A Case Study of Usable Security: Usability Testing of Android Privacy Enhancing Keyboard

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Abstract. We invent a novel context aware privacy enhancing keyboard (PEK) for touch-enabled devices to keep users safe from various password inference attacks. When a user inputs normal text like an email or a message, PEK shows a normal QWERTY keyboard. However, every time a user of a touch-enabled device presses a password input box on the screen, we will randomly shuffle the positions of the characters on the keyboard and show this randomized keyboard to the user. PEK was released on the Google Play in 2014, but the number of installations is below our expectation now. For the purpose of usable security and privacy, we design a two-stage usability test and perform extensive experiments to evaluate the user experience of PEK and discover the reason behind the lukewarmness of using PEK. We implement two new features so as to improve PEK based on the feedback of usability tests.

Keywords: Usability Testing, Android, Keyboard, Privacy, Touch Screen, PEK

1 Introduction

Touch-screen enabled devices have become a burgeoning attack target. Many attacks target sensitive information such as passwords entered on mobile devices by exploiting the soft keyboard. In residue-based attacks [1, 20, 10, 22], oily or heat residues left on the touch screen indicate which keys are tapped. By measuring the heat residue left on the touched positions, even the order of tapped keys may be determined. In computer vision-based attacks [4, 3, 5, 8, 19, 18, 16], the interaction between the hand and the keyboard is exploited. For example, the hand movement and finger position indicates which keys are being touched [19, 18, 21, 7]. In sensor-based attacks [6, 17, 12, 9, 2, 15, 13], the malware senses a device's motion difference via its accelerometer (acceleration) and gyroscope (orientation) when different keys are touched and the device moves slightly.

To fight against these attacks listed above, we invent a novel context aware privacy enhancing keyboard (PEK) for touch-enabled device. The attacks introduced above can work because the keyboard keys are always at the same position. With PEK, every time a user of a touch-enabled device presses a password input box on the screen, we will randomly shuffle the positions of the characters on the keyboard and show this randomized keyboard to the user. That is, the user can derive a randomly shuffled keyboard every time while tapping their passwords on the screen. We maintain PEK's usability through its context aware feature: a randomized keyboard only shows up when a user inputs a password or pin. When a user inputs normal text like an email or a message, PEK shows a normal QWERTY keyboard or a system default keyboard. **We are the first to design a generic randomized keyboard for Android** while the idea of randomizing the key layout was proposed before for other applications with dedicated keypads [14]. PEK can be chosen as the default keyboard for Android so that it can be used for any app.

We released PEK as a free Android app to Google Play in August 2014 after our presentation at Black Hat USA [19]. It has been downloaded 2352 times at the time of writing. We released 7 versions of PEK, correcting bugs and improving the interface. PEK 1.0 is based on an Android code example. PEK 2.x.x is based on OpenWnn [11] although we fixed bugs and adapted it to later versions of Android. The current version of PEK is 3.1.0.0.

Since the number of PEK installations is below our expectation, for the purpose of usable security and privacy, we designed a two-stage usability test to evaluate the user experience of PEK and find out the reason behind the lukewarmness of using PEK. The first usability test was a pilot usability test. A major finding from the pilot test is the complicated installation and configuration processes discourage users from using PEK although installation and configuration instructions are given. We then performed the main usability test including a web survey and a focus group usability test. The web survey used Amazon Mechanical Turk. A major finding from the web survey and focus group study is that more people show interest in using PEK if a randomness toggle button is provided. With the button, users may enable or disable the random keyboard on the fly. Based on the usability test, we implemented a PEK app that allows a user to configure and enable PEK through an app on the launcher screen. We also add a randomness toggle button to the randomized keyboard.

The rest of this paper is organized as follows. We introduce the design and implementation of the third party keyboard of PEK in Section 2. The methodology of the usability test is presented in Section 3. The results of the usability test are given in Section 4. We conclude this paper in Section 5.

2 Privacy Enhancing Keyboard

In this section, we present the basic idea of the privacy enhancing keyboard. Given the limited space allowed in the paper, we do not include the technique details of PEK implementation. An extended version of technical report is available on demand.

To mitigate various attacks including residue-based attacks, computer vision-based attacks, and sensor-based attacks, we randomly shuffle the positions of keys of a software keyboard on a touch screen in order to show the user a randomized keyboard each time they input a password. As a result, profiles for particular keys cannot be established via vibration or orientation information through an accelerometer. Finger oily or thermal residue left on the screen does not imply particular keys. Vision based attacks also fail since a touched position by a finger does not refer to a fixed key.

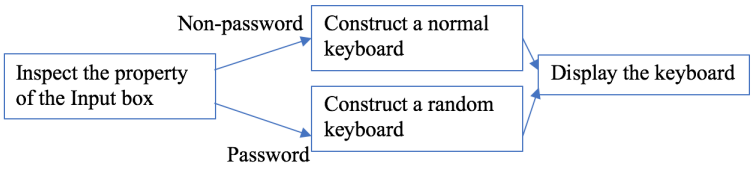

Fig. 1. Workflow of PEK Constructing a Keyboard

Figure 1 shows the basic idea and the workflow of PEK constructing a keyboard when a user touches an input box. First, we inspect the property of the input box to determine whether or not the input box is a password input box. If the input box is a password input box, we parse the property of the keys from a XML file that stores the layout of the keyboard, and change the label and value of the keys so as to shuffle the positions of the keys. If the input box is not a password input box, a QWERTY keyboard is shown.

We implemented two versions of PEK. One version is a third party keyboard implemented through an Android service that runs in the background. A third party keyboard is installed in the format of an Android app. A user has to find the system input setting menu in her phone in order to enable PEK. However, the location of the input setting menu is different in distinct phones. Before PEK 3.0, we provided a generic introduction to the input setting process and pretty much count on users to find the input setting menu. A note is we are also able to revise the source code of the Android system default keyboard and recompile it with the entire Android project. Apparently such a strategy implementing PEK is not practical for users. The second version of PEK is a 10-digit keypad for the unlock screen. To implement the randomized keypad, we have to revise the Android system source code, override the method "createKeyFromXml()" in the code file "PasswordEntryKeyboard.java" and recompile the entire Android project. Since a user has the option of choosing a conventional keyboard for the unlock screen and recompilation of the entire Android project is not feasible for broad adoption, our usability study below focuses on the PEK - a third party keyboard and the term PEK refers to the third party keyboard particularly.

3 Usability Testing Methodology

In this section, we present our two-stage usability study of PEK: the pilot study and the main study, which are similar although the main study involves more participants, questions, and other measurements. In a usability study, in general there are not too many participants in the interview and focus group study.

However, face-to-face interaction with participants provides us lots of detailed information/insights about users' view to our research questions. A web survey engages more subjects and produces quantitative and statistic results. That's the main difference between qualitative research (e.g., interview, focus group) and quantitative research methods. We used multiple methods to gather users' information from different perspectives.

3.1 Pilot Usability Test

There are two sessions in the pilot usability test that forms and improves the main usability test conducted after the completion of the pilot usability test. The first session is composed of a pre-survey with 10 questions, an interview with 5 open ended questions, and a post survey with 4 questions. Both the pre-survey and post-survey have multiple-choice questions so that the answers are easily interpreted and classified. Two to three days after the first one, the second session is conducted and includes an interview with 10 open ended questions. The interview involves recording the participants' answers and there is a portion of the interview, which was timed to see how long participants took to install and configure PEK. Three major issues are addressed during the pilot test.

- ***PQ1:*** After the release of PEK, there are some complaints on the Google Play Store page for PEK that specified that the configuration process was difficult. Hence, we want to find out the answers to the following questions. How easily can smart device users install and configure PEK onto their smart devices? Does the installation and configuration process discourage users from using PEK?
- ***PQ2:*** Perhaps the underlying reason why smart device users are not broadly employing PEK is simply because they are not interested in protecting their information and/or they are uneducated about security on their smart devices. Therefore, we ask: are smart device users in general concerned with the security on their phones?
- ***PQ3:*** When PEK is enabled and the user selects a password input box, the keyboard is randomized, therefore, it takes users longer to find the characters compared to when using a regular QWERTY keyboard. Do users think the extra input time needed when using PEK is worth protecting their passwords and/or pins?

3.2 Main Usability Test

The main usability test consists of a web survey and a focus group usability test based upon the findings in the pilot usability test. The web survey is hosted on the Qualtrics platform on Amazon Mechanical Turk and does not require any tasks from participants except completing the survey. Each participant is compensated a dollar for following directions and answering the survey honestly and correctly. The focus group usability test involves an interview. The participants are asked to install and configure PEK on their own devices and answer several questions. Four major issues are addressed during the main test.

- ***MQ1:*** What are the most frequent activities performed by smart device users on their personal devices? If the results showed one of the most frequent activities performed by smart device users involved sensitive information, they could be apart of PEK's target audience.
- ***MQ2:*** Do smart device users utilize any default security precautions already provided on their smart devices? This question relates to the one from the pilot usability test and whether or not typical smart device users are concerned with the security measures on their personal devices.
- ***MQ3:*** Do users consider that their smart devices are properly protected from outsider attacks?
- ***MQ4:*** Would smart device users consider implementing more security measures on their devices?

4 Usability Testing Results and Interpretation

This section presents results from the pilot usability test and main usability test performed between May and July 2016.

4.1 Answers for Pilot Usability Test

In the pilot usability test, there are 2 male participants who have Android mobile smart phones. During the interview, participants have to install and configure PEK on their own devices. They are timed for how long it takes them to successfully configure PEK and for the randomized keyboard to show up successfully when they try to input a password and/or pin.

Answers to question PQ1: Users are able to find PEK on Google Play and install PEK without difficulty. However, when it comes to configuring PEK, some issues arise. Table 1 illustrates the time of installation and configuration during the pilot usability test. The configuration time is obviously longer. Along with the longer times, we note that both participants are not able to configure PEK by themselves; both of them need additional instructions from the researcher to configure the application. The participants **look for a PEK application icon** on their devices but find none. When they try to login to one of their accounts, such as an email, they are confused when the randomized keyboard does not show up when they hit a password field. The participants are frustrated during the configuration process. If the researcher does not aid them during the process, both of the participants most likely would have given up trying to configure PEK.

Table 1. Installation and configuration time of PEK

Participants	Installation Time (seconds)	Configuration Time (seconds)
Participant 1	29.01	45.79
Participant 2	15.00	125.00

Answers to question PQ2: Both participants admit that they would not use PEK on a regular basis on their own personal devices. Neither participant has information on their personal device that they consider sensitive. Nor do

either of them have any other security enhancements enabled on their smart devices. The only security precaution Participant 1 admits undertaking is not using applications or services that request important data or sensitive data on their mobile phone; they prefer doing those types of activities in their home on their laptop or on their desktop. However both participants acknowledge that they might not be apart of PEK's target audience since both of them considered themselves educated about mobile security and how to prevent related attacks.

Answers to question PQ3: Participant 1 during the second session after two to three days, does not consider the tradeoff between his time spent entering, for example, his pin to open his phone, worth protecting whatever personal information that is contained on his mobile phone. Participant 1 predicts that a user could never get better at entering a password and/or pin using PEK since the keyboard is randomized each time and no key is in the same place. Unlike a regular QWERTY keyboard, which a user can memorize and use easily, PEK cannot be learned. It is also challenging to multi-task when using PEK. For instance, if a user is on the move and trying to login to their phone, it is more difficult to login when using PEK than a regular QWERTY keyboard. Another difficulty that Participant 1 encounters is their mobile phone go to asleep when they attempt to enter their password using PEK to unlock their phone and the user has to enter their password all over again; this leaves Participant 1 frustrated at his time lost by using PEK. Unlike Participant 1, Participant 2 reckons his time lost by entering passwords using PEK is worth protecting the information stored on his mobile phone. Participant 2 compares PEK to someone using their hand to cover their screen while inputting their password with their other hand; except that PEK is more practical and dependable than a user's hand covering their screen.

Two observations can be made from the pilot usability test.

1. The configuration of PEK is difficult for both participants during the pilot usability test. Neither could complete configuration without aid. To remedy this, it is desirable to have more instructions on the Google Play Store to assist users and an icon for users to open when PEK is installed. Both the participants look for a PEK icon on their mobile phone's interface when the application finishes downloading, however, PEK does not have an icon.
2. Participant 1 mentions difficulty using PEK when attempting to access their mobile phone quickly and while multitasking. We decide to create a separate button on the privacy-enhanced keyboard to allow the user to easily disable PEK. Thus, if a user needs to quickly unlock their mobile phone, they are able to disable PEK to enter their password and/or pin and avoid the extra input time needed to use PEK. It is preferred that PEK is the default keyboard when a user clicks on a password field. Then, if the user wants to use the regular QWERTY keyboard, they can easily hit a button on the privacy-enhanced keyboard to disable it and use the QWERTY keyboard instead.

4.2 Main Usability Test - Web Survey

The main usability test has 2 participants in the focus group usability test and 266 participants, including 132 females and 134 males, in the web survey. The ages of the participants range from 18 years old to above the age of 50. 136 participants use Android devices, which PEK is compatible with, and 123 participants use Apple devices. The other 7 participants choose the "Other, please specify" option during the web survey. We have 21 questions and obtain 266 responses. There is a combination of multiple choice questions and open-ended questions.

Answers to question MQ1: The purpose behind this research question is to find out whether any of the most frequent activities performed by mobile smart device users involve users' personal information that may be considered sensitive. Smart device users that do bank mobilely, shop online, and/or social network may enter sensitive personal information that could be susceptible to being stolen. Figure 2 shows statistics from the web survey. Internet use is the top answer at 8.0%. Comparably, 5.4% of the web survey takers shop online, 5.7% bank mobilely, and 7.1% use social networking sites. Any of these actions could result in personal information being leaked and an account being hacked. The web survey takers that do perform any of the actions we listed above could be apart of PEK's target audience if they are interested in protecting their information that bank applications or online shopping applications require to use.

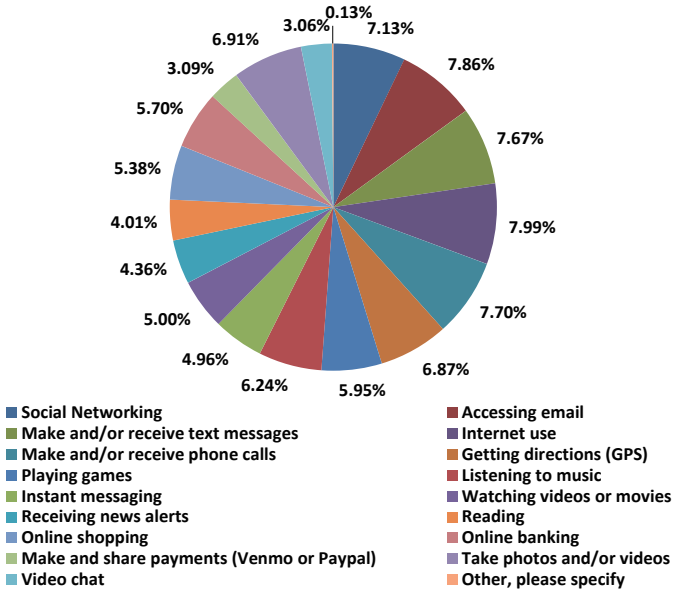

Fig. 2. Answers to question MQ1

Answers to question MQ2: If smart device users do not implement other security precautions that are already provided on their mobile devices, it is likely they would not utilize PEK. The amount of smart device users who employ

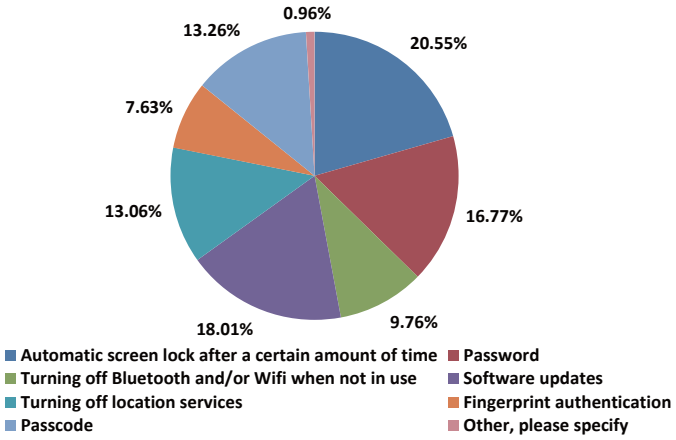

Fig. 3. Distribution of security precautions

other security precautions on their mobile smart devices was not significant. However, this may be a result of most smart device users being unaware of potential attacks that can be performed on their smart devices. Figure 3 shows the distribution of security precautions that the web survey takers implement on their own personal mobile smart devices. At 20.55%, automatic screen lock after a certain amount of time was the top answer amongst web survey takers. The results of these particular questions lead to more questions about smart device users. Are smart device users generally unconcerned with security or are they just uninformed about the lack of security on their mobile devices and the potentiality of malicious attacks?

The question is purposefully worded to discover the opinions of the web survey takers and whether they consider their own personal smart devices properly protected against outsider attacks. This can further lead us to determine whether smart device users are simply uneducated about attacks to their devices or they just are not concerned with security. The answers to this question varied by the degree to which the web survey takers were concerned with security. The top answer was "Probably yes" at 36.59%, followed by "Maybe" at 29.27%, then "Probably not" at 20.05%. How users rate the degree of protection on their personal mobile devices may differ a lot from how they are actually protected. The high level of certainty the web survey takers display about their smart devices being protected is a little worrisome. Every smart device user should feel doubt when it comes to how well protected their smart devices are. Figure 4 portrays the distribution of answers web survey takers chose when asked this question.

Answers to question MQ4: Surprisingly, depicted in the web survey results, users are willing to consider implementing more security features to their mobile smart devices. Although this differs from users actually implementing more security features, it is a start. Figure 5 illustrates the distribution of the answers resulting from the web survey; 37.67% of the web survey takers answered "Probably yes", followed by 30.62% of survey takers answering "Maybe", then 10.84% of the survey takers said "Definitely yes". This portion of web survey takers could be potential users of PEK as long as the user experience and promise of security is ensured.

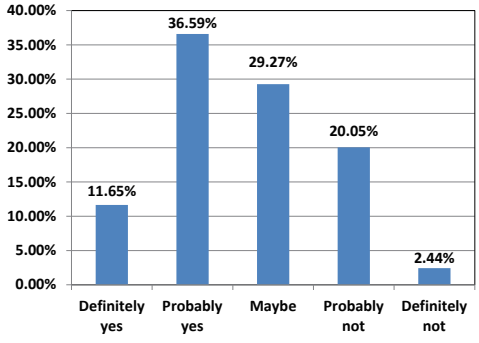

Fig. 4. Distribution of answers to question MQ3

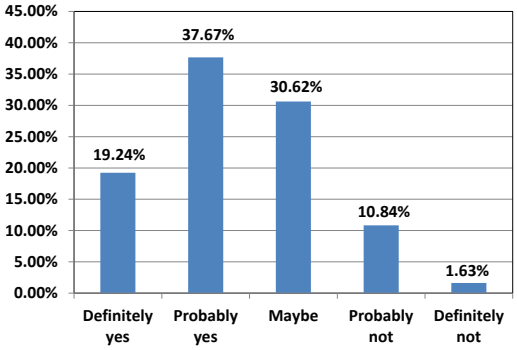

Fig. 5. Distribution of answers to question MQ4

4.3 Main Usability Test - Focus Group Usability Test

Apart from the web survey, a focus group usability test is conducted with 2 participants. This test is a recorded interview with 19 questions, all open ended. There is one session and both participants were interviewed at the same time. Similar questions are asked during this group usability test as during the web survey. Both the participants use mobile Android smart phones.

a) What three activities do you primarily do on your mobile phone? Participant A lists using the alarm, reading the news and listening to music as the activities they perform the most on their Android smart phone. Participant B says sending/receiving texts, taking photos and using social network applications as their top three activities they perform on their mobile smart device. Participant A most likely would not have a use for PEK. Participant B may be a more likely candidate for PEK and have more use for it than Participant A. However, neither lists any activities that were prominently chosen by the web survey takers on the web survey.

b) What kind of security have you implemented on your mobile phone? Both Participant A and Participant B have the same exact answer for this question, "Nope." Neither has any default security installed on their mobile phones.

c) Are you satisfied with the level of security on your mobile phone? Again, both Participant A and Participant B have the same answer for this question, a simple "Yes."

d) Would you ever consider adding more security features to your mobile phone? Surprisingly both participants are somewhat open to considering implementing more security features to their mobile phones. Perhaps it is out of pure laziness that they do not have any security installed on their mobile devices, or they are sure to not perform any actions that require sensitive data on their mobile phones.

e) At this point during the interview we have both participants install and configure PEK.

f) Would you recommend this application to a friend? Participant A says yes they would recommend it to a friend who is concerned with security and who might be in public a lot. Participant B says as well that they would recommend

PEK to a friend if and when a friend asks them about adding more security to their mobile phone.

g) Do either of you have any suggestions about improving the application? Participant B's first impression of PEK is, "It can be used, but I will not use it." Participant A complains about the keys on PEK, how the larger popup disappears too quickly. For example, when you hit the key "U" on PEK, a popup will emerge from the key "U" and display a larger version of the letter, and that is for any letter when typing on PEK. Participant A recommends getting rid of this feature since he considers it annoying.

4.4 Improvements in PEK 3.x

In the pilot usability test, we learn that both two participants take long time to configure PEK, since they cannot find the PEK icon on their smartphones. To mitigate this problem, we put an icon of the PEK on the Android home screen as shown in Figure 6. A user can tap the icon and configure the settings of PEK as shown in Figure 7. Then, the user can click the "Open Android Input Settings" and set PEK as a keyboard available for users.

In addition, the participants suggest creating a new button for turning on/off the randomization of the PEK. Because PEK cannot be learned and it is inconvenient to use PEK in some circumstances. To this end, we implement a random toggle button on the PEK as shown in Figure 8. Then, users can decide to save time using a regular keyboard to input the password or protect their password using PEK.

Fig. 6. Home Screen App

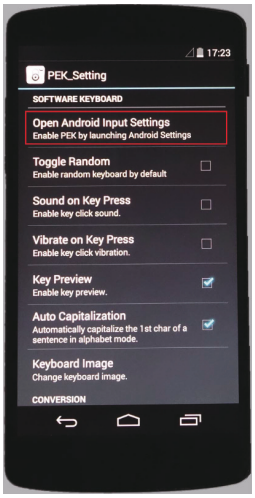

Fig. 7. PEK Setting

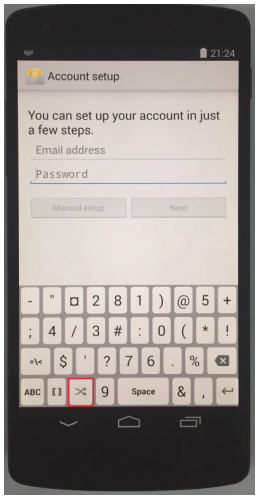

Fig. 8. Toggle Button

5 Conclusion

This paper conducts a full-scale usability testing of a generic Android privacy enhancing keyboard (PEK) that can prevent various attacks against touch-enabled

devices from inferring user pins or passwords. We perform both the pilot usability test and main usability test in order to identify how to improve PEK for broad adoption. Based on the results of the usability study, we implement two new features in PEK 3.x, a home screen app to easily activate PEK and a toggle button to enable/disable randomness of PEK. The usability test also demonstrates the worrisome phenomena that many users blindly trust their phones for security or are not concerned with the possible breaches. This phenomena demonstrates the human factor that contributes to the vulnerabilities of the cyber space. For future work, we plan to continue to improve PEK and perform another round of usability test in order to find out if the improved PEK attracts more adoption and better rating.

Acknowledgments

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