Effects of Perceived Speed on Performance Between Eye-Gaze and Mouse Input in a Rhythm Game

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ABSTRACT

UPDATED—May 29, 2020. In recent years, eye tracking has become a more popular input modality and is utilized in both assistive applications and immersive computer games. Related work within the subject indicate that the implementation of gaze-awareness can increase efficiency in some applications, but also that results vary greatly between different types of applications and types of technical implementations. This paper aims to investigate how well eye tracking performs in a rhythm game when compared to input from a tradition pointing device (mouse) at different stages of perceived speed and limited reaction time. For the study, a gaze-based video game called Gaze Hero has been developed, in which the player must hit notes that timely appear in a one-dimensional array, similar to gameplay in the Guitar Hero game series. From the evaluation of the game, in which 16 participants played on 3 different levels of perceived game speed, no evidence was found to support that using gaze as input modality results in better performances in a game where timely precision and continuous saccadic motions are required with high accuracy. Contrarily, participants performed better when using mouse as input in fast perceived situations where objects move fast and require quick reaction times. However, in situations where the player has a greater time to react and plan upcoming saccadic motions, no statistical significant difference was found in the performance between gaze and mouse. This suggests that gaze input may be a sufficient substitution for interactions in which the user has at least 1.14 seconds to react and plan gaze movement.

Author Keywords

eye tracking; performance; gaze-based video game;

INTRODUCTION

In recent years, eye tracking as an input modality has become an increasingly popular choice of implementation in commercial video games. Eye tracking hardware is becoming cheaper to make due to the increasing availability of fast image processing hardware, and the limited components required to make the eye-tracking device. As the cost of manufacturing these devices are decreasing, eye tracking technology is becoming more accessible to casual users [3].

While the eyes are foremost used to receive and transform visual information to the brain, the use of eye tracking technology allows developers to utilize the gaze position as an input modality which enables new types of attention aware games and applications. The use of eye tracking in video games and other computer applications has many benefits, and using gaze position as an input modality enables completely new ways of playing.

The most straightforward is to replace existing input modalities with gaze input. In games that utilize gaze position as input, gaze is often used as an additional input modality to more traditional input modalities such as mouse and keyboard or a handheld controller. In these cases, the goal is to complement other input devices thus increasing efficiency, immersion or user experience through the added gaze-awareness in the application. This implementation method is referred to by Jakob as gaze-augmented input [12].
However, in other cases, it can also be feasible to replace an existing input modality completely with eye tracking. This method of implementing and using gaze input is referred to by Jacob as gaze-based input [12], and is also used in gaze-enabled assistive technology which can enable physically disabled users and users with other motor-impairments to play games and use applications that would otherwise be unavailable to them, and in this way partake in virtual communities and learning environments [10].

Another benefit is related to how gaze is used in non-verbal human-human interactions. In social interactions, humans change the direction of their gaze for either monitory or expressive reasons. By gazing towards another individual, we can observe or monitor their behaviour. Simultaneously, we can direct our gaze if we seek to express something, or regulate the behavior of other individuals. This expressive use of gaze is, for instance, used to communicate our attention, or to direct verbal communication towards a specific individual in a conversation with multiple parties [13][23].

In addition to gaze being a natural part of social interactions, gaze can also provide context for a non-social interaction.

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When intending to interact or perform communicative actions, humans often most address the target of the interaction by directing their gaze towards it. For instance, when interacting with devices in an office using verbal commands, users almost always look at the device prior to issuing the voice command [15]. With this in mind, through the use of gaze position, we are more easily able to make presumptions about the user's intentions, and for instance, use that information to make the interaction more seamless or efficient.

Lastly, and as furtherly described in a later section, eye movements such as saccades can be performed at a very high frequency and velocity. Moreover, saccades are made more than 100,000 times a day (approximately 3 times a second in average) and have very little effect on eye-fatigue [8]. This allows gaze interactions to be performed very efficiently and at a high frequency, as long as the user interface is designed to support it.

In this study, it is investigated how well gaze as an input modality performs when compared to a more traditional input device (a mouse), more specifically in relation to perceived game speed and limited reaction time. By developing a game that is entirely gaze-based, users with motor-impairment and other physical disabilities have an equal opportunity to play the game. Additionally, using gaze may also increase or result in similar player performance, and be a viable input modality for competitive games. As eye tracking hardware is becoming more accessible to users, the incentive for developing gaze-based and gaze-augmented games also increases.

For the study, a gaze-based video game, called *Gaze Hero*, has been developed. The game is a gaze-based adaptation of the rhythm game Guitar Hero [24].

RELATED WORK

In order to develop a gaze-based video game, it is important to understand the different types of eye movements that exist, and how they can each be utilized for gaze interactions in software applications. In this section, different types of eye movement will be explored.

Eye movements

The movement of the eye can generally be categorized into four different types of eye movement; stabilized fixations, saccades, smooth pursuits and vergence.

Fixations refer to the eyes being in a relative still state while fixated on an object. During fixation, micro-movements (micro-saccades, tremors and drifts) of the eyes still occur in order to constantly gain new information through the retina [16].

Saccades describe rapid movements of the eyes between two or more fixation points. Saccades vary in speed and duration, but the eyes will always move as fast as possible during a saccade (up to a maximum velocity of $500° s^{-1}$). The highest frequency at which saccades can be made is once every 130ms ($4 s^{-1}$), which for instance can occur when rapidly reading some text or scanning through a scene [14][3].

Smooth pursuits refer to fixations on a (smaller) moving target. When a stationary fixated target starts moving, the eye begins following the object with a slight delay (~100-150ms) in a smoothly manner [14].

Vergence movements describe the adjustment of the angle between the eyes. When changing fixation points between objects that vary in distance (depth), the angle between the eyes are adjusted in order to clearly fixate on the object (also referred to as non-conjugate movements, contrary to conjugate movements where the eyes move the same direction).

While these different eye movements naturally occur, they have each been exploited to different extends in the field of Human-Computer Interaction, with the purpose of developing usable gaze interaction techniques.

Gaze interactions and -gestures

Gaze interactions refer to any interaction performed using only gaze, while gaze gestures is defined by Istance et al. as "*a pattern of eye movements performed within a limited time period*", "*and used to signify a particular command or intend*" [11].

The purpose of using gaze gestures in order to signify intend, is to accommodate the *Midas Touch Problem*. *The Midas Touch Problem* arises as the eyes function as an always-on device, which results in challenges recognizing user intend. It is not desireable to initiate system commands simply by using gaze location, as users expect to be able to scan through items with their gaze without immediately relaying intend [12].

The three different interaction types presented, fixation-based, saccade-based and smooth pursuit-based, are all attempts to accommodate this problem by recognizing different types of eye movement as intended system input.

Fixation-based interaction (dwelling)

Fixation based interaction refers to interacting with objects and activating buttons and other elements on the screen by holding the gaze upon the object. In order to activate elements, fixation on the desired element must be continuous for the duration of a set dwell-timer, which then results in the element being selected.

It is important to recognize that dwelling is a separate action from the initial inspection of the element, which is why a dwell-timer is required to reduce the amount of unintended selections. Regardless of the dwell time, fixation-based interaction sets a limitation to both inspection time and efficiency of the interaction. Furthermore, dwelling for longer durations can be fatiguing for the eyes and result in unintentionally moving the gaze away from the target before the required dwell time is reached [9]. Dwell times have been evaluated in previous research, and often in correlation to a specific task or interaction.

In a study by Jacob, it is underlined that in interfaces in which undoing an unintended selection is easy and efficient, dwell times can be as low as 150-250 milliseconds, while interfaces where undoing a selection is more difficult or time-requiring should make use of higher dwell times [12]. Møllenbach et al. emphasizes that when comparing different dwell times, error rates are in direct correlation with the layout of the interface and nature of the task [16].

Saccade-based interaction

Saccade-based interaction refers to gaze gestures in which the user performs a sequence of intended saccades between set fixation points, called a stroke. A stroke is defined as a saccadic motion between two or more intended fixation points. Strokes differs from a saccades as the fixation points in a saccadic motion are arbitrary, and not necessarily intended.

Advantages of using saccade-based interaction include efficiency, as saccades can be very quick. Moreover, this type of interaction can be designed to require strokes that differ greatly from regular saccade patterns, and therefore result in a lesser likelihood of unintended selections [16].

Even though saccadic motions can be performed quickly, Istance et al. found that completion times for strokes with two or tree fixation points (two and three-legged gestures) are similar to dwell-based interaction times, and found that not having to fixate on an object for a set dwell duration is the main advantage of using saccade-based gestures [11].

Likewise, Møllenbach et al. did not find any significant difference in completion times when comparing dwell interactions with saccade-based ones. They suggest that mixture of dwelling and gaze gestures is the key to implement gaze selection strategies [16].

Smooth pursuit-based interaction

Interactions that utilize smooth pursuits describe interactions in which the user follows a moving object with their gaze in order to interact with it.

Esteves et al. found that using this interaction method for smart-watch interactions such as volume control yielded a very low rate of false positive selections. Furthermore, using this type of interaction allows for continuously adjusting a parameter depending on the duration of the pursuit which can be beneficial for some interactions. However, they also found that users don't immediately understand how to interact using smooth pursuits, as it is unintuitive even for users who are experienced with eye tracking [4].

In a study by Špakov et al., smooth pursuit-based interactions are compared with dwelling-based interactions for continuously adjusting values. They found that interacting with smooth pursuits (both rotary and linear pursuits) were rated lower with regards to usability than dwelling by test participants [26].

In the game developed for this study, Gaze Hero, a combination of gaze interaction techniques are utilized. Firstly, the user is tasked with selecting lanes in which objects appear by gazing at them. The interaction is fixation-based, and the selection is instantaneously thus not requiring any dwelling at the target. The reason for this decision is due to the game's reaction-based nature, as it is essential to be able to select a lane as quickly as possible. As it is underlined by Jakob [12], selections that efficiently can be undone or overwritten by a new selection, and cause no adverse effect, do not require a long dwell timer. In the game, any lane selection is only active for as long as the player gazes at it, and is immediately overwritten by gazing at a new lane.

Additionally, saccade-based interactions are used in the game. This is due to the game requiring the player to quickly change the selected lane by performing saccades between them, depending on the lanes in which the objects appear. To elaborate, the game does not require the player to perform fixed gaze gestures in order to perform specific interactions, however saccadic motions are required in order to finish the game with a high player score. The difference here, is that the saccades required changes depending on the objects that appear, and are not saccadic patterns that needs to be learned.

Performance of gaze controls in games

Using gaze as input may be more efficient and yield a higher accuracy in some games. This is however dependent on the type of game and type of eye tracking implementation, as well as the task performed.

In a study by Prada [5], it is shown that the implementation of gaze-awareness as an additional input modality, can be used effectively to draw attention to game objectives by highlighting those that the user has not gazed at yet. In the study, this implementation significantly reduced the time required for users to complete tasks in a custom space-shooter style game, whilst also being perceived as more enjoyable [5].

While the study by Prada does not focus on replacing an existing modality with gaze input, it shows how gaze-aware game implementations can assist players in improving their performance, which underlines the ability of the modality to increase task completion efficiency.

In a study by Smith and Graham [17], performance of gaze-augmented input is compared to traditional mouse-input in relation to three different games: *Quake 2*, *Neverwinter Nights* and *Lunar Command*. All three games were modified to enable gaze input, and in each game the mouse-input would be replaced with gaze-input for that test condition (keyboard-input remained in all three games on both conditions). 12 participants played all three games, and task completion times were collected for Quake 2 and Neverwinter Nights, while score was collected from Lunar Command. Results from the study showed no statistical significant between completion times in Quake 2 and Neverwinter Nights. However, participants scored significantly higher in Lunar Command using mouse [17].

The study demonstrates that replacing traditional mouse input with gaze input can yield a similar player performance, but also that results depends on the game objective and implementation of the gaze-based controls. In Quake 2, gaze was used to rotate the in-game first person camera; looking towards a target would rotate the camera until that target was centered on the screen. This implementation utilizes the contextual information provided by the gaze position (users look towards objects that they want to interact with), and is complementary to the game's objective of shooting the targets in sight. Likewise, in Neverwinter Nights, players had to look towards a position on the screen and hit a button in order to initiate character movement towards that location. This interaction is simple, and follows the same concept of using the contextual information provided by the gaze. Lastly in Lunar Command, players had to shoot targets in a 2D space with projectiles that launched towards the gaze position when pressing a keyboard button. However, as targets were moving through space, players had to accommodate for this by leading their aim in front of the target. Participants found it difficult to fixate on an empty space in front of the target, as their gaze would naturally

follow the target in smooth pursuits, which would result in a miss.
What is important to note from this study, is that in both Quake 2 and Neverwinter Nights, the implementation of gaze-input was very complementary to the objective of the game, and in most cases, the the players' gaze position would naturally be in the desired position for the gaze interaction. This means that players did not have to intentionally move their gaze point unnaturally in order to issue a specific gaze interaction. This however is the case in Lunar Command, where players would have to unnaturally move their gaze point in front of the target to succeed.

In a study by Dorr et al. [2], a paddle-type game called Breakout 2 was modified to function with gaze as primary input (replacing mouse input). The game is based on the original Pong in which the player controls a paddle in the bottom of the screen. The objective in Breakout is to destroy as many bricks in the top of the screen by continuously hitting a ball with the paddle, while also keeping the ball from exiting through the bottom of the screen. In the study, 20 participants were playing against each other in pairs, half of which were playing using gaze while the other half played with a mouse. The results showed a that participants playing with gaze had a significant advantage as they won almost two thirds of all rounds played. [2].
This study is particularly relevant, as it in a similar regard investigates and compares performance between gaze and mouse as input in a video game. However, the results might be a consequence of the simplicity of the game, as the player only have to follow a single object (the ball) with their gaze in order to succeed: "*Apparently, she had just constantly looked at the ball (and therefore always hit it with the paddle) without even realizing that the paddle followed her gaze!*" [2].
This limits the interaction drastically, as the players only need to perform smooth pursuits, which is a very natural type of eye movement, and does not require performing any intended eye movements or -gestures.
In contrast, in the game developed for this study, Gaze Hero, players have to perform saccades between different objects, rather than just follow a single object.
One thing that was inspired by the Breakout study however, is the always-on interaction method that is utilized. Rather than having to control the paddle through an overlay interface or similar, the paddle simply follows the gaze position, which is very intuitive and fits the game's one-dimensional nature perfectly. Similarly, the player can select lanes in the game made for this study, simply by gazing at them, without having to perform any gestures or dwell at the location for a set dwell-time.

Istance et al. [11] developed an overlay that uses gaze position to emulate mouse and keyboard events, which allows the user to play the online game World of Warcraft. However, World of Warcraft, is a very complex game that requires many different inputs to be played efficiently, and often multiple at once. To accommodate for this complexity, Istance et al. developed the overlay in such a way, that users would have to access specific modes of the overlay (locomotion, left- and right-clicking) by performing gaze gestures, after which, dwelling in specific spots of the screen would initiate commands (such as moving the character). Not surprisingly, they found that using the overlay decreased the efficiency of completing in-game objectives when compared to using mouse and keyboard as input devices. Additionally, they found that users' gaze would act unintendedly as input in certain situations where the intend was to scan through a scene or read text [11]. This issue is directly related to the previously described Midas Touch Problem.
This study demonstrates that using gaze as the primary input-modality does not necessarily increase efficiency and player performance. The results indicate that the player performance could vary depending on the type of technical implementation used. In this case, a third party software is used to translate input, whereas other other games are developed from scratch, or modified directly in the source code to support gaze interactions.
There is a concern regarding The Mida's Touch Problem that arises from this study in relation to Gaze Hero, however, as the interactions required to play are fundamentally different between World of Warcraft and Gaze Hero, this concern is lessened. In World of Warcraft, players are constantly prompted with new visual information and texts that can be read, which more easily leads to unintended dwell selections, than what you would expect in a game where the primary task is to gaze at appearing objects. However, with new objects constantly appearing, the player may become conflicted as to which objects to gaze at, rather than gazing at the objects in the sequence that they appear.

DESIGN OF GAZE HERO

In this section, the game developed for this study, Gaze Hero, will be presented. The design of the gameplay has been made to imitate Guitar Hero as close as possible, but to allow for a fully gaze-based interaction.

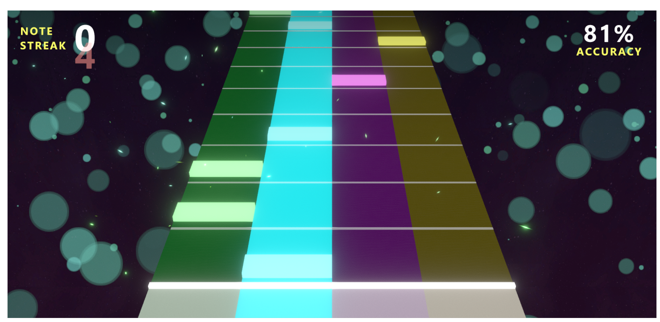

Figure 1. Screenshot from Gaze Hero during gameplay, where the blue lane is highlighted. Incoming notes are seen in all four lanes. The white line near the bottom of the screen is the strum line, which will play the notes if the corresponding lanes are highlighted as the notes hit the line.

The game is based on the genre *rhythm games*, in which the objective is to hit as many *notes* as possible, each simulating the sound of a musical note being played. The gameplay is similar to that in the rhythm game Guitar Hero [24], in which the player uses a guitar-based controller to play incoming notes. In Gaze Hero, the player uses their gaze to play notes by looking at the lane that they move in.
The notes are rectangular objects that will appear on the screen in a fixed sequence (but varies between different music played),

and gradually moves towards the player's point of view on a *highway* (from the top of the screen to the bottom). The highway consists of a set amount of *lanes*, each colored differently to visualize the separation clearly. Notes are colored depending on which lane they appear in, and can be hit by *highlighting* (selecting) the corresponding lane, before or as the note hits the *strum line* near the bottom of the screen. A screenshot from the game can be seen in figure 1.

In Gaze Hero, the highway consists of four individual lanes: green, blue, purple and yellow. The number of lanes were initially selected as to reduce the number of false selections for the gaze-based interaction, as a lower number would allow for wider lanes. As the player selects a lane, which is done by gazing at it, or by hovering the cursor over it depending on which input-modality is used to play, notes in the highlighted lane will be played as they hit the strum line. Notes can also be played by highlighting the corresponding lane of a note that is currently touching the strum line.

Highlighted lanes are visually highlighted by brightening the color of the lane. When notes are hit, a small explosion is appears at the strum line in the lane where the note was hit, and the note disappears immediately. The explosion is also colored correspondingly. In case of a miss, the note will continue moving and disappear outside of the screen. To further indicate the miss, the strum line will turn red for a short period, an auditory cue will be played (a *woosh* sound) and the volume of the music track will lower shortly.

While the gameplay in Gaze Hero and Guitar Hero is very similar, the design of the main gameplay mechanic (playing notes) has been slightly altered. In Guitar Hero, players use one hand on the controller to highlight the lanes corresponding to appearing notes, and play them as they hit the strum line by using the strum bar on the controller with the other hand, effectively separating the mechanic of playing a note into two interactions that must be performed simultaneously. In Gaze Hero, players highlight lanes using their gaze, and no further action is required in order to play notes that appear in the highlighted lane; the notes will play automatically as they hit the strum line on the screen. This decision was made to eliminate the use of an additional button, ultimately allowing for a fully gaze-based interaction.

Technical implementation

Gaze Hero has been developed in Unity [18], a 3D application development tool and game engine. In order to support eye tracking, gaze functionality has been implemented using Tobii Core SDK, which provides a framework for developing gaze-enabled games that utilize Tobii's eye trackers [19]. By utilizing this development kit, implementations were made to support the Tobii Eye Tracker 4C.
The game can be played using either of two enabled input-modalities, gaze and mouse. When playing with gaze, mouse input is completely disabled in order to have a true gaze-based gaming experience.

As Gaze Hero is a rhythm game, in which playing a particular song or piece of music is simulated, it is important to ensure that the notes match the music track played in regards to tempo. Tempo describes how fast a song is played, and is often most measured in BPM (Beats Per Minute) [25]. In Gaze Hero, each beat is separated into a fixed number of *ticks*, and each tick can contain a note, or a blank space. For instance, a song that plays at 60 BPM with 4 ticks per beat will have 240 ticks per minute or 4 ticks per second. The number of ticks is optional and determine the lowest possible distance in time between notes, while BPM has to match the music tempo in order for the ticks to match the beats of the music. BPM has been measured using an online tool [6].

Eye tracking accuracy, precision and latency

While it is beyond the scope for this project to determine the accuracy, precision and latency of the Tobii Eye Tracker 4C, it is still relevant to consider these variables when designing gaze-based interactions.
Tobii defines accuracy as the average distance between the actual gaze point and the measured gaze point, and precision as the variance in the measurements. The latency is the measured interval between the point of an image capture by the sensor and the point that the gaze data is available for that image [20].

The predecessor to the Tobii Eye Tracker 4C, the Tobii EyeX, was measured in previous work to have an accuracy of 0.6°, a precision of 0.25° and a latency of <50 ms [7]. The Tobii Eye Tracker 4C has a sampling rate of 90 Hz, and purportedly includes other performance enhancement when compared to the EyeX [22]. We can therefore assume that the 4C has an equal or better performance in regards to accuracy and precision, and an equal or lower latency.

Assuming a combined accuracy and precision of 0.75° at a distance of 60 cm from the screen, the eye tracker will vary in measurements up to ~0.8 cm, or ~0.3 inches $((sin(0.75)x60)/sin(180-0.75-90) = 0.78541)$. On a screen with a PPI (pixels per inch) of 96 (1920x1080 resolution on a 23" display), the combined accuracy and precision should range within 30 pixels. A PPI of 129 (1920x1080 resolution on a 17" display) yields a combined accuracy and precision within 40 pixels.

Game variables

In Gaze Hero, there are three primary variables which can be changed in order to change the difficulty or perceived speed of the game: *ticks per beat*, *strum window size* and *distance between ticks*. Each variable will be presented, and the potential effects of altering the variable will be discussed with the research topic in mind.

Ticks per beat, as described before, determines the lowest possible distance in time between notes. By increasing this value, the distance in time between notes in adjacent ticks decrease, thus increasing the difficulty of the game, as saccades between lanes must be performed more quickly. However, this variable cannot simply be increased in order to increase the difficulty, as the notes should match the musical notes in the song played. If increased, the number of empty ticks between ticks that contain notes must be increased correspondingly (otherwise notes will no longer match the music, and will appear too quickly).

Strum window size determines the time window in which it is possible to hit a note after it has reached the strum line. The default value, 1, allows the player to hit the note in a time window of approximately 60 milliseconds from the moment it touches the strum line. Increasing this value may allow the player to hit notes that has already passed the strum line, and therefore decreases the difficulty of the game, as the required precision of timing saccades between lanes decreases. This value is afterwards multiplied by the *highway speed* in order to keep the time window constant (equal to the distance between ticks multiplied by ticks per second).

Distance between ticks determines the visual distance between ticks. As the visual distance is changed, but the time between ticks remain the same, the highway speed must change accordingly to compensate for the change in distance. This effect is in this paper referred to as ***perceived speed***. As an effect of increasing the perceived speed, the time that notes are visible in the game is reduced, which ultimately reduces the time that the player has to react to appearing notes.
In addition to the distance between notes, BPM and ticks per second also have an effect on the highway speed, and ultimately the perceived speed. This is a result of the distance between ticks being unaffected by these values.

EVALUATION

To evaluate the game, two independent user studies have been performed. This section will describe the purpose, method, procedure and outcome of those studies.

Apparatus and test setup

The intention for the test setting was to set install a desktop in a laboratory equivalent setting, in a closed room with no distractions.

The test setup would consist of a desktop PC, capable of running the game consistently at 200+ frames per second, a Tobii 4C Eye Tracker and a 23,5" Samsung monitor (with a refresh rate of 144 Hz) placed at a distance of approximately 60 centimeter, as to follow the guidelines regarding screen size and viewing distance set by Tobii [21]. Sound for the game would be provided through the use of a HyperX headset which would further reduce potential auditory distractions.

Test participants were primarily recruited online, through advertising on forums and in university working groups. A copy of the recruitment advertisement can be seen in appendix A.

First evaluation: Camera angle

The first evaluation was performed with the primary purpose of selecting an in-game camera angle. A total of four different camera angles were priorly established through exploration, with the intention of selecting one of these angles to be used in the final evaluation. Moreover, this study would function as a pilot-study in order to see how well the test setup and data collection would function.
The camera angles included in the test varied on two parameters: Y (height above the highway), and FOV (Field of View), and were named accordingly: (1) *high Y high FOV*, (2) *low Y high FOV*, (3) *high Y low FOV*, (4) *low Y low FOV*. A comparison between the angles can be seen in appendix C.

Method

A total of 7 test participants were recruited, 4 of those from online advertisement (who participated remotely). A pilot test was performed with a single participant, and were included in the test results as the test setup did not change afterwards. All participants played using gaze as input modality. Each participant played the same sequence of 99 notes four times, each time from a different camera angle, resulting in a sample of 28 sets of data, and a total of 396 notes per participant (excluding a short tutorial, from which no data was gathered). The order of camera angles were chosen at random. After finishing the test, the participants were asked about their preferred camera angle, and asked to input any comments or issues that they had during testing.

Procedure

All participants were required to play through a short tutorial of 13 notes, in-between which short texts explaining the gameplay and interaction would appear. No further condition was set for successfully finishing the tutorial. After finishing the tutorial, the participants played through the same sequence of notes four times, one time on each camera angle. For each trial, data were recorded in a spreadsheet, containing information about each note: whether it was hit (hit/miss), the type of hit (direct/late), gaze location (lower/middle/upper) and more. An example of the gathered data can be seen in appendix B. Lastly, the game would ask the participant about their preferred camera angle, and allow them to add comments. Participants would then be thanked for their participation and test results would automatically be uploaded.

Results

The primary outcome of this evaluation used to determine the camera angle was the *note hit percentage*, and *preferred camera angle*. Camera 1 and 4 yielded the highest hit percentage (both 84.7% hit, SD = 14.5, and = 15), camera 3 yielded a hit percentage similar to camera 1 and 4 (83.2% hit, SD = 15.7), while camera 2 yielded the lowest hit percentage (77.3% hit, SD = 14.5). The hit percentages gathered from the test can be seen in table 1. A One-Way Repeated Measures ANOVA revealed no statistically significant difference between the groups ($p = 0.06$, see appendix E).
Camera 3 was the most preferred camera angle with 4 total votes. The other camera angles received 1 vote respectively.

Cam no.	Hit percentage	Std.dev.
1	84.7	14.5
2	77.3	14.5
3	83.2	15.7
4	84.7	15.3

Table 1. Note hit percentage by camera angle from first evaluation

Discussion

Looking at the results, the hit percentages are very similar between the camera angles. The highest deviation is camera angle 2, which yielded the lowest hit percentage (~6-7 percentage lower than other angles). This may however be explained by the randomization of the order that the camera angles appeared in. This led to camera 2 appearing earlier in the test

than other cameras angles on average (see appendix D). This was a result of the low number of participants, as no complete Latin square randomization of the order of camera angles was possible.
The intention was to select a camera angle that received an average hit percentage whilst also being well-received by participants. For these reasons, camera angle 3 was selected.

Second evaluation: Effects of perceived speed on performance between gaze and mouse

The purpose of the second and final evaluation conducted was to evaluate how well gaze-based input performs in Gaze Hero when compared with mouse-input, more specifically with respect to perceived speed and reduction in time that notes are visible in the game.
For the evaluation, 3 different degrees of perceived speed were selected, identical for both the gaze and mouse test condition. The values were set by adjusting the distance between notes, which in addition to altering the highway speed also had an effect on the time that notes were visible on screen, as previously described. Higher perceived speed would therefore effectively reduce the reaction time window for hitting newly appearing notes. The strum window size would remain the same in regards to time for all three values.
The three values were selected through exploration, and selected to ensure that all participants would be able to react to incoming notes, even at the highest value. Furthermore, they were selected to increase systematically in speed, effectively doubling the value for each step. The values for *distance between notes* selected, were the following: **0.625**, **1.25** and **2.5**. This resulted in notes being visible on the screen for respectively **2.3**, **1.14** and **0.58** seconds, which is well above the average human reaction time for visual stimuli at 250 milliseconds [1].

Method

In order to compare performance between two different input modalities (gaze and mouse), an AB test was conducted with two groups of participants. A total of 16 participants were recruited for this evaluation divided between the two test conditions, 8 for the gaze condition and 8 the mouse condition. No participants were allowed to participate in both test conditions, in order to allow for an independent sample test of statistical significance. Participants consisted of 13 men and 3 women, ranging from 22 to 70 years old (mean = 30, SD = 12,6). 12 out of 16 participants participated remotely.
Each participant played the same sequence of 99 notes three times, one time for each value of perceived speed which were determined prior to the test. The sequence that the three values would appear in was chosen at random. Data from each note was gathered from all three tests in the same manner as the first evaluation, resulting in a sample of 297 notes per participant (excluding a short tutorial, from which data was not gathered). Additionally, data were gathered about the demographics of the participants, how often they played video games and how much experience they had with eye tracking devices. Lastly, participants were also able to leave any comments and asked to report if they encountered any issues during the test.

Procedure

When the participants first entered the game, they were asked about their gender, age, how often they play video games, and for the gaze test condition, how much experience they had with eye tracking. The participants for the mouse test condition would be asked about their mouse DPI as a substitute question. Like in the first evaluation, participants were required to play through a tutorial, after which, they would play a longer sequence of notes a total of 3 times, one for each value of perceived speed. Lastly, the participants were asked if they had any comments, and asked to report any potential issues experienced. Participants were then thanked for their participation, and test results would automatically be uploaded.

Results

Results from all trials performed were used in the analysis, as no outliers were found using a Z-score analysis. Performance results with respect to perceived speed values can be seen in table 2. A more detailed overview of the data and mean hit percentages can be seen in appendix H. Performing

		Slow	Medium	Fast	*mean*
gaze	mean	**75.63**	**82.07**	**60.10**	**72.60**
	variance	137.85	156.04	150.24	102.43
	st.dev.	11.74	12.49	12.26	10.12
mouse	mean	**87.5**	**86.36**	**83.96**	**85.94**
	variance	99.21	108.15	354.67	158.28
	st.dev.	9.96	10.40	18.83	12.58

Table 2. Mean hit percentages with respect to perceived speed values

an independent t-test showed a statistical significant difference between the performance between participants using gaze and mouse as input-modality (disregarding the perceived speed values). Participants using mouse performed significantly better in average than participants using gaze ($p = 0.046$).
Comparing the two groups by performing independent t-tests with respect to each value of perceived speed yielded a significant difference in performance when playing on the fast perceived speed value ($p = 0.013$), but no statistical difference was found between performances on respectively slow and medium speeds ($p = 0.061$ and 0.495). Independent t-tests performed between groups with respect to different values of perceived speed can be seen in appendix F.

Additionally, dependent t-tests were performed between different values of perceived speed within both groups. The t-tests revealed a significant difference in performance for participants using gaze, respectively between slow and fast speeds ($p = 0.004$) and medium and fast speeds ($p = 0.002$). No significant difference was found in performance of participants using gaze when comparing slow and medium speeds ($p = 0.201$), nor for participants using mouse between any speeds (slow-medium $p = 0.398$, slow-fast $p = 0.455$, medium-fast $p = 0.561$). Dependent t-tests performed within groups can be seen in appendix G.

Lastly, performing an independent t-test with respect to eye tracking experience showed no statistical difference between players who are active users and developers when compared to players with none or little experience ($p = 0.939$). Likewise,

no statistical significant difference was found between participants using gaze when comparing the participants who play video games monthly or weekly with those who play daily ($p = 0.136$).
However, performing an independent t-test with respect to video game playing frequency for participants using the mouse input modality, participants who play daily (mean = 95.62, SD = 1.45) performed significantly better than those who never play video games (mean = 72.05, SD = 12.12, $p = 0.031$).

Discussion
From the evaluation analysis it is clear that players that use gaze as input modality in Gaze Hero had no advantage over players using mouse. On the contrary, mouse participants performed significantly better in average, and more exceedingly in the fast perceived speed trial. While participants using mouse performed significantly better on average and in the high speed trial than participants using gaze, there is no evidence of a significant difference in the performance on slow or medium values of perceived speed. This may indicate that mouse is better suited than gaze as input modality in fast paced situations with limited reaction time and fast moving objects that must be reacted to, but also that gaze-input may perform equally in scenarios where the player has more time to respond and mentally prepare a specific saccadic motion between objects.

Additionally, it must be noted, that only 3 out of 8 participants for the gaze-input group were either active users of, or developers for, eye tracking technology, while the 5 remaining participants had either no or very little experience using it. While the experience with eye tracking had no significant impact on the performance of participants in this study, from the evaluation, it is also clear that practice does have an effect on performance; participants who play video games daily performed significantly better in the mouse-input group than those who never usually play. The fact that no significant difference was found when comparing performances in the gaze-group with respect to frequency of playing games may be explained by the lack of eye tracking experience; experience playing using regular input devices may not immediately transfer to a better performance when using gaze as input. Supporting this claim, a participant commented "*Very hard learning curve, but I definitely felt like I could get it*" later followed by "*the 3rd round seemed a lot easier once I got the technique.*", also indicating that the learning curve of the game may have been to steep for participants using gaze as input. Another participant using gaze commented "*The eyes naturally want to look at the upcoming notes.*", suggesting that gaze-participants had difficulties in forcefully looking at specific notes as they hit the strum line, while new notes continuously appeared from the top of the screen. This leads to the speculation that gaze participants may have performed better had the task been to select lanes as quickly as objects within them appeared, contrary to selecting them with timely precision.

LIMITATIONS
As an effect of the COVID-19 pandemic, it has not been advisable to facilitate physical user studies due to the risks involved. Therefore, user tests for this study have been conducted virtually by programming the game application to automatically follow the desired test procedure, without the requirement of a test facilitator.
For this reason, test setting, apparatus and setup varied between tests, as participants would complete the test on their own setup, and in varying environments. As an effect, it has not been possible to control variables in relation to screen size, hardware performance, eye tracking calibration and environmental distractions, which may have affected the results of some evaluations. A few potential participants also reported that they were unable to complete the test as they encountered issues or bugs within the game that seemingly only occurred on their system.
Additionally, as the number of potential test participants was unpredictable, it has not been possible to carry out evaluations in a specific Latin square pattern in regards to the order that different values of the independent test variables would appear in. The camera angles for the first evaluation, and perceived speed for the second evaluation, were selected in a random order for this reason. As an effect hereof, different values of the independent variable varied slightly in average trial order number after conducting the tests.
To conclude, the results from this study should be considered with this in mind, as some degree of error is probable due to the variation in test apparatus and setting.

CONCLUSION
Concluding on this study, no evidence was found to support that using gaze as input modality results in better performances in a game, in which timely precision and continuous saccadic motions are required with high accuracy. Contrarily, participants performed better when using mouse as input in fast perceived situations where objects move fast and require quick reaction times (0.58 seconds and less). However, in situations where the player has a greater time to react and plan forthcoming saccadic motions, no statistical significant difference was found in the performance between participants respectively using gaze and mouse as input. This suggests that gaze input may be a sufficient substitution for interactions in which the user has at least 1.14 seconds to react and plan gaze movement. Conclusively, more work is required within the field of eye tracking as input modality with respect to performance in video games, notably with focus on alternate gaze interaction methods outside those already acknowledged and presented in this paper.

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Appendices

List of appendices

APPENDIX A: FIRST USER STUDY RECRUITMENT ADVERTISEMENT

Hello fellow Eye Tracking enthusiasts!

My name is Søren, and I am currently working on a masters thesis at Aalborg University, during which I have made a gaze-controlled video game called Gaze Hero!

Screenshot from the game: https://i.imgur.com/qtY2G4n.jpg

And now, I need your help to try it out!

IF you have, a TOBII Eye Tracker 4C, I would love if you would like to play through a game test that I have prepared. It takes 5-10 minutes to complete, and you'll get to try a new way of playing video games, using only your eyes!

Download links:

Google Drive ZIP download: https://drive.google.com/open?id=1YGtbBv41RN74GnR1Ugjt5f8CXU6eZss0

Google Drive EXE download (self-extracting RAR): https://drive.google.com/open?id=1D9uT5Sn8-Biho3YMyTHKuOZTyF3lOF3S

I need as many people to try it out as possible, and it's super easy to participate if you have a TOBII Eye Tracker!

Thank you very much for your interest, and please share with anyone who you think might be interested aswell!

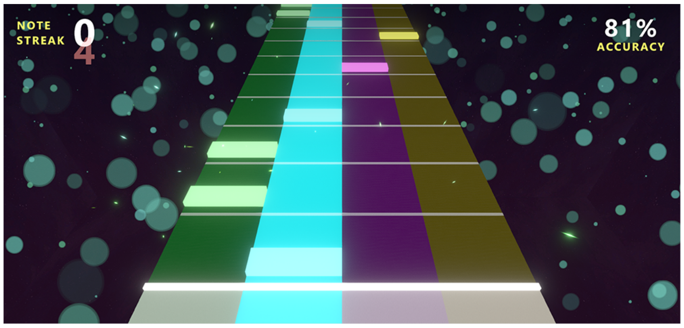
Let me know if you have any questions at all (here or by sending an email to sthoma14@student.aau.dk)

Have a nice day!

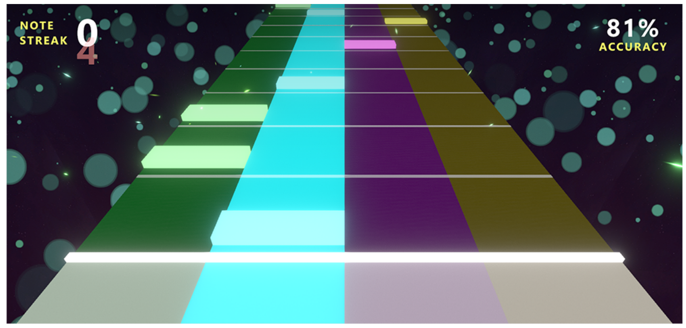
APPENDIX B: FIRST USER STUDY DATA EXAMPLE

#	Lane	Lane color	Hit (bool)	Hit type	Gaze dist:	Gaze distance: lanes	Dist to last: lanes	Dist to last: ticks	Dist to last: seconds
1	3	purple	hit	direct	middle				
2	4	yellow	hit	direct	middle		1	6	0.947
3	2	blue	hit	direct	middle		2	10	1.578
4	1	green	hit	direct	middle		1	6	0.947
5	3	purple	hit	direct	middle		2	10	1.578
6	4	yellow	hit	direct	middle		1	6	0.947
7	2	blue	hit	direct	middle		2	10	1.578
8	1	green	hit	direct	middle		1	6	0.947
9	3	purple	hit	direct	middle		2	10	1.578
10	4	yellow	hit	direct	middle		1	6	0.947
11	2	blue	hit	direct	middle		2	10	1.578
12	1	green	hit	direct	middle		1	6	0.947
13	3	purple	hit	direct	middle		2	10	1.578
14	4	yellow	hit	direct	middle		1	6	0.947
15	2	blue	hit	direct	middle		2	10	1.578
16	1	green	hit	direct	middle		1	6	0.947
17	3	purple	hit	direct	middle		2	10	1.578
18	4	yellow	hit	direct	middle		1	6	0.947
19	2	blue	miss		upper	1	2	10	1.578
20	1	green	hit	direct	middle		1	6	0.947
21	3	purple	hit	direct	middle		2	10	1.578
22	4	yellow	hit	direct	middle		1	6	0.947
23	2	blue	hit	direct	middle		2	10	1.578
24	1	green	hit	direct	middle		1	6	0.947
25	2	blue	hit	direct	middle		1	10	1.578
26	1	green	miss		middle	1	1	1	0.157
27	1	green	hit	direct	middle		0	1	0.157
28	2	blue	hit	late	lower		1	1	0.157
29	3	purple	hit	late	lower		1	2	0.315
30	2	blue	hit	direct	middle		1	3	0.473
31	1	green	hit	direct	middle		1	1	0.157
32	1	green	hit	direct	lower		0	1	0.157
33	2	blue	miss		lower	1	1	1	0.157
34	2	blue	hit	direct	middle		0	5	0.789
35	1	green	hit	direct	middle		1	1	0.157

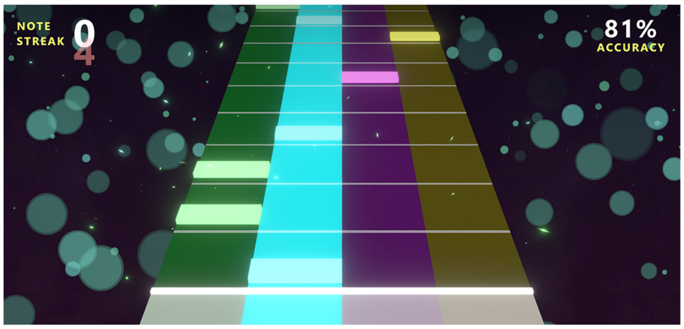
APPENDIX C: FIRST USER STUDY CAMERA ANGLES



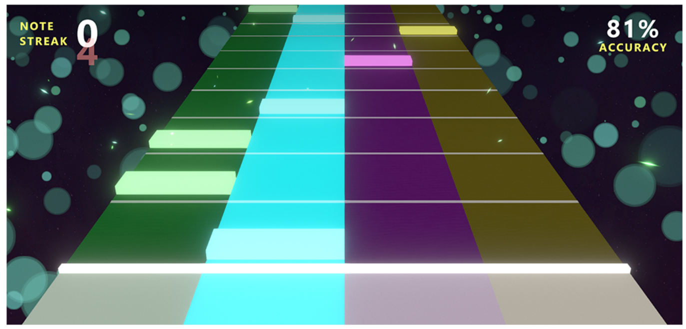
#1:High Y High FOV



#2:Low Y High FOV



#3:High Y Low FOV



#4:Low Y Low FOV

APPENDIX D: FIRST USER STUDY CAMERA ANGLE ORDER

Camera order data

Order	Pilot	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6
1	2	3	1	2	2	3	1
2	3	2	4	3	1	2	3
3	4	1	3	1	4	4	2
4	1	4	2	4	3	1	4

Average camera order position

Cam no.	Avg position
1	2,57
2	2
3	2,14
4	3,28
avg	*2,5*

APPENDIX E: FIRST USER STUDY RESULTS REPEATED MEASURES ONE-WAY ANOVA

Data Entry

Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
91.92	74.75	84.85	89.9	
63.64	63.64	58.59	69.7	
66.67	60.61	63.64	57.58	
94.95	87.88	88.89	95.96	
80.81	66.67	93.94	88.89	
97.98	96.97	96.97	95.96	
96.97	90.91	95.96	94.95	

Reset Calculate

Data Summary

	Samples					
	1	2	3	4	5	Total
N	7	7	7	7		28
ΣX	592.94	541.43	582.84	592.94		2310.15
Mean	84.7057	77.3471	83.2629	84.7057		82.5054
ΣX^2	51493.2448	43146.7765	50020.0184	51589.1342		196249.173
Variance	211.3064	211.4522	248.5158	227.288		209.2379
Std.Dev.	14.5364	14.5414	15.7644	15.0761		14.4651
Std.Err.	5.4942	5.4961	5.9584	5.6982		2.7336

standard weighted-means analysis

ANOVA Summary Correlated Samples k=4

Source	SS	df	MS	F	P
Treatment [between groups]	258.0489	3	86.0163	2.95	0.060537
Error	525.6429	18	29.2024		
Ss/Bl	4865.7313	6			
Total	5649.4231	27			

Graph Maker

Ss/Bl = Subjects or Blocks depending on the design.
Applicable only to correlated-samples ANOVA.

APPENDIX F: ANALYSIS OF PERFORMANCES BETWEEN PARTICIPANTS USING RESPECTIVELY GAZE AND MOUSE AS INPUT MODALITY (INDEPENDENT T-TESTS)

Mean performance
(A) Gaze - (B) Mouse

Data Summary

	A	B	Total
n	8	8	16
ΣX	580.82	687.55	1268.37
ΣX^2	42988.2996	60356.9791	103345.278
SS	819.3155	1266.3538	2797.6251
mean	72.6025	85.9438	79.2731

Results

For independent samples, these results pertain to the "usual" t-test, which assumes that the two samples have equal variances.

$Mean_a - Mean_b$	t	df			
-13.3412	-2.19	14	P	one-tailed	0.0229765
				two-tailed	0.045953

F-Test for the Significance of the Difference between the Variances of the Two Samples

df_1	df_2	F	P
7	7	1.55	0.288643

[Applicable only to independent samples.]
P>.05 indicates no significant difference detected between the variances of the two samples.

t-Test Assuming Unequal Sample Variances
[Applicable only to independent samples.]

$Mean_a - Mean_b$	t	df			
-13.3412	-2.19	13.39	P	one-tailed	0.02385
				two-tailed	0.047700

	Observed	Confidence Intervals 0.95	0.99
$Mean_a$	72.6025	± 9.027	± 13.3875
$Mean_b$	85.9438	± 11.2227	± 16.6438

For purposes of significance tests and calculation of confidence intervals, values of df associated with the unequal-variance condition are rounded to the nearest integer.

Slow perceived speed performance
(A) Gaze - (B) Mouse

Data Summary

	A	B	Total
n	8	8	16
ΣX	605.069999	700.010000	1305.08
ΣX^2	46866.3137	62045.2603	108911.574
SS	1102.6006	793.5103	2459.4611
mean	75.6337	87.5013	81.5675

Results

For independent samples, these results pertain to the "usual" t-test, which assumes that the two samples have equal variances.

$Mean_a - Mean_b$	t	df			
-11.8675	-2.04	14	P	one-tailed	0.0303415
				two-tailed	0.060683

F-Test for the Significance of the Difference between the Variances of the Two Samples

df_1	df_2	F	P
7	7	1.39	0.337430

[Applicable only to independent samples.]
P>.05 indicates no significant difference detected between the variances of the two samples.

t-Test Assuming Unequal Sample Variances
[Applicable only to independent samples.]

$Mean_a - Mean_b$	t	df			
-11.8675	-2.04	13.64	P	one-tailed	0.03037
				two-tailed	0.060740

	Observed	Confidence Intervals 0.95	0.99
$Mean_a$	75.6337	± 10.4719	± 15.5304
$Mean_b$	87.5013	± 8.8837	± 13.175

For purposes of significance tests and calculation of confidence intervals, values of df associated with the unequal-variance condition are rounded to the nearest integer.

Medium perceived speed performance
(A) Gaze - (B) Mouse

Data Summary

	A	B	Total
n	8	8	16
ΣX	656.58	690.920000	1347.5
ΣX^2	55135.2544	60536.3506	115671.605
SS	1248.0923	865.0448	2186.8394
mean	82.0725	86.365	84.2188

Results

For independent samples, these results pertain to the "usual" t-test, which assumes that the two samples have equal variances.

$Mean_a - Mean_b$	t	df			
-4.2925	-0.7	14	P	one-tailed	0.247698
				two-tailed	0.495396

F-Test for the Significance of the Difference between the Variances of the Two Samples

df_1	df_2	F	P
7	7	1.44	0.321224

[Applicable only to independent samples.]
P>.05 indicates no significant difference detected between the variances of the two samples.

t-Test Assuming Unequal Sample Variances
[Applicable only to independent samples.]

$Mean_a - Mean_b$	t	df			
-4.2925	-0.7	13.55	P	one-tailed	0.2480675
				two-tailed	0.496135

	Observed	Confidence Intervals 0.95	0.99
$Mean_a$	82.0725	± 11.1414	± 16.5233
$Mean_b$	86.365	± 9.2755	± 13.756

For purposes of significance tests and calculation of confidence intervals, values of df associated with the unequal-variance condition are rounded to the nearest integer.

Fast perceived speed performance
(A) Gaze - (B) Mouse

Data Summary

	A	B	Total
n	8	8	16
ΣX	480.830000	671.72	1152.55000
ΣX^2	30101.7983	59238.6317	89340.4301
SS	1202.1122	2837.662	6317.2112
mean	60.1038	83.965	72.0344

Results

For independent samples, these results pertain to the "usual" t-test, which assumes that the two samples have equal variances.

$Mean_a - Mean_b$	t	df			
-23.8612	-2.81	14	P	one-tailed	0.006952
				two-tailed	0.013904

F-Test for the Significance of the Difference between the Variances of the Two Samples

df_1	df_2	F	P
7	7	2.36	0.139934

[Applicable only to independent samples.]
P>.05 indicates no significant difference detected between the variances of the two samples.

t-Test Assuming Unequal Sample Variances
[Applicable only to independent samples.]

$Mean_a - Mean_b$	t	df			
-23.8612	-2.81	12.03	P	one-tailed	0.007884
				two-tailed	0.015768

	Observed	Confidence Intervals 0.95	0.99
$Mean_a$	60.1038	± 10.9343	± 16.2161
$Mean_b$	83.965	± 16.7996	± 24.9146

For purposes of significance tests and calculation of confidence intervals, values of df associated with the unequal-variance condition are rounded to the nearest integer.

APPENDIX G: ANALYSIS OF PERFORMANCES WITH RESPECT TO LEVEL OF PERCEIVED SPEED WITHIN GROUPS (DEPENDENT T-TESTS)

Gaze
(A) Slow - (B) Medium

Data Summary

	A	B	Total
n	8	8	16
ΣX	605.069999	656.58	1261.65
ΣX^2	46866.3137	55135.2544	102001.568
SS	1102.6006	1248.0923	2516.5229
mean	75.6337	82.0725	78.8531

Results

$Mean_a - Mean_b$	t	df	p one-tailed	p two-tailed
-6.4388	-1.41	7	0.1006955	0.201391

Gaze
(A) Slow - (B) Fast

Data Summary

	A	B	Total
n	8	8	16
ΣX	605.069999	480.830000	1085.9
ΣX^2	46866.3137	30101.7983	76968.1120
SS	1102.6006	1202.1122	3269.4364
mean	75.6337	60.1038	67.8688

Results

$Mean_a - Mean_b$	t	df	p one-tailed	p two-tailed
15.53	+4.06	7	0.002405	0.004810

Gaze
(A) Medium - (B) Fast

Data Summary

	A	B	Total
n	8	8	16
ΣX	656.58	480.830000	1137.41
ΣX^2	55135.2544	30101.7983	85237.0527
SS	1248.0923	1202.1122	4380.7084
mean	82.0725	60.1038	71.0881

Results

$Mean_a - Mean_b$	t	df	p one-tailed	p two-tailed
21.9688	+4.57	7	0.001287	0.002574

Mouse
(A) Slow - (B) Medium

Data Summary

	A	B	Total
n	8	8	16
ΣX	700.010000	690.920000	1390.93000
ΣX^2	62045.2603	60536.3506	122581.610
SS	793.5103	865.0448	1663.7193
mean	87.5013	86.365	86.9331

Results

$Mean_a - Mean_b$	t	df	p one-tailed	p two-tailed
1.1363	+0.9	7	0.199012	0.398024

Mouse
(A) Slow - (B) Fast

Data Summary

	A	B	Total
n	8	8	16
ΣX	700.010000	671.72	1371.73
ΣX^2	62045.2603	59238.6317	121283.892
SS	793.5103	2837.662	3681.1925
mean	87.5013	83.965	85.7331

Results

$Mean_a - Mean_b$	t	df	p one-tailed	p two-tailed
3.5363	+0.79	7	0.227726	0.455452

Mouse
(A) Medium - (B) Fast

Data Summary

	A	B	Total
n	8	8	16
ΣX	690.920000	671.72	1362.64
ΣX^2	60536.3506	59238.6317	119774.982
SS	865.0448	2837.662	3725.7468
mean	86.365	83.965	85.165

Results

$Mean_a - Mean_b$	t	df	p one-tailed	p two-tailed
2.4	+0.61	7	0.280567	0.561134

APPENDIX H: SPREADSHEET WITH AVERAGE HIT PERCENTAGES FOR ALL PARTICIPANTS AND HIT PERCENTAGES WITH RESPECT TO PREVIOUS EXPERIENCE AND GAME FREQUENCY

Hit percentages (gaze)

Participant no.	Speed 1	Speed 2	Speed 3	mean	Z-score
1	84,85	91,92	81,82	86,20	1,34
2	79,80	66,67	68,69	71,72	-0,09
3	76,77	89,90	62,63	76,43	0,38
4	64,65	70,71	55,56	63,64	-0,89
5	57,58	89,90	52,53	66,67	-0,59
6	87,88	90,91	53,54	77,44	0,48
7	62,63	61,62	38,38	54,21	-1,82
8	90,91	94,95	67,68	84,51	1,18
mean	75,63	82,07	60,10	72,60	
variance	137,85	156,04	150,24	102,43	
std. Dev	11,74	12,49	12,26	10,12	

Hit percentages (mouse)

Participant no.	Speed 1	Speed 2	Speed 3	mean	Z-score
1	94,95	88,89	96,97	93,60	0,61
2	82,83	82,83	86,87	84,18	-0,14
3	98,99	94,95	94,95	96,30	0,82
4	96,97	96,97	96,97	96,97	0,88
5	85,86	89,90	93,94	89,90	0,31
6	94,95	96,97	92,93	94,95	0,72
7	72,73	72,73	69,70	71,72	-1,13
8	72,73	67,68	39,39	59,93	-2,07
mean	87,5	86,36	83,96	85,94	
variance	99,21	108,15	354,67	158,28	
std. Dev	9,96	10,40	18,83	12,58	

Analysis results (independent t-test between groups)

	Speed 1	Speed 2	Speed 3	All data
P-value	0,06	0,495	0,013	0,046
F-test P-value	*0,337*	*0,321*	*0,14*	*0,288*

Since F-test P-value is insignificant between groups (variances)
a T-test has been performed assuming equal variances

Hit percentage with respect to **eye tracking exp** (gaze)

Eye tracking exp	Speed 1	Speed 2	Speed 3	mean	*count*
None	78,28	78,28	65,66	74,07	*2*
Tried it	80,47	82,49	53,20	72,05	*3*
Active user	84,85	91,92	81,82	86,20	*1*
Developer	61,11	80,30	54,04	65,15	*2*

Hit percentage with respect to **game frequency** (gaze)

Game frequency	Speed 1	Speed 2	Speed 3	mean	*count*
Never					*0*
Monthly	62,63	61,62	38,38	54,21	*1*
Weekly	76,26	80,81	54,55	70,54	*2*
Daily	77,98	86,67	66,67	77,10	*5*

Hit percentage with respect to **game frequency** (mouse)

Game frequency	Speed 1	Speed 2	Speed 3	mean	*count*
Never	77,78	75,25	63,13	72,05	*2*
Monthly					*0*
Weekly	84,51	86,53	85,52	85,52	*3*
Daily	96,97	93,60	96,30	95,62	*3*

Hit percentage with respect to **game frequency** (**both** modalities)

Game frequency	Speed 1	Speed 2	Speed 3	mean	*count*
Never	77,78	75,25	63,13	72,05	*2*
Monthly	62,63	61,62	38,38	54,21	*1*
Weekly	81,21	84,24	73,13	79,53	*5*
Daily	85,10	89,27	77,78	84,05	*8*
mean	76,68	77,59	63,11	72,46	

Hit types with respect to speed (out of total hits)

Hit type	Speed 1	Speed 2	Speed 3	mean
direct	76,46	77,85	78,15	77,49
late	23,54	22,15	21,85	22,51
control	*100*	*100*	*100*	*100*

APPENDIX I: AVERAGE TRIAL POSITION OF PERCEIVED SPEED VALUES AND GAZE POSITION (DEPTH) FOR ALL NOTES, HITS AND MISSES

Speed value orders (gaze)

Test 1	Test 2	Test 3
1	3	2
2	1	3
3	2	1
1	2	3
1	3	2
3	1	2
2	1	3
3	1	2

Speed value order averages (gaze)

Speed 1	1,75
Speed 2	2,25
Speed 3	2
control mean	*2*

Gaze depth percentage with respect to speed

Depth	Speed 1	Speed 2	Speed 3	mean
Lower	95,08	67,30	43,81	68,73
Middle	4,80	32,20	49,24	28,75
Upper	0,00	0,25	6,19	2,15
Outside	0,13	0,25	0,76	0,38
control	*100*	*100*	*100*	*100*

Gaze depth percentage for **hits** (out of total hits)

Depth	Speed 1	Speed 2	Speed 3	mean
Lower	96,99	66,15	32,98	65,38
Middle	3,01	33,69	58,19	31,63
Upper	0,00	0,15	8,82	2,99
control	*100*	*100*	*100*	*100*

Speed value orders (mouse)

Test 1	Test 2	Test 3
2	1	3
2	3	1
2	1	3
1	3	2
1	3	2
1	3	2
2	1	3
3	1	2

Speed value order averages (mouse)

Speed 1	1,75
Speed 2	2
Speed 3	2,25
control mean	*2*

Gaze depth percentage for **misses** (out of total misses)

Depth	Speed 1	Speed 2	Speed 3	mean
Lower	89,12	72,54	60,13	73,93
Middle	10,36	25,35	35,76	23,82
Upper	0,00	0,70	2,22	0,97
Outside	0,52	1,41	1,90	1,28
control	*100*	*100*	*100*	*100*