
Do Cognitive Styles of Users affect Preference and Performance related to CAPTCHA Challenges?

Marios Belk

Department of Computer Science, University of Cyprus
CY-1678 Nicosia, Cyprus
belk@cs.ucy.ac.cy

Christos Fidas

Department of Computer Science, University of Cyprus
CY-1678 Nicosia, Cyprus
christos.fidas@cs.ucy.ac.cy

Panagiotis Germanakos

Department of Management and MIS, University of Nicosia
CY-1700 Nicosia, Cyprus
Department of Computer Science, University of Cyprus
CY-1678 Nicosia, Cyprus
pgerman@cs.ucy.ac.cy

George Samaras

Department of Computer Science, University of Cyprus
CY-1678 Nicosia, Cyprus
cssamara@cs.ucy.ac.cy

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Abstract

A Completely Automated Public Turing test to tell Computers and Humans Apart (CAPTCHA) is nowadays a widely used security mechanism for constructing a high-confidence proof that the entity interacting with a remote service is actually a human being. Aiming to investigate the relation among users' cognitive styles, and CAPTCHA challenges in terms of preference and performance, a study is in progress which entails a psychometric-based survey for extracting users' cognitive styles, combined with a real usage scenario with two variations of CAPTCHA mechanisms. A total of 131 participants of age between 19 and 25 participated in the reported study providing interesting insights with respect to users' cognitive styles and CAPTCHA preference and performance issues.

Keywords

Usable Security; CAPTCHA Challenges; Cognitive Styles

ACM Classification Keywords

H.5 Information Interfaces and Presentation

General Terms

Human Factors, Design, Security



Figure 1. A typical text-based CAPTCHA example

Introduction

The World Wide Web is becoming gradually the primary medium, used on a daily basis by millions of users, for accomplishing important tasks like digital and commercial transactions, distance learning, social networking, etc. Within this realm a particularly important security concern of Web application providers is to protect themselves against automated software agents whose purpose is to degrade the quality of a provided service, whether due to misuse or resource expenditure (e.g., protect against automated creation of user accounts or content).

In order to defend against such threats, Web application providers utilize CAPTCHA challenges as a defense mechanism [1]. A typical example of a text-based CAPTCHA challenge is shown in Figure 1. It requires from a legitimate user to type letters or digits based on a distorted image that appears on the screen. Such a challenge is based on the assumption that a distorted text-based image can be easily recognized by the human brain but present significant difficulty for computer OCR (Optical Character Recognition) or other image recognition systems.

Research on CAPTCHA challenges has received significant attention lately. Researchers promote among others interaction with pictures, audio and video as a possible alternative to text-based CAPTCHA [2, 3, 4, 5]. A recent study which investigated users' perceptions towards CAPTCHA challenges underpins the necessity for user friendly CAPTCHA challenges as current implementations do not provide an acceptable trade off solution with regards to usability [6]. Results have shown that even experienced users expressed their

difficulties in solving a CAPTCHA challenge during their first attempt [6].

As a consequence, an acceptable CAPTCHA solution should embrace both security and usability aspects as its purpose is to provide safety of operation to Web application providers but as well usability and transparency to its end users, aiming to minimize the added cognitive effort of a casual user interacting with it. Taken into consideration that users do not necessarily share common cognitive backgrounds in which CAPTCHA decisions are required to be taken, we argue that such individual differences should be investigated and integrated in the user interface design process of CAPTCHA challenges, with the aim to personalize CAPTCHA interactions.

In this context, the work presented in this paper constitutes an effort towards understanding user preferences and performance related to CAPTCHA challenges by introducing the notion of individual differences as a core element, focusing mainly on users' cognitive styles and characteristics and their potential role in information processing during CAPTCHA challenges within Web-based environments.

Cognitive styles represent an individually preferred and habitual approach to organizing and representing information [7]. Various research attempts have been reported [8, 9] that investigate the effect of cognitive styles of users on preference and performance issues in Web-based environments. Accordingly, a number of proposed theories of individual style [7, 10, 11] are utilized in hypermedia information spaces. In this respect, this study utilizes Riding's Cognitive Style Analysis (CSA) [7]. Riding's CSA might be applied



Figure 2. A text-based CAPTCHA used during the study



Figure 3. A picture-based CAPTCHA used during the study

effectively on designing appropriate information spaces, since it consists of distinct scales that correspond directly to different aspects of the World Wide Web [12]. In particular, Riding's CSA classifies users to various cognitive typologies (i.e., Verbalizer, Imager or Intermediate). Users that belong to the Verbalizer class can proportionally process textual and/or auditory content more efficiently than images, whereas users that belong to the Imager class the opposite. Users that belong in between the two end points (i.e., Intermediate class) do not differ significantly with regards to information processing.

The rest of the paper is structured as follows: next we describe the context of an empirical study, methods, and developed null hypotheses. Thereafter, we analyze and discuss the findings of the study. Finally, we summarize our findings and outline the implications of the reported research.

Method of Study

Procedure

A Web-based psychometric instrument, exploiting Riding's CSA [7], was developed that measures the response time of 48 statements and computes a ratio between the response times for each statement type in order to highlight differences in cognitive style.

Furthermore, one text- and one picture-based CAPTCHA mechanism were developed using available open-source software [13, 4, 5]. In Figure 2 and Figure 3 we illustrate an example of the text- and picture-based CAPTCHA mechanisms used during the study, respectively. The text-based mechanism produced distorted images of random characters whilst the picture-based mechanism produced pictures and asked

the participants to select the appropriate pictures belonging to a specific group (i.e., select pictures that illustrate cats). Both CAPTCHA's contained a refresh button that initialized the CAPTCHA with a new sequence of characters or pictures, whereas, the text-based CAPTCHA also contained a sound button that narrated the characters illustrated in the challenge.

An invitation was announced on the Web-sites of three Computer Science (CS) undergraduate courses of two Universities in order to recruit the participants. The aim of this selection process was to recruit a representative sample of participants that were already familiarized with CAPTCHA challenges based on the fact that CS students are faced daily with CAPTCHA challenges in online courses, forums, blogs, social networking Web-sites, etc.

The participants were asked to visit a Web-page in order to take part in the study. The users were first required to choose between two variations of CAPTCHA (i.e., text- vs. picture-based) and then solve the preferred CAPTCHA challenge. After solving the CAPTCHA, the users were redirected to the psychometric test aiming to identify the users' cognitive styles.

Hypotheses

The following null hypotheses were formulated for the purpose of this research: i) there is no general preference of users towards text- or picture-based CAPTCHA challenges, considering also various main effects and interactions with respect to cognitive styles of users, ii) there is no significant difference with regards to time needed to solve a CAPTCHA challenge

Table 1. Users' Cognitive Style vs. CAPTCHA Preference

Cognitive Style	CAPTCHA Type	
	Text	Picture
Verbalizer	42	23
Imager	24	19
Intermediate	14	9
Total	80	51

Table 2. Users' Cognitive Style vs. CAPTCHA Performance (in seconds)

Cognitive Style	CAPTCHA Type	
	Text	Picture
Verbalizer	23.83	45.26
Imager	22.93	35.39
Intermediate	15.74	40.14
Total Average	22.14	40.68

among users belonging to the Verbalizer, Imager and Intermediate class.

Demographics of Participants

A total of 160 people participated so far in the study between November and December 2011. Participants varied from the age of 19 to the age of 25, with a mean age of 22 and were undergraduate students of Computer Science Departments. 29 of them completed half the psychometric test or had double answers and were omitted from the sample. The final sample included 131 participants.

Results and Discussion

For our analysis, we separated users in three categories based on cognitive styles: Verbalizers (N=65, f=49.61%), Imagers (N=43, f=32.82%), and Intermediates (N=23, f=17.55%), which consisted of participants that belong to the Verbalizer, Imager and Intermediate class, respectively.

Preference related to CAPTCHA challenges

The participants were asked to choose between two variations of CAPTCHA (i.e., text- vs. picture-based). In Table 1 we summarize the CAPTCHA preferences according to the users' cognitive styles.

A binomial statistical test was conducted to examine whether there is a general preference relating text- or picture-based CAPTCHA challenges ($H_0: p(\text{text-based})=0.5$ and $p(\text{picture-based})=0.5$). The result revealed that there is significant preference towards text-based CAPTCHA challenges ($p<0.02$). Furthermore, a Pearson's chi-square test was conducted to examine whether there is a relationship between users' cognitive style and their preference

towards a specific type (i.e., text- or picture-based) of CAPTCHA challenge. The results revealed that there is no significant relationship between these two variables (Chi square value=0.844, $df=2$, $p=0.656$). As a consequence, no safe conclusion can be drawn at this stage whether cognitive styles of users influence their preference towards a specific type (i.e., text- or picture-based) of CAPTCHA challenge.

However, examining each cognitive style group individually with respect to preference towards a particular CAPTCHA type, it has been identified that users of the Verbalizer class have significant positive preference towards text-based CAPTCHA (Chi square value=5.554, $df=1$, $p<0.02$). In contrast, users belonging to the Imager class (Chi square value=0.581, $df=1$, $p=0.446$) and Intermediate class (Chi square value=1.087, $df=1$, $p=0.297$) have not shown a clear preference towards one or the other direction (i.e., text- vs. picture-based CAPTCHA challenges).

Performance related to CAPTCHA challenges

A three by two way factorial analysis of variance (ANOVA) was conducted aiming to examine main effects and interactions between the users' cognitive style (i.e., Verbalizer, Imager and Intermediate) and CAPTCHA preference (i.e., text- vs. picture-based) over the time needed to solve a CAPTCHA challenge. We summarize the results in Table 2. Figure 4 illustrates the means of performance per cognitive style group and preference towards CAPTCHA.

The analysis revealed that, the main effect of users' cognitive style on time needed to solve a CAPTCHA challenge is not significant ($F(2,131)=1.166$, $p=0.315$). In contrast, a significant main effect of the CAPTCHA

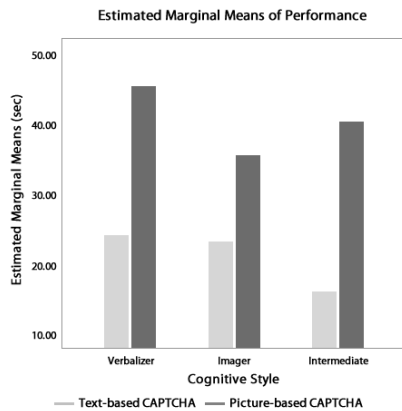


Figure 4. Estimated Marginal Means of Performance per Cognitive Style Group and CAPTCHA Preference

challenge type (i.e., text- vs. picture-based) with regards to the time needed to solve a CAPTCHA challenge has been identified ($F(1,131)=21.706$, $p<0.001$), as users solved text-based CAPTCHA significantly more efficient than picture-based CAPTCHA (Table 2). Furthermore, a pairwise comparison between cognitive styles (i.e., Verbalizer, Imager and Intermediate) and types of CAPTCHA challenges (i.e., text- vs. picture-based CAPTCHA) has been conducted to examine whether they have a significant effect on the time required to solve a CAPTCHA challenge. Results, revealed that users of the Verbalizer and Intermediate class performed significantly faster in text- than in picture-based CAPTCHA challenges (Verbalizers: $F(1,125)=15.007$, $p<0.002$, Intermediates: $F(1,125)=7.167$, $p<0.01$). However, users belonging to the Imager class had no significant effect on performance between text- and picture-based CAPTCHA challenges ($F(1,125)=3.621$, $p=0.059$), as they performed faster in the picture-based CAPTCHA challenges compared to the other two groups (Table 2).

Conclusions and Future Work

The purpose of this paper is to present results of a study in progress, with the aim to gain empirical knowledge for supporting usable security on the World Wide Web as an effort to apply User Centered Design (UCD) methodologies related to CAPTCHA challenges. In this context, the reported research provides indications that cognitive styles of users have an influence towards preference and performance with respect to CAPTCHA challenges.

At this point in time, no safe conclusion can be drawn, whether there is a thorough significant relationship between users' cognitive styles (i.e., Verbalizer,

Imager, Intermediate) and their preference towards a specific type (i.e., text- or picture-based) of CAPTCHA challenge. Nevertheless, our research underpins that there is a significant preference for users belonging to the Verbalizer class to choose text- than picture-based CAPTCHA challenges, also, as the sample increases there is a growing trend for users belonging to the Imager class to prefer picture-based CAPTCHA challenges. In this respect, a further analysis with a greater sample is required in order to draw more concrete conclusions.

With regards to performance, this research underpins that users belonging to the Verbalizer and Intermediate class solve significantly faster text- than picture-based CAPTCHA challenges. In contrast, in the case of users that belong to the Imager class, no significant difference in performance was observed between the two variations of CAPTCHA since they solved picture-based CAPTCHA challenges much faster than the other two cognitive style groups (Table 2). Taking into consideration that a picture-based CAPTCHA challenge is from a cognitive point of view a more demanding task than a text-based CAPTCHA this finding indicates a relation between users' cognitive style and CAPTCHA preference towards time needed to solve a CAPTCHA challenge.

Finally, participants in general preferred significantly text- than picture-based CAPTCHA challenges and solved text-based challenges significantly faster (Tables 1, 2). This finding can be explained by taking into consideration that the majority of Web application providers utilize text-based CAPTCHA, and thus, users are more familiar in solving text- than picture-based CAPTCHA challenges.

The limitations of the reported study are related to the self-reporting character of the psychometric approach which has been applied in order to elicitate the cognitive styles of the participants and that the participants were only students of Computer Science Departments with an age between 19 to 25 years. On the other hand, there has been an effort to increase ecological and internal validity of the research since the participants were involved at their own physical environments without the intervention of any experimental equipment or person, and the sample involved rather experienced and average than novice users with respect to CAPTCHA.

Studies like the reported one can be useful for improving usable security on the World Wide Web through adaptivity in user interface designs with regards to CAPTCHA challenges, aiming to organize and present information and functionalities related with security tasks in an adaptive format to diverse user groups, by using different levels of abstractions through appropriate interaction styles, terminology, information presentation and user modeling techniques.

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