and performance. This gives us:

RQ1: Which aiming method is the most immersive?
RQ2: Which aiming method has the best gameplay experience?
RQ3: Which aiming method performs the best?

Performance can be measured by the movement time between targets, the consistency of hitting a target, the number of misses, and the distance between the target and the shot. This last metric can be used to distinguish between bulls-eye hits, hits on the edge of the target, near-misses, and total misses. Another factor to consider is the distance between the player and the target, as well as moving targets versus stationary targets. Taking these factors into consideration, we can further subdivide RQ3 into:

RQ3.1: Which aiming method has the shortest movement time between targets?
RQ3.2 Which aiming method has the most consistent number of consecutive hits?
RQ3.3 Which aiming method has the lowest number of misses?

These three questions can be asked while taking into consideration:

- Only close moving targets
- Only close stationary targets
- Only medium moving targets
- Only medium stationary targets
- Only far moving targets
- Only far stationary targets

From these 6 different categories of targets, certain subsets will be interesting to look at:

- All targets
- Only stationary targets
- Only moving targets
- Only close targets
- Only medium targets
- Only far targets

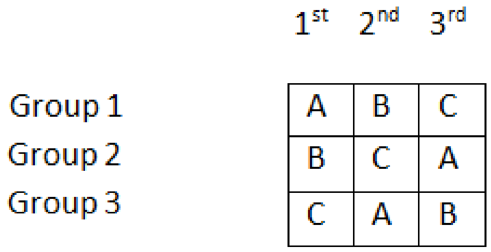
Note that it is not necessary to split all these categories into separate tests. All of these categories can be interspersed pseudo-randomly, where any category of target will appear no more than two times in a row to prevent predictability, while keeping the targets varied enough while not over or under-representing any category. Furthermore, the spawn locations of each target can be distributed evenly and pseudo-randomly as well.

4 Approach

To answer the research questions, we need to gather good data, and analyse the results. To gather good data, we need sufficient people to participate. If only a handful of people participate, the resulting data might have outliers, that might skew the results of the experiment, which in turn can lead to false conclusions. Even when the conclusions might be correct, the certainty of making these conclusions is in jeopardy when not using enough participants to be statistically significant.

According to books on research, the number of participants needed for the results to be statistically relevant is 24. In practice, there are always participants who signed up, but cannot participate during a variety of reasons, or instances in which the data is incomplete. To account for this, more than 24 participants are needed. 36 participants will provide us with a large buffer against unforeseen events. Every additional participant provides us with extra data, adding weight to whatever conclusion we might reach.

Order effects are both the expected improvement as participants perform the task, as well as decrease in performance because of fatigue or boredom. To control for order effects, the 36 participants will test the three different aiming methods in three different orders, such that every method will have participants using it as their first, second, or as their third method. This way of dividing the order that participants are exposed to the variants that you want to examine is called a Latin square. In a reduced Latin square design, the first row and column are in their natural orders. For aiming methods A, B and C, each method occurs exactly once in every row and column. in a reduced Latin square design we get:



	1st	2nd	3rd
Group 1	A	B	C
Group 2	B	C	A
Group 3	C	A	B

The three aiming methods we are comparing are:

A) Aiming with Mouse

B) Aiming with Head

C) Aiming with Gun

Every row is an order participants will test in. The column number represents the order in which the aiming methods are tested. Each of the 3 groups will get assigned roughly the same number of participants.

4.1 Aiming with Mouse

Aiming with a mouse is a very popular method of aiming in first-person shooters when it comes to aiming with a traditional monitor. Playing with a mouse usually means you use a keyboard with digital inputs. The mouse controls the view direction and is tied to the aim direction. However, when using a Head-Mounted-Display, the movement of your head can be considered an additional input, meaning you don't necessarily have to aim at the middle of your view. The idea with this aiming method is to make global movements with your head to find the targets, while using the strengths of the mouse to fine-tune your movements in order to hit the target.

4.2 Aiming with Head

Aiming with head is the aiming method where the cross-hair is in the middle of the screen, and only the movement of the head is used to aim. The movement of the eyes is not tracked. Pulling the trigger can be done using the trigger of an Oculus touch, the same one being used in Aiming with Gun.

Aiming by moving your head has the advantage of being very easy to learn. Naturally, we move our heads to "aim" at the things we look at. However, the amount of things to look at in a shooting gallery is much greater than in a normal situation. This might possibly lead to neck fatigue. Careful testing needs to be done to ensure this fatigue won't be a hindrance during testing.

People who don't normally play video games might not be very good at moving a mouse or motion controller to aim, but since this method requires the least amount of new things to learn, they might excel at this method. Conversely, people with a lot of experience playing video games might have to unlearn the normal way of shooting, and this method might prove difficult to adapt to.

4.3 Aiming with Gun

Aiming while holding a simulated gun in a Virtual reality means that you need some sort of device that can track both its own position and rotation in 3D space. This device does not need to resemble a gun, a handle and a trigger button is all that is required physically, the rest can be replaced with a 3D model to resemble any gun. This can be done using an Oculus Touch controller. The device has infrared lights, internal sensors to sense rotation and external cameras to track position.

With this data, the aim vector can be calculated. The hand can move independently of the head, meaning it might be faster finding a new target, but since we as humans are unable to hold our arms perfectly still, accuracy and consistency might be lower compared to a gaming mouse, for example.

While the Oculus Touch is a light device, using it for an extended period of time might cause "Gorilla arm" or arm fatigue. A careful balance needs to be struck between getting enough data, and not having participants test to the point of exhaustion.

4.4 Questionnaire Design

The goal of the questionnaire is to evaluate the immersion and gameplay experience for each aiming method. The main questions that we want to know, are:

1) How fun is this aiming method?

2) How immersed did you feel while using this aiming method?

It is possible to have the participants rate the aiming method right after they have used it. Another possibility is to ask users to rank the three aiming methods after they have used all of them. The first approach has the benefit of the aiming method being very fresh in their minds, while asking them after using all three gives them more complete information. A combination of both questions will be asked, since it will provide us with a first impression as well as an overall ranking. This is true for both question 1 and 2. Questions about immersion and fun will be asked both directly and indirectly. This is to ensure that the questions that were answered accurately reflect how they feel. For all the questions asked after each aiming method, see appendix A.

After all three aiming methods have been used, the participant has enough information to rank the methods. This will be asked both in general terms, and in different categories, such as ranking them in terms for shooting far away targets, which is the most fun, Etc. A few general questions about their previous experience playing VR games are asked here as well. For a full list of questions, see appendix B.

Because of the structure of asking questions 4 times, the amount of questions taken from appendix B of the Jennett et al paper [4] are pruned somewhat. Other questions were removed because they are not relevant for this experiment.

5 Experiment

This section will describe the experiment in such a way that it can be replicated by anyone.

5.1 Experiment Design

The experiment will consist of three parts, lasting roughly 15 minutes each, to test each aiming method. This will be a within subjects experiment where all participants are exposed to all variants, with a reduced Latin square design to ensure each aiming method has roughly the same amount of people testing it first, second, or third. The target number of participants is 36.

Aiming with a motion controller or head would not require a flat surface like aiming with a mouse does. To work with this restriction, and to eliminate all the factors of standing versus sitting, all three aiming methods will be tested seated, in front of a desk. The distribution of targets will be spread out in a horizontal 180 degree arc. Vertically, the targets will spread out in a 70 degree arc, from the horizon level to high up, without having to look straight up. This will ensure that the users can always use the mouse on the desk, without having to twist the body in uncomfortable ways.

The test itself will consist of a simple environment that has disk-shaped targets that are all the same size, but vary in position, distance, and movement. All targets are facing the user. These targets will be calculated in advance, and will be distributed pseudo-randomly. This is to ensure that the targets don't all spawn in the same place, or that for example, stationary far targets are over-represented or all put at the start. The distribution of targets will be done by dividing the spawn area into a grid, and every section will be distributed the same number of targets. While distributing targets, we will make sure that no more than 2 of the same type of target will spawn right after each other. Finally, we will make sure that each type of target will have the same number with each shooting session.

There are 6 major variations of targets. They are:

Close stationary targets (CS)	Close moving targets (CM)
Medium stationary targets (MS)	Medium moving targets (MM)
Far stationary targets (FS)	Far Moving Targets (FM)

To measure the performance, we need to record data. This is the data we record, per target:

- *Target Acquisition Time* is the time it takes from the spawning of the target until the first hit.
- *Inter-target Distance* is the distance between the two targets.
- *Consistency* is measured as the number of times two consecutive shots hit the target.
- *Misses* is the number shots that missed the target.
- *Accuracy* is the distance between the centre of the target and the point where the shot intersects the plane extending out from the target.

Every time a bullet is shot, a line is traced from the barrel of the gun. If it hits the target, the distance between that point and the center of the target is determined. If it missed the target, shortest distance between the line of the bullet path and the center is calculated. Every shot, depending on the distance from centre D of a target with radius R, will have each shot categorized as follows:

Hits	Misses
Bulls-eye Yellow (D < 0.2R)	Near Miss (D => 1.0R & D <= 1.5R)
Inner Red (D => 0.2R & D < 0.4R)	Complete Miss (D > 1.5R)
Half Blue (D => 0.4R & D < 0.6R)	
Outer Black (D => 0.6R & D < 0.8R)	
Outer White (D=>0.8R & D < 1.0R)	

Each target data element will have a varying amount of missed shots, and exactly three shots that hit the target, since this will trigger the next target to spawn. Each target will have a label on them to identify what category of target it is. All of the shots will have a label on them as described above.

For each of the 6 categories, we will generate 21 targets. These will be distributed pseudo-randomly, and split into three shooting sessions of 42 targets, totalling 126. This will be repeated for all aiming methods, and after each aiming method has had three shooting sessions, a questionnaire is presented to ask participants about their experience. After all three aiming methods have been done, a final questionnaire is presented.

It is expected that users need a bit of time to get familiar with each aiming method. The performance scores on the first few targets will probably be much worse than the rest of the shooting session. To account for this learning period, an additional 18 targets are generated at the start of the first shooting session for each aiming method. These 18 targets will contain all 6 different types of targets and will not be considered part of the performance scores.

To combat fatigue and motion sickness, regular breaks will be scheduled, with the option to pause or abort the experiment if the motion sickness and fatigue get too overwhelming. Between switching aim methods there is already a pause, since the participants will be asked to remove the headset and fill in a questionnaire about the method they just used. Additional breaks between shooting sessions, and the length of a single shooting session should be determined experimentally before applying these standards to participants.

5.2 Questionnaire

The questionnaire part of the experiment consists of four parts. One list of questions is asked after using one of the three aiming methods, and a final list of questions is presented once all three aiming methods have been used.

5.2.1 Questionnaire After Each Method

This questionnaire is to measure the participants first impression of the aiming method, while it is still fresh in their mind. The questions are to determine to what extent an aiming method felt immersive and fun to play with. This is done by both asking direct and indirect questions. Additionally, questions about neck and arm fatigue are asked, which are best done right after the participant is done using the aiming method. For a full list of the questions, see appendix A.

5.2.2 Questionnaire After All Three Methods

This questionnaire is to ask about their previous experience, as well as ranking the three methods once they have tried all three. These user ratings give an additional way of evaluating which of the three methods is best, and in what circumstances.

5.3 Performance Metrics

In order to determine which aiming method is best, we need to quantify the raw data and perform some analysis to make sense of it. Previous studies [2][7] used ANOVA, or Analysis of Variance. Each of the aiming methods is tested by all participants. This is called a within-subject design. For the shooting performance, each aiming method produces a score (see section 5.4). After all participants have completed the testing, we will have an average score for each of the three aiming methods. To test if the difference between these scores is statistically significant, We will use repeated measures ANOVA. The same will be done by looking at certain subsets, such as comparing the average score of only the faraway targets of all three methods. Some differences in scores may be much more pronounced, indicating that there might be aiming method better suited for certain circumstances. With an overall average score µ, and group averages of the three aiming methods (mouse, head, and gun) we have $\bar{Y}(m)$, $\bar{Y}(h)$, and $\bar{Y}(g)$. Finally, we have the score of each individual i with each aiming method $Y(im)$, $Y(ih)$, and $Y(ig)$. We can now calculate three different variances:

1. Variance between groups ($\bar{Y}(m)$ to , $\bar{Y}(h)$ to μ, etc.)
2. Variance within groups, between each individual and the group average e.g. $Y(im)$ to $\bar{Y}(m)$.
3. Total variance, between each individual and the total average e.g. $Y(ig)$ to μ.

An ANOVA test is performed to see if the differences of the mean scores of the three aiming methods are significant. p is the chance that you would get the same scores if the null-hypothesis is true (the null-hypothesis is the understanding that there is no difference between the three aiming methods, which is what we are trying to disprove). If $p < a$ (with a set at 0.05 as a standard in these tests) then the difference in scores is significant. If this turns out to be true, the ANOVA only tells us that there is a significant difference, but not between which aiming methods. This is where the t-test comes in.

A t-test is used to find out of difference between two groups is significant. If they are not significant, we cannot reject the null-hypothesis, meaning the differences in score between groups is more likely attributed to random chance. Because we are comparing the same people using different aiming methods, we can use a paired two sample for Means t-test. This process can be repeated for all sub questions outlined in section 3.

5.4 Performance Score

The score of a shooting gallery session should represent how well the person performed. The score should be based on the shots, the movement time between targets, and the number of consecutive hits. A detailed explanation of the performance score can be found in section 6.3.

5.5 Immersion Score

While the shooting gallery program can measure the performance in numbers, immersion and gameplay experience are not so easily expressed in numbers. This means we need a different approach in analysing the data. Mann Whitney and Spearman Correlation were used for analysis in the Jennett et al. [4] paper. They performed separate analysis of the direct single question (How immersed are you) and the rest of the questionnaire containing multiple indirect questions. These two are then tested to see if they have a positive correlation with Spearman Correlation. The same holds true for this experiment. If two variables that are being compared have a Spearman Correlation of 1, then the variables are monotonically related. This means that for any increase in x, there's an increase in y, even if it is a non-linear increase. The answers to the immersion questions are considered quasi-intervals, since they are all answered in 5 levels of agreement. These levels are considered to have an equivalent "distance" from each other. The answers to all the indirect questions about immersion are counted up in a Likert scale, which is the sum of the first 8 questions in appendix A. If a participant fully agrees with the questions about immersion, they have the maximum score of 10. Since all 8 question have 5 scales, this score can be calculated by multiplying each 1 through 5 question by 0.25 and adding them up. This score is the $X(i)$ score. The participant is then asked to rate their immersion from 1 to 10 with the aiming method directly in question 11 of appendix A. This score is the $Y(i)$ score. The Spearman correlation r_s is calculated as follows:

$$r_s = \frac{cov(rg_X, rg_Y)}{\sigma_r g_X \sigma_r g_Y} \tag{4}$$

Where:

- $cov(rg_X, rg_Y)$ is the covariance of rank variables.
- $\sigma_r g_X$ and $\sigma_r g_Y$ are the standard deviations of the rank variables.

The Spearman correlation gives us a measure of certainty as to how well these two variables measure the same thing, and how well they can be combined into an immersion score for each of the three aiming methods. These scores can then be compared to question 14, which asks to rank the three methods according to immersion. The questionnaire at the end (appendix B) asks participants to rank the three methods. These rankings can then be broken down into how many people ranked method A first, second, and third, with the same being done for aiming methods B and C in a 3 x 3 table. This gives us insight into the preference of the participants. A similar method is used in Erin Martel et al. [5].

5.6 Gameplay Experience Score

Question 10 in appendix A asks the user how fun they found the aiming method. Question 13 of appendix B will then ask to rate the aiming methods according to fun. Adding the scores from question 10 will give us a ranking which is more based on first impressions and incomplete information (the participants might not yet have tried the other methods yet) and the ranking question 13 will give us an overall ranking, which gives us a more complete picture but might suffer from the primacy (You remember the first task the best) or recency (you remember the most recent task the best) effects. In other words, participants might be a bit overwhelmed with ranking everything with so many categories, but have the benefit of complete information, whereas the first impressions questions have the benefit that the aiming method in question is still fresh in their mind.

An additional way of rating the gameplay experience of the three methods is to look at the rankings in the final questionnaire, and see if the users rank them higher than the score suggest, or lower. If a participant ranks an aiming method higher, even though they scored worse with it, this might suggest a good gameplay experience with that method. The same can be said of the inverse. If a participant ranks the method lower than the scores indicate, this discrepancy suggest the gameplay experience is not very good.

6 Implementation

In order to test the different aiming methods and generate data, we need a testing program. The user will need to use the three different aiming methods, each method using a combination of a headset, a mouse, and a motion controller. The test takes the form of a shooting gallery part and a questionnaire part. The questionnaire part of the test can be done using Google Forms, between switching from one aiming method to another. The shooting gallery is a 3D environment, and needs a system that spawns targets according to a predetermined list. A game engine with great documentation, VR support, and use in commercial games is Unreal Engine 4. It has a basis in C and C++, and its functionality is extended and visualised in the visual scripting language Blueprint.

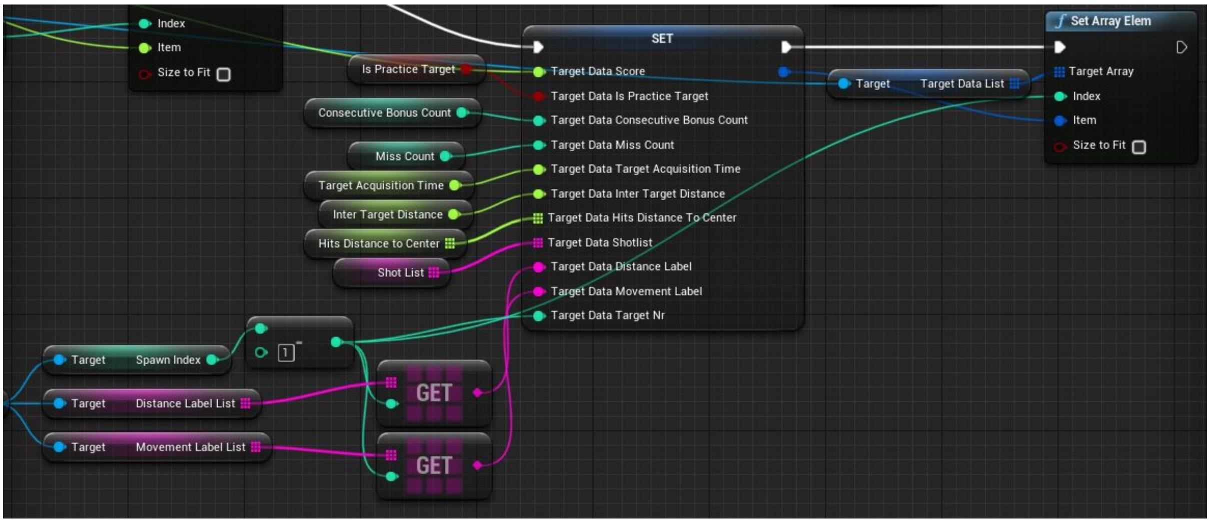


Figure 8: A small part of the Pass Along Score function in the Target blueprint. Before deleting the target, all relevant data is collected in this data structure and stored in an array called Target Data List.

Blueprints are similar to Classes in traditional programming, the main difference being the visual presentation of the structure. Certain functionality, like reading and writing data from a file, needs to be compiled in C++ before their functions can be called in blueprint.

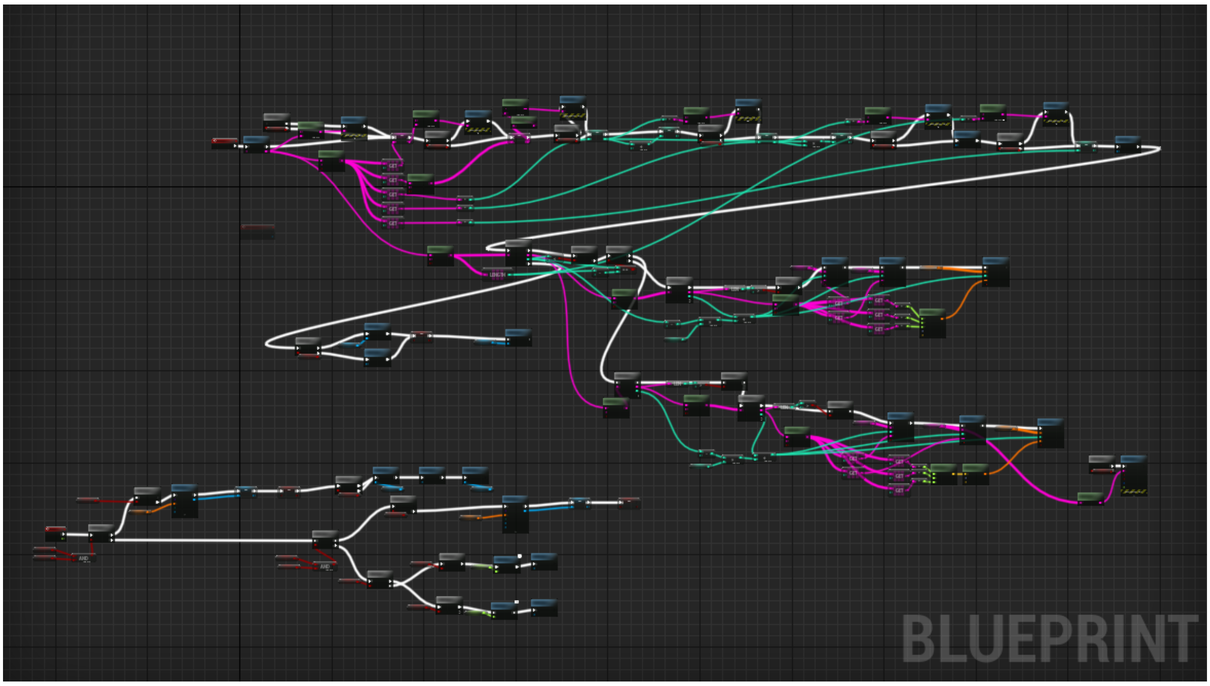


Figure 9: Overview of the *TargetSpawner* blueprint. The pink lines are strings, the teal lines are integers. The white lines indicate in what order the program is executed. On start, the program reads the input file and puts all the information into variables and lists to be used later. When the reading is done, the green light is given to begin spawning the first target. The upper part is executed on the start of the program. The lower part is executed every frame, and checks if it is time to spawn a target.

6.1 Target Generation

Because the targets need to be the same for each player and unique for each aiming method, this is best done offline, before the test. This is done by a small C++ program called *TargetGenerator*. This program generates random numbers on a unit sphere, with upper and lower limits for polar angle and left and right limits for the azimuth angle. The program then proceeds to randomly assign half the targets with a “dynamic” label, the other half a “static” label. Within these two sets, both are randomly divided into three groups of equal size, with the labels “close”, “medium” and “far”. All these points on the unit sphere (of radius 1) are then multiplied according to their distance label. This process creates three sets of 42 targets, and creates a separate set of 18 practice targets.

In order to properly compare aiming methods, the difficulty of the target set should be comparable. The targets for the other two aiming methods are generated by shuffling each session, randomizing the order, but keeping each individual target location the same. This is done in the C++ program *TargetShuffler*. This program reads a given target list generated by *TargetGenerator* and shuffles all the targets and generates a new set. Every session still has the same targets, but in a different order.

In order to easily stitch these target lists together and generate unique names for each participant, a third small C++ program called *TargetConcatenator* does exactly that. It also organizes the target sets by aiming method, and ensures the three different aiming methods are used as the first, second and third method roughly the same amount. Of the three different aiming method orders, every third person gets the third, every second person gets the second etc. If for some reason I am unable to find enough test persons, the missing data is spread out across the three orders. By automating this pipeline, it is relatively simple to change a variable, and create a new set of targets for each test person.

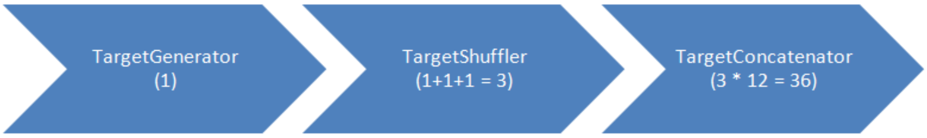


Figure 10: Process of generating targets. The numbers below indicate how many target lists there are. TargetGenerator creates one, TargetShuffler takes that list and creates two more, and TargetConcatenator concatenates these lists into three different aiming method orders, then repeats this process 12 times and gives each list a unique test person name.

6.2 General Structure

The Shooting gallery has a basic level and uses three major blueprints: *Player*, *TargetSpawner*, and *Target*.

Player handles inputs and aiming methods, as well as shooting and determining hits and misses and their subcategories (bullseye versus edge hit, etc.) while determining these categories, the target's score is also updated, and the data is stored on a custom Target Data structure, containing all data for every target. Player also handles the three different aiming methods, by disabling the respective controls for the other two aiming methods, and enabling the specific controls for the active aiming method. The three different aiming methods have separate gun models, with separate markers that indicate where the bullets will come from.

TargetSpawner reads the input file with all the targets, and determines what session the test is in. It also determines when it is the start of a new aiming method and begins with spawning the practice targets first. When a target is destroyed, the target lets the TargetSpawner know that a new target is needed. Finally, the *TargetSpawner* writes the results of the test, per target, in a text file after every session. This is a fail-safe in the case of a program crash, in which case the test can be resumed from the session that the program crashed in, rather than having to start the test all over again, (which will also influence how well they will perform). This backup system is also used when one aiming method is complete, and the second aiming method behaves erroneously. The program can be stopped, the results copied into a new folder, started up again, and skipped to the relevant session.

Target is a blueprint class that is created for every target, creating a convenient reset of all relevant variables. By the lists in *TargetSpawner*, every target gets a label letting the target know if it is supposed to remain still or move around in a circular strafing motion around the participant. When a target is hit 3 times or when 15 shots are fired, the target is instructed to pass along the score, give *TargetSpawner* a sign that it is destroyed, and is then destroyed and deleted. On every first hit of the target, The acquisition bonus is determined. The lifetime of the target is recorded as well as the rotational distance and the width value. Below is a general overview of the three blueprints:

6.3 Score Calculation

The rotational distance D is the combined absolute azimuth and polar angle between the current target and the previous target. The width W is determined by the Euclidean distance label of the target. Using an adapted version of the Index of Difficulty, which was originally an attempt to quantify the difficulty of a pointing task on a 2D screen [3], we can take into account both the distance between the new target and the width of the target. Recall that the Index of Difficulty is defined as:

$$ID = \log_2 \frac{2D}{W} \tag{5}$$

And subsequently, a measure of the performance is this Index of Difficulty divided by the time it takes to complete the task. Fitts called this the Index of Performance:

$$IP = \frac{ID}{MT} \tag{6}$$

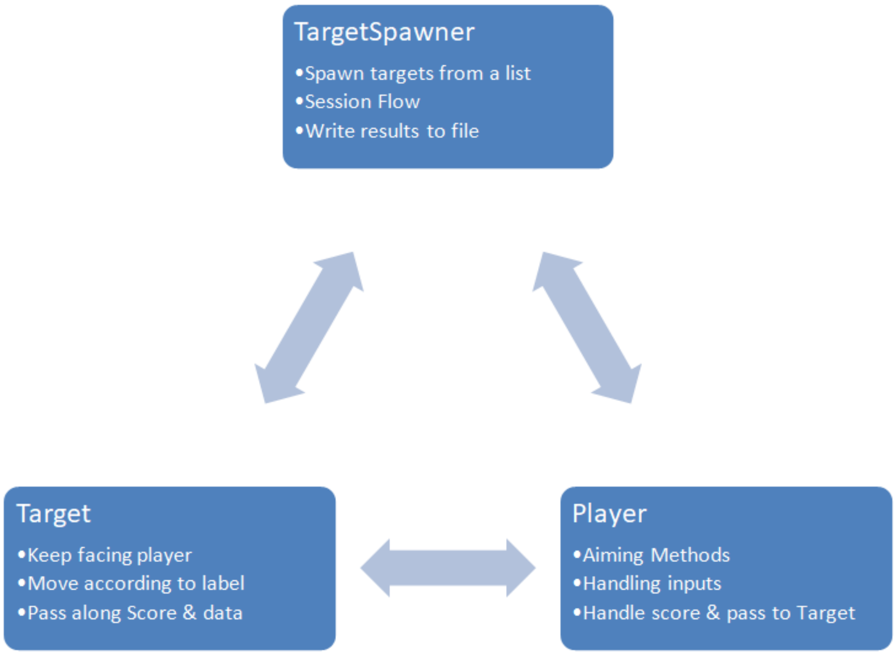


Figure 11: Overview of the general structure of the program.

The time it takes from the target spawning to the target getting hit the first time is considered the movement time MT. In testing the speed at which the participant can find and hit a target, it makes sense that a harder target will have more time to score a bonus than an easy target. The size of this bonus is gradually reduced until it reaches zero. The maximum time is granted to the hardest target, which has the largest rotational distance D and smallest Width of the target W. The maximum rotational distance, which is the positive sum of the azimuth (left to right, 180 degrees) angle and the polar angle (up to down, 52,56 degrees), is set at 232,56 degrees. This value will be called $MaxD$. These limits were determined experimentally, seeing at what limits the targets could spawn before it would get too uncomfortable. The logarithmic factor with base 2 in the *Index of Difficulty* calculation will have to be accounted for. Ideally, we want the ID to be a positive number between 0 and a certain maximum, and avoid $\log_2(0)$ since that equals negative infinity. To do this, we clamp the measured rotational distance between 1 and $MaxD$.

The lowest ID would be a close target with a rotational distance ranging from 0 to 1 degrees between targets. The highest ID would be a far target with 170 horizontal + 62,56 vertical degrees of rotational distance. This maximum rotational distance is called $MaxD$. This difficulty calculation will determine the amount of time the player will have to score the first hit on the target. With a minimum of one second, a linear drop-off of score happens until the calculated end time. If the target is hit before the 1 second mark, 50 points are awarded. If the target is hit after this maximum time, 0 points are awarded. If the target is hit between the minimum and maximum times, for example, with only 20% of the time left, only 20% of the points are rewarded. In the case of 50 points, 10 points acquisition bonus are awarded. The rest of the scores are more straightforward. Every shot is divided into seven categories:

- A bulls-eye hit (inner 20% of the target) 100 points
- An inner red hit (20-40% of radius) 90 points
- A Half blue hit (40-60% of radius) 85 points
- An Outer Black hit (60-80% of radius) 80 points
- An Outer white hit (outer 50% of the target) 75 points
- A Near-miss (Within 150% of the radius) - 10 points
- A Complete miss (more than 150% of the radius) – 20 points.

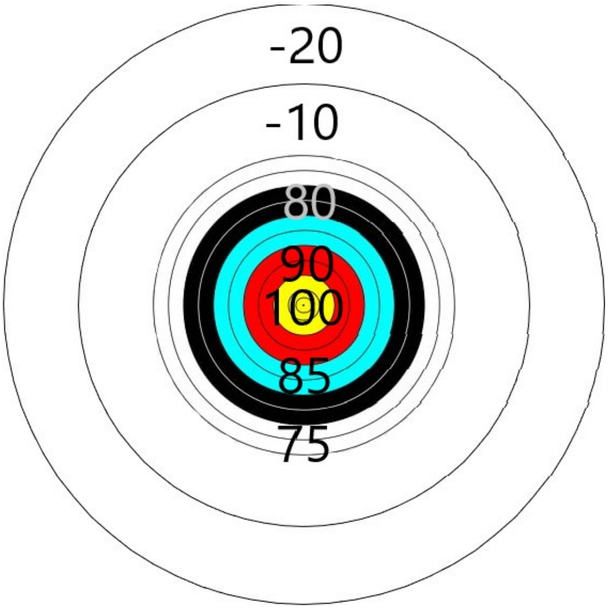


Figure 12: A score reference, seen below the *Pause Target.*

- Consecutive hit bonus (100 points extra if the previous shot was also a hit)

Each of the seven shots has a unique sound, so players get feedback on how well they are shooting, and if they need to make adjustments. There is also a visual feedback in the form of a score pop-up, which will appear in the same colour as the disc that was hit, or appear in the air where the miss took place.

A perfect score, which is achieved by hitting three consecutive bulls-eye hits, no misses, with a quick response on the first hit for a maximum score of $300 + 200 + 50 = 550$ points. The worst score of a target is also defined, since after 15 shots, the target is despawned. After 15 complete misses, $15 * -20 = -300$ points are awarded.

With all of the scores awarded for each target, along with all of the data that is recorded from the moment that the target spawned until that target is destroyed, every target creates an item in a list. This list will eventually be the output data. This consists of a long list of every non-practice target, with every target separated by a new line, and every subsection divided by a — symbol. Formatting the data this way makes it easy process this data later by importing it into spreadsheets and making graphs out of specific points of data.

6.4 Sessions

For every aiming method the participant has one practice session and three normal sessions. The practice session consists of 18 targets, and the normal sessions each consist of 42 targets. Before a session starts, a special target with an information board spawns called *Pause Target.* This target will always be static, always spawn in the central position of the shooting gallery, and will require 10 successful hits to be destroyed. The information board above it displays the instruction to shoot the target 10 times, the upcoming session and the current aiming method. The information board below the target is a score reference and a bonus score reference. These *PauseTargets* provide a natural stopping point, which can provide a moment to adjust the headset, take it off and take a break, etc. If the program crashes during a session, for example session 4, only session 4 and onward need to be played. The program includes a skip session button, and the data of every session is stored separately in case of such crashes.

After one practice session and three normal session of each aiming method, a special End Target is spawned. This target works similarly to an Pause target, but it has message above it telling the participant that the current aiming session is over, and that asks them to remove the headset and move on to the questionnaire.

Shoot the target 10 times to continue

Upcoming Session nr: 1 Aiming Method: Aiming with Mouse

Practice Session. No score will be kept.

Figure 13: Pause Target. The information board above provides information about the upcoming session. The information board below provides score reference as well as a bonus score reference.

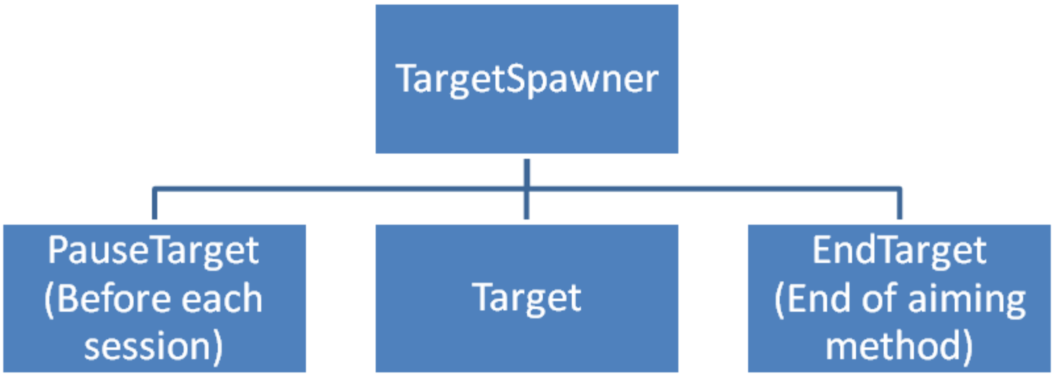


Figure 14: *TargetSpawner* spawns three different kinds of targets.

6.5 Live Adjustments

In a live environment, many things can go wrong. While most things can be fixed with a restart, it is good to have some tools at hand to handle unexpected behaviours. In this testing program there are several adjustment buttons that can adjust several positions and rotations.

For example, the default rotation can be adjusted so that the test person is both facing the desk in the real world, as well as facing the first target straight on. It should be as comfortable as possible to turn the head left and right, to the edges of where the targets will spawn. At a distance, a wireless keyboard is used to turn the player if needed.

The second adjustment is the player location. If the player is somehow not in the middle of the shooting gallery, the player can move forwards and backwards, depending on where they are looking. With a six-degrees of freedom headset, the position is not strictly fixed. This greatly helps with the user's comfort, but it can displace a person in virtual space. The grid on the floor, and the lines coming from the edge of the walls to the centre can help guide both the participant and the researcher to the middle of the virtual room.
The third adjustment is the position of the motion controller, used in the aiming with Gun method. Sometimes, the position of the gun is not where the participant has his or her hand in real life. Instead

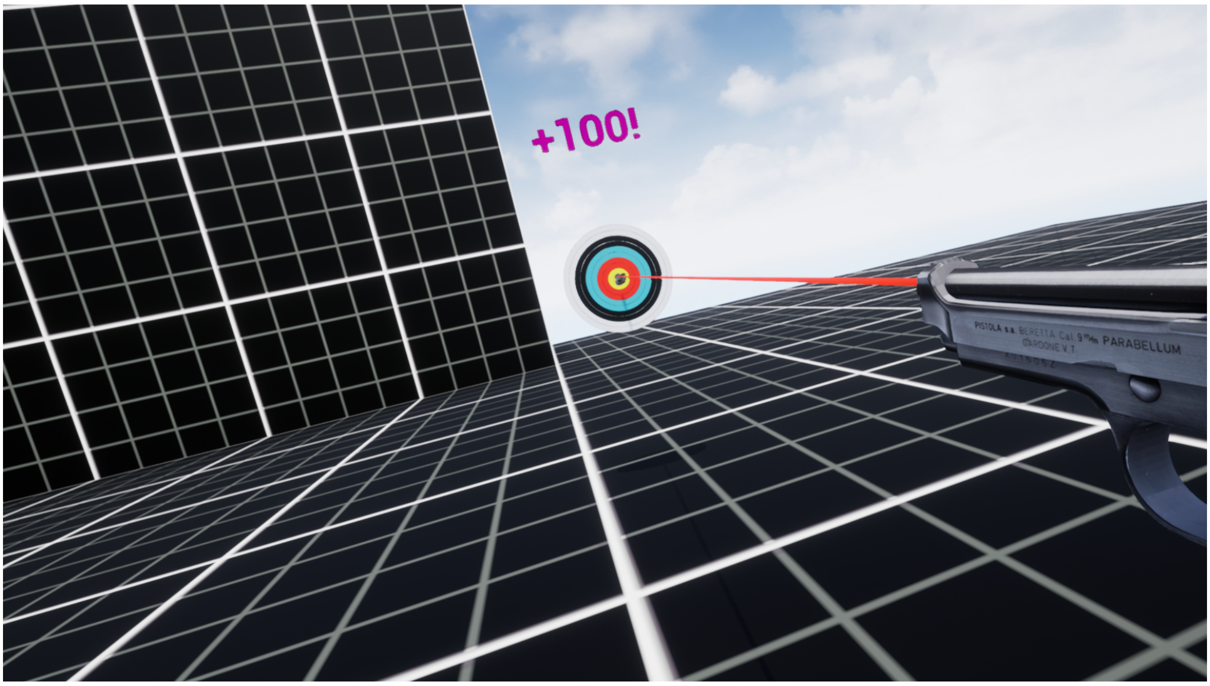


Figure 15: The lines on the floor can help to indicate the middle of the room.

of restarting the whole test, a few adjustment buttons can correct this.

The fourth adjustment is the rotation of the motion controller. It can adjust the rotation by a tiny amount, so the player can aim where it points to in the real world. Note that these adjustments are only in place to restore to the intended way of using the aiming methods. The goal is to have each person using this particular aiming method to have a similar experience.

If the adjustments cannot remedy the situation, the program is terminated, and the results up until that point are copied. The program is then started again, with skip keys to skip to the right session.

7 Results

This section describes the results of the VR shooting gallery and questionnaires.

7.1 Participants

There were 36 participants in total. All participants used all three aiming methods, but there were three different orders in which the aiming methods were tested. The first participant was placed in the Gun ⇒ Head ⇒ Mouse group, the second in the Head ⇒ Mouse ⇒ Gun group, the third in the Mouse ⇒ Gun ⇒ Head group, then the process repeats until all three groups had 12 participants. The only factor determining which participant went in which group was their participant number. Out of the 36 participants, 28 were male (77.78%), and 8 were female (22.22%). The average age was 31.2 years, with an age range of 20 - 65 years. When asked about their previous First-Person Shooter experience, 25 of the participants have medium to high amounts of FPS experience (69.44%). The other 11 participants had little to no FPS experience (30.55%). Out of 36, 8 of the participants had medium to high amounts of VR experience (22.22%). The other 28 participants had little to no VR experience (77.78%).

7.2 VR Sickness

All of the 36 participants completed the test successfully. Two participants experienced some form of VR sickness, and needed a short break before finishing the test. The other participants didn't mention having any VR sickness.

7.3 Performance

The results from the shooting gallery program is a list of data, with every line of data denoting a separate target, and information about the shots fired while that target was active. All of the scores and measurements are continuous, with no significant outliers. When comparing scores and measurements of different aiming methods, note that all participants have used all three aiming methods, so the individuals are the same. A repeated measures ANOVA is performed to see if the differences between the three scores is due to the aiming method, or due to other random factors. If the P-value is below .05, then the difference is significant. It cannot tell you *which* differences however, that is where the paired two sample for means t-test comes in. This test looks at two aiming methods at a time, and tells us if the difference between those methods is significant or not. It has the same threshold as the ANOVA test: .05

7.3.1 Accuracy

The accuracy score is the same as the overall score minus the acquisition bonus and consecutive bonus. With minimum of -300, and a maximum of 300, the average was 270.11 points ($SD = 7.404$). *Aiming with Gun* scored the highest with 272.75 points, the second best was *Aiming with Head* with 269.96 points, and the lowest scoring method was *Aiming with Mouse* with 267.63 points. A repeated measures ANOVA was performed ($P < .001$). A paired two sample for means t-test was performed between the highest and the second highest scoring method($P = .002$). The same kind of test was performed between the second and third ($P = .002$), as well as the first and third ($P < .001$). All P values are well below 0.05, meaning that *Aiming with Gun* is the most accurate, followed by *Aiming with Head* is the second most accurate, and the least accurate is *Aiming with Mouse*.

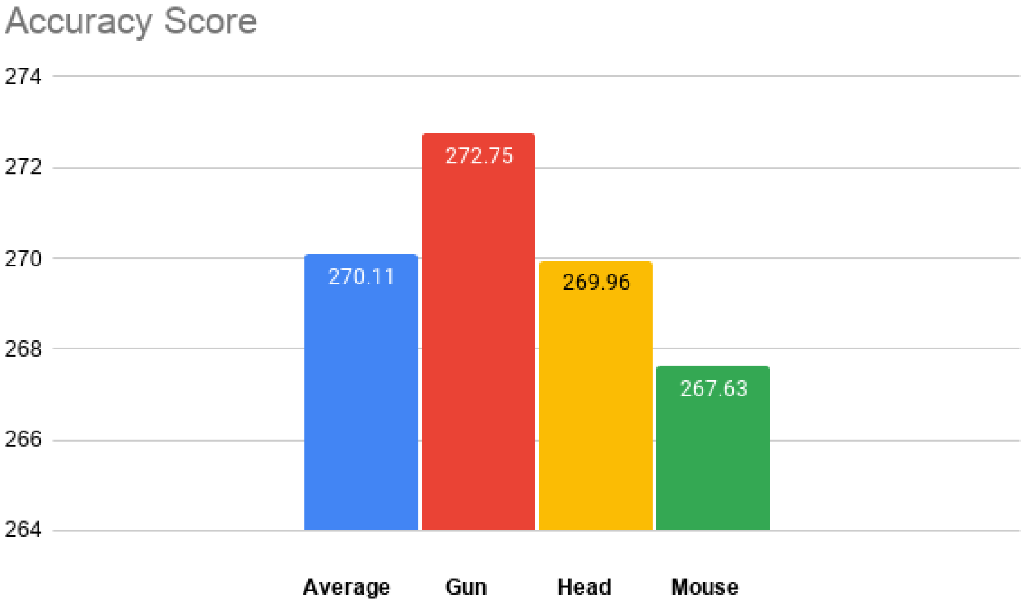


Figure 16: Accuracy Score.

Another way to look at accuracy is to look at the number of misses. While shooting three times at 126 targets, we see that *Aiming with Gun* is the most accurate with an average of 35.4 misses, *Aiming with Head* is the second most accurate with an average of 42.8 misses, and *Aiming with Mouse* being the least accurate with an average of 50.6 misses.

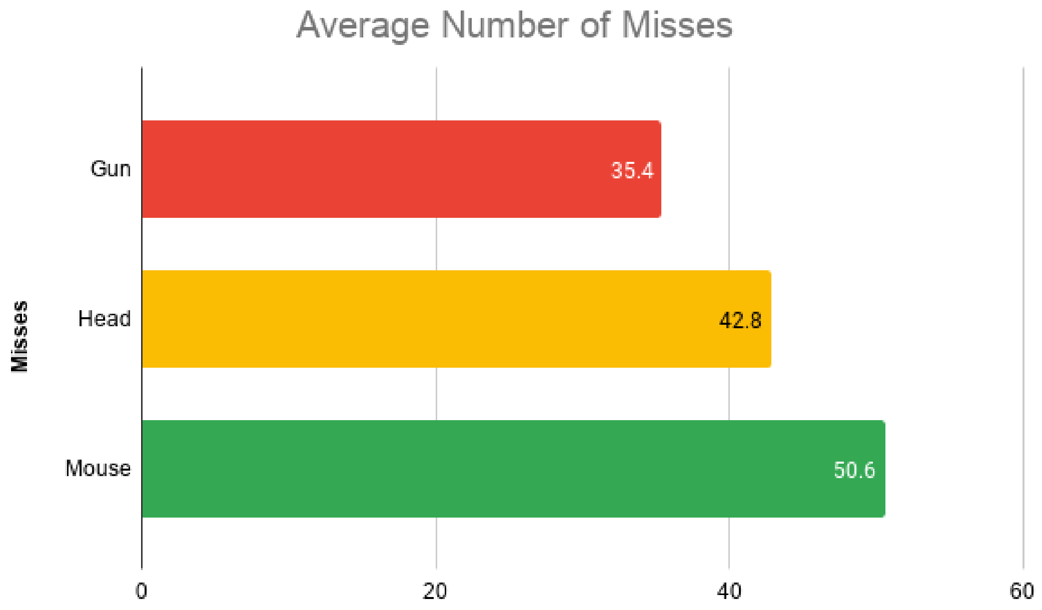


Figure 17: Average number of misses.

7.3.2 Target Acquisition

When regarding the Target Acquisition score, with a minimum of 0 and a maximum of 50, the average was 29.16 points ($SD = 8.261$). *Aiming with Gun* scored the highest with 31.01 points, the second best was *Aiming with Head* with 29.35 points, and the lowest scoring method was *Aiming with Mouse* with 27.10 points. A repeated measures ANOVA was performed ($P < .001$). A paired two sample for means t-test was performed between the highest and the second highest scoring method($P = .03$). The same kind of test was performed between the second and third ($P = .002$), as well as the first and third ($P < .001$). All of the tests have a P-value below the threshold of 0.05, meaning the results are significant, and not due to random chance. This means we can say that *Aiming with Gun* is the best at hitting new targets quickly, followed by *Aiming with Head*, with the worst method being *Aiming with Mouse*.

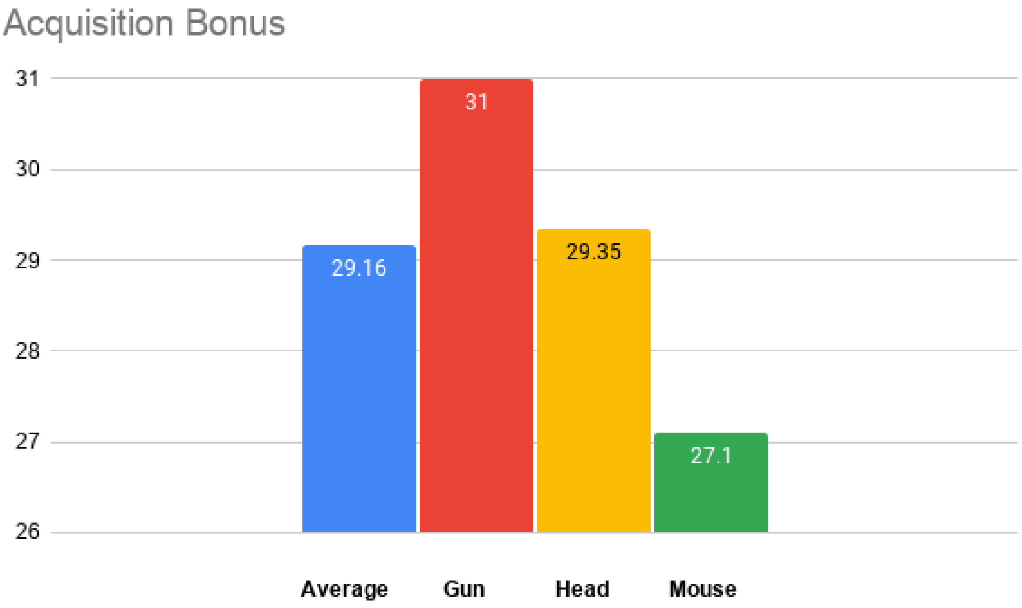


Figure 18: Acquisition bonus score.

7.3.3 Consistency

When regarding the consistency of shots, the consecutive bonus score rewards participants 100 points every time a target is shot twice in a row. With a minimum of 0 and a maximum of 200, the average was 186.21 points ($SD = 6.587$). *Aiming with Gun* scored the highest with 187.74 points, the second best was *Aiming with Head* with 186.08 points, and the lowest scoring method was *Aiming with Mouse* with 184.80 points. A repeated measures ANOVA was performed($P = .016$). A paired two sample for means t-test was performed between the highest and second highest scoring method($P = .07$). The same kind of test was performed between the second and third ($P = .07$), as well as the first and third ($P = .003$). This means that the difference between the consecutive scores of *Aiming with Gun* and *Aiming with Head* are too close to call, as well as those of the *Aiming with Head* and *Aiming with Mouse* scores. However, we can say that *Aiming with Gun* hit more consistently than *Aiming with Mouse.*

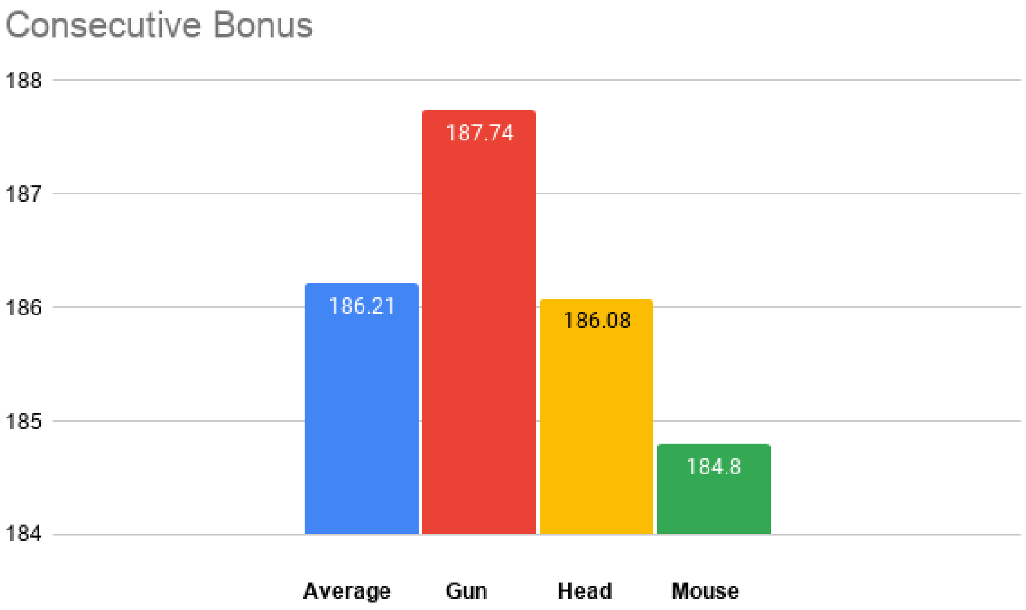


Figure 19: Consecutive Bonus score.

7.3.4 Overall Score

When regarding the overall score, with a minimum of -300 and a maximum of 550 points, the average was 485.47 points ($SD = 16.416$). *Aiming with Gun* scored the highest with 491.50 points, the second best was *Aiming with Head* with 485.40 points, and the lowest scoring method was *Aiming with Mouse* with 479.53 points. A repeated measures ANOVA was performed ($P < .001$). A paired two sample for means t-test was performed between the highest and the second highest scoring method($P = .005$). The same kind of test was performed between the second and third ($P < 0.001$), as well as the first and third ($P < .001$). All of the tests have a P-value well below the threshold of 0.05, meaning the results are significant. This means we can say that in terms of performance, overall *Aiming with Gun* performs the best, followed by *Aiming with Head*, with the worst performance being *Aiming with Mouse*.

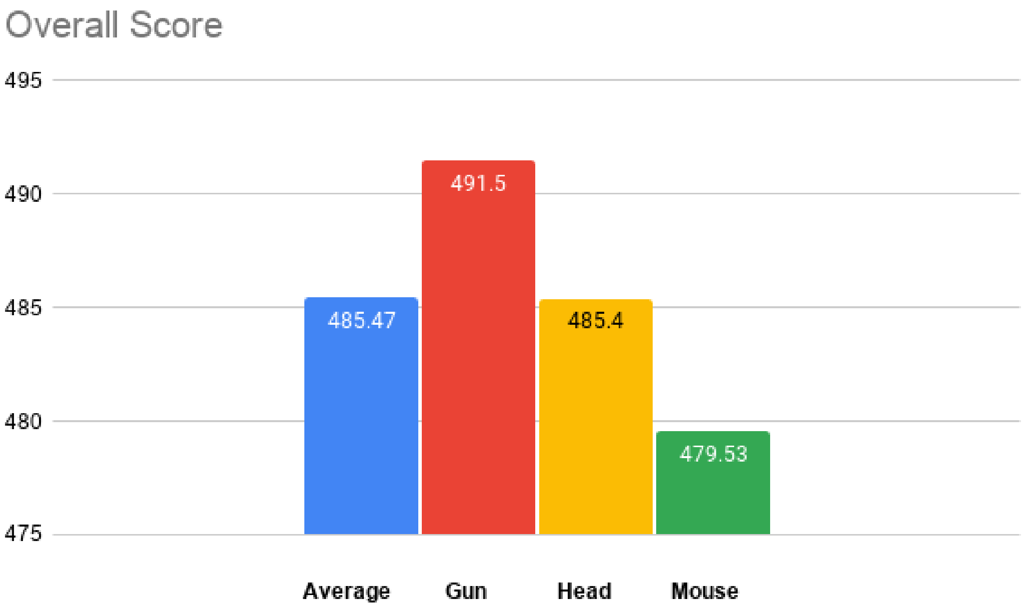


Figure 20: Overall score.

By tallying which aiming methods scored the highest, second highest and lowest, we get the three pie charts below. *Aiming with Gun* was the highest scoring method with the most participants (22 highest, 9 second highest, and 5 lowest). *Aiming with Head* was the method with the most second highest scores (10 highest, 19 second highest, 7 lowest). *Aiming with Mouse* was the method with the most lowest scores (4 highest, 8 second highest, 24 lowest).

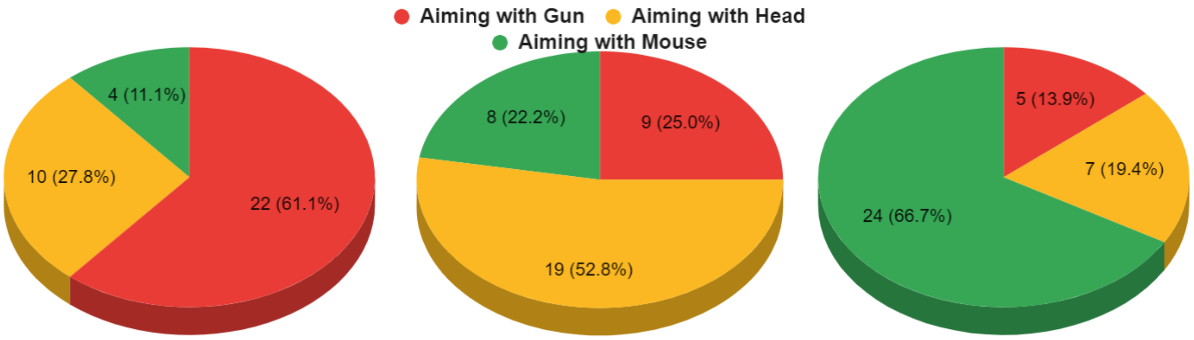


Figure 21: Highest scoring, Mid Scoring and Lowest Scoring count.

7.3.5 Distance

Each target had their distance label added so that a distinction could be made between *Close targets* (3 meters away), *Medium targets* (6 meters away) and *Far targets* (9 meters away) Even if a target is moving, it moves along a circular path, maintaining the same distance. Below is a score comparison between the *Average, Gun, Head,* and *Mouse* scores of all close targets (darker shade colours), all medium targets (regular colours), and finally all faraway targets (lighter shade colours).

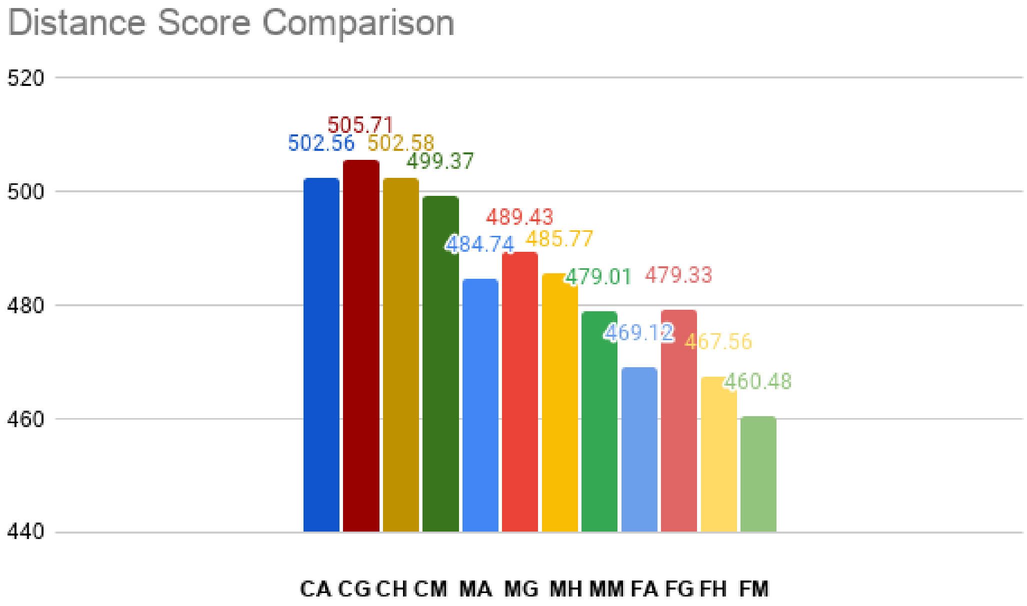


Figure 22: Distance score comparison.

When analysing the *close* scores, a repeated measures ANOVA was performed ($P = .005$). *Aiming with Gun* scored the highest with 505.71 points, the second highest method was *Aiming with Head* with 502.58 points, with the lowest scoring method being *Aiming with Mouse* with 499.37 points. A paired two sample for means t-test between the first and second highest scoring method was performed ($P = .07$). The same test was performed between the second and third ($P = .03$), as well as the first and third ($P < .001$). This means that the difference between *Aiming with Gun* and *Aiming with Head* is a little too close to call, but both are definitely better than *Aiming with Mouse* on close-by targets.

When analysing the *medium* scores, a repeated measures ANOVA was performed ($P < .001$). *Aiming with Gun* scored the highest with 489.43 points, the second highest method was *Aiming with Head* with 485.77 points, with the lowest scoring method being *Aiming with Mouse* with 479.01 points. A paired two sample for means t-test was performed between the first and highest scoring method ($P = .09$). The same test was performed between the second and third ($P = .003$), as well as the first and third ($P < .001$). This means that the difference between *Aiming with Gun* and *Aiming with* is a little too close to call, but both are definitely better than *Aiming with Mouse* on medium range targets.

When analysing the *far* scores, a repeated measures ANOVA was performed ($P < .001$). *Aiming with Gun* scored the highest with 479.33 points, followed by the second highest method *Aiming with Head* with 467.56 points, with the lowest scoring method being *Aiming with Mouse* with 460.48 points. A paired two sample for means t-test was performed between the first and the second highest scoring method ($P < .001$). The same test was performed between the second and third ($P = .005$), as well as the first and third ($P < .001$). This means that when it comes to faraway targets, *Aiming with Gun* is clearly the best, followed by *Aiming with Head*, with the lowest scoring method being *Aiming with Mouse*.

From all three distances, *Aiming with Gun* scores the highest, *Aiming with Head* scores the second highest, and *Aiming with Mouse* scored the lowest. On close and medium targets, *Aiming with Head* scored close enough to *Aiming with Gun* that their performance can be considered to be similar. The difference between aiming methods gets more and more pronounced as the targets get farther away from the target. This makes sense, as the further a target is away from the shooter, the harder it is to hit. If an aiming method is good for all distances, any method that is not as good is more prone to mistakes with harder targets. There is not a distance where another aiming method excels in, *Aiming with Gun* is the overall best method across all distances.

7.3.6 Stationary Targets versus Dynamic Targets

Stationary targets do not move after they spawn. Dynamic targets move at a constant speed, alternating from left to right, similar to *strafing* behaviour found in multiplayer shooter games, where the goal is to make it hard for your opponent to hit you. What follows is a score comparison between the *Average, Gun, Head,* and *Mouse* scores of stationary targets (regular colours), followed by the dynamic targets (darker shade colours).

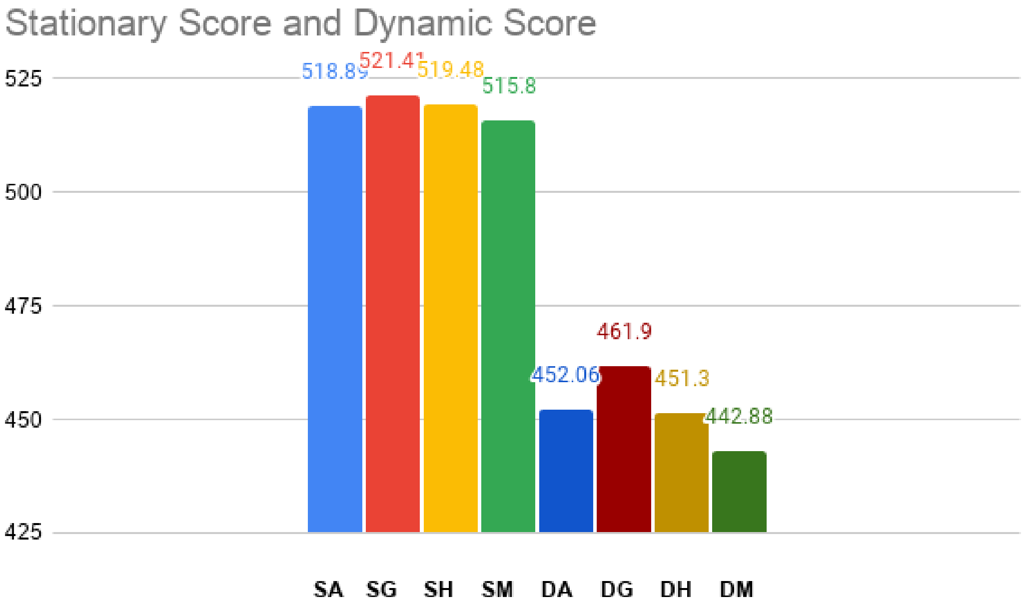


Figure 23: Stationary score and dynamic score.

When analysing the *Stationary* scores, a repeated measures ANOVA was performed ($P < .001$). *Aiming with Gun* scored the highest with 521.41 points, followed by *Aiming with Head* with 519.48 points, with the lowest scoring method on stationary targets being *Aiming with Mouse* with 515.80 points. A paired two sample for means t-test was performed between the first and second highest scoring method ($P = .049$). The same kind of test was performed between the second and third ($P < .001$), as well as the first and third ($P < .001$). All of these P-values are below 0.05, meaning that for stationary targets, *Aiming with Gun* is the best method, followed by *Aiming with Head*, with the last place being for *Aiming with Mouse*.

When analysing the *Dynamic* scores, a repeated measures ANOVA was performed ($P < .001$). *Aiming with Gun* scored the highest with 461.90 points, followed by *Aiming with Head* with 451.30 points, with the lowest scoring method being *Aiming with Mouse* with 442.88 points. A paired two sample for means t-test was performed between the first and second highest scoring method ($P = .004$). The same kind of test was performed between the second and third ($P = .002$), as well as the first and third ($P < .001$). All of these P-values are below 0.05, meaning the differences are statistically significant. For dynamic targets, *Aiming with Gun* is the best method, followed by *Aiming with Head*, with the worst method being *Aiming with Mouse*.

The differences between the tree aiming methods become more pronounced when the targets move around. It becomes much harder to hit a target consistently, as well as hit it in the middle. One participant neatly explains the difference between the aiming methods:

> *"I have the feeling that I can react more quickly with the gun only. With the head only is not precise enough, and with the head and the mouse even takes longer to coordinate with the two."*

Another participant explains the difference when it comes to hitting stationary targets:

> *"Aiming with gun is most precise. Aiming with mouse is good for adjusting small movements. That's not possible with only head-aiming, but there is not a lot of difference."*

For both stationary and moving targets, *aiming with Gun* is the best method, followed by *Aiming with Head*, with the last place being *Aiming with Mouse*. As can be seen in Appendix C, looking at the scores of subsets with any combination of distance and movement label, they show a similar pattern. The harder the target, the greater the difference in scores, where *Aiming with Gun* always scores the highest, followed by *Aiming with Head*, with the lowest scoring method being *Aiming with Mouse.*

7.3.7 FPS experience

Out of the 36 total participants, 25 of them indicated that hey had a medium to high experience playing First Person Shooters games. When comparing the overall scores of this group and the people with little to no FPS experience, *Aiming with Gun* is still the highest scoring method (494.28 & 485.92 points respectively). What's noticeable is that the difference between *Aiming with Head*(487.36) and *Aiming with Mouse* (485.12) of the high FPS experience group is quite small, whereas the group with little to no FPS experience has a very large difference (474.74 & 466.81 points respectively). This difference can be explained by the fact that people with FPS experience have an easier time using the mouse to aim. While *Aiming with Mouse* isn't exactly the same as aiming in a traditional FPS, it is similar enough that it gives them an advantage.

7.4 Immersion

The participants were asked about immersion after using every aiming method, using six positive and two negative indirect questions, and one direct question. The questions were taken from the immersion paper of Jennett et al.[4], and their method combines these questions into one number, the immersion score. The direct question has a weight of 0.5, and the score of the two negative questions are inversed and the total eight indirect questions make up the other half of the total score. With a minimum score of 1 and a maximum score of 10, The average score was 6.88. The highest score was *Aiming with Gun* with 7.45 points. The second highest score was *Aiming with Head* with 6.71 points. the lowest score was *Aiming with Mouse* with 6.42 points.

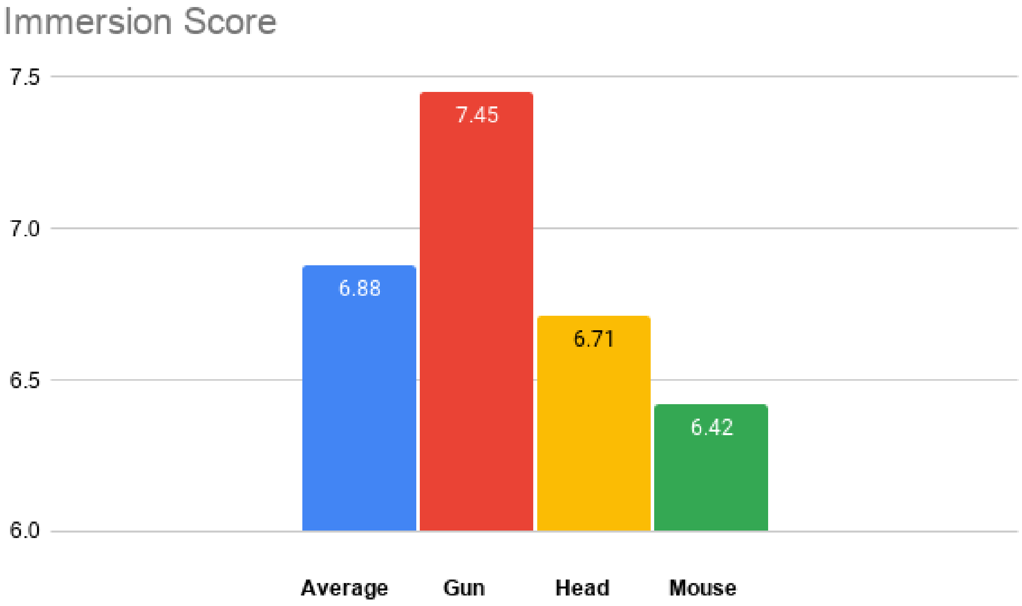


Figure 24: Immersion score.

When looking at the Immersion Ranking results, the participants favor *Aiming with Gun.* Many of them mentioned that the gun felt the most realistic, while the mouse reminded them that they were using a computer. Many people had trouble getting used to the dual control of the gun with *Aiming with Mouse.* With both head movement and mouse movement influenced the direction of the gun, people had trouble with getting immersed, as one participant writes:

> *"My mind follows my hands or head in the literal direction of the target, this is less so with the mouse method where I needed more brain power to focus on the target and was less immersed in the shooting experience."*

However, there was one participant who was so involved with the aiming method that it became very immersive:

> *"With the mouse I was so busy that I forgot everything other than the targets."*

This person is an outlier, since many people responded that not having to think about the controls freed their mind up to become immersed, as well as not having the frustration of struggling with controls, which is both a distraction and reduces fun. A few people mentioned a high fun factor helped with immersion.

When looking at both the rankings and the immersion score, it is clear that *Aiming with Gun* is the most immersive method. It feels the most realistic, while being less frustrating and more fun. *Aiming with Head* is the second most immersive, with both a higher immersion score and 11 more people ranking it the second most immersive over *Aiming with Mouse.* The former having the advantage of being so easy to learn that they forget that they are using controls, the latter has the disadvantage of reminding people they are using a computer and is harder to learn, leading to frustration and distraction from the experience.

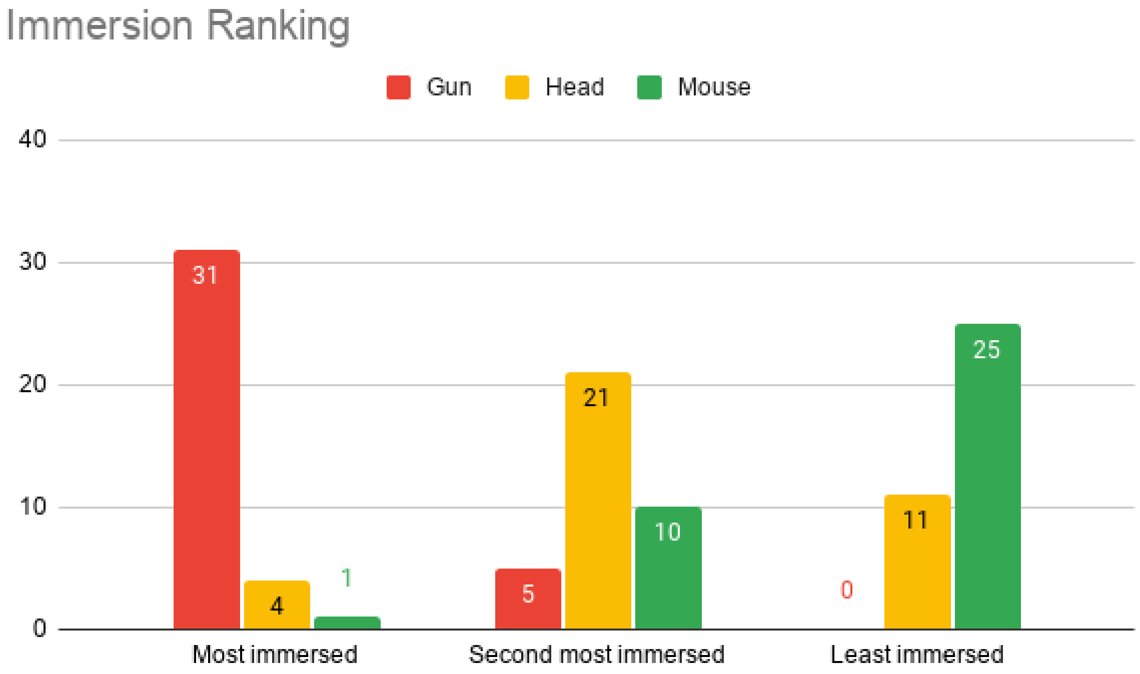


Figure 25: Immersion Ranking.

7.5 Fatigue

After using each aiming method, people were asked how tired their neck was, as well as how tired their arm was. Because fatigue is undesirable, the score is inverted, with low levels of fatigue giving a high score and high levels of fatigue giving a low score. If we look at the neck fatigue scores, we can see that *Aiming with Gun* is not very tiring. It is the only aiming method where the neck movement is not influencing the aim direction, meaning that the neck only has to move when finding a new target out of their field-of-view, or when a moving target is moving out of the field-of-view. *Aiming with Head* scores the lowest, since people have to use their neck to aim. Participants were slightly less fatigued while using *Aiming with Mouse*, since they can also move their mouse to aim. This is mostly used when fine-tuning the aim for faraway targets, as well as positioning and following a close by moving target.

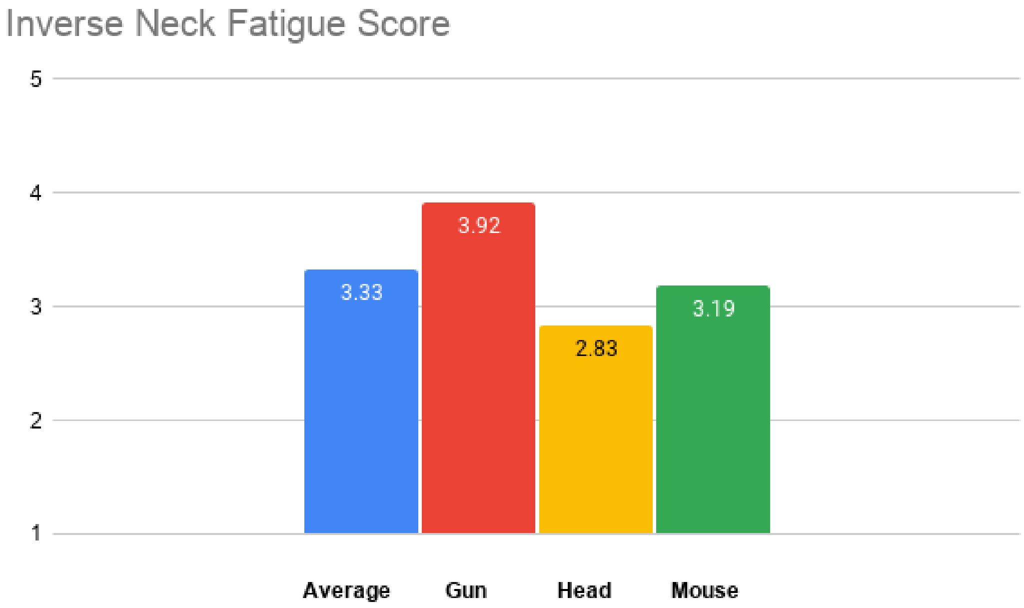


Figure 26: Inverse neck fatigue score.

When looking at the inverse Arm fatigue score, we see that participants feel their arm getting tired a lot more when they have just finished with the *Aiming with Gun method*. This makes sense, as they have just shot 144 targets 3 times, as well as a few pause targets. We see that the *Aiming with Head* method induces the least amount of arm fatigue, since the only action required from the arm is pressing a button, where as moving around the mouse in *Aiming with Mouse* is a little more involved.

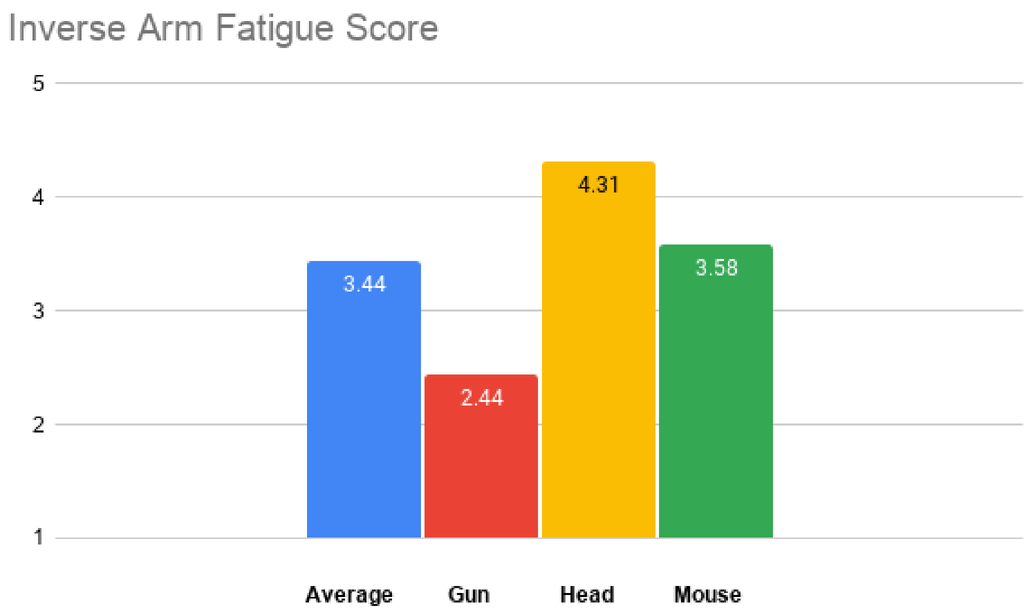


Figure 27: Inverse arm fatigue score.

7.6 Comfort

Comfort is related to fatigue, but it's not quite the same. An aiming method might be tiring, but not *uncomfortably* so. When asked to rank the aiming methods from most comfortable to least comfortable, these were the responses: (see figure 28)

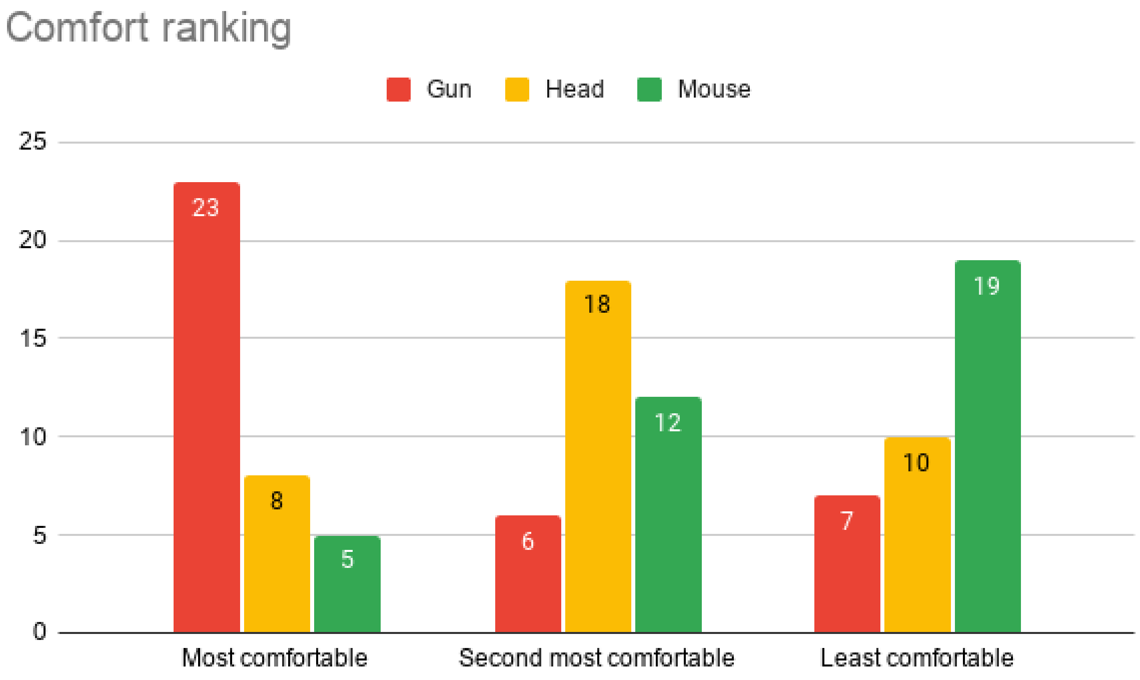


Figure 28: Comfort Ranking.

As we just learned from the inverse arm fatigue score, *Aiming with Gun* is the method that makes your arm the most tired. However, it is ranked by 23 out of 36 people as the most comfortable aiming method.

The reasons that people gave for this method being comfortable is that it feels the most natural, and because there isn't a requirement to sit at a desk, you can more easily turn the chair around without having to turn your head and torso.

> *"Aiming with Gun is most natural and feels most comfortable. Aiming with the mouse I know from 2D FPS but using it in combination with a HMD made it a bit more involved and a bit more work, aiming seemed more precise due to the mouse precision. Aiming with the head was enjoyable, I just needed to click to fire - this unexpectedly felt enjoyable and more comfortable then the mouse aim method"*

Besides being restricted to a desk when using these methods, participants indicated that both *Aiming with Head* and *Aiming with Mouse* occasionally put their heads in uncomfortable positions. One participants (translated from Dutch) writes:

> *"With Head and Mouse I occasionally had the feeling that I had to move my head in uncomfortable positions. The headset is so sensitive to small movement of your head which made aiming difficult. Aiming with Gun didn't have these issues."*

Some people were very familiar with aiming with a mouse, and felt it was less tiring than *Aiming with Head*. However, many people struggled with the controls, where sometimes the movement of the head and movement of the mouse would cancel each other out. This struggle was less so with *Aiming with Head*, where the control scheme was simply to look and fire. While testing this method, few people exclaimed that this way of shooting feels *"laid-back."*

In conclusion, *Aiming with Gun* feels the most comfortable, followed by *Aiming with Head* and in overall least comfortable aiming method is *Aiming with Mouse.* The difference between the last two is less pronounced than the difference between the most comfortable method.

7.7 Fun

Fun was measured in two ways: as a first impressions question after each aiming method (see Appendix A, question 12), and as a ranking question in the final questionnaire (See appendix B, question 13). If we look at the fun rank chart below, the responses are overwhelmingly placing *Aiming with Gun* as the most fun aiming method(35 out of 36 participants). The second most fun method is *Aiming with Head*, according to 26 people. The same amount of people ranked *Aiming with Mouse* as the least fun aiming method.

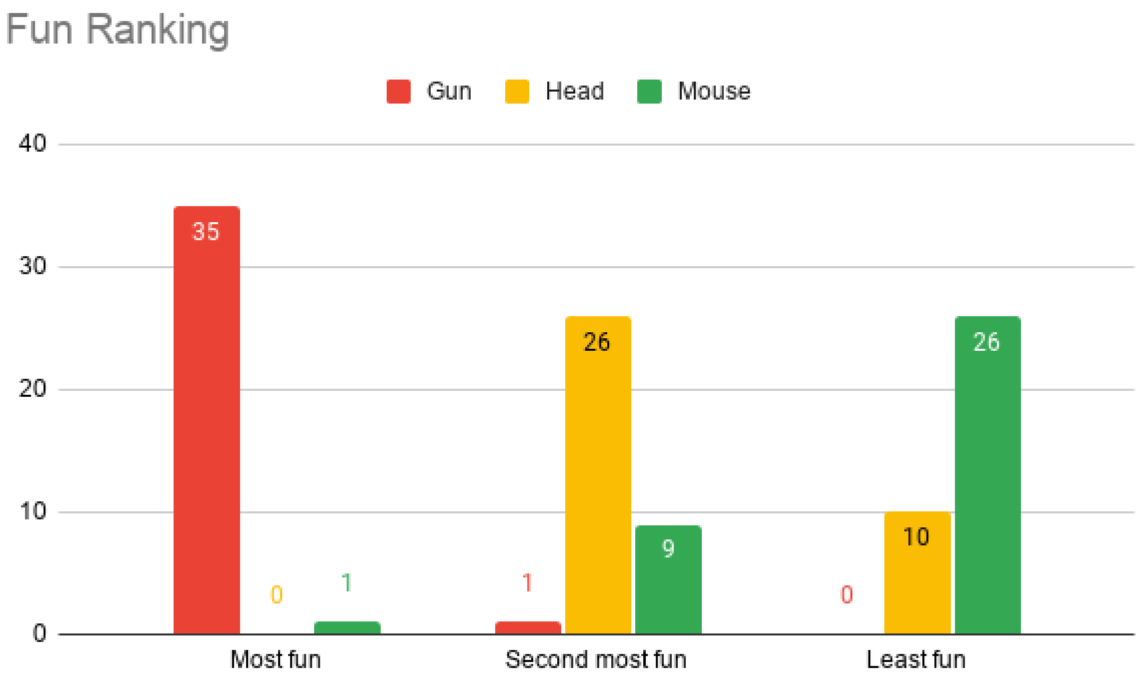


Figure 29: Fun ranking.

When looking at the enjoyment scores, we see a similar hierarchy, but with a difference between *Aiming with Head* and *Aiming with Mouse* that is less pronounced. Note that two-thirds of these questionnaires were filled in without having used all aiming methods. With a minimum score of 1 and a maximum of 5, the average score was 3.85 points. The highest enjoyment score was given to *Aiming with Gun* with 4.72 points. *Aiming with Head* scored lower with 3.5 points, closely followed by *Aiming with Mouse* with 3.28 points.

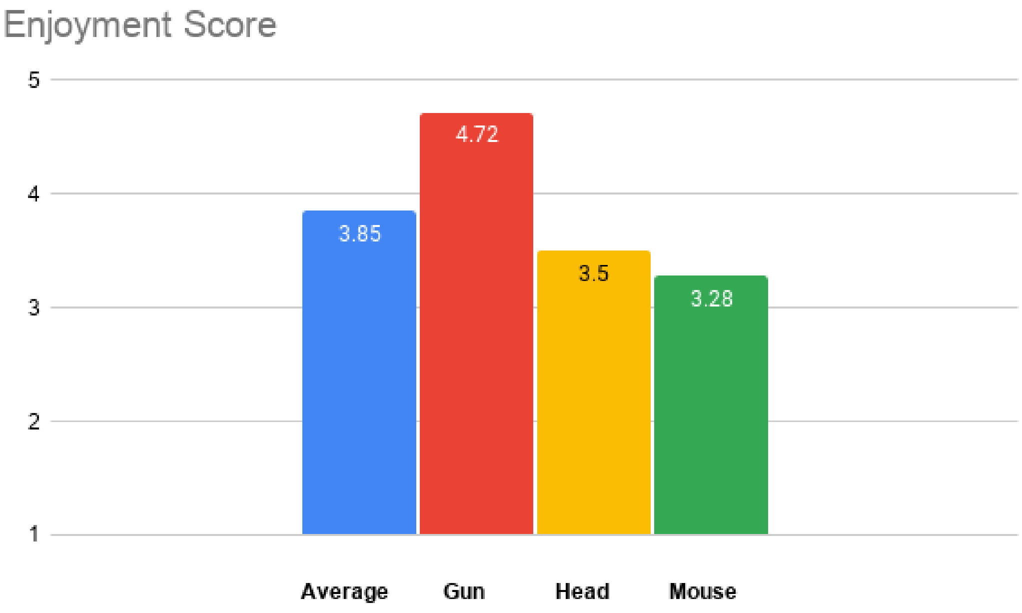


Figure 30: Enjoyment Score.

7.8 Gameplay Experience

While fun is an indicator of a good gameplay experience, another way of measuring gameplay experience is the discrepancy between how well people think they scored and how well they actually scored. The participants saw direct feedback on their current shot, but saw no overall score counter during their tests. There are downsides to this scoring method, namely that the highest scoring method cannot be overestimated, and the lowest scoring method cannot be underestimated. As described in section 5.6, we tally the amount of overestimation and underestimation separately. If the participants ranks the method one rank higher, one point is awarded. If the participant ranks the method two ranks higher, two points are awarded. The same is true for underestimation. No points are awarded when the participant ranks it in line with the scores. This is done for both the *first impression score*, (Appendix A question 11 turned into ranks compared to the overall performance score ranks), the *overall impression score* (appendix B question 15 ranks versus overall performance score ranks) as well as the close, medium, far, stationary and dynamic ranks versus their respective scores.

The 36 participants overestimated *Aiming with Mouse* the most with 114 points, followed by *Aiming with Gun* with 94 points, and the least overestimated aiming method is *Aiming with Head* with 63 points. On the other end, participants underestimated *Aiming with Head* the most with -133 points, followed by *Aiming with Mouse* with -81 points, with the least underestimated method being *Aiming with Gun* with -57 points.

the fact that *Aiming with Mouse* is the most overestimated is partly explained due to the fact that it was the lowest scoring method (24 out of the 36 participants scored the lowest with this method, see the pie charts in see section 7.3.4) What's noticeable about these results is that *Aiming with Gun* scored much higher than *Aiming with Head*, despite not being able to be overestimated in 22 out of the 36 cases, because for these participants, it scored the highest. This also means it had the most potential to be underestimated, but in fact had the least amount of underestimation with -57 points. *Aiming with Head* was the most underestimated, however keep in mind that *Aiming with Mouse* could not be underestimated by 24 participants, because it was their lowest scoring method.

7.9 Best Overall Ranking

The final question of the final questionnaire asks which aiming method was the best overall. This ranking encompasses all of the other factors, and some participants valued some aspects more than others, but fun factor, gameplay experience (i.e. how it "feels" to play), and accuracy where the main reasons for ranking *Aiming with Gun* as the best method overall. One participant explains:

> *"The gun method is so precise because you can use your wrist and because you can just turn your whole body it feels more fun. It felt way better than the other methods. I absolutely noticed myself having more fun with the gun than with the other methods. The head method can be nice too, but you quickly feel your neck protest. With the gun method this doesn't happen because the upper body moves as a whole."*

A big advantage of using motion controllers is that it doesn't require a flat surface in front of you to use. This helped *Aiming with Gun* in terms of immersion and comfort. In hindsight, perhaps it was better to let *Aiming with Head* users use the trigger of the motion controller instead of a mouse on the desk, allowing more freedom of movement.

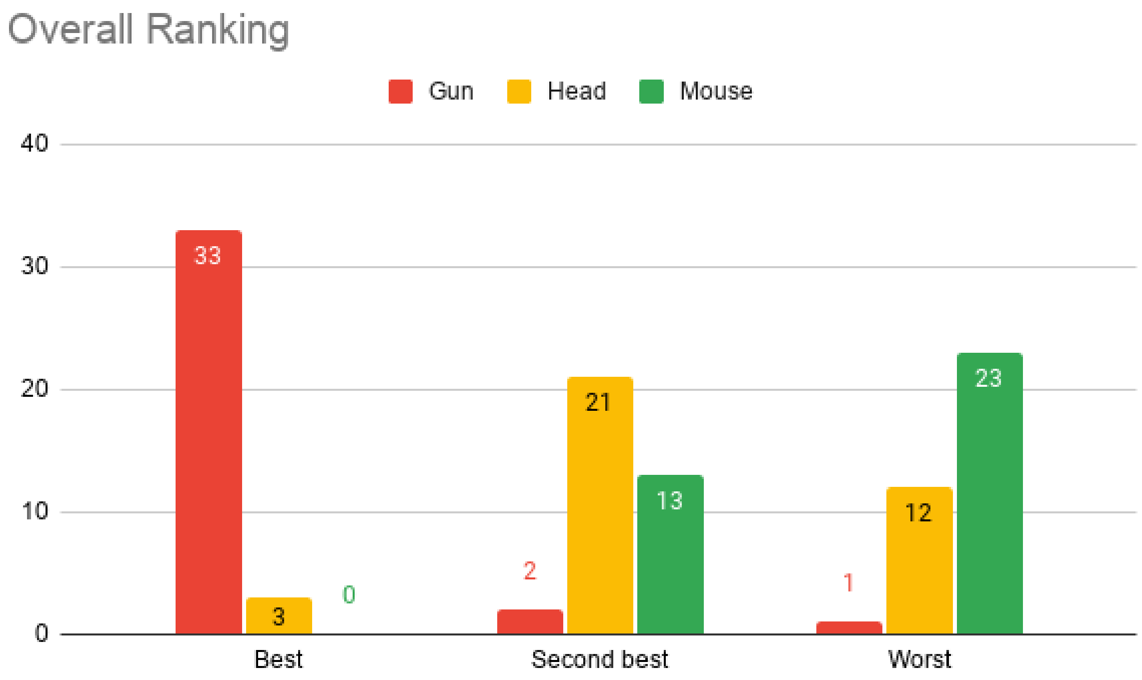


Figure 31: Overall best ranking.

As you can see, an overwhelming 33 out of 36 participants ranked *Aiming with Gun* as the best method. the majority of participants (21) ranked *Aiming with Head* as the second best, and a slightly higher majority (23) rated *Aiming with Mouse* as the worst aiming method. Another participant commented on the difference between aiming methods when firing on different targets. He writes:

> *"Aiming with Gun is the best method, it feels real and the handling is nice, therefore precision wins over the other two methods. In stationary targets or close ranged targets the difference between gun and head is a bit smaller."*

When regarding *Aiming with Head*, many participants found it easy to use, though some had trouble with uncomfortable neck positions when hitting targets at the edges of the target zone, as well as having difficulties with precision when it comes to faraway moving targets.
When regarding *Aiming with Mouse*, the main complaint about this method was the dual custody over the aiming direction. If they used both at the same time, sometimes the movement of the head and mouse would cancel each other out, or amplify movement where they would overshoot their targets. Some did mention that when shooting faraway stationary targets, holding your head still and moving the mouse felt a bit more precise than *Aiming with Head*.

8 Conclusion

The goal of this thesis is to find the best aiming method for VR shooters. In terms of immersion, *Aiming with Gun* is the best method because it closely mimics the real-life action of holding and shooting a gun. It also has the best gameplay experience because it is overwhelmingly rated as the most fun to play with. It rated as second most overestimated aiming method, despite the fact that it can only be overestimated if the method is not the highest scoring method already. Despite this method making your arm the most tired, it is rated as the most comfortable method by a *comfortable* margin (23 out of 36 ranked it the most comfortable method). When asked which method was the best directly, 33 out of 36 participants answered that *Aiming with Gun* is the best aiming method.

This assessment is further supported by the performance scores. Whether look at the overall performance score, or we break down the score in to its constituent parts, *Aiming with Gun* seems to score the highest. It is both the best at finding new targets quickly, as well as accuracy. Only when we look at consistency, the results are a little too close call with the *aiming with Head* being close to both other two methods, but it can be said for certain that *Aiming with Gun* is more consistent than *Aiming with Mouse*. The average amount of misses is the lowest in *Aiming with gun*(35.4), followed by *Aiming with Head*(42.8) with highest average misses being *Aiming with Mouse*(50.6).

When breaking down the scores according to target category, we see that the differences between aiming methods increase as the difficulty of the targets increase. The performance edge of *Aiming with Gun* is especially apparent in moving and/or faraway targets. The other two aiming methods do not excel in any subset of targets.

The main reason why *Aiming with Mouse* scores low, is because many people are struggling with using two types of movement to control the aim, which takes time to master, is distracting, and therefore is less fun and immersive. Performance suffers as well because of this. It should be noted that people with moderate to high levels of FPS experience had a much easier time with using the mouse to aim, Even though *Aiming with Mouse* is not quite the same using a mouse to aim on a flat screen.

Aiming with Head is the closest competitor in terms of performance, and because of it's simplicity it is easy to pick up and play with. However, having the aim tied to the head does lead to some problems, namely neck fatigue, and a difficulty in hitting targets that require precision. However, tracking close by moving targets was as simple and intuitive as following a moving target with your head.

Overall, *Aiming with Gun* is the best aiming method for VR shooters.

9 Future Work

This experiment shows that *Aiming with Gun* is the overall winner. This method is also widely used in commercial VR Shooter games. An interesting follow up experiment would be to take a closer look at other aiming methods with motion controllers, and comparing them to *aiming with Gun*. Dual-wielding guns is a popular way of shooting in VR games, as well as shooting with a rifle. Protube simulates the fixed relative hand positions when holding a rifle with a rod that magnetically connects the two motion controllers, see the image below.

Figure 32: Protube VR: a rod that holds the two motion controllers in place, simulating the hand positions when holding a rifle. The shoulder stock on the left simulates the kickback when firing a rifle.

Comparing a single gun, two guns, and a rifle would give further insight into how well these aiming methods perform, and in what situations. A possible extension to the testing program is to vary the targets that teleport each time that they are hit, targets that rapidly move towards you, or disappear behind cover occasionally. Dynamic targets could also move up and down, and any number of complex movements to simulate any game environment. When testing dual wielding, it would be interesting to how many targets at once can be handled by one person, slowly turning up the number of targets until the participant starts missing targets. Eye tracking built into VR headsets could help determine what the users intention is. If the eye tracking is accurate, it could help to improve *Aiming with Head*, and reduce neck fatigue.

Other forms of aiming that could be further explored with this testing program would be bow and arrow, as well as throwing and slinging rocks. These methods of aiming would suit games in a more medieval setting. Throwing in VR still has some hurdles to overcome. When slinging an object, the timing of letting go determines where your object will go. This timing is very precise in real-life, and a small amount of lag will have a noticeable effect on the trajectory. With future iterations of controllers, the responsiveness will improve, opening up new possibilities for VR experiences.

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10 Appendix A Questionnaire Part 1

To be asked after every aiming method.

Please answer the following questions by circling the relevant number.

1) To what extent is your neck tired?

Not at all 1 2 3 4 5 Very tired

2) To what extent is your arm tired?

Not at all 1 2 3 4 5 Very Tired

3) To what extent did you feel you were focused on the game?

Not at all 1 2 3 4 5 A lot

4) To what extent did you lose track of time?

Not at all 1 2 3 4 5 A lot

5) To what extent did you feel consciously aware of being in the real world whilst playing?

Not at all 1 2 3 4 5 Very much so

6) To what extent did you forget about your everyday concerns?

Not at all 1 2 3 4 5 A lot

7) To what extent were you aware of yourself in your surroundings?

Not at all 1 2 3 4 5 Very aware

8) To what extent did you feel as though you were separated from your real-world environment?

Not at all 1 2 3 4 5 Very much so

9) To what extent was your sense of being in the game environment stronger than your sense of being in the real world?

Not at all 1 2 3 4 5 Very much so

10) At any point did you find yourself become so involved that you were unaware you were even using controls?

Not at all 1 2 3 4 5 Very much so

11) How well do you think you performed with this aiming method?

Very Poor 1 2 3 4 5 Very well

12) How much would you say you enjoyed playing with this aiming method?

Not at all 1 2 3 4 5 A lot

13) immersion is the feeling of being present in the virtual world, and this world feels “real”. According to this definition of immersion, on a scale of one to 10, how immersed did you feel?

Not at all 1 2 3 4 5 6 7 8 9 10 Very much so

11 Appendix B Questionnaire part 2

To be asked after all three aiming methods have been used.

Please answer the following questions by circling the relevant number or filling it directly.

1) Do you have experience with First-person shooter games?

Not at all 1 2 3 4 5 A lot

2) Do you have experience with Using a Head-Mounted Display?

Not at all 1 2 3 4 5 A lot

3) Do you have experience playing VR First-person shooter games?

Not at all 1 2 3 4 5 A lot

4) Do you have experience firing real guns?

Not at all 1 2 3 4 5 A lot

5) What is your gender?

6) What is your age?

7) Please rank the three aiming methods. Which one was the most comfortable to use? Which one was the second most comfortable?

1st [ ] 2nd [ ] 3rd [ ]

Please explain why:

8) Please rank the three aiming methods. Which one is the best for stationary targets? Which is the second best?

1st [ ] 2nd [ ] 3rd [ ]

Please explain why:

9) Please rank the three aiming methods. Which one is the best for moving targets? Which is the second best?

1st [ ] 2nd [ ] 3rd [ ]

Please explain why:

10) Please rank the three aiming methods. Which one is the best for far away targets? Which is the second best?

1st [ ] 2nd [ ] 3rd [ ]

Please explain why:

11) Please rank the three aiming methods. Which one is the best for close range targets? Which is the second best?

1st [ ] 2nd [ ] 3rd [ ]

Please explain why:

12) Please rank the three aiming methods. Fill in the letters corresponding to the aiming methods. Which one is the best for medium range targets? Which is the second best?

1st [ ] 2nd [ ] 3rd [ ]

Please explain why:

13) Please rank the three aiming methods. Fill in the letters corresponding to the aiming methods. Which one is the most fun to use? Which is the second best?

1st [ ] 2nd [ ] 3rd [ ]

Please explain why:

14) Please rank the three aiming methods. Fill in the letters corresponding to the aiming methods. Which one made you feel the most immersed in the experience? Which is the second best?

1st [ ] 2nd [ ] 3rd [ ]

Please explain why:

15) Please rank the three aiming methods. Fill in the letters corresponding to the aiming methods. Which one did you think you scored the best in? Which one the second best?

1st [ ] 2nd [ ] 3rd [ ]

Please explain why:

16) Please rank the three aiming methods. Fill in the letters corresponding to the aiming methods. Which one is the best overall? Which is the second best?

1st [ ] 2nd [ ] 3rd [ ]

Please explain why:

This is the end of the experiment. Thank you for participating!

12 Appendix C Master Results Sheet

Below included is the master results sheet in one page. Every test person has four lines, The first line includes all the aiming methods combined, followed by the aiming methods in the order that the person took the tests. Below the purple line are the four lines which are the average of the scores, followed by scores split by levels of experience. At the end, all scores are sorted per aiming method for an easy application of ANOVA and t-tests in a separate sheet.

Testperson Nr	Subset	Overall Score	Close Score	Medium Score	Far Score	Static Score	Dynamic Score	Overall Accuracy	Conservative Bonus	Acquisition Bonus	First Hit Time	Distance from Previous Target	Speed (degrees/s)	Bullseyes	Misses
1	all	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Gun	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Head	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Mouse	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	all	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Head	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Mouse	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Gun	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	all	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Mouse	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Gun	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Head	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	all	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Gun	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Head	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Mouse	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	all	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Head	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Mouse	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Gun	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	all	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Mouse	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Gun	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Head	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	all	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Gun	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Head	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Mouse	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	all	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Head	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Mouse	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Gun	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	all	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Mouse	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Gun	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Head	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10	all	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Gun	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Head	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Mouse	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
11	all	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Head	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Mouse	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Gun	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12	all	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Mouse	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Gun	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Head	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
13	all	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Gun	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Head	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Mouse	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
14	all	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Head	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Mouse	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Gun	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]