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Usability Investigation on the Localization of Text CAPTCHAs: Take Chinese Characters as a Case Study

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Abstract. Text CAPTCHA has been an effective means to protect online systems from malicious attacks. However, nearly all the Text CAPTCHA designs are based on English characters, which may not be the most user-friendly option for non-English speakers. Therefore, there is an increasing interest in designing local-language CAPTCHAs, which are expected to be more usable for native speakers. However, systematic studies on the usability of localized CAPTCHAs are rare, and a general procedure for the design of usable localized CAPTCHA is still unavailable. Here, we comprehensively explored the design of CAPTCHAs based on Chinese characters from a usability perspective: a usability comparison of CAPTCHAs based on Chinese and English characters, then the evaluation of intrinsic design factors of Chinese CAPTCHAs. It's found that Chinese CAPTCHAs can be equally usable comparing with alphanumeric ones. Meanwhile, guidelines for designing user-friendly Chinese CAPTCHAs are also presented. Those design practices are further summarized as a general procedure which is expected to be applicable for the design of CAPTCHAs based on other languages.

Keywords. Text CAPTCHA, Usability, Human Factors, Cross-culture Design

Introduction

CAPTCHA (Completely Automated Public Turing test to tell Computers and Humans Apart) has always been an effective means to defend automatic scripts and protect online systems from spam and abuse [1]. CAPTCHAs today are mainly based on Image, Sound or Text [2]. For Image CAPTCHAs, a set of images are presented and the user is instructed to click on particular image(s) to solve them [3]. A sound-based CAPTCHA usually requires users to solve audio-recognition tasks. Text CAPTCHAs usually include several alphanumeric characters (a-z, A-Z, 0-9) that are distorted and added with background noises [4], human users are required to correctly input those characters [5]. Given that this paper focuses on Text CAPTCHA, the word CAPTCHA mentioned afterwards represents only the text one unless otherwise specified.

With the increased distortion of texts and backgrounds, CAPTCHAs are more efficient to defend automatic scripts [4] but also at the cost of degraded usability. Therefore, many studies have been conducted to investigate the usability of CAPTCHAs. For example, Chellapilla [6] presented the limits of distortions that are acceptable for users; Elie Bursztein [7] investigated the effects of visual features, anti-

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segmentation and anti-recognition features on the usability of CAPTCHAs. Belk [8] revealed that participant's cognitive styles also affect the usability of CAPTCHAs, etc. In addition to those usability studies, there is also an increasing importance to design localized CAPTCHAs due to the large number of non-English Internet users. Localized CAPTCHAs could have several advantages: (i) Familiar for local users: it is intuitively more comfortable with native languages; (ii) More durable with design factors: for local languages that are complex in form, it may not be easily confused with security features such as distortion; (iii) More candidate characters and better security: there are 26 letters and 10 numbers for alphanumeric CAPTCHAs, however, take Chinese characters for example, it can provide thousands of different candidate characters. For instance, Shirali-Shahreza [9] designed CAPTCHAs that employed Persian/Arabic characters with improved security and usability. Yang [10] explored the application of Korean characters in CAPTCHAs and revealed that the Korean CAPTCHAs could be easily understood by native Korean speakers while difficult to be defeated by OCR (Optical Characters Recognition) programs. Banday [11] investigated the usability of CAPTCHAs based on Urdu, one of the regional languages in India. The results indicated that, for native speakers of Urdu who had little familiarity with English, they solved Urdu CAPTCHAs significantly faster and more accurately than those based on English. There is also an emerging interest in developing new algorithms for Chinese CAPTCHAs. Wang [12] proposed double-layer Chinese CAPTCHAs against OCR. Several other methods for generating Chinese CAPTCHAs are also reported [13-15].

However, previous studies are mostly focused on new means of generating localized CAPTCHAs while lack systematical investigations on the usability of such CAPTCHAs. Particularly, the general procedure for designing localized CAPTCHAs is still unavailable yet. In this study, taking the usability investigation of Chinese CAPTCHAs as a case study, we compared the usability of CAPTCHAs based on English and Chinese (Experiment I), and explored the intrinsic design factors that may affect the usability of Chinese CAPTCHAs (Experiment II). Such comprehensive practices on Chinese CAPTCHAs were further generalized as a standard procedure, which is expected to be applicable for the localization of CAPTCHAs based on any other regional language.

1. Methods

The three key dimensions of usability [16] were used to evaluate the usability of testing CAPTCHAs: effectiveness, efficiency and satisfaction. The effectiveness and efficiency were measured by the correction rate and average solving time for each type of CAPTCHA, respectively. The satisfaction was obtained through online questionnaires and face-to-face interviews. The satisfaction questionnaire, which used a 5-point Likert scale (1=strongly disagree, 5=strongly agree), focused on the following three aspects: Q1. It is visually comfortable; Q2. It's easy and efficient to recognize and input; Q3. It's appropriate for wide application. Testing CAPTCHAs were generated through the revision of Securimage [17], a widely-used open source code. Except for the characters in each CAPTCHA, all other design factors were kept the same, such as the font size, interfering lines, etc. Furthermore, the average number of keystrokes [18] required for the input of English and Chinese CAPTCHAs were kept the same under current experimental setting, i.e. 8 keystrokes. The keystroke number of Chinese characters were based on the predominant input method in China--Pinyin [19] input method. Therefore, it maintained a similar workload to input different CAPTCHA types and provided a similar condition to evaluate the efficiency of different designs.

1.1. Experiment Design

1.1.1. Experiment I: usability comparison between English and Chinese CAPTCHAs.

See in Figure 1, four kinds of CAPTCHAs were deployed to compare the usability of English and Chinese CAPTCHAs: Random English Characters (REC), Frequent English Words (FEW), Random Chinese Characters (RCC) and Frequent Chinese Words (FCW). Each REC CAPTCHA included 8 English letters and each FEC CAPTCHA included a single English word that is consisted of 8 letters. The RCC CAPTCHA is the counterpart of REC CAPTCHA and it randomly included 3 or 4 individual Chinese characters. The FCW CAPTCHA is the counterpart of FEW CAPTCHA and it included a single Chinese word that is composed of 4 individual Chinese characters. Testing characters or words were those frequently used in daily life.

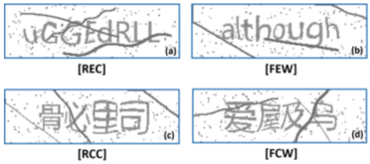

Figure 1. Illustration of CAPTCHA designs in the usability comparison of English and Chinese in current study: (a) Random English Characters (REC); (b) Frequent English Word (FEW); (c) Random Chinese Characters (RCC); (d) Frequent Chinese Word (FCW).

1.1.2. Experiment II: Evaluation of intrinsic usability factors of Chinese CAPTCHAs

Experiment II focused on some unique design factors of Chinese characters, which included different font families, characters that are similar in form or pronunciation, characters of different usage frequencies, etc. The four fonts studied were (a) Yahei, (b) Songti, (c) Heiti and (d) Caoshu, see in Figure 2. The first three fonts are widely used on the Internet and have better readability comparing with the last one, Caoshu. Among all those fonts, the boldness of characters is the main difference. In addition to the fonts, Figure 3 (a) and (b) show two other design factors: CAPTCHAs based on less frequently-used characters and characters with similar appearance, respectively. Generally, the Pinyin of a Chinese character includes two parts: initial consonant and vowel. However, the pronunciation of several pairs of initial consonants, “z” and “zh” for example, are similar, which may mislead the input of characters that contain those initial consonants. It is the same case for vowels. Therefore, the last two factors focused on the influence of easily-confused Pinyin: Figure 3 (c) and (d) are examples of CAPTCHAs that employed characters with similar initial consonants (z/zh, c/ch, s/sh, r/l, l/n, f/h) and similar vowels (an/ang, en/eng, in/ing), respectively.

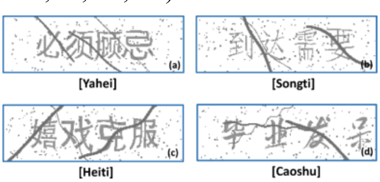

Figure 2. Illustration of Chinese CAPTCHA designs based on four different fonts: (a) Yahei, (b) Songti, (c) Heiti and (d) Caoshu.

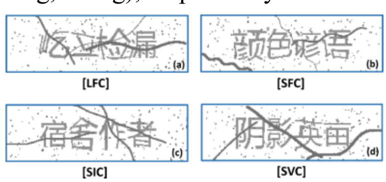

Figure 3. Example of CAPTCHAs based on (a) less-frequent characters [LFC], (b) similar-form characters [SFC], (c) characters with similar initial consonants [SIC], and (d) characters with similar vowels [SVC].

1.2. Participants

Thirty participants (13 males, 17 females; aged from 18 to 25, M=21.6, SD=1.3), who were native speakers of Chinese with English as a familiar second language, were recruited for Experiment I. They were students at Shanghai Jiao Tong University from different majors. All the participants had passed the College English Test Band 6, a language proficiency test held by the Ministry of Education of China. Therefore, they were familiar with all the testing English words. Another 30 native speakers of Chinese (14 males, 16 females; aged from 18 to 25, M=21.4, SD=2.17) were recruited for Experiment II. They were also students from different majors at Shanghai Jiao Tong University. All participants for both experiments were experienced computer users who spent at least 2 hours per week on word processing. Furthermore, Pinyin was their daily-used input method for Chinese characters and they all had encountered English and Chinese CAPTCHAs during their previous online activities. Also, none of the participants had trouble reading on the screen.

1.3. Apparatus

The two experiments were both conducted in a controlled lab environment. All participants were instructed to solve CAPTCHAs on a same setup, which included a computer with 20-inch liquid crystal display, a set of regular QWERTY keyboard and mouse as the input devices. Microsoft Pinyin was used for the typing of Chinese characters. All CAPTCHAs were generated on a remote server and downloaded in the form of webpages to the local browser, which was Google Chrome in this study.

1.4. Procedure and tasks

The experiments were carried out in three stages—preparation, testing, and interview. During the preparation stage, the apparatuses were reset and each participant was informed of the experiment tasks. After that, the participant was instructed to get familiar with the experiment apparatuses by solving five CAPTCHAs. During the test session, the participant was left alone in the lab and different types of CAPTCHAs were presented one by one through the web interface, 12 pieces for each type. After the submission of each CAPTCHA, a record would be generated on the remote server, indexing the solving time, the input values and whether the CAPTCHA was solved correctly. The webpage also refreshed automatically after submission and the participant was directed to solve the next CAPTCHA till the end of the task cycle. After solving all the CAPTCHAs, an online questionnaire was presented for the participant to fill. The questionnaire contained pictures of each type of CAPTCHA to help participants better rate testing CAPTCHAs. After that, each participant was also asked to share his/her subjective opinion about the testing CAPTCHAs. Finally, he/she was paid to appreciate the cooperation.

2. Results and Discussion

2.1 Usability Comparison between English and Chinese CAPTCHAs

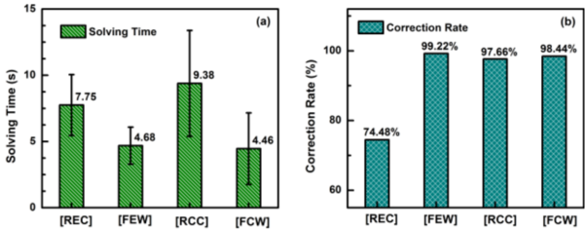

Figure 4. (a) Average Solving Time and (b) Correction Rate for four kinds of CAPTCHA design: Random English Characters (REC), Frequent English Words (FEW), Random Chinese Characters (RCC), Frequent Chinese Words (FCW).

The average solving time and correction rate for all four kinds of CAPTCHA design, which based on Random English Characters (REC), Frequent English Words (FEW), Random Chinese Characters (RCC), or Frequent Chinese Words (FCW), are illustrated in Figure 4. The solving time of FEW (M=4.68s, SD=1.4s) is essentially the same as that of the FCW (M=4.46s, SD=2.7s). This is because all participants were familiar with both the English and Chinese words tested in this study. CAPTCHAs based on RCC (M=9.38s, SD=4s) have the longest solving time, followed by REC (M=7.75s, SD=2.3s). Meanwhile, the solving time of both RCC and REC are longer than that of FEC and FCC. Because, for both languages, it took a longer time for participants to recognize and type individually each random character. The similar solving time for FEC and FCC further shows it took basically the same efforts for participants to response to their native language and a familiar second language. Also, CAPTCHAs based on frequently-used English and Chinese words have better efficiency than those employing random characters, while there is no significant difference in the solving time of frequent English and Chinese words.

The effectiveness of those four CAPTCHA designs are represented by the percentage of CAPTCHAs that were correctly solved, see in Figure 4 (b). The accuracy for FEW (99.22%), RCC (97.66%) and FCW (98.44%) are similar and significantly higher than REC (74.68%). The high correction rates for the first three kinds of CAPTCHAs demonstrate there was no difficulty for participants to correctly recognize CAPTCHAs of both languages. As to the low correction rate of REC CAPTCHAs, a majority of those incorrect inputs were caused by similar letters, such as “I” and “L”. When we removed the results from CAPTCHAs that contained confusing letters, the accuracy of REC was improved from 74.48% to 85.31%. However, such an accuracy is still lower than the other three CAPTCHA designs. This is further attributed to the random lines, background noises and distortions, while FEW CAPTCHAs maintained a high correction rate of 99.22%, indicating FEW design was less sensitive to the security features such as random lines than REC. The satisfaction questionnaires are summarized in Table 1. The results indicate that FEW and FCW were the most preferred CAPTCHAs, while REC and RCC were negatively rated. The face-to-face interview further revealed that, more than 97.3% of the participants believed it was easy to recognize FEW and FCW CAPTCHAs with just a single glance. On the contrary, for CAPTCHAs based on random characters, it took more efforts to recognize each character individually.

Table 1. Satisfaction of CAPTCHAs based on Random English Characters (REC), Frequent English Words (FEW), Random Chinese Characters (RCC), Frequent Chinese Words (FCW).

	Yahei		Songti		Heiti		Caoshu	
	AVG	SD	AVG	SD	AVG	SD	AVG	SD
Q1. It's visually comfortable	3.03	1.13	4.13	0.78	2.87	1.17	4.13	0.78
Q2. It's easy and efficient to recognize and input	2.93	1.20	4.60	0.50	2.53	1.22	4.40	0.72
Q3. It's appropriate for wide application	2.63	1.13	4.50	0.86	2.07	1.23	4.20	0.87

2.2 Intrinsic design factors that may affect the usability of Chinese CAPTCHAs

Experiment I indicated that, for native speakers, the usability of Chinese CAPTCHAs can be the same as those English ones in terms of efficiency, effectiveness, and satisfaction. Therefore, we further explored the design factors that may affect the usability of Chinese CAPTCHAs. However, we mainly focused on some intrinsic factors rather than external factors such as background noises, strikethrough lines, etc., which had been extensively studied in previous publications, like [4, 7].

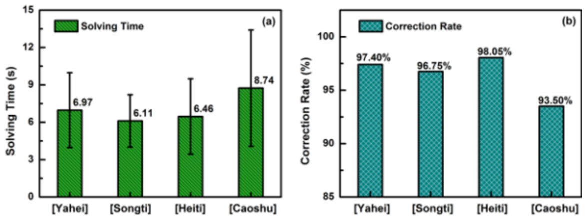

Figure 5. (a) Solving time and (b) correction rate of CAPTCHAs based on four different fonts: Yahei, Songti, Heiti and Caoshu.

The solving time and correction rate for the four different fonts, Yahei, Songti, Heiti and Caoshu, are introduced in Figure 5. The solving time of Yahei (M=6.97s, SD=3.01s), Songti, (M=6.11s, SD=2.11s), and Heiti (M=6.46s, SD=3.04s) are similar while shorter than that of Caoshu (M=8.74s, SD=4.69s). The correction rate of Yahei (97.40%), Songti (96.75), and Heiti (98.05%) are also similar while higher than that of Caoshu (93.5%). Those results reveal that the efficiency and effectiveness are the same for the first three fonts and better than that of Caoshu. Because the most prominent difference among the first three fonts is the boldness of characters, the results indicate the usability of Chinese CAPTCHA is insensitive to the thickness of characters. Participants' relatively poorer performance with Caoshu can be explained by the lower readability of Caoshu.

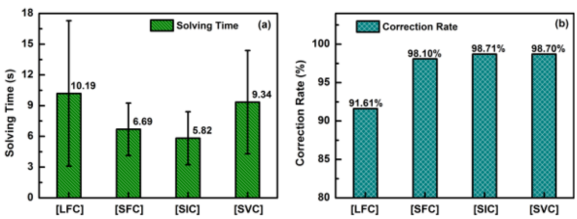

Figure 6. Solving time and correction rate of Chinese CAPTCHAs based on (a) low frequency characters [LFC], (b) similar form characters [SFC], (c) similar initial consonant characters [SIC] and (d) similar vowel characters [SVC].

The solving time and correction rate of four other factors are shown in Figure 6. For CAPTCHAs employed low-frequency characters (LFC), the solving time (M=10.19s, SD=7.77s) and correction rate (91.61%) are longer and lower comparing with that of the reference group, Yahei in Figure 5, respectively. This reveals that, CAPTCHAs based on unfrequently-used characters have lower usability in terms of efficiency and effectiveness. For CAPTCHAs based on similar-form characters (SFC), there were at least two similar characters. The solving time (M=6.69s, SD=2.57s) and correction rate (98.10%) of SFC have no much difference with that of Yahei in Figure 5, the reference group. This means even if the candidate Chinese characters look similar, no notable confusion or difficulty would be imposed on the solving efforts. The last two factors focused on the characters that contain easily-confused Pinyin. For CAPTCHAs containing similar initial consonant characters [SIC], the solving time (M=5.82s, SD=2.60s) and accuracy (98.71%) are similar with that of the reference group of Yahei in Figure 5. However, for CAPTCHAs containing similar-vowel characters [SVC], the solving time (M=9.34s, SD=5.05s) is slightly longer than the reference group of Yahei in Figure 5. This implies participants had been confused to some extent and it took longer time to figure out the correct vowels. However, the accuracy remains high (98.70%), because participants were familiar with the appearances of the characters and could recognize the characters correctly.

As to the satisfaction, see in Table 2, among all the four fonts, participants were highly satisfied with Yahei, Songti and Heiti. The font Caoshu, which is relatively harder to recognize, was not preferred. In addition, CAPTCHAs that contained less frequently-used or similar-form characters also turned out to be less favored. Although participants reported characters with similar pronunciations were visually comfortable, they believed that CAPTCHAs based on those characters were less efficient. This is probably because that it takes extra efforts to distinguish similar pronunciations.

Table 2. Satisfaction of Chinese CAPTCHAs based on four different fonts (Yahei, Songti, Heiti and Caoshu), low frequency characters [LFC], similar form characters [SFC], similar initial consonant characters [SIC] and similar vowel characters [SVC].

	Yahei		Songti		Heiti		Caoshu	
	AVG	SD	AVG	SD	AVG	SD	AV	SD
Q1. It's visually comfortable	4.43	0.86	4.10	0.99	4.40	0.81	2.60	0.93
Q2. It's easy and efficient to recognize and input	4.43	0.90	4.23	0.97	4.47	0.90	2.83	1.23
Q3. It's appropriate for wide application	4.10	0.82	4.10	0.92	4.40	0.86	2.43	0.86
	LFC		**CFS**		**SIC**		**SVC**	
	AVG	SD	AVG	SD	AVG	SD	AV	SD
Q1. It's visually comfortable	3.53	1.14	3.97	1.03	4.20	1.00	4.17	0.95
Q2. It's easy and efficient to recognize and input	2.93	0.91	4.06	0.94	3.90	0.99	3.53	1.04
Q3. It's appropriate for wide application	2.77	0.97	3.90	0.84	3.87	0.94	3.5	1.00

2.3 Procedure for the localization of Text CAPTCHAs

The localization study of Chinese CAPTCHAs presented here is expected to be capable of generalizing to many other languages, such as Arabic, Japanese, Korean, etc. Figure 7 shows the general procedure we proposed for the localization of CAPTCHAs, which consists of three consecutive steps: (i) Comparing the usability of CAPTCHAs based on English and local language; (ii) Evaluating the design factors that may affect the usability of localized CAPTCHAs; (iii) Refining CAPTCHA designs according to security analysis and medium-scale user test. Step I is to determine if CAPTCHAs based on local language is comparable or better than English ones. The first thing is to analyze the cognitive processes of inputting local language and English. According to the analysis, a design matrix is generated to help prepare English and local CAPTCHAs within a similar frame (fonts, noises, workload, etc.) for the comparison of usability. Thereafter, native speakers of local language who are also familiar with English are recruited to perform the usability tests. For speakers who are unfamiliar with English, their performance on English CAPTCHA is expected to be lower than those who know English, as is the case for Urdu [11]. As a consequence, if the usability tests indicate that participants perform equally or better with local language CAPTCHAs, it is worthy to localize CAPTCHAs based on that local language. Otherwise, it is suggested to use English CAPTCHAs.

If CAPTCHAs based on local language provide equal or better usability than English ones, then move to the next step: evaluating the design factors that may affect the usability of localized CAPTCHAs, including intrinsic factors and general factors. The intrinsic factors are defined as those uniquely related with a particular language, for example, similarity of characters in form or pronunciation, typical font families, etc. All other design factors are classified as general factors, such as background noises, distortion, etc. For the full process of CAPTCHA localization, it is recommended to evaluate both the intrinsic and general factors. During the last step, security evaluation and medium-scale user test are suggested to further polish the design of localized CAPTCHAs, followed by the actual deployment.

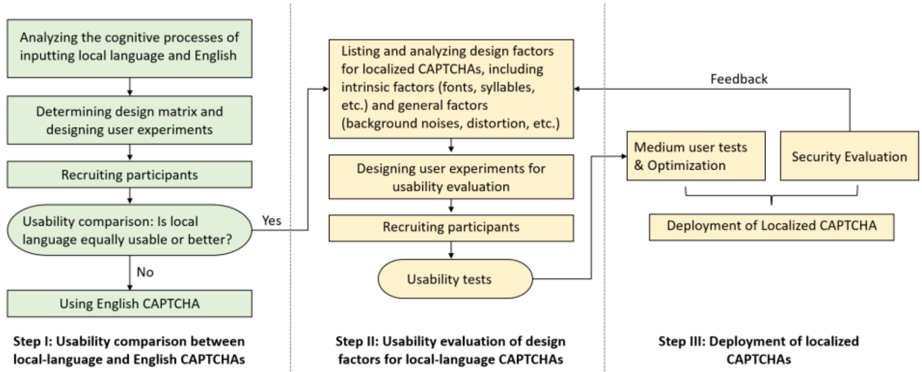

Figure 7. Procedure for the localization of text CAPTCHAs.

Limitations of this study

The current study mainly focused on the usability while the security of localized CAPTCHAs was not discussed. Another limitation is the scale of the usability test. Large-scale evaluations are expected to provide more specific results, such as how people of different ages may perform. Also, the CAPTCHAs studied here were not deployed in real-life situations.

3. Conclusion

In this study, we compared the usability of CAPTCHAs based on Chinese and English, evaluated the intrinsic design factors that may affect the usability of Chinese CAPTCHAs, and finally proposed a procedure that is applicable for the design of user-friendly CAPTCHAs based on other languages. The usability comparison experiments indicated that CAPTCHAs based on the two languages can be almost equally usable within the same design factors such as background noise level and typing workload. Comparing with CAPTCHAs that employ random English or Chinese characters, those based on frequently-used English or Chinese words provide the best usability. Further analyses on intrinsic design factors of Chinese CAPTCHAs revealed the usability of those CAPTCHAs is less sensitive to the daily-used fonts. Meanwhile, although the characters that are similar in form don't affect the usability, characters that are similar in pronunciation may bring confusions to users. Basing on the comprehensive evaluation on the localization of Chinese CAPTCHAs, a generalized procedure for the localization practice of other languages is proposed, which includes three steps: usability comparison between English and local-language CAPTCHAs, evaluating design factors that may affect the usability of local-language CAPTCHAs, medium-scale deployment for feedback and final deployment of localized CAPTCHAs. This study may shine a light for designing usable CAPTCHAs that employ local languages.

Acknowledgement

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