Eye Gaze Based Dynamic Warnings

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***Abstract*—Various websites and mobile applications collect personal identity information. Personal privacy might be in danger if we exposed our identity information to a malicious third party. Warning countermeasures have been designed to mitigate identity theft. However, people often click the OK button without reading warning messages. We propose a dynamic warning system based on eye gaze information. The warning messages display just-in-time, and they fade out after users read them. To evaluate attention switch and maintenance, we developed an Eye Tracking Information Analysis tool. In addition, we built a simulated restaurant reservation app, named ReservME that integrated our dynamic warning system. We conducted a three-condition experiment with a comprehensive follow-up survey. Our experiment results show that the eye gaze based dynamic warning system helped participants reduce unnecessary identity disclosure.**

Keywords-Dynamic warning; Eye gaze interaction; Identity theft; Warning design and evaluation.

I. INTRODUCTION

People encounter many web-based security warnings in browsers and apps. People often ignore them [1] or do not even realize that a security warning is present. When individuals were asked about their concerns about the safety of their private information, they claimed that they were careful about their information when sharing [2]. This contradiction can be explained by the ineffectiveness of warnings [3].

Researchers have been studying the effectiveness of warnings for years. Frameworks such as the communication-human information processing (C-HIP) model and a sequential model of human information processing [4][5], were introduced to use as a guide to analyze the effectiveness of warnings [4]. In recent years, some web-based and mobile-based warnings have been introduced [6]–[9] to improve users' attention to warnings and risk evaluations. However, limitations exist in previous warning designs and evaluations as follows. First, surveys and interviews are widely used to analyze the effectiveness of warnings. Users' attention on warnings was not quantitatively analyzed. Second, users' attention was not used to interact with warnings. Third, attention switch and the cost of compliance are hard to evaluate. For example, active warnings with a "close" button could switch attention to a high level. However, this behavior costs time in terms of compliance, which may make users annoyed if the warnings show up too many times. Users' attention is critical to warning designs [10], but previous research has not made optimal use of it.

In this research, we propose a dynamic warning system based on eye gaze information. The dynamic warning message included a security metaphor, a message about the consequences of not complying, and a recommended safe response message, and was integrated into a restaurant table reservation app. Users' eye gaze information influenced show-up time, fade-out time, and location of the dynamic warning message. We developed an Eye Tracking Information Analysis (ETIA) tool to determine the warning's show-up time and fade-out time. ETIA is also used to evaluate the effectiveness of the dynamic warning and to record the experiment. We conducted a three-condition experiment on 128 participants. Follow-up surveys were used to evaluate the effectiveness of the dynamic warning in the presence of an identity attack.

Our study makes three main contributions. First, we provide a dynamic warning system using eye gaze information. The dynamic warning shows "at the right time and at the right place." Second, we provide a tool to analyze and visualize users' attention on warning messages. The output is used as feedback to further improve the design of future warnings. Third, the dynamic warning fades out when users do not read it.

This article is organized as follows. The next section outlines the background and related work. Then, we present an eye gaze based dynamic warning approach and its integration to a Windows 8 app. Section IV illustrates an Eye Tracking Information Analysis tool. The fifth section discusses the evaluation on the dynamic warning approach. Finally, Section VI concludes the paper.

II. BACKGROUND AND RELATED WORK

Warning countermeasures are widely used to prevent privacy attacks. Researchers have developed several frameworks [11]. Wogalter's C-HIP model [4], shown in Figure 1, is one of the most widely used frameworks in warning design. The C-HIP model is used as a guideline to warning design and identifies the reason of a warning's effectiveness or ineffectiveness. It consists of nine levels, starting with a source by using visual, tactile or auditory channel to deliver to receivers. Factors such as font size, color and audio volume in the warning stimuli have influences on behavior. The attention switch, attention maintenance, comprehension, memory, and attitudes and belief stages could also affect a receiver's behavior. Cranor

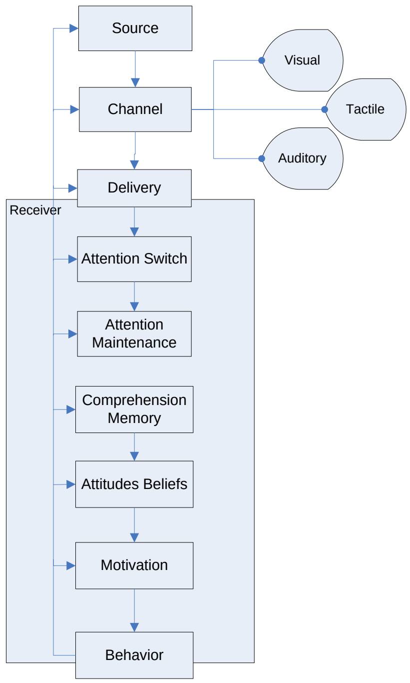

Figure 1. Diagram of the expanded C-HIP model [4]

extended C-HIP model into a human-in-the-loop security framework [12]. The human-in-the-loop security framework could be able to help design understand the behavior of humans on security-critical functions.

The typical Windows program has warnings seemingly everywhere, with warnings about things that have little significance [13]. “Over warning” makes using a program feel like a hazardous activity, and it detracts from truly significant issues [13]. The problem is, when an individual habituates to a warning, he may not have acquired all the information from the warning. Kim and Wogalter mentioned four solutions to deal with the problem of habituation [14]. First of all, incorporate features (e.g., size and color) to enhance conspicuity. Second, modify or change the warning’s appearance. Third, allow warning designers to deviate from the standards. Fourth, use dynamic (changeable) warnings [14]. According to research by Racicot and Wogalter, in the workplace and in hazardous environments, warnings could be presented only during the points in time when the risk information is needed [15]. Highly sophisticated detection and warning systems could also enable personalization of the warning and varied presentation patterns that will prevent or delay habituation [16]. A warning will be more likely to attract and maintain attention when individuals are in an information-seeking mode than in other modes of thinking [17]. In other words, a person who is actively looking for hazard-related information will be more likely to see and hear a warning than a person occupied with other tasks.

Our warning design is inspired by previous research on physical security metaphor images used on security-related warnings, such as a thief sneaking away. Physical security metaphors could provide a vivid image to inform users about hazards. Raja and colleagues designed firewall warnings whose functionality is based on a physical security metaphor [8]. According to their evaluation results, their warnings facilitated the comprehension of warning information, better communicated the risk, and increased the likelihood of safe behavior. Sunshine and Egelman redesigned secure sockets layer (SSL) warnings. Their severe warning has a red background and a “Stop sign officer” security metaphor [18]. Also, research on eye movement has suggested that the pictorial-color icon produced better performance compared with those without pictorial icon or color icon [19].

According to Wogalter’s suggestion [20], dynamic warnings are more noticeable than static warnings. Because dynamic aspects of warnings should be conspicuous to attract and sustain attention, they could reduce the problem of habituation. If the warning is presented distant from the hazard in terms of location and time, people may not recognize the connection or may not remember the hazard. By working with detectors or sensing devices the dynamic warning can be noticed when a warning is needed [21][22].

Our experiment is conducted to evaluate the effectiveness of dynamic warnings in the context of a mindlessness attack. A mindlessness attack is a psychological attack that attempts to access more information from users [23]. Our previous research instituted the mindlessness attacks within a web-based online shopping context and an automobile insurance quote and was shown to be effective [24][25]. Our current goal is to mitigate the effects of the mindlessness attack.

Eye tracking technology in human–computer interaction (HCI) has been highly promising for many years. Jones and Milton (1950) captured eye movements with cockpit-mounted mirrors and movie cameras to study eye movement data with painstaking frame-by-frame analysis of the pilot’s face [25]. Crowe and Nrayanan emphasized that aggregating, analyzing, and visualizing eye tracking data in conjunction with other interaction data could be a powerful tool for designers and experimenters in evaluating interfaces [26]. Nielsen and Pernice use eyed tracking on web usability to discover 2503 usability guidelines for Web sites, intranets, social network postings and e-mail newsletters [27]. Takeuchi and colleagues measured participants’ pupil diameter with an infrared-video-based eye-tracking device and found that pupil size increased rapidly as the learning proceeded in the early phase of training and decreased at the later phase to a level half of its maximum value [28]. In recent years, researchers started to use eye movement as an input in HCI systems. Jacob in the Naval Research Laboratory applied eye movement for object selection, moving an object with the eye controlling both scrolling text and defining a “listener” window [29]. In our research we used the eye tracking information to guide our design of the dynamic warning.

III. EYE GAZE BASED DYNAMIC WARNING SYSTEM DESIGN

We focus on four issues. What should the warning message be like? When should the warning show up? Where should the warning show up? How does the system work?

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These four questions will be answered in the following subsections.

A. ReservME software

ReservME (Figure 2) is a Window 8 app running on a Microsoft Surface Pro. It is a restaurant table reservation app similar to Opentable, which is a top ten app on Windows, iOS, and Android. ReservME is using HTML5, CSS3 and JavaScript. A personal information form appears after a restaurant is chosen. First name, last name, email, phone number, address, city, state, zip code, and credit card information were requested in the app. Considering the safety of participants' privacy, we did not collect this information. Rather, we captured whether any information was entered into the data fields, represented as 0 for input, 1 for no input. Our previous research found that users are concerned about their email, phone, and zip code being exposed [25][30]. In our dynamic warning system, we use zip code as the identity element to trigger a warning. A dynamic warning appears when a user's eye gaze focuses on a field into which they can input their personal information.

B. Dynamic warning message design

The dynamic warning message includes three sentences as follows "DO NOT disclose this information!" "Someone may steal your private information here!" "TIPS: You can falsify them." We added a theft metaphor image to the right of the warning message. The pictorial theft metaphor showed a thief sneaking away with keys in one hand and a bag of stolen items in the other hand. The metaphor works with the second sentence in warning message. This provides an emotional influence on a user's risk evaluation. From the C-HIP model, an effective warning should provide instructions for avoiding consequences of a risk or indicating that effective preventive behavior cannot be guaranteed. A recommended safe response in an online table reservation context was therefore provided by the third sentence to make this warning message more effective.

From the C-HIP model and Wogalter's research [31][32] interactive warnings should be noticed, recalled and understood better than static warnings (or on-product warnings). Researchers also found that over time and exposure to environmental elements, warnings can result in habituation and become less noticeable [10]. We therefore decided to design a warning to "pop up on time" and "fade out in time." The "pop up" action of this warning should enhance the attention switch of C-HIP model, and the duration of the warning plays a role in attention maintenance. The "fade out" action could reduce habituation and the "over warning" issue by removing the warning when users do not really need the warning.

C. Dynamic warnings show up time and fade out time

The key to effective warnings is to display them the moment that users need the warning and to remove them the moment that users do not need the warning. These moments could be found by using eye information. Laughery's research on the human's eye movement on reading a warning suggested that the time people interacted with a warning

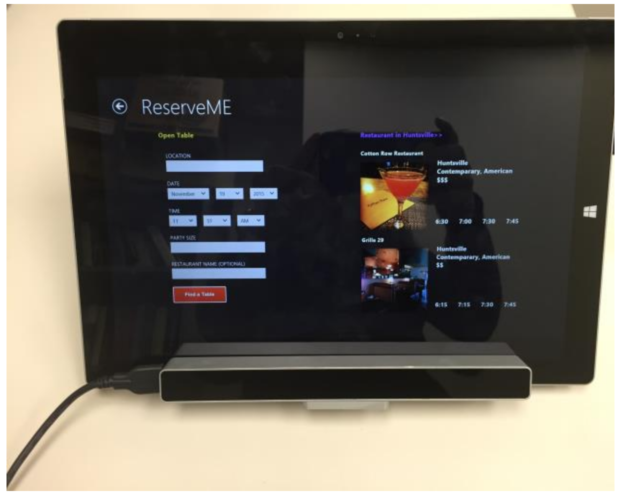

Figure 2. ReservME is running on Microsoft Surface Pro with an eye tracker

could be separated to a location time and a decision time [33].

In the pilot study, we separated the total time of eye gaze into searching time, location time, and decision time. The searching time starts from the time the identity page loaded to the time a participant's eye gaze entered the target area (the zip code data entry field in this pilot test). The location time started from when a participant's eye gaze entered the target area to when the participant's eye gaze left the area. The decision time started from when a participant's eye gaze left the target area to the time participants started to type on a key board or click on the touch screen. The mean searching time on our pilot testing was 1258ms. The mean location time was 311ms. The mean decision time was 485ms.

Based on pilot testing, we decided that the warning should show up when participant's eye gaze was maintained in the zip code data entry field for 350ms. In this way, we could make the dynamic warning pop up when a user focused on the target area (i.e., zip code data entry field) before they made a decision to input this information.

To determine the time for the fade-out of the dynamic warning, we did a second pilot study with another 12 students. This time, we added the dynamic warning that popped up on the top of the zip code data entry field but it did not fade out. We changed the target area to the warning area. By using the ETIA tool, we could ascertain searching time, location time, and decision time on this area for each participant.

In this pilot testing, searching time begins from the warning pop up to the start time of the longest duration on the dynamic warning. The location time is defined as the longest duration of eye gaze on dynamic warning. The decision time begins from the end timestamp of the longest duration of gaze on the dynamic warning to the timestamp of when a participant input something on the key board or clicked on the touch screen. The mean searching time on this pilot test is 652ms. The mean location time is 3285ms. The mean decision time is 1874ms and the max decision time is 3144ms. From these pilot testing results, we decided to

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design the warning message fade out if any of the following three conditions are present.

The first condition is if a participant's eye gaze leaves the warning area for 3500ms. The second condition is if the participant starts to type in something from keyboard. The third condition is if the participant clicks the touch screen. The "fade out" action relies on these three conditions because when the participants' behavior fits these conditions, they are not interested in the warning and have made decisions already. According to the location time statistic result, we decided to add a new feature to the "pop-up" action. If the participant's eye gaze duration on a warning message lasted less than 3000ms, the dynamic warning popped up again because the participants did not read the warning message carefully. We employed a red box to show the area at which participants are looking approximatly.

D. Dynamic warning location

The warning message should also be spatially optimized. Our strategy is to show the warning right next to the eye gaze spot when a user's eye gaze stays in the target area (zip code area) for 300ms. In this way, the dynamic warning could improve the attention switch indicated by the C-HIP model because the warning message shows up very close to the exact spot participants are looking. Another foundation in the eye gaze based dynamic warning interaction system is to map the two dimensional (2D) eye tracker data from EyeTribe SDK to the 2D dimensions of the ReservME App. The EyeTribe server provides a timestamp, raw gaze coordinates in pixels, average eye gaze coordinates in pixels, raw and smoothed gazed coordinates in pixels separated by left eye and right eye, pupil size, and normalized pupil coordinates.

In general, we could obtain average eye gaze coordinates $(x_{current\ avg}, y_{current\ avg})$ of left and right eyes on current time from EyeTribe SDK. Then we have the 2D eye gaze coordinates $(App.X_i, App.Y_i)$ by using (1) and (2).

$$App.X_i = \left(\left(\frac{x_{current\ avg}}{Width} \times \frac{Smooth}{100}\right) + App.X_{i-1} \times \left(1 - \frac{Smooth}{100}\right)\right) \times Width \quad (1)$$

$$App.Y_i = \left(\left(\frac{y_{current\ avg}}{Length} \times \frac{Smooth}{100}\right) + App.Y_{i-1} \times \left(1 - \frac{Smooth}{100}\right)\right) \times Length \quad (2)$$

Where, *Width* and *Length* are the screen resolution. *Smooth* is a constant to smooth current eye gaze spot with the previous eye gaze spot $(App.X_{i-1}, App.Y_{i-1})$ indicates 2D eye gaze coordinate mapping on ReservME App on the previous frame $(App.X_0, App.Y_0)$ equals (0,0).

E. Design of the dynamic warning system

Our dynamic warning system interacts with the EyeTribe SDK and the ReservME App. The dynamic warning server, developed by NodeJS, has architecture as shown in Figure 3.

The EyeTribe server collected gaze coordinates from an EyeTribe device attached under a Surface Pro. The EyeTribe tracker allows head movement in a 40cm*30cm box at a 65 distance on a 30Hz sampling rate [34]. The EyeTribe user interface (UI) provided by EyeTribe could help us to do calibration. The EyeTribe server provides a 0.5 to 1 degree average accuracy of visual angle. The dynamic warning server communicates with the underlying EyeTribe server to get raw eye gaze data. The communication uses Transmission Control Protocol (TCP) Sockets to exchange JSON message asynchronously [34]. The ReservME App communicates with the dynamic warning server to collect smoothed eye gaze data and times. We implemented the dynamic warning using eye control by applying constraints mentioned in previous paragraphs.

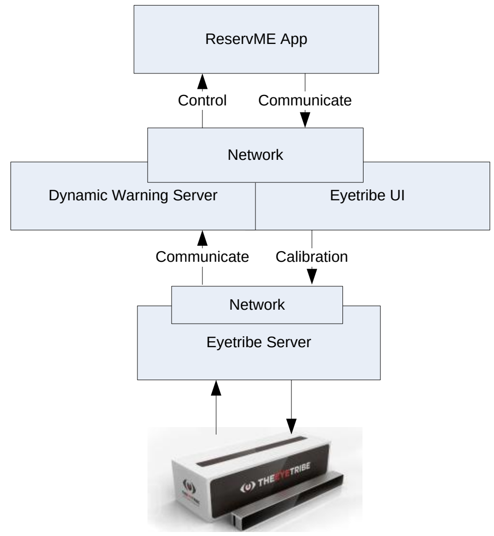

Figure 3. Eye gaze based dynamic warning system architecture

The dynamic warning server is at the center of this system. It sets up a TCP socket connection with the EyeTribe server and connects with ReservME. Figure 4 illustrates the details of communications and controls of this system. The dynamic warning server acquires eye information data from the EyeTribe server. Once the identity page in ReservME showed up, the socket between ReservME and the dynamic warning server was created. ReservME acquires the smoothed eye gaze coordinates data (App.X and App.Y calculated by (1)) and timestamps from the dynamic warning server asynchronously. The dynamic warning server checks the eye gaze coordinate and if the user's eye gaze stays in the zip code area for 350ms, the dynamic warning will pop up in ReservME and put a warning flag to an ON state. If the dynamic warning server discovers that the user's eye gaze leaves the warning for more than 3500ms or a user types on keyboard or touches the screen on a click, the dynamic warning in ReservME will fade out and the warning flag switches to an OFF state. If the dynamic warning is off, and eye gaze location time on the dynamic warning is less than 3000ms, then the dynamic warning pops up again. Step 7 to step 13 loops when the socket between the dynamic warning server and ReservME is on. The socket disconnect when the identity page is not on the browser.

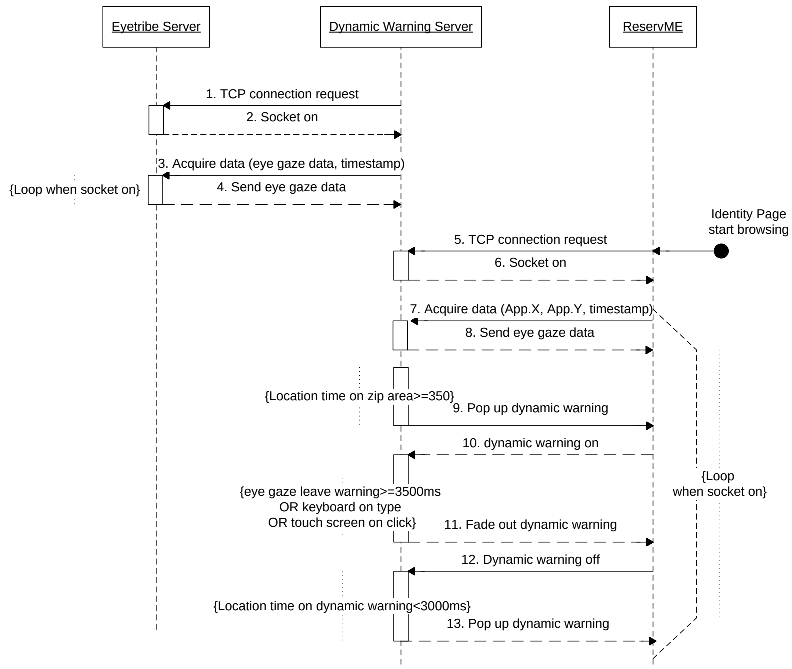

Figure 4. Dynamic warning system communications and controls

IV. EYE TRACKING INFORMATION ANALYSIS

We developed a tool named Eye Tracking Information Analysis (ETIA) as show Figure 5. It records the eye movement interaction between the dynamic warning system and ReservME. It was created using C# and Aforge.NET framework [35]. Mouse movement and eye gaze box locations are also recorded. Frames per Second (FPS) could be defined. Calibration on EyeTribe UI is required before this software is connected to the EyeTribe. Connection state, pupil size and smoothed eye gaze coordinates are captured and stored by ETIA. Smoothed eye gaze coordinates, pupil size and timestamp data are saved in a txt file. The ETIA tool was used in pilot testing and the experiment to evaluate the dynamic warning system. Another feature of the ETIA tool is EyeGaze Box (a red box show the eye focus area). The EyeGaze box indicates the eye focus area approximately.

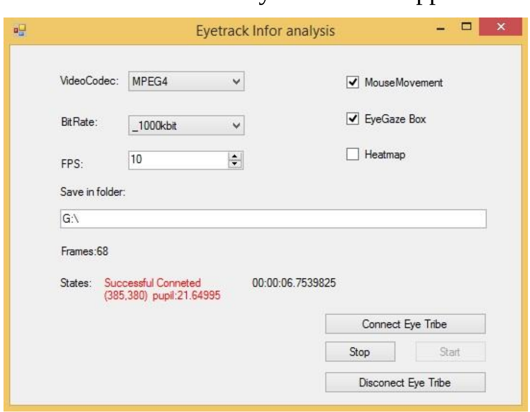

Figure 5. Eye Tracking Information Analysis Tool

V. EVALUATION

A. Participants

We recruited 128 participants to attend our experiment. They were undergraduate students across various majors. These students received partial course credit for their participation. Of the 128 participants, 77 were women, and their age ranged from 17 to 48 with a median 20 years. With respect to ethnicity, 69 participants were Caucasian, 29 had African heritage, 11 were Asian, 7 had Hispanic heritage, 2 reported Pacific Island heritage, and 10 reported other ethnicities. Seventeen additional students from the psychology and computer science department were recruited as volunteers on the pilot test. The procedures of the experiment were approved by our university's Institutional Review Board (IRB).

B. Procedures

In ReservME App, identity information was requested, and the mindlessness attack message explains the reason for requiring the identity information. For example, the reason that email is requested is "You will receive electronic coupons for the restaurant you reserved." If the participants focused on the zip code area, a dynamic warning was presented in the form of warning text and a theft metaphor image background by a yellow rectangle. The design of this experiment has three conditions: (a) *control condition* with no attack and no warning, (b) the *mindlessness attack condition* with mindlessness attack messages but no warning, and (c) the *dynamic warning condition* with the dynamic warning message showing up under mindlessness attacks.

We hypothesized that participants under the mindlessness attack would be more likely to disclose information than in control condition. We also predicted that participants in the dynamic warning condition would be less likely to disclose information than in the control condition and mindlessness condition. Additionally we explored whether participants did read the warning message carefully in dynamic warning condition.

Participants were randomly assigned to one of the three ReservME app conditions. There were 41 participants in control condition, 46 participants in mindlessness condition without a warning, and 41 participants in a dynamic warning condition under attack. They provided informed consent prior to participating. Participants were given the cover story that the app was developed by a third-party software design company, and the company was interested in feedback on its app design.

Participants were asked a variety of identity questions (including first name, last name, email address, home address, phone number, credit card information) in the context of restaurant reservation. For each type of identity information, participants could choose whether or not to provide it. Participants did not know that we were not storing any of the identity information they input before they completed a post-experimental survey. They were debriefed that their identity information was not stored or provided to a third party at the end of the experiment.

After participants completed their reservation on ReservME, they were asked follow-up survey questions about their opinion on the design of ReservME. Participants were also asked whether they had responded with truthful information when asked for identity information. We considered falsified information provided to be the same as no information provided in our analyses. The effectiveness of the dynamic warning system was evaluated by the whether or not participants disclosed their accurate identity information. We use ETIA tool to record the experiment. Our primary dependent variable was the percent of participants who disclosed truthful identity information.

C. Results

Figure 6 shows the percent of participants who provided truthful identity information under the three conditions. The percent of disclosure increased in the mindlessness condition compared with the control condition. The percent of participants who provided truthful identity information in the dynamic warning condition decreased dramatically compared with the mindlessness and control conditions. Zip code was the identity element for which the dynamic warning popped up when participants looked at the zip code textbox area. The dynamic warning successfully decreased disclosure from 89.1% to 26.8%. However, zip code is not the only element influenced by the dynamic warning. For email, the dynamic warning reduced disclosure under mindlessness attack from 93.5% to 31.7%. Similar reductions occurred for phone and address identity information.

Zip code is the identity element for which disclosure increased the most in the mindlessness condition compared with the control condition. The percentage increased from 68.3% to 89.1%. Zip code is also the element for which disclosure decreased the most in the dynamic warning condition compared with the mindlessness condition.

We used one-tailed Z-tests to compare the percentage of participants disclosing their identity information in the three conditions. The analysis showed significant differences between the control condition and the mindlessness condition for zip code (*p=0.0082*) and for credit card information (*p=0.0268*), as shown in Table I. The Z-tests between the mindlessness condition and the dynamic warning condition showed significantly differences for all identity information ($p<0.05$), as shown in Table II.

Odds ratios were also calculated. In Table I odds ratios indicate the increased likelihood that people will disclose their identity information under mindlessness attack conditions.

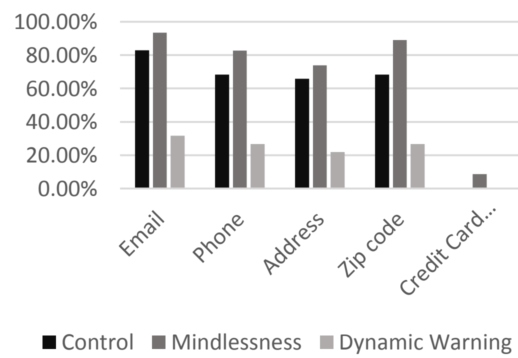

Figure 6. Percent of participants under the three conditions providing identity information

TABLE I. Z-TESTS COMPARING CONTROL AND MINDLESSNESS CONDITIONS

Identity information	**Z-score**	**p- value**	**Odds ratio**
Email	-1.5402	0.06178	3.48
Phone	-1.5581	0.05938	2.21
Address	-0.8198	0.20611	1.47
Zip Code	-2.3953	0.0082	3.81
Credit Card information	-1.9336	0.0268	8.79

TABLE II. Z-TESTS COMPARING MINDLESSNESS AND DYNAMIC WARNING CONDITIONS

Identity information	**Z-score**	**p-value**	**Odds ratio**
Email	5.7829	0.0001	30.87
Phone	5.0754	0.0001	15.11
Address	4.713	0.0001	10.07
Zip Code	5.7142	0.0001	22.36
Credit Card	1.9336	0.0268	8.79

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The odds ratios in Table II refer to the decrease in people providing their information in the dynamic warning condition compared with mindlessness attack condition. The odds ratio of zip code is 22.36, which means the odds of exposing zip code in the dynamic warning condition were around 22 times less than in the mindlessness attack condition with no warning.

D. Discussion

The results of the experiment show that a dynamic warning could prevent users from disclosing identity information that they were asked to provide. The results also show that dynamic warnings can be an effective countermeasure for a mindlessness identity attack. Dynamic warnings not only impacted disclosure of the targeted identity element, but also impacted disclosure of all identity elements in the same page. ETIA video and data indicate that dynamic warnings did attract users' attention and maintained attention.

Our study has a few limitations. First, the participants in our experiment were students. Thus, the data may be biased by an age factor. We are currently conducting research using a non-student sample with a wider range of ages. Second, our experiment focuses on whether dynamic warnings changed users' behavior on identity disclosure under mindlessness attacks. The results might not be applied to other attacks that are launched to elicit private information from users.

VI. Conclusion

In this paper, we propose an eye gaze-based dynamic warning solution. The dynamic warning message integrated a security metaphor, a vivid consequence message, and a recommended safe response message. Eye gaze information interacted with the dynamic warning system to control the dynamic warning's pop up time, fade out time, and location. We also developed an ETIA tool to record participants' eye gaze information. ETIA was applied in pilot tests and the main experiment. Experimental results show promising impacts of the warning countermeasure to protect identity information on a web-based app. The design of dynamic warnings may reduce habituation. The eye gaze based feature is an effective way to switch and hold a user's attention at the right time in the right place. ETIA provides a virtualization and replay tool to analyze the interaction of users' eyes gaze on specific apps and warnings.

The dynamic warning system and ETIA tools can explore some of the principles of the C-HIP model and could offer guidelines for designing effective warnings to interact with the eye gaze data. We are conducting experiments to compare the effectiveness of our dynamic warning system with the traditional warnings. In addition, we are improving the effectiveness of the dynamic warning system by combining pupil size data as another interaction factor. We are also adding virtualization features to ETIA.

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