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# Eyes Only: Navigating Hypertext with Gaze

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**Abstract.** Eye gaze tracking is an obvious candidate for a future input device, perhaps even for everyday computing. The hard problems with gaze-controlled interfaces are inaccuracy and inadvertent clicking. We attempt to mitigate these problems in the context of a gaze-controlled web browser. Four click alternatives (Dwell, Single Confirm, Multiple Confirm and Radial Confirm) were implemented along with a fifth mouse-controlled version for comparison. Two alternatives make use of additional buttons that confirm a selection made previously by dwell, hence improving accuracy. Our results indicate that the Multiple Confirm alternative performed best among the gaze-based alternatives; it makes use of multiple confirmation buttons when letting the user choose between different options. When compared to the mouse, the clicking times were worse but the accuracy was indistinguishable. User feedback also indicates that, although mouse was considered best, Multiple Confirm was not perceived as slow and generated excitement. This indicates that the Multiple Confirm click alternative has potential as an interaction method for gaze interfaces.

**Keywords:** Eye gaze tracking, dwell, navigation.

## 1 Introduction

An eye gaze tracker makes it possible to monitor the user's point of gaze, i.e. where the user is looking on the screen. It is considered a promising component of future natural user interfaces. A gaze tracker as an input device is easy to learn and use [1], and it is the fastest pointing device in some metrics [2]. Also, users necessarily look at the task-relevant objects [3], [4], [5] regardless of the input device used, so intuitively a synergy can be expected if gaze is used as an input device.

Pointing with gaze tracking is relatively straightforward, but using it for performing actions (or clicks) is challenging. Inaccuracy and inadvertent clicking are the main drawbacks of using a gaze tracker as an everyday input device. The inaccuracy can be caused by gaze tracker error, or it can stem from fundamental limitations such as involuntary eye movements (including jitter and drifts) and the lack of pixel-pointing precision [6]. Inadvertent clicking, also known as the *Midas Touch* problem, occurs because eyes are sensory (input) organs and this creates a mismatch when using them as a means of communicating intention to the computer.

Techniques devised to perform actions (or mimic mouse clicks) are called *click alternatives*. There are many such alternatives being researched for encoding an action with gaze. The most obvious and natural one is called *dwell* or fixation, which triggers an action when the gaze dwells on (i.e. fixates) the same area for a defined time interval. There is a reported preference for simple and natural gaze interaction techniques, requiring minimal deliberate eye movements [7]. Conscious gazing or blinking as a control mechanism is unnatural and tiring. Consequently, complicated selection techniques are only feasible for limited accessibility uses. Since we consider gaze interaction for all users, the click alternatives being investigated in this study will be based on dwell. The users will not be required to learn or perform anything other than just looking at particular user interface components.

The suitability of gaze tracking as an alternative to the mouse may depend on the application domain. Therefore we decided to narrow the investigation down to a limited but highly relevant use case: gaze tracking for navigating hypertext, i.e. clicking text hyperlinks (or hypertext). We used Wikipedia for our study as it is one of the most visited websites, and it is close to the original vision of hypertext. We consider it therefore representative for hypertext navigation. The specific question being investigated is how inaccuracies and inadvertent clicks can be mitigated when navigating hypertext. The investigated gaze tracking techniques were also compared with the mouse.

Four click alternatives, referred to as Dwell, Single Confirm, Multiple Confirm and Radial Confirm, were developed. All of them use a different way of clicking with gaze, but all are based on dwell, as explained before. After a pilot study, two of the click alternatives (Dwell and Radial Confirm) were discarded from further experimentation as they did not seem to be usable enough. The remaining alternatives were fine-tuned and a full experiment was performed.

The experiment yielded the following main finding: Multiple Confirm, although slower than the mouse, is a feasible click alternative using the gaze and should be explored further. We conclude that eye gaze tracking has the potential to be used as an efficient input method, as long as certain design parameters are considered.

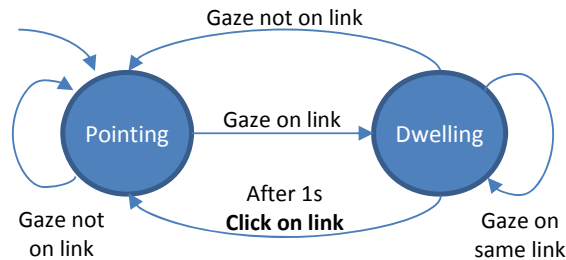
Section 2 summarizes related research. Section 3 describes the experiment design, detailing the click alternatives and tasks performed. Section 4 provides an overview of the findings of the pilot study and the changes made for the full experiment. The results are presented in Section 5, followed by a discussion of the results (Section 6) and limitations (Section 7). The paper ends with a conclusion, which summarizes the findings and identifies further research in this area.

## 2 Related Work

The first reported study of how the gaze behaves in a reading task dates back to 1878, and was probably the first to analyze the gaze as a combination of saccades and fixations [8]. Considerable effort has been invested in finding efficient click alternatives. The most straightforward one is considered to be dwelling or fixating on a clickable area. Formally, this is described by a two-state machine, as shown in Fig. 1. This

click alternative primarily suffers from inadvertent clicking, a problem that can be mitigated if it is possible to place the content or labels outside the clickable areas [9].

Blinks, winks and different muscle sensors have also been experimented with, to minimize inadvertent clicking, especially for limited-accessibility applications [10]. Other alternatives are based on recognizing eye gestures [11] or anti-saccades [12] to indicate a click, or using a physical button for clicking [2]. Different techniques for selecting menu options with gaze have also been evaluated (e.g. [13], [14]).



**Fig. 1.** State machine for the Dwell click alternative

Research has also focused on compensating for the inaccuracy and imprecision of gaze tracking. MAGIC is one such example in which the user relies on explicit commands using other input devices, e.g. the mouse, while also benefiting from the speed of pointing with gaze [15]. This approach moves the mouse pointer quickly to the area being gazed at, but relies on the mouse for finer adjustments and clicking. Different zooming [16], [17] and fish-eye methodologies [18] have been evaluated for the same purpose. The EyePoint [19] is another possible solution to cater for lack of accuracy and precision in gaze tracking. This solution involves magnification (of the area being gazed at) on the press of a keyboard button. In the magnified view, the key can be released while dwelling at the object of interest, resulting in an action on that object (e.g. left or right click). However, these techniques either block or distort the screen content, and loss of contextual information can be inconvenient and problematic, especially for tasks involving visual search [20].

Some recent work has been carried out on gaze-aware or gaze-controlled web browsers. The Text 2.0 Framework [21] allows setting and using gaze handlers the same way mouse and keyboard event handlers are used in HTML and JavaScript. The primary objective of this framework is to detect and assist in comprehension difficulties while reading. The IntelliGaze Desktop 2.0 [22] extension allows web browsing with the gaze by magnifying the area being gazed at if there are multiple clickable options (hyperlinks, buttons or fields) in the gaze area. Dwell is used to click on a link or field in a rectangular magnified view, which always appears in the center of the window. A ‘close’ button accompanies the magnified view, which can be gazed at to close the magnified view if no click was intended. More controls are dynamically provided in the right margin of the window.

Our aim is to extend this work by evaluating if a more natural click alternative is feasible that supports everyday computing for a general population.

### 3 Experiment Design

#### 3.1 Variables

The experiment was performed using a within-subjects design with “click alternative” as the independent variable, using a nominal scale. The dependent variables measured are “time to click,” “number of incorrect clicks” and “number of failed clicks.” Furthermore, user satisfaction was measured with a questionnaire.

#### 3.2 Click Alternatives Design

In the following we describe each of the investigated click alternatives.

**Dwell.** Fixating or dwelling on any hyperlink for one second would click that particular link. Visual feedback, using a darkening outline around the hyperlink being gazed at, is provided to indicate the time progression. A state diagram for this click alternative is shown in Fig. 1.

**Single Confirm.** When dwelling on a hyperlink, a confirm button is activated in the right margin. The user has to look at this button to click the hyperlink. A screenshot of the implementation is shown in Fig. 2 and the state machine in Fig. 3. This design tries to control inadvertent clicking by providing a confirmation step. The confirm button has a darkening border to show time progression during dwell.

The initial design had the button appearing right next to the line with the hypertext being looked at, in order to minimize gaze travel. A light grey line extended from the button to the edge of the hyperlink to disambiguate among multiple links present in the same line. This was changed after the pilot, as outlined in Section 4.



Fig. 2. Single Confirm: User navigating to “UNESCO World Heritage Site”

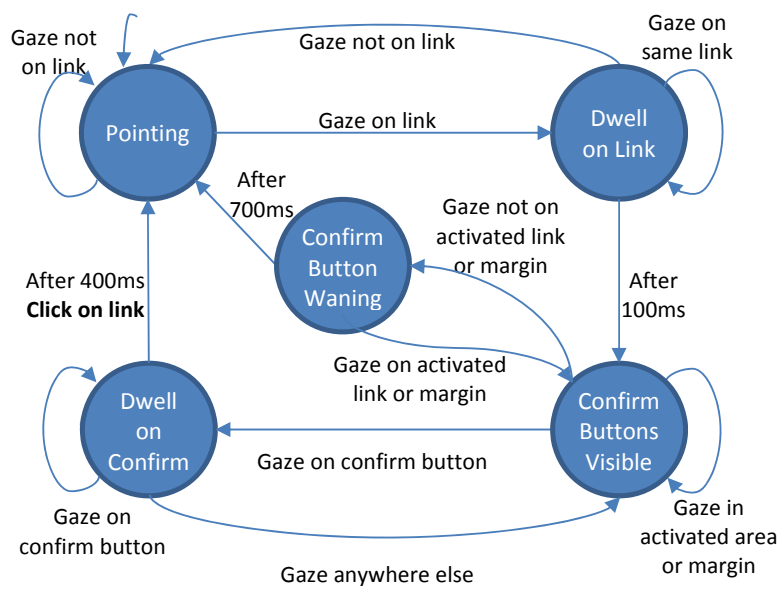
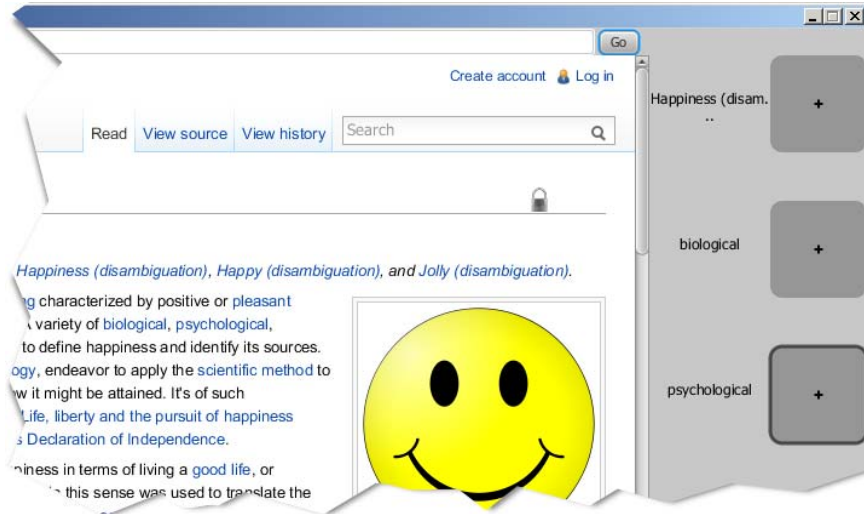
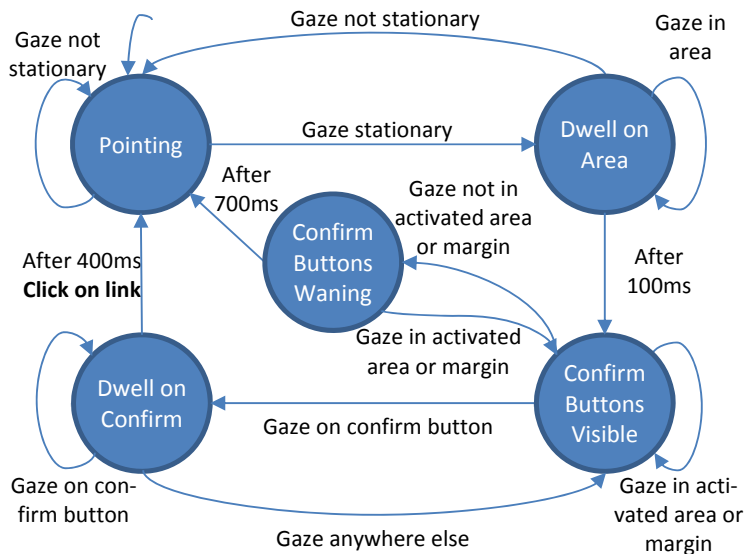


Fig. 3. State machine for Single Confirm click alternative

**Multiple Confirm.** On dwelling, the confirm buttons of all hyperlinks, in a specified radius around the reported gaze, were activated in the margin. A screenshot of the implementation is shown in Fig. 4 and the state machine in Fig. 5. While avoiding inadvertent clicks, we also expected this alternative to compensate for the inaccuracy and imprecision of gaze trackers, similar to magnification, but in a more natural way. Some changes were made to the user interface after the pilot (outlined in Section 4).



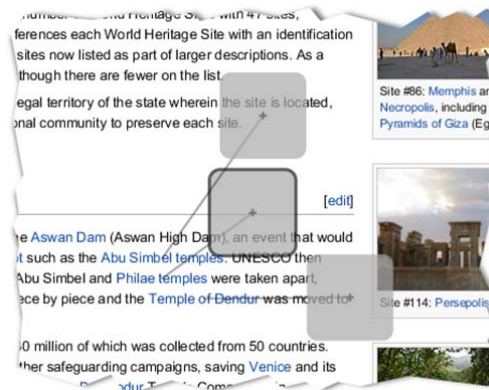
**Fig. 4.** Multiple Confirm: User navigating to “psychological”



**Fig. 5.** State machine for Multiple Confirm click alternative

**Radial Confirm.** This click alternative is based on the same idea as the Multiple Confirm alternative (and therefore has the same state machine). Additionally, it was de-

signed to minimize the gaze travel from the hypertext to the confirm buttons. A screenshot of the implementation is shown in Fig. 6. Instead of appearing in the right margin, the confirm buttons are drawn around the reported gaze point on the web page. Each confirm button is placed in the direction of the corresponding hyperlink from the gaze point. In case the gaze point is near an edge of the browser and drawing a confirm button is not possible in one direction, the button gets drawn in a different direction where space is available. The confirm buttons in this click alternative are connected to the respective hypertext with light grey lines for disambiguation.



**Fig. 6.** Radial Confirm: User navigating to “Philae temples”

**Mouse.** Standard mouse interaction was used as a control condition, while performing the tasks in the same prototype web browser.

### 3.3 Setup

The web browser prototypes were developed in Java. The stereo infrared cameras of a non-invasive remote gaze tracker were mounted below a 15 inch LCD screen running at a resolution of 1280 x 1024 pixels. The gaze direction was determined by the gaze tracker software using the pupil-center-corneal-reflection (PCCR) method. A fully adjustable chair with headrest was used to help maintain the participant's head position, as the maximum freedom of head movement allowed by this gaze tracker was only 2.7 cubic inches. The LCD screen and the gaze tracker cameras were mounted on a movable arm (complete setup shown in Fig. 7). A travel pillow was also used by the participants to help keep their head rested in one position without getting tired. The lab was illuminated with fluorescent lights, and sunlight from windows was blocked during the experiments.

The participants were first given an overview of the equipment and the experimental tasks. After responding to the demographics questionnaire, participants were comfortably seated and the chair's height and distance from the gaze tracker were



adjusted. The LCD screen and cameras were then adjusted on the movable arm, if needed. The gaze tracker was calibrated, taking 15 to 20 seconds, before starting the tasks for each gaze click alternative.



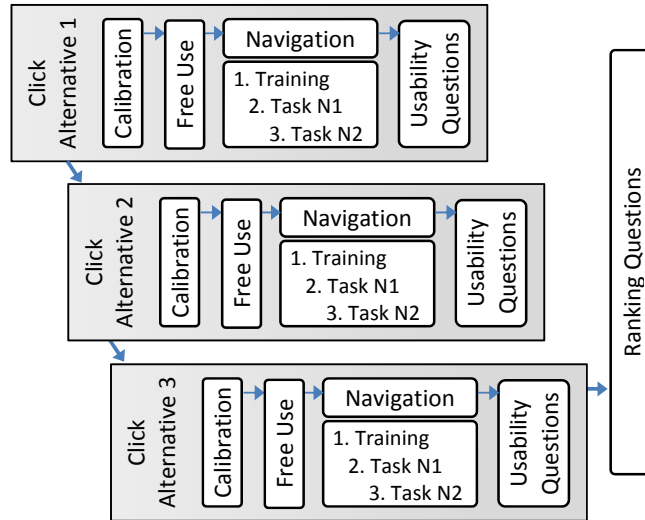
**Fig. 7.** Gaze tracking setup

### **3.4 Task Description**

The participants performed the same two navigation tasks using each click alternative (as shown in Fig. 8). Before starting a task, the contents section of the involved Wikipedia pages was collapsed using its 'hide' option and any banner appearing on the top (e.g. for fund raising) was also closed, to maximize the space used for the actual page content. Since Wikipedia content is being updated continuously, specific versions of the pages were used to ensure uniformity. Participants were allowed to familiarize themselves with a gaze click alternative for a few minutes before using it in the tasks.

For each navigation task, a start page was shown and the participants were told to click four hypertext links one after the other. The first navigation task involved clicking four hyperlinks with comparatively few links in the vicinity, while the second navigation task had a higher hyperlink density in the involved pages. The same two navigation tasks were used for training before performing the actual trials.

Participants were allowed to request assistance if they faced difficulty in clicking any hyperlinks. In that case, the experimenter would click the link with the mouse. If an incorrect link was clicked by the participant, the experimenter would use the mouse to go back to the previous page. No scrolling was required for the tasks.



**Fig. 8.** Experimental procedure for each participant

### 3.5 Data Collection

The order of click alternatives was permuted to mitigate order bias and training effects. As the experiment (after the pilot) had three alternatives, six permutations were used. Therefore, a multiple-of-six number of participants were recruited.

Events were logged for each web page along with timestamps in CSV log files for each participant's use of each click alternative. The types of events logged included "Gaze on Link," "Button Drawn" and "Click." The data from these log files was analyzed to find the time required for each click, the incorrect links clicked and the mouse clicks done by the experimenter (when assistance was requested by the participant). Six usability questions, derived from the System Usability Scale [23], were answered on a 5-point Likert-scale after using each click alternative. The responses were scored for each participant and averaged to get the usability score of each alternative, with a range from -12 to +12. After completing the experiment, the participants ranked the click alternatives. These ranks were scored (two points for being ranked first, one for being ranked second and zero for being ranked third) and summed up to form a total ranking score for each click alternative. Comments were also solicited in the questionnaire to help explain the rankings.

## 4 Pilot Study Results

Five participants took part in the pilot study, one of which had difficulties using the eye tracker and could not complete the experiment. All participants were university students aged 19 to 23. The pilot exposed important shortcomings which are documented in this section.

Out of the five click alternatives, Dwell turned out to be very problematic. The first two participants had so much difficulty that it was decided to not evaluate it further. Users found it extremely difficult to hold the gaze on a link for the required 1 second. In case multiple links were present close to each other, an incorrect link would get highlighted or clicked more often than the correct one.

We believed the Radial Confirm alternative to be very promising, but it turned out to have the following problems. The buttons were drawn depending on the reported gaze location. This resulted in a different and unpredictable button arrangement every time the buttons were drawn. If the text had four or more hyperlinks in an area, it was difficult to find the right button to click. While looking for the right button, there was a possibility of the buttons disappearing and more buttons being drawn. If the gaze was near the border of the web page, especially in any of the four corners, the buttons ended up appearing in a non-intuitive pattern. This added to the difficulty of finding the right button associated with each hyperlink. Moreover, the buttons and connecting lines occluded the web page content. In short, this design had many usability issues. According to the participants:

- “Radial Confirm is easier to select links as you don't need to look away to select them. However, it is impossible to read other text.”
- “Radial Confirm was bad as while reading the buttons were easily clicked by mistake.”

The Dwell and Radial Confirm were discarded from further experimentation. On the other hand, Single and Multiple Confirm buttons were equally preferred in the pilot. The following are some comments from the participants:

- “Single Confirm is easier to use as there are less chances of making mistakes with it. Multiple Confirm was easiest to use but did have difficulties looking at the link as well as looking for the words shown up on the side.”
- “Single Confirm was useful, however, having several words on the same line made clicking the button very hard.”
- “Single Confirm is better than Multiple Confirm as you don't need to look away if the right link has been selected. However, this can be replaced by something that doesn't cover any text (e.g. underline). In Multiple Confirm, need to look away constantly to check if the right link has been selected and also takes time to do so. So it was distracting when trying to read through text.”

Many refinements were made in the Single and Multiple Confirm alternatives after conducting the pilot. An underlying objective of these refinements was to minimize confounding factors by making the Single and Multiple Confirm designs more similar to each other. For both alternatives, text was placed outside the buttons to avoid inadvertent clicking and a crosshair was added in the center of buttons to provide a visual anchor, in accordance with earlier findings [9]. More text was made visible in button labels since some links were not disambiguated easily by only the first five letters. These text labels were placed between the web page and buttons, so that the gaze would not have to travel over the buttons to read the labels. As a result, the con-

necting line was removed from the Single Confirm alternative as the text label would already associate the button with a hyperlink. Highlighting of hypertext was also considered but not implemented in order to minimize the design space (e.g. color and type of highlighting) and visual distractions.

The size of the right margin was increased accordingly. This increase in size has the disadvantage of using up more screen real estate, which can be problematic on mobile devices. However, the buttons can be moved off-screen for such devices. The users would then just look at the edge of the device next to the text label to click that link (most gaze trackers can still track the gaze when slightly outside of the screen).

Since the predictability of the button location helps in reducing inadvertent clicks, the Single Confirm button was made to only appear vertically centered in the margin. The Multiple Confirm buttons would always start from the top of the margin. Based on observations, the threshold values were adjusted as well. The first threshold to activate the confirm buttons was reduced to 100ms, while the threshold to click a confirm button was reduced to 400ms. The threshold to deactivate or remove the confirm buttons was increased slightly to 700ms.

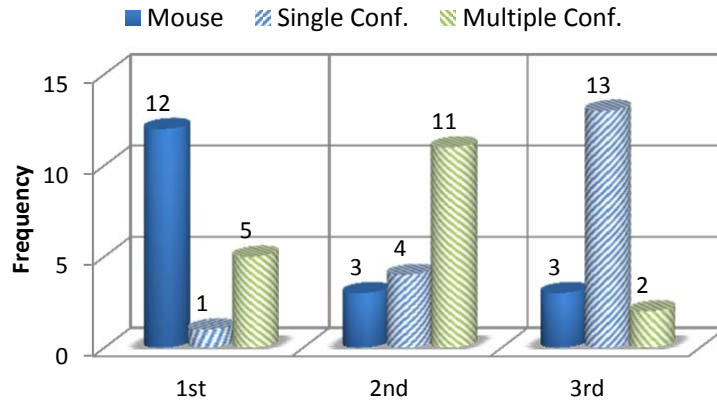
## 5 Main Study Results

A total of 19 volunteers performed the experiment, out of which 18 (13 men and 5 women) were successful. The age of the participants varied from 20 to 39, including one professional worker, one post-doctoral researcher, two lecturers and 14 students. The participants reported reading English text for between 10 and 80 (averaging 40) hours weekly and using computers for between 2 and 14 (averaging 7.8) hours daily.

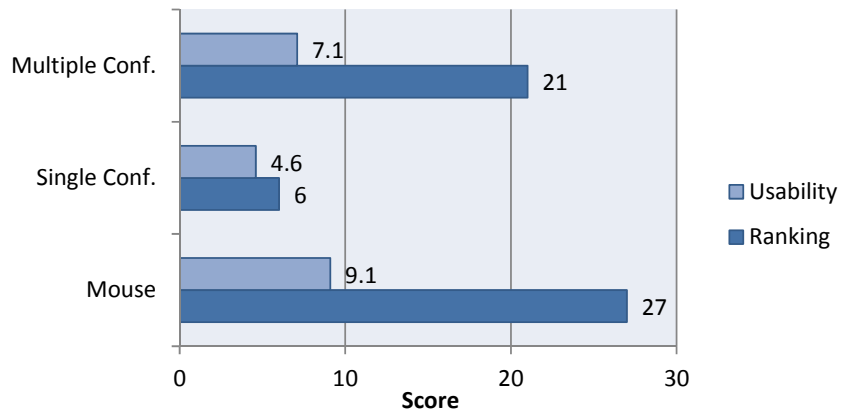
### 5.1 Ranking

In the click alternative ranking, eight participants ranked Mouse as the best, five participants ranked Multiple Confirm as the best, while one participant ranked Single Confirm as the best (Fig. 9). The Mouse is the clear (Condorcet) winner; Multiple Confirm is the clear second. Some comments of participants who did not rank Mouse as the best are copied below, with minor grammar corrections:

- “Multiple Confirm is much better than Single Confirm and it's more interesting to use than regular mouse click.”
- “As I sometime feel RSI, for me this alternative (Multiple Confirm) is good. Though a more mature solution would be great.”
- “Multiple Confirm is probably the better one as it gives more options while clicking. Mouse, however, requires using hands which is more physical as compared to eye-tracking single and multiple buttons alternatives.”



**Fig. 9.** Histogram of click alternative rankings



**Fig. 10.** Total usability and ranking scores of each click alternative

**Table 1.** Performance of all click alternatives

	<i>Mouse</i>	<i>Single Confirm</i>	<i>Multiple Confirm</i>
Average time to click a link (sec)	2.1	10.3	7.4
Number of incorrect links clicked	0	4	0
Number of times clicked with mouse	n/a	26	1

Out of the 12 participants who ranked Mouse as best, eight indicated that they preferred the mouse over the gaze-tracking alternatives as they had been using mouse for many years and are so well-trained with it. Some comments of such participants are copied below:

- “I only faced occasional issues in using Multiple Confirm buttons. It is unfair to compare Mouse with eye gaze tracking as I am well-trained with the mouse but used eye gaze tracking just once. My response might be different if I had used gaze tracking for longer.”
- “I found the Multiple Confirm to be better than Single as it was easier to choose between links close by using multiple buttons. Mouse is only the best because it is what I am most used to.”
- “If I use the mouse too much, I might just end up having CTS in the future. I found Multiple Confirm buttons just right. It is a promising click alternative. I think there's something that can be done about the head movements.”

## 5.2 Usability

The usability scores (Fig. 10) confirm the user satisfaction measured by the ranking, i.e. Multiple Confirm is a bit worse than Mouse, and Single Confirm is the worst. As evident from the comments, two participants mentioned Repetitive Strain Injury (RSI) or Carpal Tunnel Syndrome (CTS) as a concern with using the mouse. The equipment's constraints on head movement, which was also mentioned in the responses, likely had a negative effect on the usability of the gaze alternatives.

## 5.3 Performance

Looking at the data from the navigation tasks, Single Confirm does not seem feasible as it was the slowest as well as the most inaccurate (Table 1). While using Single Confirm, 16 participants required clicking with the mouse at least once, as they could not get the required hyperlink activated in the margin. Four users ended up on an incorrect page by mistake. They thought that the button appearing in the margin was for the correct hyperlink and did not read the button label to validate this. The more difficult navigation task of the two had more problems due to the higher hyperlink density. Single Confirm did not take a lot longer than Multiple Confirm, but it did require many ‘mouse clicks’ and suffered from inadvertent clicking. Both Multiple Confirm and Mouse were fully accurate and did not result in any incorrect click. There was only one instance with Multiple Confirm where the participant asked for assistance and the link was clicked with the mouse. Pairwise testing of the average time to click a link indicates that the differences between all click alternatives are significant at the 1% level, using the Wilcoxon Signed-Rank test.

The following are some observations from the experiment:

1. Some participants were impressed and excited to use eye gaze tracking with comments like “that's pretty cool,” “wow” and “that's so quick”. This ef-

fect was most prominent when Multiple Confirm was being tested after the Mouse but before the Single Confirm alternative.

2. Single Confirm seemed to be easier to learn and easier to use than Multiple Confirm as it did not require choosing from multiple buttons (less cognitive load). But due to inherent inaccuracy, it was the most irritating and error-prone.
3. Multiple Confirm was easiest to learn and use when it was the last click alternative tested. This learning effect indicates that users can get better at using this click alternative with more practice. This effect was not noted with Single Confirm, probably because it was already relatively easy to learn.

## 6 Discussion

The time taken to click during the navigation tasks shows that Multiple Confirm was slower than the Mouse, but the users did not report that as a shortcoming. One user did mention that the speed of the computer was slow, which was evident by the time taken to load webpages (about 5 to 7 seconds depending on page size) in all click alternatives.

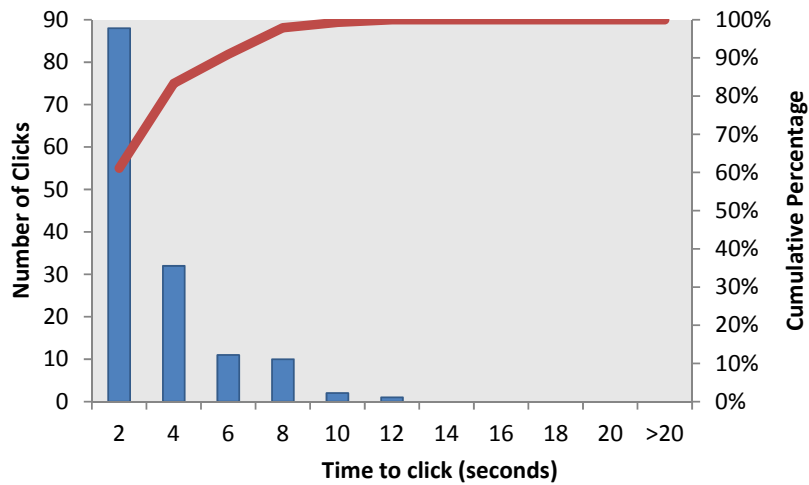
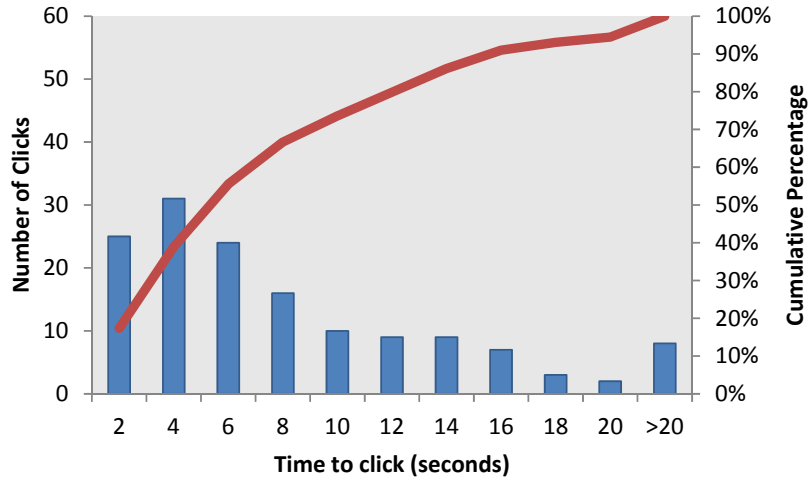


Fig. 11. Frequency distribution of time to click using Mouse



**Fig. 12.** Frequency distribution of time to click using Multiple Confirm

Single Confirm is problematic and not feasible due to the inherent gaze tracker inaccuracy as well as eye jitter. It was difficult for users to activate the confirm button by looking at a particular link. The problems are similar to those of the “Dwell” click alternative, in which users had difficulty holding the gaze on the correct hyperlink.

Multiple Confirm, as expected, was not as fast as the mouse. But contrary to expectations, not all participants found the mouse to be the best. Even some of those who judged it best believed that with some more practice they would likely change their ranking. The Multiple Confirm buttons were able to solve the two problems associated with gaze tracking, namely inaccuracy and inadvertent clicking. It should be noted that conceptually the Multiple Confirm buttons are performing the same function as magnification techniques, without any visual magnification. The small size of hyperlinks makes it difficult to click with gaze tracking due to the inherent lack of precision, equipment error and involuntary eye movements. Multiple Confirm buttons seem to be able to compensate for these difficulties.

In order to better understand the difference in the average times to click for Mouse and Multiple Confirm, further analysis was performed by looking at the frequency distributions and cumulative percentages of the times to click (Fig. 11 & Fig. 12). The analysis shows that most of the links were clicked within 2 seconds with the mouse and within 6 seconds using the Multiple Confirm buttons. Although not as good as the performance of the mouse, Multiple Confirm worked reasonably well. With further research and better equipment (e.g. allowing for more head movement), we expect that the performance of Multiple Confirm can be improved further.

Multiple Confirm involves two steps for each click: first, looking at the hyperlink; then, activating the correct confirm button. Consequently, we expected Multiple Confirm to be slower than the mouse. However, the time difference is bigger than we expected. It can be explained by considering the following additional factors:



- Evaluating the labels next to the confirm buttons to find the right button took some time.
- Sometimes the desired button was not among the buttons shown in the margin, and the user had to look back at the hyperlink to activate the confirm buttons again.
- Activating the confirm buttons again delayed the clicking time further, due to the time thresholds for removing the previously activated buttons and activating the buttons again.
- Occasionally, users had difficulties triggering a confirm button by dwelling on it, especially when the head was moved slightly outside the optimal tracking volume. Some users quickly moved their heads a bit to get the accuracy back, and in some cases this did not help or even decreased the accuracy.
- During page loading, some participants already moved the mouse near the expected location of the next hyperlink, before the page was loaded. This somewhat obfuscated the speed advantage of the gaze over the mouse.

## **7 Limitations**

One limitation was the time it took for the web browser to load and display web pages after a click was performed. These page load times varied from 3 to 10 seconds, depending on the amount of text and the number of images on the web page. Since the log file had only recorded the times between the clicks including the page load times, the page load times were subtracted from the click times later for analysis. The load time for each page was fairly constant, so this did not affect the precision of our measurements much. However, as mentioned before, the page load times favored the mouse as participants had time to move the mouse to the expected areas of the screen before the page was fully loaded.

The other major limitation was the restriction on head movement. Not only was this restriction unrealistic, it also added to the inaccuracy of the gaze click alternatives. The navigation task had to be restarted for a few participants as their gaze was not being tracked anymore after they had moved their heads more than the equipment allowed.

The findings cannot be generalized to all users as most participants had similar demographics. Additionally, only two participants had used an eye tracker before, in another experiment. Finally, it is not unreasonable to assume that there was a bias in favor of the gaze tracking alternatives due to the novelty factor.

## **8 Conclusion**

An important finding is that eye gaze tracking has the potential to be used as an input method for web browsing. The inherent inaccuracy due to eye jitter and equipment error, lack of precision and inadvertent clicking can be compensated for by using the Multiple Confirm click alternative. The confirm buttons should have visual anchors, and button labels (text) should be outside the buttons, preferably between the web

page and the buttons. Such a user interface was easy to learn and use, and was preferred by some users over the mouse despite using it only for a few minutes.

The biggest challenge was the limited freedom of head movement afforded by the equipment used. Even slight head movement could cause the gaze error to increase and affect the performance. As newer equipment allows more freedom of movement, the usability of the Multiple Confirm click alternative is expected to improve.

Further research is necessary to evaluate if hyperlinks can be highlighted in a non-distracting manner as visual feedback to efficiently identify the hyperlinks that have activated confirm buttons. Underlining the hypertext seems to be a feasible option. The order and location of confirm buttons might also be improved, e.g. to have the multiple confirm buttons centered vertically. There might also be a potential of using 'grab and hold' [24] to compensate for eye jitter and equipment error when clicking a confirm button.

There is also room for improvement in other design parameters. The inactivation, or removal, of confirm buttons (currently after 700ms of looking at other text) could be optimized. The time thresholds to activate and click the confirm buttons (currently 400ms) and the boundary radius of the gaze area from which buttons are activated (currently 30 pixels) may be fine-tuned further. The way confirm buttons are currently drawn in the margin is a potential distraction, which could be minimized in many ways, e.g. by keeping all the buttons visible, possibly with reduced contrast. The labels would only appear and the button would be made fully visible when a confirm button is activated. The labels may also be faded in and out, instead of appearing and disappearing abruptly.

## 9 Acknowledgement

We would like to acknowledge the assistance of Yoonseok Hong and Gen Li in designing the prototypes and performing the pilot study, and the voluntary participation of all users without which this study would not have been possible.

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