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Do human cognitive differences in information processing affect preference and performance of CAPTCHA? ☆

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ABSTRACT

A Completely Automated Public Turing test to tell Computers and Humans Apart (CAPTCHA) is a widely used security defense mechanism that is utilized by service providers to determine whether the entity interacting with their system is a human and not a malicious agent. Common design practices of current CAPTCHA schemes barely take into account cultural, contextual, and individual cognitive characteristics and abilities of users. Motivated by recent research which underpins the necessity for designing more user-friendly CAPTCHA, this paper investigates the effect of users' cognitive styles and cognitive processing abilities towards preference and task performance of CAPTCHA challenges. In the frame of the reported research, two user studies were conducted. The first study ($n=131$) explored the effect of users' cognitive styles (Verbal/Imager) on user preference and task performance of two complementary types of CAPTCHA mechanisms; text-recognition and image-recognition. The second study ($n=125$) explored the effect of users' cognitive processing abilities (speed of processing, controlled attention, working memory capacity) on task performance in regards with different levels of complexity of both text-recognition and image-recognition CAPTCHA. Analysis of results revealed interaction effects of users' cognitive processing characteristics towards preference and performance of CAPTCHA, suggesting that individual differences at such an intrinsic level are important to be considered for designing more usable and user-centric CAPTCHA challenges.

1. Introduction

Human Interaction Proofs (HIP) are wide spread security defense mechanisms for constructing a high-confidence proof that the entity interacting with a remote service is a human being, and not malicious software (Chellapilla et al., 2005). A Completely Automated Public Turing test to tell Computers and Humans Apart (CAPTCHA) (von Ahn et al., 2004) is a HIP challenge-response test widely used today to protect Web applications, services and interfaces against automated software agents whose purpose is to degrade the quality of a provided service. CAPTCHA mechanisms commonly require users to respond to visual cognitive-based challenges (e.g., recognize and type characters that are illustrated in a distorted form on the screen) or audio-based challenges for individuals with vision problems. Such challenges are based on the assumption that they can be easily solved by humans but present significant difficulty for computing systems.

Designing a CAPTCHA mechanism is an inevitable balancing act between usability and security. Increasing the complexity of a CAPTCHA challenge (e.g., by increasing the distortion of characters or increasing the number of images), increases the security of the mechanism, but significantly decreases its usability (Bursztein et al., 2011, 2014; Golle, 2008). Recently, a high number of research works underpinned the necessity for designing user-friendly CAPTCHA since several studies revealed that requiring users to solve CAPTCHA challenges is a difficult and demanding task that decreases the overall user experience with an interactive system (Fidas et al., 2011; Bursztein et al., 2010; Yan and El Ahmad, 2008). Such tasks are known to add a considerable cognitive burden to users (Fidas et al., 2011). In addition, since these challenges interrupt the users' primary task of interaction, users might not be able to complete or even abandon their task with a system. From an accessibility perspective, studies have shown that visual CAPTCHA offer little support for users with vision problems (Bigham and Cavender, 2009; Holman et al., 2007).

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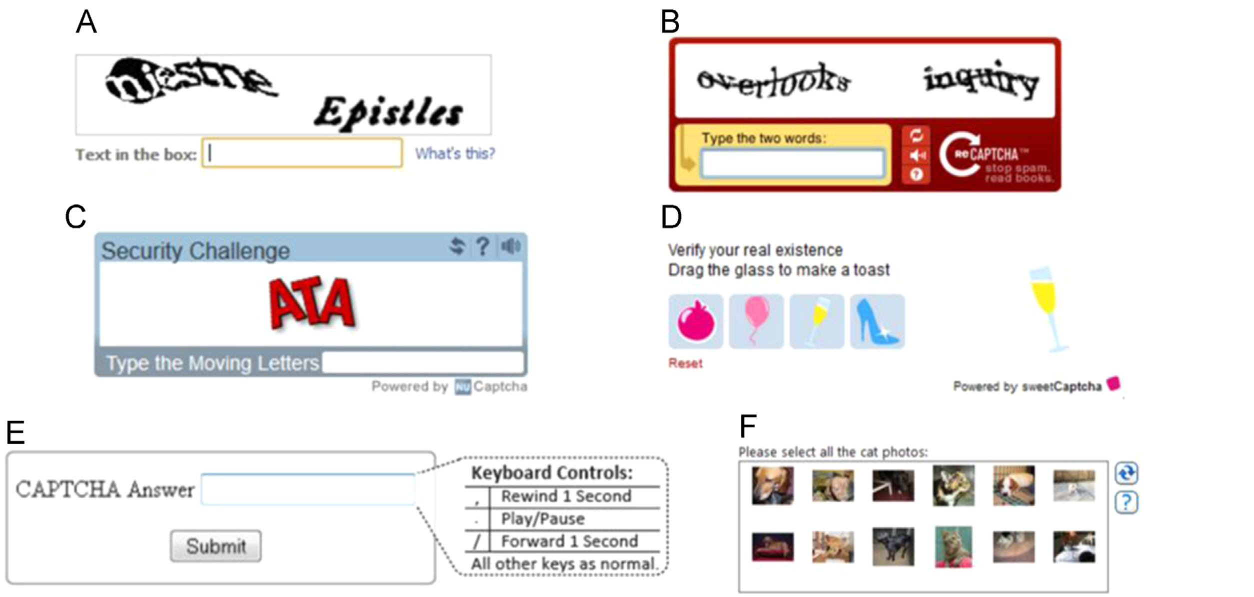

Fig. 1. (A) Facebook CAPTCHA (text-recognition), (B) reCAPTCHA (text- and speech-recognition), (C) NuCAPTCHA (animated text-recognition), (D) SweetCAPTCHA (drag-and-drop interaction), (E) non-visual Access CAPTCHA (speech-recognition), (F) Microsoft ASIRRA (image-recognition).

In this realm, aiming to improve the user experience during such interactions, but at the same time preserve security of applications and services, researchers promote different visual and interaction designs of CAPTCHA challenges (see Moradi and Keyvanpour, 2014 for a recent review). Current CAPTCHA implementations can be classified into three broad categories: *text-recognition*, *image-recognition*, and *speech-recognition*. Fig. 1 illustrates some noteworthy CAPTCHA implementations of each category.

Text-recognition CAPTCHA mechanisms are currently the most widely used (Bursztein et al., 2010, 2014) and require from a legitimate user to type alphanumeric characters based on a distorted image that appears on the screen. Popular text-recognition CAPTCHA include among others reCAPTCHA (von Ahn et al., 2008), Google CAPTCHA (Bursztein et al., 2014) and BaffleText (Chew and Baird, 2003). *Image-recognition CAPTCHA mechanisms* are usually based on image puzzle problems and annotation of static and animated images. For example, in ASIRRA (Elson et al., 2007) users are required to select pictures that illustrate cats among dogs. SEMAGE (Vikram et al., 2011) similarly requires users to recognize the content of a set of images, but as well understand and identify the semantic relationship between a subset of them. Another popular example includes What's Up CAPTCHA (Gossweiler et al., 2009) that requires from users to adjust randomly rotated images to their upright orientation. *Speech-recognition CAPTCHA mechanisms* are usually based on audio comprehension which principally require users to enter alphanumeric characters listened from a recording of a combination of simple words and numbers where disturbance and noise has also been added. Speech-recognition CAPTCHA are more difficult to solve and internationalize, and more demanding in terms of time and efforts compared to text-recognition and image-recognition CAPTCHA (Bigham and Cavender, 2009; Bursztein et al., 2010). Nevertheless, speech-recognition CAPTCHA have become an alternative for visually-impaired people that aim to improve usability and allow easy access to users (Davidson et al., 2014; Bigham and Cavender, 2009; Holman et al., 2007; Gao et al., 2010).

The literature also reveals a high number of alternative CAPTCHA mechanisms that follow hybrid approaches that combine text- and image-recognition challenges, drag-and-drop interactions, semantic approaches, etc. Examples include NuCAPTCHA that illustrates animated instead of static text in the challenge (NuCAPTCHA Inc., 2015), Emerging CAPTCHA (Xu et al., 2014) which is an alternative approach that addresses security flaws found in NuCAPTCHA, Solve-Media CAPTCHA that incorporates brand advertisements in the challenge and users are required to type the text of an advertiser's brand text (SolveMedia, 2015), video approaches such as the work of Kluever and Zanibbi (2009) that proposed a technique for using content-based video labeling as a CAPTCHA challenge and users are then required to label these videos to pass the challenge, and SweetCAPTCHA (2015) that is an action-based CAPTCHA in which users are required to drag-and-drop specific objects onto other objects (e.g., *"drag the shoes into the box"* or *"drag the glass to make a toast"* (Fig. 1D)).

A common practice with regards to the aforementioned visual and interaction designs of CAPTCHA mechanisms is that they do not primarily take into consideration the individual characteristics of users but rather follow a one-size-fits-all paradigm, i.e., the visual and interaction design of CAPTCHA is rarely personalized to the individual characteristics of users (e.g., cognitive processing abilities). Nevertheless, recent research revealed that individual differences have a main effect on task performance and user preference of CAPTCHA (Fidas and Voyiatzis, 2013; Belk et al., 2012; Wei et al., 2012; Albert et al., 2010; Banday and Shah, 2011), suggesting that user-adaptive and personalized CAPTCHA mechanisms could improve the user experience and user acceptance of CAPTCHA. Consequently, an important step toward designing personalized and user-centric CAPTCHA mechanisms is to identify which individual characteristics are considered important enough and might affect users' interactions with such security mechanisms.

In this context, bearing in mind that solving a CAPTCHA challenge (text, image, sound) is primarily a human cognitive processing task; users are required to process and recognize textual, graphical or audio information, we suggest that human cognitive differences in information processing should be investigated and integrated in the user interface design process of CAPTCHA challenges. Accordingly, this paper reports two subsequent user studies that aim to further understand human-computer interactions in such realms and investigate the effect of users' cognitive processing characteristics on preference and task performance of different designs of CAPTCHA challenges. The