A Study on Gaze Control - Game Accessibility Among Novice Players and Motor Disabled People

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Abstract. Gaze control is a substitution for disabled people to play computer games. However, many disabled people may be inexperienced in games and/or novices using gaze-control. This study presents a game accessibility approach using gaze control modality for novice players and disabled people. A workshop was conducted involving a playtest on three games with gaze-control. The game experiences were observed, recorded, and evaluated with mixed methods. The study estimated the gaze control game accessibility by System Usability Scale (SUS), Game Experience Questionnaire (GEQ), and an open-ended questionnaire. The gaze control modality demonstrated possible game accessibility to people with motor disabilities. The results also indicate that the challenge of game mechanics and the accuracy of the gaze-control system are two significant impact factors. Further research will be conducted on gaze-control games including more disabled people, and also develop the data analysis methods for evaluating gaze-control modality for game accessibility.

Keywords: Gaze control · Game accessibility · Motor disabled · Novice

1 Introduction

Computer games are a global cultural phenomenon that calls for inclusion of all, regardless of disabilities or other limitations. Game interactions require physical manipulation of game controls by hands and body motions (such as keyboard, mouse, gamepad and joystick), which may exclude motor disabled people [1]. Gaze control is a substitution for motor disabled people to play some computer games, but many may be novices of using this relatively new modality. Although gaze control transforms game controls and liberates the hands, challenges remain on how to design gaze control for different game mechanics and various motor disabled people. The problem is that motor disabled people may have difficulties playing games with conventional game controls requiring physical manipulation, such as keyboard, mouse, gamepad and joystick. The research questions are: What is the acceptance of gaze control among novice players and upper-limb motor disabled people for game accessibility? What would need to be improved upon regarding usability and game experience to enhance acceptance?
2 Related Research

2.1 Gaze-Control Interaction

Gaze-control interaction has emerged in computer games in recent years. Early applications of eye gaze as game control modality can be retrieved in a research article from 2004 when Layba J et al. [2] implemented an eye-tracking game control experiment, with the Tobii ET-1750 eye tracker. Following this gaze control experiment, more researchers have tried to design and optimize more gaze-control game mechanics over the past decade [3–5]. There are various game mechanics for gaze control, summarized in five categories as Selection & Commands, Aiming & Shooting, Navigation, Implicit Interaction, and Visual Effects [6]. Ramirez et al. further classified Selection & Commands, Aiming & Shooting, and Navigation as the primary game mechanics for gaze control [7]. Both gaze selection and gaze aiming & shooting are operated by eye fixation [8, 9], which is the principal function of human eyes. Gaze selection is when people gaze at an object on the screen, the cursor (which is the gaze plot) can click or select the object [10]. In some games, the fixation has to last for a dwell time to trigger the selection [11, 12]. Gaze aiming & shooting indicates aiming at a target and shoot it, for example, firing [13] and pinpoint bombing [14]. And gaze navigation means the game camera (field of vision) follows where the eyes look [13]. Some games used saccade for gaze navigation [15] (rapid movement of the eye between fixation points), and some other games use head orientation as direction control [16].

2.2 Game Accessibility and Game Experience

Game accessibility can be defined as the usability of computer games under restricted circumstances (e.g., motor impairment, visual impairment, and auditory impairment) [17]. Game accessibility in gaze-control modal is affected by deliberately designed challenges of different games, i.e., normative game rules and performative game mechanics [18]. S. Almeida et al. [19] summarize the effects of eye-tracking technologies on different game genres, showing that racing games are less accessible with eye tracking. As racing games require a long duration of gazing and visual attention, unexpected eye distractions or non-intentional absence of gaze are likely to cause in-game crashes. Antunes. J et al. [20] noted that multimodal, for example, keyboard integrated with gaze control is more accessible than unimodal gaze control, proven in a shooting game playtest.

Furthermore, gaming skills of players also affect game experiences. Cain M. S et al. shows that novices spend significantly more response time in unfamiliar game tasks and are less flexible in switching tasks [21]. When novice players encounter game failure, they may be frustrated to utilize a novel game control modal in the future. This is especially relevant for accessibility where novel game controls are common. However, the views of novice players and motor disabled people for gaze control have been less explicated in previous research.
This study presented a game accessibility approach using gaze-control modality for novice players and disabled people. A workshop was conducted involving a sample of eight mid-age to elderly people with multiple sclerosis, stochastically selected by an organization for multiple sclerosis. Two of the participants had severe motor disabilities in hands and arms, and two were middle level disabled in hands and arms, four were minor disabled in hands.

Three typical gaze control modals were tested utilizing an infrared eye tracker (Tobii 4C) in three games: (1) Beatshot (BS)\(^1\), a shooting game, game mechanics used gaze fixation to hit the moving target while avoiding the interfering penalties. (2) Patin Grappin (PG)\(^2\), a navigating game, the game mechanics used gaze control to control a skier going downhill, turning and jumping by a grappling hook with a rope to make long jumps. Turning was implemented by head orientation (head yawing for left and right, pitching for up and down) and grappling by dwell clicks, looking at clouds for perhaps a second. (3) Fast Sight (FS)\(^3\), a cooperative racing game with a multimodal of keyboard and eye gaze, to control the avatar rolling across a valley. Aiming at the falling rocks from aside and press Space key simultaneously to shoot the rocks, while pressing Left and Right keys to control direction and avoid obstacles on the way.

### 3.1 Pre-game Session

An introduction about the eye tracker and the three tested gaze-control games were given. Each participant signed an informed consent form for participating in the study. Then, the participants watched the presentation of how to use eye tracker and short tutorials on how to play the tested games. Next, each of them played the tested games to get familiar with the graphical user interfaces for the tested games in five minutes.

### 3.2 Playtest Session

A playtest was conducted per participant with one-to-two minutes for Beatshot, a variation of time with Patin Grappin that depended on how long the player was able to get before s/he failed, and two minutes with Fast Sight. Fast Sight was tested with two participants at a time, pairing one severe disabled participant to gaze control and one with better motor ability to command the keyboard. The total time per playtest session was ten minutes including time to shift between games. Observation were noted based on a systematic user experience scheme of the observations (see Table 1 in the Results section). The gameplay was recorded by the screen recorder Bandicam v4.2.0.1439 and the user interaction was recorded by a video camera installed behind the participants. The performances of the eight participants were observed and recorded. The in-game observation with participants’ behaviors was thematically coded based on five game

\(^{1}\) https://gaming.tobii.com/games/beatshot/.

\(^{2}\) https://www.youtube.com/watch?v=sHNrzG2zR_o.

\(^{3}\) https://gaming.tobii.com/games/fast-sight/.
experience dimensions: Enjoyment [22], Flow [23], Immersion [24], Challenge [25], and Sensory experience [26] with gaze control.

### 3.3 Post-game Session

The participants were asked to complete the System Usability Scale (SUS) [27] and Game Experience Questionnaire (GEQ) [28]. Then, retrospective think-aloud of observation results and video recordings were included, in which the participants were asked to explain why they answered the questionnaires the way they did. Furthermore, the participants were asked to answer an open-ended questionnaire. The SUS results were estimated with maximum likelihood estimation (MLE) and t-distribution. This work hypothesizes that the user experience rating of novice players and disabled people is in Gaussian distribution (Normal distribution). Therefore, it implemented the MLE estimation to indicate the result of the target group. The GEQ results for the three gaze-control modals were estimated by eight game experience dimensions: Competence, Sensory experiences, Flow, Challenge, Tension/Annoyance, Negative affect, Positive affect, and Tiredness. The Tiredness here is also designed as a specific dimension for eye fatigue caused by gaze control. The results from eight participants were computed with arithmetic mean and standard deviation. The open-ended questions about gaze control were developed based on playtesting questions in Fullerton et al. [29]. The answers of eight participants were summarized by merging similar answers and listing the representative answers.

### 4 Results and Analysis

The gaze control modality demonstrated possible game accessibility to people with motor disabilities. The results also manifest that the challenge of game mechanics and the accuracy of the gaze-control system are two significant impact factors for game accessibility. Note that the observation form is a presentation of findings that were corroborated from the significant behaviors and refined from the repeated answers (Table 1).

#### 4.1 Playtest Session

The observation provides a triangulation of the oral answers given by participants. It also reveals some unintentional in-game motions of the participants and explains the reason why they have such game experiences.

**Enjoyment.** Most of the participants enjoyed the games. Negative emotions only occurred when they faced in-game crashes or gaze control inaccuracy.

**Flow.** Although the participants were novices with gaze control, they desired to learn how to score more and they became better during the gameplay session.
Immersion. The participants showed the most significant immersion in *Beatshot*. For the other two games, some participants were focused on the game. However, some participants had some problems that affected the immersion: a) The buttons of the two games’ menus were too small for most people to click on correctly, considering the gaze control has limited precision. Particularly, two participants also had difficulties on gazing at falling rocks in the racing game due to inaccuracy of the gaze control; b) The participants reacted slower than the speed of the game. In *Patin Grappin*, the participants spent more time on searching the game scene than racing on the racetrack.

**Challenge.** The unimodal gaze control required much effort, especially when the game mechanics were complicated, the participants felt eye strain after playing for a while. For gaze control, the participants had to look at numerous information in the scene and try to control the game by eye-gaze simultaneously. *Patin Grappin* and *Fast Sight* have more sophisticated controls and are thus harder to start playing.
Sensory Experience with Gaze Control. In terms of the gaze control, three participants encountered different degree of difficulties on gaze tracking, thus caused the games to crash, especially in *Patin Grappin*. In terms of the hardware sensor, the participants showed no sign of distraction from the infrared lights of the eye tracker. Firstly, the participants noticed the lights, but when they played games, they focused on the game.

The factors that caused the gaze control’s inaccuracy observed were: A) Three participants had unintentional head movements while playing. This situation recognized as unintentional movements and inevitable when the players are immersive in-game. B) One participant was significantly shorter than the others. When she sat in front of the computer, her position was remarkably lower than the other participants as her wheelchair was at a fixed height compared to the regular, adjustable chair. The eye tracker in front of the laptop screen could hardly capture her eyes (intermittently).

4.2 Post-game Session

Gaze Control Usability. To indicate the usability for the group of novice players and disabled people, the playtest session was estimated by SUS and the data was evaluated by MLE and t-distribution (see Fig. 1). The estimated Gaussian model (mean = 80.625, std = 13.332) and the t-distribution model of the eight users (mean = 79.362, std = 13.332, df = 7) are in the B level of SUS standard [29]. The height of each bar illustrates the likelihood of the user’s SUS score. As shown by the SUS distribution curve, the gaze control usability has the highest likelihood at 80.625 and is downward by aside.

![Fig. 1. Histogram of the SUS distribution model estimated by MLE and t-distribution. The histogram illustrates the score of the eight participants. The height of the histogram is the Gaussian Kernel Density (KDE) value indicating the likelihood of the SUS scores.](image)

Gaze-Control Game Experiences. The results of GEQ (see Fig. 2) show no statistical significance ($p > 0.05$, $t$-test) between the three game modals. The highest game experience dimension was the Positive affect, which decreased remarkably from 2.925 to 2.563 following the game sequences *Beatshot* (BS), *Patin Grappin* (PG) to *Fast Sight* (FS). Similarly, the Competence decreased from 2.45 to 2.0 in the three games.
The Sensory experiences fluctuated slightly between 2.3 and 2.5, while the Flow was almost static in approximately 2.0 in the three games. The Challenge is between 1.6 and 1.9. The lowest dimensions were Tension/Annoyance and Negative affect between 0 and 0.4. The Tiredness for gaze control is between 0.6 and 0.9.

The open-ended interview showed that most participants had positive perspectives on the gaze control modality. Notably, there were two remarkable gaze control designs reported by the participants. First, the eye tracker can transform the tracking modes as tracing left/right eye or both eyes, which enabled the accessibility of divergent squint people. Second, the cooperative multimodal design with gaze control and keyboard enabled severe hand disabled participants play more complex game mechanics together with another player. The remaining open-ended questions confirmed what was found in the observations. The result of the open-ended interview was showed in Table 2.
Table 2. Answers from the open-ended questionnaire.

| Q                                                                 | A                                                                                                                                                                                                 |
|-------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| What was your first impression of gaze-control games?              | –It is my first time to hear about eye-tracking games, and it is exciting and fresh to me  
–I read the news that there were devices people can connect and control the computer with eye gaze, is it (Tobii) the device on the news?  
–I want to try it!                                                                 |
| Has the impression changed after you play the gaze control games?   | –It is more complicated than I thought to play eye-tracking games  
–I felt disappointed that I could not play the game because it cannot track my eyes. (PG)                                                                 |
| Is there something challenging in using the gaze control modals?    | –The eye-tracking device could not track my eyes, so I could not enjoy the game  
–Play games with gaze control is very difficult for me, especially to play the skiing game  
–I tried to fix my gaze on the target, but it was not on the right location where I gazed.                                                                 |
| Did the gaze control modals drag or bug at any point?              | –Yes. The game (PG) could not capture my eye gaze, so the game crashed once it launched  
–Yes. When I played the game (BS), my gaze plot was always in the wrong place                                                                 |
| Were there particular features that you found satisfying in terms of game mechanics of gaze control models? | –The unimodal of gaze control is convenient for playing games  
–It is thoughtful of the system that can track a single eye (divergent squint)  
–The cooperate modal is helpful for me. (The participants with severe hand disabilities.)  
–When I played BS, the prized targets had the same color as the punished targets. The colors are disguising, and it is a challenge to shoot the right target. (Positive commend) |
| How well do you think you performed the gaze control in-game?       | –Very well, I worked better than the other people. (Feeling proud)  
–Just OK  
–Not very well                                                                 |
| Were the procedures and rules of gaze-control games easy to understand? | –Yes. The unimodal is easy to understand                                                                 |
| What do you think the cons and pros with gaze control of the games? | –The eye-tracking system worked not very well to capture my eyes  
–The game speed (FS) is too fast to control the avatar  
–The buttons in the game (FS) were in a small size, and the gaze plot was unsteady (PG and FS), I could not gaze at the button correctly  
–At the beginning of the games (PG and FS), I had to learn information of the game scenes (by my eyes), too many figures came from me, and I felt too rush to control the avatar (by eye gaze) appropriately  
–Watching the scene and controlling the target at the same time was intensive and stressful  
–There was a little eye strain after playing the games. I could not keep playing for a long time. I hope the game can designed as pause after playing for a while                                                                 |
5 Discussion

This study tested three typical gaze-control modals, covering primary gaze-control game mechanics: Selection & Commands, Aiming & Shooting, and Navigation [7]. While the study used existing games developed by others, the acceptance of the games may have been affected by the situation and presentation by the authors. The gaze control game accessibility is discussed in three perspectives: usability, gaze-control game experiences and the designs in gaze-control modal.

5.1 Gaze Control Usability

The average SUS results demonstrated that the gaze-control modality manages to provide accessibility for most novice players and disabled people. This work hypothesizes that the user experience rating of novice players and disabled people is in Gaussian distribution (Normal distribution), while the rating of the small probability sample is in t-distribution. The likelihood model of Gaussian distribution predicted with MLE differs from the model of t-distribution. It implies that the exact gaze-control acceptance may be higher than the expectation of the sample. This study introduces MLE to address the problem that severely upper-limb motor disabled people are a relatively small group of society who are not readily available for game accessibility research recruitment. Thus, it concludes a reliable estimation of the gaze-control acceptance among the novice players and the disabled people.

5.2 Gaze-Control Game Experiences

The results of GEQ and the open-ended questionnaire indicate that the gaze-control game accessibility is affected by the eye-tracking accuracy and the game mechanic design. In the GEQ results, the values of Competence, Sensory experiences, Flow, Challenge, Positive affect are considerably high, while the values of Tension/Annoyance, Negative affect are low, suggesting high game accessibility of gaze control among the majority. The GEQ results in the three gaze-control modals are examined by t-test and show no statistical significance between each other. The cause can derive from the GEQ scales (0-4). Only five-integer-scales caused the SD values between participants in each game remarkably significant than the difference between games.

Although the p-value with t-test shows no statistical significance between the three games, combined with the observation, the minor trends can show the differences between the three game experiences. The Competence and Positive affect slightly decrease from BS to FS, while the Challenge, Tension/Annoyance, and Negative affect slightly increase. It shows an inversed correlation between game difficulties and the command of gaze control. The participants present strong learning abilities of gaze control in BS, which has the most straightforward game mechanic. However, they report the difficulties of PG and FS. In PG, the participants have difficulties in controlling the avatar on the racetrack. When the avatar falls out, they find it hard to find a new racetrack by saccade and head yawing control simultaneously. In FS, the participants think the game pace is too fast for them to control the direction. Although keyboards were controlling the direction, the game performance of the keyboard player was affecting the gaze-control player.
The Tiredness increased gradually in PG and FS. Corresponding to the observation, the participants proposed that eye fatigue arose when the game mechanics are more challenging in the post-game interview section. When the game scenes are complex (PG and FS), the participants reported tension and visual overload due to the massive information. It is more likely to cause eye strain and cognition overload in a started period of the games.

5.3 Designs in the Gaze Control Modals

**Minimum Button Size.** This study finds that significant number of gaze-control players have difficulties on aiming at the rocks in FS as they are in smaller size compared to the targets in BS. This situation also occurs during the game menu selection in FS. It indicated that the gaze plot has minor jitters, so the size of a selected or aiming target should be designed big enough to be accessible. Earlier findings proved that target sizes below 1.5–2° caused increased selection error [30, 31], while recent studies noted gaze calibrating difficulties on a minimum target size about 3° [32, 33]. Also, eye gaze selection time (period between target initialization and gaze entry into the target circle) increased remarkable when the target size bel owed 2° [34]. In light of these studies, the button size above 2° ensure game accessibility of gaze control.

**Special Needs of Motor Disabilities.** The observation manifests that gaze control should consider people with various severe motor disabilities and individual conditions (e.g., eye divergent squint and body height). It reveals the accessibility demand for synchronizing eye trackers individually and gaze-adaptive methods for special needs.

6 Conclusion

The current work presented a game accessibility study of gaze control modality for novice players and disabled people and addressed two research questions. First, gaze control modality demonstrated possible game accessibility to people with motor disabilities. The acceptance of gaze control among novice players and upper-limb motor disabled people for game accessibility is high. Second, it indicates that the challenge of game mechanics and the accuracy of the gaze-control system are two significant impact factors. The game mechanics need to be designed thoughtfully for the conditions of disabled peoples, including gaze-control-friendly user interfaces, appropriate challenge, simple game scenes, and appropriate game duration for each round to avoid being overwhelmed by visual feedback and eye fatigue. Furthermore, the accuracy of gaze control system should be improved to enhance the acceptance of gaze-control modality.

Future research will focus on a broader range of gaze-control games, a larger scale of disabled people, and also develop more data analysis methods for evaluating gaze-control game accessibility. This study suggests that game duration is an impact factor on gaze control game accessibility. However, it cannot inform about the optimal game duration for gaze control. Thus, it raises a further question of how long game duration should be in gaze-control games. Appropriate game duration (ensures game enjoyment whilst avoiding eye fatigue) will be examined in future research.
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