Human-Computer Interaction using eye-gaze:

Formation of user interface design guidelines from a cognitive science perspective.

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Master's dissertation 30 Credits

Media technology | Spring semester 2019

Interactive Media Design Program

SÖDERTÖRN UNIVERSITY | STOCKHOLM

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ABSTRACT

Motor and communication disabilities are common conditions that may implicate restrictions in daily life. With development of eye tracking technology, a solution referred to as eye-gaze interaction has been generated to support people with their limiting conditions to solve communication and computer access issues. By using eye tracking technology, which calculates the user's eye-gaze location on a computer screen, user's are able to control computers with their eyes as an input. This interaction method is quite unique and complex since the eyes serves both as an input and output source. Usability aspects revolving human information processing are therefore important to consider when designing user interfaces. In collaboration with Tobii AB, the study evaluated two separate eye-gaze interaction systems for controlling computers. 7 participants conducted user tests, one for each application, and answered interview questions during the tests regarding their usability experience. Based on the collected data, 17 design guidelines was established with a purpose to enhance usability for eye-gaze interaction systems.

Author Keywords

Human-Computer Interaction; Gaze interaction; Gaze-based control system; Eye tracking; Cognitive Science; Design Guidelines; Visual Perception; Usability; User Interface.

INTRODUCTION

In relation to the development of technology, cognitive science has started to play an important role in designing user interfaces for computer-based systems [22]. To design a usable system that will enhance learning as well as credibility, the system process needs to be designed in parallel with the user's information processing and mindset [5]. The ultimate construction would be if the user were capable to express their thoughts and needs to the computer for it to mirror their thought processes [24]. The more a system is designed to advanced in mirroring human information processing the more user friendly the system will be, and will result in the user being more motivated to use it to solve their problems [9]. To include cognitive science aspects based on theories of working memory, two way coding, cognitive load, generative theory and SOI model (organisation, integration and selection) in design can therefore be considered as vital [23].

The eye tracker is a device that can estimate where the eye-gaze of a person is positioned in a certain space, achieved by an algorithm which can detect the eye-gaze position [11]. Eye trackers can be used in a variety of research areas including neurology, psychology, ophthalmology, marketing, advertising, and human factors engineering for usability measurement purposes [15]. By using eye tracking technology, gaze-based control systems are able to accept the eyes as an input and respond to the user's eye movement. The eye-gaze control program is displayed as options on the computer monitor, and operates when a user is looking at a given position, the corresponding option in the menu (taskbar) gets selected and invokes. These kind of systems replaces the traditional keyboard and mouse, while it may also serve an ergonomic purpose. This technology works as a great tool for people living with motoric or verbal impairments [17], due to the method making it possible for people to access all the functions provided on their computers. They are able to manage applications, control external devices or use it for communication purposes, with no need for movement of the body [11].

BACKGROUND

Tobii AB is the world's leading developers of eye tracking technology. Tobii comprises of three business units called Tobii Pro, Tobii Tech and Tobii Dynavox. Tobii Dynavox is specialized and global leaders in assistive technology of communication. They develop software and devices that are adapted to fit the needs of users with conditions causing motor and speech impairment like cerebral palsy, ALS, autism, spinal cord injury, rett, aphasia/stroke, neurological conditions, traumatic brain injury and intellectual disabilities. Eye tracking technology makes interaction with a computer via eye gaze possible, and this combination of technology can be used as devices for a lot of different purposes, including a speech generating device. Gaze interaction systems can be used to control a computer system entirely via eye-gaze or in combination with a physical controller called switch (tactile button). There are some competitive software programs existing on the market that serves the same purpose while it differs in some interactive functions and design structures. This study has been in collaboration with Tobii AB, and evaluates two third party applications to get insights in usability issues in eye-gaze interaction systems for controlling computers. The insights were later used as a base to the research and formation of design guidelines. The purpose was to deliver the design guidelines to Tobii AB, for their further development of gaze interaction systems. The applications are not approved to be mentioned by the owner company and therefore the applications are briefly explained in text only and referred to as program 1 and 2. The purpose of the study is to examine which cognitive science theories can be applied on the user interface of gaze-based control systems, to enhance the usability for the end-user. The result is going to be formulated as design guidelines. The research question is: which cognitive science theories can be applied on interfaces of gaze-based control systems to optimize the usability?

METHOD

Participants

10 people participated in the study, whereas 3 participants data got lost. The lost data was caused by technical issues, leaving a total of 7 participants data usable. Desired participants were primarily people with no previous experience with gaze-based control systems. This, to get usability insights from a new user perspective and to analyze their intuition during their interaction. One of the participants was a current user of gaze-based control systems and therefore considered as an expert user. The expert user was the only participant with motor impairments and speech difficulties, and was included in the study to get an insight of an experienced user's opinion. The rest of the 6 participants had no previous experience of gaze-based control systems.

Instrument and Material

The participants underwent user tests for two competitive gaze-based control systems. In this study they are referred to as program 1 & 2. The participants gaze was registered during the test by using a Tobii eye tracker 4c attached below a laptop computer screen (13 inches screen). Program 1 and 2 are built in a similar construction where the interaction method and system structure are the same. In both programs, the user is able to look around freely on the computer screen, and whenever the user wants to interact with the computer they use tools from the application system. The tools are provided in an interaction menu, called taskbar, which offers tools in order to interact with the computer system. The taskbar corresponds with the classic computer mouse functionality, with functions such as left-click, right-click, double-click, drag and drop, scroll and a keyboard option. One disparity in program 1 is that the settings is not accessible with gaze interaction, as it is in program 2. Settings is an available function of program 1, although, only accessible with a computer mouse or a switch device. Therefore, settings in program 1 was excluded from the evaluation.

Tobii Pro Print was the used web-based application that made it possible to record sound and capture the users interaction on the screen. The interaction was captured by recording where the participant was looking on the screen, using the eye tracker, while the participant was performing the given task.

The data was collected and visualised by Tobii Pro Sprint as a video recording of the participants comments, their actions on the screen, and a small circle representing the participant's eye movement at all times during the tests. 2 questions were asked after each task regarding their experience and an additional semi-structured interview with 5 questions was made at the end of each test (see Appendix A to review the interview questions). The user study with the expert user was conducted individually in a quiet groop room at Tobii AB office. The non-expert participants were tested in their home individually.

Procedure

Participants were recruited privately by email communication depending on their experience with gaze interaction systems. The tests were conducted individually. The user test for program 1 (test 1) consisted of 3 tasks to generate interaction with the taskbar and keyboard. The user test for program 2 (test 2) consisted of 4 tasks to generate interaction with the taskbar, keyboard and settings. The amount of tasks for each program differed due to gaze interaction with setting only being accessible in program 2, and not in program 1. The test instructions were only focused on the tasks, and no instructions on how to correctly accomplish them was provided, unless the user could not complete the task or struggled for a longer period of time. This to let the user solve the task intuitively by themselves, to get an insight of their intuition when interacting with these systems. In test 1, the first task was to find a specific tv-show on a tv website. The second task involved typing some sentences in a word document. The third task involved moving files on the desktop. In test 2, the first task was to "order" 3 products from a pharmacy website. The second task was to type some sentences in a word document. The third task was to move files on the desktop. The fourth task was to adjust a number of settings, such as change language for the keyboard, adjust dwell time for a "button" to be selected when observing it and selecting specific interaction tools to appear in the taskbar. The participants were asked to use the "think-loud" method (except the experienced participant, who had speech impediments). That is, they were encouraged to talk about their thoughts whilst navigating the program to complete their tasks. This method provided information about their current opinions and experience. The participants started by testing program 1 (test 1), and were initially asked 2 questions after completing each task regarding their experience, to ensure that all their thoughts and opinions were mentioned. When test 1 was completed, they were asked 5 questions as a semi-structured interview about previous experience with this technology and their thoughts and opinions about their overall experience with the program (see Appendix A to review the interview questions). Test 2 was outlined exactly as test 1, but with slightly different tasks to achieve some variation of experience for the participant, avoiding repetitive tasks. After test 1 and 2 was completed, the participants were asked to rate the difficulty level of the taskbar, keyboard and settings from 1 to 5 (see Appendix C to review the participants rating). Interview questions for test 1 and 2 corresponded, to get comparative data. The data was generated by the video recording of the users interaction performance, their comments and the interviews. All the data were compiled into a list of all the problem areas and experienced difficulties of the overall usage, with a particular focus of the experience of the taskbar and keyboard (and settings for program 2). Additionally, a compilation of positive opinions and experience was listed. An investigation of research in the field of cognitive science and cognitive psychology resulted in a compilation of 16 design guidelines. The guidelines involved visual perception, object recognition, color processing, visual search, readability, visual attention and memory. Some of the cognitive design guidelines were further explained in images.

RESULT

The compilation of the data is based on 7 video recordings of participants using program 1 and 2, whereas 1 participant was considered to be an expert user and the 6 remaining users was considered to be inexperienced users. The data compilation stated below is a general summarization of the collected data for both programs (for more specific information about the finding see Appendix B to review compilation of data. The participants were asked to rate their experience of each function from 1 to 5 (1 being difficult to use, 5 being easy to use) (see Appendix C to review scoring of the functions). The following main issues in both programs were discovered:

Issue number 1. Participants were feeling stressed during the tasks, and was afraid to accidentally click on something. They described it as them not knowing if they accidentally will interact with something just by looking around on the screen.

Issue number 2. Participants with no previous experience of gaze interaction had some problems when deciding what type of interaction tool to use in some occasions. For example, they often used a left-click tool when they preferably would have wanted to use a double-click tool. Most of them explained their actions as them not knowing what type of click they usually perform when using a mouse.

Issue number 3. Participants were asked to open Google Chrome during the first task of the user test. During this sekvence, they often started off by looking at the chrome icon first. Some participants explained it as they were expecting to interact with the Google Chrome icon just by looking at it. When participants wanted to interact with something on the screen, they occasionally looked at the object they intend to interact with first for a longer period of time, and later realized that they have to select a tool in order to interact with the object. This made them look back at the taskbar to perform the desired action correctly.

Issue number 4. During the tasks when participants were asked to use tools in the taskbar, they usually started to look at the tool that was placed at the top of the taskbar and later looked down at the rest of the tools.

Issue number 5. The keyboard in program 2 provided the user with feedback of what word they were currently writing. This feedback was presented on the keyboard letter the user was currently looking at (while they were typing). The users did not seem to use this feedback and only looked at up in the dokument to read what they have written instead. The color of the feedback text was blue.

Issue number 6. Some of the participants had a hard time to understand and interpret the meaning of some icons, often interaction tool icons. This was problematic since they could not interpret the function of the specific interaction tools, which caused the participant to make mistakes when using them.

Issue number 7. When a selectable menu option had a text on it (describing the functionality of the option), the participant stated that they experienced anxiety. This might have been caused by the fact that the user wanted to read and understand the information, meanwhile a dwell time for selecting the "button" started and the "button" got selected by accident.

Take Aways

- People use computers differently when it comes to interfaces. Some people prefer to use a computer mouse, or a mousepad and some prefer to use a device that provides a touchscreen. These different interfaces/interaction tools has different ways of clicking, selecting and scrolling. Therefore, the participants in this study may have performed differently depending on which interaction tool they are most experienced and comfortable with. One participant was not familiar with using a computer mouse and this resulted in the participant having a hard time understanding what type of click-tool to use when interacting with something, since all the interaction tools resembles a computer mouse interaction functionality.

- Participants started to understand the meaning and functionality of all the menu options and interaction tools the more time they had spent on using the system. Based on their comments and gaze movement, their problem solving and planning seemed to get more efficient.

- The two interaction alternatives left-click and double-click may add an extra step for the user to process when it comes to selecting suitable tools for their interaction purpose. The user may have to consider what type of click they would normally do if they were using a computer mouse.

- In this case of using gaze to achieve interaction, the eyes functions as a tool for both input and output. Meaning that while our eyes works as a tool for our visual perception, they also interact with the computer screen at the same time. This complicates the interaction experience due to the system not being able to recognize if the user is simply looking around to gather perceptual information or if the user wishes to interact with an element displayed on the screen.

Research and Design Guidelines

Based on the data compilation from the recordings and interviews, an investigation of existing research regarding cognitive science theories was made, and 17 design guidelines were created (8 guidelines were based on the issues found and 9 additional guidelines were added only from the research). The design guidelines involves humans cognitive abilities such as visual perception, object recognition, color processing, visual search, readability, visual attention and memory. Some of the cognitive design guidelines are further explained in images. The following design guidelines were created:

Guidelines based on the issues found

1. Avoid the need to recall motoric actions memories

It can be problematic and time consuming if the user needs to recall memories of morotic actions such as "when to use left-click, right-click or double-click to interact with a computer correctly using a computer mouse" and apply them to another type of context or verbally recall them. Therefore, it might be considerable to avoid putting the user in a situation where they have to recall how to use a computer mouse [8]. The guideline is based on issue number 2.

2. Avoid blue as a focus point color

Essential information, that the user will have to focus their eye-gaze on, should preferably be colored in red or green and not blue. It is difficult for the eyes to focus on the color blue, and therefore blue is suitable as a background color. The fovea is responsible for our focus point sight and for the perception of fine details of the scenes we perceive [15]. The fovea offers sharp resolution sight compared to peripheral vision. The center of the fovea contains few blue sensitive cones which makes it difficult for an eye to focus on the color blue (see figure 1 & 2). Therefore, blue is ideally more usable as a background color as it will not distract the user from the essential information presented on the screen [10]. The guideline is based in issue number 5.

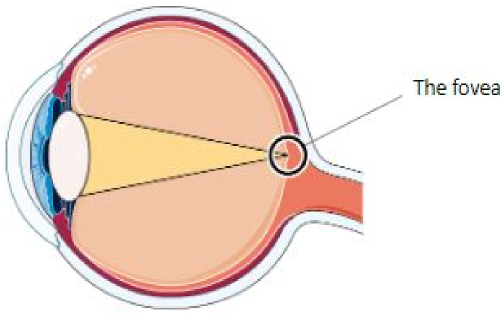

Figure 1. The image is an illustration of the human eye and where the fovea is placed [2].

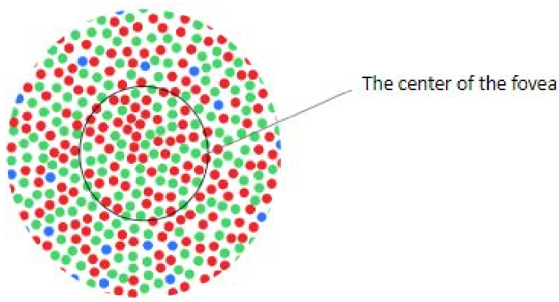

Figure 2. The image is an illustration of how color receptors (cones) is distributed in the fovea.

3. Top to bottom

Vital information should be placed in the top part of the screen, while the rest of the information should be placed in the users reading direction. Prominent and highly colored objects attracts the users attention quickly, and after analysing the most important information, they will analyze information in a similar way as reading gravity. Reading gravity means that the eye wanders down the page roving between information [26]. The guideline is based on issue number 4.

4. The canonical perspective

Users recognize an object or icon faster if they are presented in the canonical perspective, which is slightly above the object from the side. This visual perspective makes it easier for the users to identify and remember the icon. Studies have shown that when people are asked to draw a coffee cup they usually draw them in the canonical perspective, and rarely from an "above perspective" (see figure 3). The canonical perspective phenomenon seems to be a universal trait [25]. The guideline is based on issue number 6.

Figure 3. This is what most people draw when they are asked to draw a coffee cup [25].

5. Inhibition of return

Aim to place information in a way that the user does not need to repeatedly look back at the same previous point. Research shows that we are slower to find stimulus that is presented in a region where we previously fixated our gaze, and we are faster to find the stimulus if it is presented in a visual region which we have not visually searched yet. If we move our eyes to location A and later to location B, we are slower to return our eyes to location A than to a new location C (see figure 4) [13]. This is still substantial when we move our attention without moving our eyes [18]. This phenomena should be considered when designing gaze interaction systems since it may affect the cognitive load negatively if the user needs to look back at a certain point occasionally. The guideline is based on issue number 3.

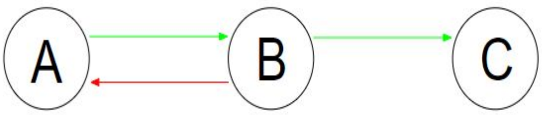

Figure 4. An illustration of an eye movement from A to B to C, alternatively a movement from A to B and back to A. Returning our gaze fixation to a previous location is a slower process and requires additional attention and effort, as opposed to fixation of gaze to a new location in the visual field.

6. Looking without seeing

Keep in mind that the user's visual information processing is limited, meaning that they can attend to one information source at a time. If the user is focusing on a challenging task, they will probably filter out distracting stimuli in their peripheral sight. This is shown in research about a phenomenon called inattentional blindness, which means failure to see visible objects while the attention is directed elsewhere. [25]. If the user is fixating their gaze at something on the screen, it does not guarantee that the user "see" it. [16]. The position of the eye fixation is not equivalent with seeing. The part of the visual field or scene the person is attending to might be what the person is aiming to encode to store into memory [14]. Therefore, it is important to consider what might attract the user's attention and focus, if there is information that might distract the user from not seeing what they are looking at. The guideline is based on issue number 5.

7. Seeing without looking

If a person fixate their gaze at a certain point on a screen and a change appears further than 2 degrees away from the fixation, there is a distinctive drop in the probability to detect the change [16]. This is important to keep in mind if you are aiming to inform the user with necessary information, such as interaction feedback or important messages. The guideline is based on issue number 5.

8. Limit the stress

Aim for the user experiencing a moderate amount of stress. The feeling of stress will implicate the users performance during tasks depending on the complexity level of the task (see figure 5). The Yerkes-Dodson Law implies that a small amount of stress may increase the level of performance because of increased awareness. However, too much stress will result in the user making more mistakes and repeatedly make the same action over and over again, and simply degrade their performance [25][28]. The guideline is based on issue number 1 and 7.

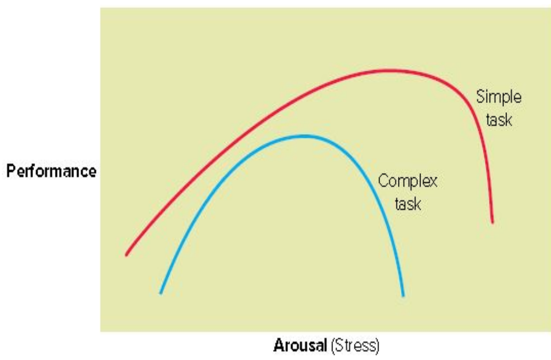

Figure 5. An illustration of how arousal may affect performance of completing a complex task versus a simple task [25].

Additional guidelines

9. Place images to the left and text to the right

Place text on the right part of the screen and images on the left part of the screen to achieve quick information identification. Placing images and text this way will facilitate the processing of text and images in the corresponding specialized hemispheres and will help reduce the cognitive load on the user (see figure 6) [7].

The brain is divided into two hemispheres. Each hemisphere is individually specialized in processing particular information. The left hemisphere is responsible for controlling the right side of the body and the right hemisphere controls the left side of the body. Likewise, the right eye is controlled by the left hemisphere which is associated with linguistic and analytical processing, and the left eye is controlled by the right hemisphere which is associated with perceptual and spatial processing. When we read, we activate a site in the left lateral occipitotemporal sulcus known as the visual word form area (VWFA), which is responsible for reading-specific processes [6]. Therefore, a person can identify text quickly if it is placed in the right visual field and identify images quickly if they are placed on the left side of their visual field [7].

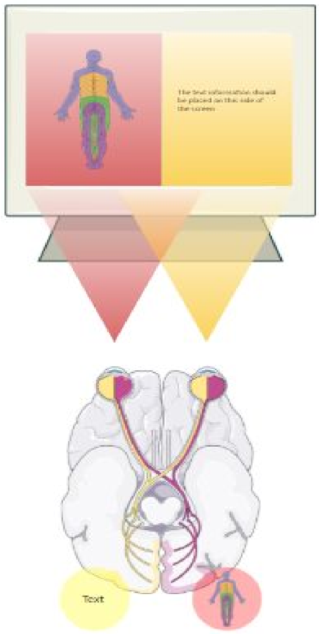

Figure 6. Illustration of the visual information process from the perception stage to the visual cortex process stage [2].

10. Avoid strong contrasts of bright and dull colors

Use bright colors moderately and only when needed. The human pupil dilates on exposure of dull colors and contracts on exposure of bright colors. Therefore, a mixture of both dull and bright colors causes eye tiredness due to constant movement of the eye muscles. This constant movement from switching between contraction and dilation of the eye muscles reduces user's readability [26].

11. Usage of lower or upper case letters

Use lower case letters if you want the user to read fast, and capital letters where more attention is needed. When reading texts in capital letter our reading speed reduces by 12% and may use around 30% more space [26].

12. Reading speed

Longer line lengths are easier to read because they interfere less with the flow of saccades and fixations. Use a longer line length (100 characters per line) if reading speed is an issue, use shorter line length (45 to 72) if reading speed is less critical [25].

13. Five to nine memory rule

Try to limit the number of choices to three or four, suggestively in menus and interfaces presenting different options. The short term memory is limited and can hold up to five to nine elements (7+-2) at a time [1]. This should be considered when designing interfaces to adapt for users memory and information process capacity, minimizing the users need of sporadically memorizing information [19]. Aim to limit the amount of colors when categorizing information or designing buttons, icons, menus or similar [21]. This helps reducing the cognitive load.

14. Use peripheral vision for object recognition

To make the user quickly understand what type of page they are entering, make sure to place information that communicates the purpose of the page in the users peripheral sight (where the users peripheral sight is most likely to be placed). Users usually decide what a page is about based on a quick glimpse of what is in their peripheral vision [25].

The brain's response to stimuli will be produced more efficient, as a fast automatic alert response, if the stimuli is placed in the users peripheral field. This has been shown in studies where fearful objects has been placed in participants center visual field or peripheral visual field. When fearful objects are placed in the central of the human visual field, the amygdala will take around 140-190 milliseconds to react. When objects are presented in the peripheral part of the visual field the amygdalas reaction responds in around 80 milliseconds [3].

15. Avoid too many automatic steps

If a user needs to perform a series of steps repeatedly, their actions will become automatic and they are not able to concentrate on their actions the same way as before. Too many automatic steps will result in the user making errors [25].

16. Attract attention by movement, colors or faces

If you need the users attention, use distinctive bright colors, faces, videos, blinking or moving objects. This is also important to avoid when you need the users attention to be directed elsewhere, otherwise it will probably distract them from completing their task [25]. It may be useful in cases where it is important that the user needs to fixate their gaze, such as the interface of the eye tracker calibration.

17. Use sound for feedback

Use sound to provide feedback in cases when the user needs to focus their attention on a task. We are only able to attend to a limited amount of information in a single motor system at a time. Eye-gaze interaction programs requires the user to use their visual system for executing and interpreting information which can be overwhelming. The human auditory system can therefore be used to provide the user with feedback since it is easier for them to perceive a sound than a visual feedback when they are already attending to another important visual field or thought. A simple sound feedback will not distract the visual system processes as a visual feedback would if it appeared in parallel with the user attending to another task involving the visual system [1][4].

DISCUSSION

This study evaluated two gaze interaction systems, to further generate design guidelines from a cognitive science perspective. The study aims to provide design guidelines that may be applied in design for similar gaze interaction systems to optimize the usability. When analysing the participants gaze pattern and comments from the first test (evaluation of program 1), the participants seemed to struggle with the program presumably by reason of it being their first attempt using this interaction method. This may have caused the participants to be biased when they use the second program, because they have started to learn the concept and process of gaze interaction for the second test caused by the “Learning by doing” effekt [20]. Thus, the more a task is practiced the more automated it gets, and less and less cognition is needed to execute the actions [1], which is a beneficial aspect regarding development of gaze interaction systems and its use in general, meaning the more people use it the more they might appreciate this way of interacting.

The eye-gaze interaction method implies the eyes being tools for both input and output. Meaning, while our eyes are tools for our visual perception of the information displayed on the screen, they simultaneously act as tools for invoking processes in the computer [11]. This complicates the interaction experience due to the system not being able to recognize if the user is simply looking around to gather perceptual information or if the user wishes to interact with elements displayed on the screen. Research shows that the auditory system can only attend to one spoken message at once, and the visual system can only attend to one image at once [1]. This is one of many confirmations showing that humans can easily feel overwhelmed when they are attempting to conduct two things at once using one motor function. As Anderson J. R. states in his book “people can process multiple perceptual modalities at once or execute actions in multiple motor systems at once, but they cannot process multiple things in a single system including central cognition”. This is why user interfaces for eye-gaze interaction systems becomes complex to design, due to it requiring the user to use one single system to process information and execute actions simultaneously. It is therefore important to separate all the processes to achieve a design where the user can feel in control and be able to interpret information without executing an action at the same time. This might be the reason why the participants in this study did not perceive some of the feedback information provided in the systems, especially when they were typing using the keyboard. When the participants were typing with the keyboard provided in program 1, they moved their eye-gaze to the next letter too quickly before the previous letter was selected, even though a dwell time feedback visualisation on the letter was provided (in the form of a clock timer). This often resulted in misspelling words. Similar behaviour was detected when the participants were typing with the keyboard provided in program 2. As they were typing, they failed to acknowledge the typing feedback (of the words they were currently constructing) displayed below the letters they were selecting. In both cases, participants were presumably attending to the typing process only, involving search of letter, selecting letter and planning their next selection of letter. This is an example of parallel tasks that the user fail to process, due to it involving different processes in a single stream at the same time [1]. Contrariwise, the keyboard provided in program 2 was used much more efficiently because of the selection feedback was presented both visually and auditory (click sound). This is an example of a parallel process which involves both the visual system as well as the auditory system, which results in a better experience for the user.

Another finding after analyzing the data was that the users experienced difficulty deciding when to use the left-click or the double-click tool. The user had to consider the appropriate tool to use, in order to execute their desired action, which required them to recall what type of click they would perform with a computer mouse in the same situation. This might add an additional step in the user’s problem solving process, as it increases the cognitive load and extends the time for performing their actions [1].

Using eye tracking for usability testing purposes has shown to be promising, yet problematic in cases of calibration and tracking success [12]. It may also entail implications regarding the previously mentioned phenomenon referred to as “looking without seeing” or inattentional blindness. A users eye fixation on an element does not necessarily mean that they are perceiving and interpreting the element, which makes it complicated to understand what information the user is attending to during usability testing [25][16]. However, combining the user comments generated from the “think-loud” method with the gaze visualization, resulted in a broader understanding for the participants experience. Also, depending on what test instructor tells the participants to do in advance of the task or while performing the tasks, the participant performance and behavior will be affected and result in them looking in a certain way while conducting the tasks [27]. This bias is important to have in mind if the research is aimed to make participants use the system intuitively.

This study did not include participants with impaired cognitive abilities, which could be of interest considering the end-users for the systems. In future research it may be important to consider the users interaction access, independence, technical competence and their cognitive and focus abilities. Also, studying eye movements during usability tests can be effective, but also misleading due to the eyes fixation on an element not necessarily means that the user “sees” the element. This study has been aware of this issue and should also be taken into consideration in future work.

This paper contributes to the field of interaction design in HCI, by providing developers and UI designers for eye-gaze interaction systems with cognitive design guidelines. The design guidelines might not only be useful for eye-gaze interaction systems and can potentially be applied in other computer-based systems.

CONCLUSION

The focus of this study was to compare and evaluate the user interface of two competitive gaze-based control systems to later investigate research regarding human information processing. This research was the basis of the design guidelines, which can be applied in user interfaces of similar systems. The design guidelines may be suitable for similar systems with a different interaction system, such as cases where interaction might be executed in another method. There are several other cognitive science theories that could potentially be applied when designing user interfaces for eye-gaze interaction systems which needs to be investigated further.

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Appendix A - Interview questions

The participants were asked two interview questions after each task, and 5 semi-structured interview questions after each test. The interview questions were asked to get a better understanding of the user experience, and complimented the video recordings of the participants eye-gaze and interaction with the system.

Test 1

Questions asked after completing task 1

- How was your experience using the taskbar and its tools?
- Did you find the task being difficult at any point, and what was the issue?

Questions asked after completing task 2

- How was your experience using the keyboard?
- Did you find the task being difficult at any point, and what was the issue?

Questions asked after completing task 3

- How was your experience using the drag and drop tool?
- Did you find the task being difficult at any point, and what was the issue?

Questions asked after completing test 2

- Tell me about your experience using the software?
- Did you find the software problematic at any point during the tasks, and what was the issue?
- Why do you think you encounter those problems?
- Would you have liked something to be different?
- Were there anything you found simple to understand and use?

Test 2

Questions asked after completing task 1

How was your experience using the taskbar and its tools?

Did you find the task being difficult at any point, and what was the issue?

Questions asked after completing task 2

How was your experience using the keyboard?

Did you find the task being difficult at any point, and what was the issue?

Questions asked after completing task 3

How was your experience using the drag and drop tool?

Did you find the task being difficult at any point, and what was the issue?

Questions asked after completing task 4

How was your experience using the settings?

Did you find the task being difficult at any point, and what was the issue?

Questions asked after completing test 2

- Tell me about your experience using the software?
- Did you find the software problematic at any point during the tasks, and what was the issue?
- Why do you think you encounter those problems?
- Would you have liked something to be different?
- Were there anything you found simple to understand and use?

Appendix B - Data Compilation

This data compilation is collected from the video recordings of the participants interviews, comments, eye-gaze movement and their general interaction with the software. This was collected to gain usability insights for Tobii AB, and to later investigate if cognitive science theories can solve some of the main issues.

Program 1. Taskbar:

- Participants looked at the object they intended to interact with for a longer period of time and expected an action, and then realized that they had to select a tool from the taskbar in order to interact with the object. *3 of 7 participants experienced this issue.*
- Some participants considered the scroller tool to be problematic. The taskbar was covering the web page scroll bar on the right side of the page, which covered the feedback on where they were looking on the web page. The scroller tool makes it difficult to control where exactly you want to view on a page, since the scroller is an up and down button that scrolls down a particular amount each time. *1 of 7 participants experienced this issue.*
- Some participants tried to scroll down the webpage using click tools on the web page scroller bar at the right side of the screen. This method of scrolling does not work effectively and the participants ended up getting frustrated. *3 of 7 participants experienced this issue.*
- Participants did not notice the secondary tool selection at first. The second selection makes the chosen tool continuously activated. The color change from the primary selection to the secondary selection was too subtle for them to perceive the change. *3 of 7 participants experienced this issue.*
- Participants tended to incorrectly select the left-click tool instead of the double-click tool. *5 of 7 participants experienced this issue.*

+ Participants found the feedback of the drag and drop tool useful. They stated that they understood that something was happening when it appeared. *1 of 7 participants experienced this.*

Program 1. Keyboard:

- On the keyboard there is a left-click tool button. By selecting the button the keyboard exits back to the taskbar. Users assumed that this button is a left-click tool since the button and icon looks equivalent to the left-click tool button in the taskbar. *5 of 7 participants experienced this issue.*
- Participants tend to move away their gaze too quickly from the desired letter or button on the keyboard they want to select, which resulted in typing mistakes. *6 of 7 participants experienced this issue.*
- When the participants were typing with the keyboard and they wanted to select the same letter again they continued to look at the same letter. Their gaze was stationary in the belief that the button would be selected again. When they realized that nothing happened, they looked away and returned their gaze to the letter to click on it. *6 of 7 participants experienced this issue.*
- The participants forgot what they had typed occasionally, leading to the common mistake to forget to ad space or type the same word again. *5 of 7 participants experienced this issue.*
- Participants stated that they a scrolling tools were missing on the keyboard. *3 of 7 participants experienced this issue.*
- Participants looked at the symbol x in the upper right corner of the keyboard assuming that it would exit the keyboard, and later realized that it was not an available tool for gaze interaction. That exit button solely works for mouse interaction. *2 of 7 participants experienced this issue.*
- Some participants perceived the keyboard as stressful because of the timer count down to selection feedback on the buttons. *3 of 7 participants experienced this issue.*
- Participants had a hard time to understand/recognize the enter button, saying that they usually look for the specific shape of enter button rather than the icon on the button. *2 of 7 participants experienced this issue.*
- Some participants did not like the fact that one can only delete one letter at a time using the backspace button. *2 of 7 participants experienced this issue.*

+ The word prediction/suggestion function was appreciated. *3 of 7 participants experienced this.*

+ Some participants liked the timer count down to selection feedback on the buttons**.** *1 of 7 participants experienced this.*
+ Participants found the buttons for numbers very quickly, their visual search time to find this alternative quick and efficient*. 6 of 7 participants experienced this.*

Program 2. Taskbar:
- In the beginning of using the taskbar, the participants looked at the tool placed on the top of the taskbar at first and later looking down to the lower tools in the taskbar. The participants seemed to analyze the tools from top to bottom order. *3 of 7 participants experienced this issue.*
- Participants tend to mistake the drag and drop tool with the double-click tool. The two different tool icons looks similar. *2 of 7 participants experienced this issue.*
- The left-click tool got mistaken with the double-click tool. *4 of 7 participants experienced this issue.*
- Drag and drop tool was considered as acting too quickly. *3 of 7 participants experienced this issue.*
-Participants experienced complications when using the scroll tool. They did not understand that they had to place the tool in the middle of the screen in order to look up and down to scroll. Once they learned how to use it correctly, they were using it effectively. *5 of 7 participants experienced this issue.*
-Some participants tried to place the scroller tool on the website's scroller bar. *2 of 7 participants experienced this issue.*
- Participants did not know how to exit the scroller tool. They selected another tool to stop it or they accidentally exit it by looking around in the taskbar. *3 of 7 participants experienced this issue.*
- Some participants stated that they where is missing feedback when they have selected an interaction tool. This was also noticeable in the their gaze in the recordings. *3 of 7 participants experienced this issue.*
- Participants did not realise when the selected tool action got cancelled. When they had selected an interaction tool they searched for the object they intended to interact and stared and focused on it. If the action got cancelled, which happened occasionally, they were rarely aware of the cancellation and continued to look at the object, waiting for the action to be initiated. *4 of 7 participants experienced this issue.*
- It was difficult for some participants to understand the function of the drag and drop tool by observing the icon**.** *3 of 7 participants experienced this issue.*

+ Participants like that all the interaction tools were visible on the screen. *3 of 7 participants experienced this.*
+ Participants liked the scroller more than the scroller in program 1, because this one had more precision. *3 of 7 participants experienced this.*
+ Participants liked that the taskbar did not overlap the screen, not covering any website information. *2 of 7 participants experienced this.*
+ Participants thought this taskbar had a nicer layout than program 1 taskbar. *3 of 7 participants experienced this.*

Program 2. Keyboard:
- Participants misunderstood the meaning of the icon for placement of keyboard. Participants expected the placement tool to be a scrolling tool at first. *2 of 7 participants experienced this issue.*
- Participants wanted a scrolling tool available on the keyboard. If they wanted to scroll on a page they had to exit the keyboard and use the scroll tool available in the taskbar, and later open the keyboard again to continue with the task. *3 of 7 participants experienced this issue.*
- While the participants were typing a sentence they got feedback of what they were typing on the lower part of the buttons. This feedback was not noticed by the participant at first, and when they notice and acknowledge the typing feedback they rarely used it and still looked up at the word document while typing to confirm that they were typing correctly. Although, they still looked up on the sentence as they were typing. *5 of 7 participants experienced this issue.*

- When the participant looked at the exit button of the keyboard, the keyboard disappeared and while their eyes were still looking at the same visual region of where the exit button was previously, they accidentally looked at a

tool that is placed in the same location as the exit button previously was. Meaning, they accidentally selected this tool since it is placed on the same spot as the keyboards exit. *3 of 7 participants experienced this issue.*
- Participants experienced difficulty when switching between the different keyboard layouts/alternatives for letters and numbers etc. They explained it to be difficult to know what keyboard is coming since they only look at arrows to the left and right side of the keyboard to switch between the keyboard alternatives. They did not understand how many keyboard alternatives existed and in which order they were in. *3 of 7 participants experienced this issue.*

+ Participant appreciated the sound feedback when they had successfully selected a key on the keyboard. *5 of 7 participants experienced this.*
+ Participants liked that there was no dwell time animation feedback on the buttons and only a subtle feedback when the selection had been successfully performed. *3 of 7 participants experienced this.*
+ Participants were using the word prediction function provided on the keyboard easily. *5 of 7 participants experienced this.*
+ Participants were using the left-click tool available on the keyboard effectively without any problems. *4 of 7 participants experienced this.*
+ The exit (x symbol) on the keyboard was used effortlessly by the participants. *7 of 7 participants experienced this.*
+ By continuously looking at a letter on the keyboard it got selected over and over again. This was effective and used effortlessly. *7 of 7 participants experienced this.*

Program 2. Settings:
- Participants had a hard time understanding the results of the eye tracking calibration. The symbols representing the result were unfamiliar and the information was not clear to them. *4 of 7 participants experienced this issue.*
- Participants experienced a stressful feeling while they were reading text on buttons because the buttons got selected automatically while they were reading. They were processing information and trying to understand the function of the buttons, meanwhile a dwell time started. Some participants mentioned that they felt like they could not read or try to interpret information without activating something. *5 of 7 participants experienced this issue.*

Appendix C - Participants ratings

Participants were asked to rate their experience of using program 1 and program 2. After completing test 1, they were asked to rate program 1 (taskbar and keyboard). After completing test 2, they were asked to rate program 2 (taskbar, keyboard and settings. This was to gain usability insights of the participants experience and opinions and which user interface solution they preferred. The scoring definition was:
1 = difficult, 2 = quite difficult, 3 = medium, 4 = quite easy, 5 = easy

Program 1	**Taskbar**	**Keyboard**	
participant 1 experienced user	4,5	3	
participant 2 no experience	4,5	4	
participant 3 no experience	3	3	
participant 4 no experience	5	4	
participant 5 no experience	4	3	
participant 6 no experience	4	3,5	
participant 7 no experience	4	3	
Total score:	*29*	*23,5*	
Program 2	**Taskbar**	**Keyboard**	**Settings**
participant 1 experienced user	4	4	5
participant 2 no experience	3,5	4	5
participant 3 no experience	4	4	2
participant 4 no experience	3	5	5
participant 5 no experience	3	4	2,5
participant 6 no experience	5	4	5
participant 7 no experience	4	5	5
Total score:	*26,5*	*30*	*29,5*